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Evaluation of Automated Decisionmaking Methodologies and Development of an Integrated Robotic System Simulation Appendix B—ROBSIM Programmers Guide

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EVALUATION OF AUTOMATED DECISIONMAKING METHODOLOGIES AND DEVELOPMENT OF AN INTEGRATED ROBOTIC SYSTEM SIMULATION

Appendix B—ROBSIM Programmer's Guide

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B-158
B-158a
B-161
B-161a
B-167a
B-167b
B-167c
B-167d
B-167e
B-167f
B-167g
B-167h
B-167i
B-167j
B-167k
B-167l
B-167m
B-167n
B-167o
B-167p
B-167q
B-167r
B-167s
B-167t
B-167u
B-167v
B-172a
B-172b
B-176
B-176a
B-177
B-177a
B-180
B-180a
B-185
B-186
B-187
B-187a
B-188
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B-189
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B-190
B-190a
B-191
B-191a
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DOUNTIL: The DOUNTIL is a loop with these characteristics:

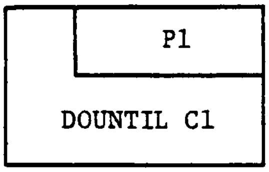
1) The counter or other item to be "incremented" is initialized before entering the loop;

2) The test is performed at the end of the loop. The conditions that must exist to exit from the loop are those that appear in the DOUNTIL test;

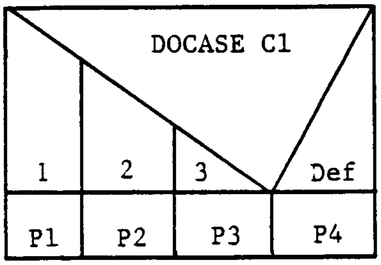
3) The item to be executed must be a standard construct or a single statement;

4) The counter is incremented or other increment-like action is generally taken (e.g., another line is read) at the beginning of the loop.

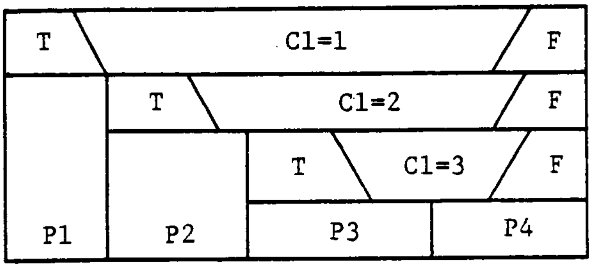
If "C1" is the condition that must exist to exit from the loop and "P1" is a standard construct or single statement, the DOWHILE would be written as



DOCASE: The DOCASE construct is for executing a different set of statements for each of several different values of a variable. If "C1" is the variable being tested and if "C1" may have values 1, 2, or 3, the construct appears



Example A



Example B

Example A is equivalent to the nested IFTHENELSE form shown in B.

Subroutine indexing. - The subroutine descriptions and VCLRs are arranged according to the number assigned in the block diagram. This label consists of three parts (n1.n2.n3). The first part (n1) indicates with which executable--(1) INITDRVR, (2) SIMDRVR, or (3) POSTDRVR--the module is associated. While some routines are used in more than one executable, each is documented only once and labeling number n1 tells which section includes that documentation.

B1 - B2

The next number (n2) indicates the level in the program hierarchy at which the routine occurs. There are three main levels under each executive driver and a fourth level that is assigned to the utility functions used by a variety of routines. The final number (n3) in the routine label distinguishes the modules within each level of one executable program.

In-code documentation. - Although the information contained in this programmer's guide provides an understanding of the overall program logic and function of the individual subroutines, the bulk of the program documentation is included in the Fortran program modules. This enhances the accessibility of the documentation and allows it to be updated as modifications are made. Each Fortran module contains a preamble that lists the routine's:

1) Purpose;
2) Input (calling arguments and terminal inputs);
3) Output (calling arguments and terminal outputs);
4) Common variables;
5) Internal variables;
6) External references;
7) Functional description;
8) Assumptions and limitations;
9) Special comments;
10) References.

Figure B-1 illustrates an example of this in-code documentation. The file SKLTN.FOR contains a skeleton of the preamble for use in writing new programs.

```
C*****************************************************************
      PROGRAM INITDRVR
C*****************************************************************
CD0
CD0   ROBOTICS SIMULATION (ROBSIM) PROGRAM
CD0   SYSTEM DEFINITION FUNCTION ROUTINE
CD0
C*****************************************************************
CD1
CD1   PURPOSE
CD1
CD1      The purpose of the ROBSIM Program is to provide a
CD1   broad range of computer capabilities to assist in the
CD1   design, verification, simulation, and study of
CD1   robotic systems.
CD1      The program INITDRVR is the System Definition Function
CD1   driver. It operates in an interactive mode, prompting the
CD1   user for the system definition option desired. Valid options
CD1   are: create or modify an arm data file, create or
CD1   modify a detailed environment file, create or modify load
CD1   objects, create a system data file, or terminate INITDRVR
CD1   program execution.
CD1
C*****************************************************************
CD2
CD2   DEFINITION OF INPUT
CD2
CD2      CALLING ARGUMENTS
CD2
CD2         SYMBOL    TYPE  DIM  DEFINITION
CD2
CD2         N/A
CD2
CD2      TERMINAL INPUTS
CD2
CD2         SYMBOL    TYPE  DIM  DEFINITION
CD2
CD2         IMODE     I*4     1  Select flag for mode of operation
CD2                               = 1, Create/modify an arm data file
CD2                               = 2, Create/modify detailed
CD2                                      environment file
CD2                               = 3, Create/modify load objects data file
CD2                               = 4, Create system data file
CD2                               = 5, End ROBSIM INITDRVR executive
CD2         ITERM     I*4     1  Program termination flag,
CD2                              requested following fatal
CD2                              error
CD2                               = 1, Reissue program mode
CD2                                     selection prompt
CD2                               = RETURN, Terminate program
CD2

C*****************************************************************
CD3
CD3   DEFINITION OF OUTPUT
CD3
CD3      CALLING ARGUMENTS
CD3
CD3         SYMBOL    TYPE  DIM  DEFINITION
CD3
CD3         N/A
CD3
CD3      TERMINAL OUTPUTS
CD3
CD3         SYMBOL    TYPE  DIM  DEFINITION
CD3
CD3         None
CD3
C*****************************************************************
CD4
CD4   COMMON VARIABLES
CD4
CD4      INPUT
CD4
CD4         LU1, LU2
CD4
CD4      OUTPUT
CD4
CD4         NONE
CD4
C*****************************************************************
CD5
CD5   INTERNAL VARIABLES
CD5
CD5      SYMBOL   TYPE  DIM  DEFINITION
CD5
CD5      IERROR   I*4     1  Error indicator flag
CD5                            =0, No errors encountered
CD5                            .NE. 0, Error has occurred,
CD5                                    contains appropriate
CD5                                    error number required
CD5                                    by routine ERRMSG
CD5      IHLP     I*4     1  The integer 911 input from terminal to
CD5                          signify user wishes to access help file
CD5      MODE     I*4     1  ROBSIM program mode flag, set to 1
CD5                          to indicate program execution is
CD5                          currently within the System Definition
CD5                          Function
CD5- - -- -
```

```
C*****************************************************************
CD6
CD6   EXTERNAL REFERENCES
CD6
CD6      I/O FILES
CD6
CD6         LU1 - Logical unit assigned for input from the terminal
CD6         LU2 - Logical unit assigned for output to the terminal
CD6
CD6      SCRATCH FILES
CD6
CD6         N/A
CD6
CD6      EXTERNAL ROUTINES
CD6
CD6        BLDARM   - Create/modify arm data file
CD6        BLDENV   - Create/modify detailed environment file
CD6        BLDLOD   - Create/modify load objects data file
CD6        BLDSYS   - Create system data file
CD6        ERRMSG   - Prints error messages for any error occurring
CD6                   during execution
CD6        LBR_HELP - Gains access to the ROBSIM help library
CD6        SETLU    - Default logical units routine
CD6
C*****************************************************************
CD7
CD7   FUNCTIONAL DESCRIPTION
CD7
CD7      The ROBSIM command file prompts the user for the
CD7   program function desired.  The three ROBSIM program
CD7   functions are System Definition, Analysis Tools, and
CD7   Post Processing.  The user may also request program
CD7   termination.  Upon receiving a valid function request,
CD7   the ROBSIM command file transfers control to and executes
CD7   the appropriate function driver.
CD7      The System Definition executive calls BLDARM, BLDENV,
CD7   BLDLOD or BLDSYS to create or modify an arm, environment,
CD7   load objects or arm system.
CD7
C*****************************************************************
CD8
CD8   ASSUMPTIONS AND LIMITATIONS
CD8
CD8      1. ROBSIM is programmed in FORTRAN 77 for use on
CD8         VAX 11/780 computers under the VMS operating
CD8         system.
CD8      2. ROBSIM uses Evans and Sutherland Multi Picture
CD8         System graphics using MPS FORTRAN callable
CD8         graphics routines.  Use of the graphics
CD8         capabilities in ROBSIM is optional, however
CD8         full utilization of the program capabilities
CD8         is greatly limited without the graphics.
CD8
C*****************************************************************
CD9
CD9   SPECIAL COMMENTS
CD9
CD9      1. If graphics is desired, the graphics work station
CD9         must be assigned using individual facility
CD9         procedures.
CD9      2. The necessary arm data files must exist prior to
CD9         building a system.
CD9
C*****************************************************************
CD10
CD10  REFERENCES
CD10
CD10     None
CD10
C*****************************************************************
C     THE FOLLOWING CREATES A HELP LIBRARY MODULE
C*****************************************************************
CDX1 INITDRVR
CDX  THIS MODULE IS EXECUTED BY THE SYSTEM DEFINITION PROCESSOR
CDX
CDX2 PARAMETERS
CDX   Qualifiers:
CDX     /IMODE
CDX3 /IMODE
CDX         TYPE   DIM DEFINITION
CDX         I*4     1  Select flag for mode of operation
CDX                     = 1, Create/modify an arm data file
CDX                     = 2, Create/modify detailed
CDX                            environment file
CDX                     = 3, Create/modify load objects data file
CDX                     = 4, Create system data file
CDX                     = 5, End ROBSIM INITDRVR executive
CDX2 FUNCTION
CDX      The ROBSIM command file prompts the user for the
CDX   program function desired.  The three ROBSIM program
CDX   functions are System Definition, Analysis Tools, and
CDX   Post Processing.  The user may also request program
CDX   termination.  Upon receiving a valid function request,
CDX   the ROBSIM command file transfers control to and executes
CDX   the appropriate function driver.
CDX      The System Definition executive calls BLDARM, BLDENV,
CDX   BLDLOD or BLDSYS to create or modify an arm, environment,
CDX   load objects or arm system.
CDX
C*****************************************************************
```

Figure B-1.- Example of in-code documentation.

Implementation Notes

This section describes the programming conventions used in implementing ROBSIM on the VAX-11 computer architecture under the VMS operating system. The program consists of a large number of FORTRAN routines and their compiled object modules, along with a limited number of executable images and VMS command files.

Executive-level command file. - The executive level of ROBSIM is handled by an interactive command file ROBSIM.COM. Figure B-2* shows this command file. This file runs one of the ROBSIM executable images (Fig. B-3) selected by the user. PREPDRVR.EXE is designed as a driver for preprocessing data that may be used by the other program executables. INITDRVR.EXE is the executable containing the system definition routines and SIMDRVR.EXE contains the analysis tools image. The postprocessor functions reside in two executable files: (1) POSTDRVT.EXE for video-terminal display of results, and (2) POSTDRHP.EXE for hardcopy plotting. This is because the display software requires linking of different modules for terminal vs hardcopy displays.

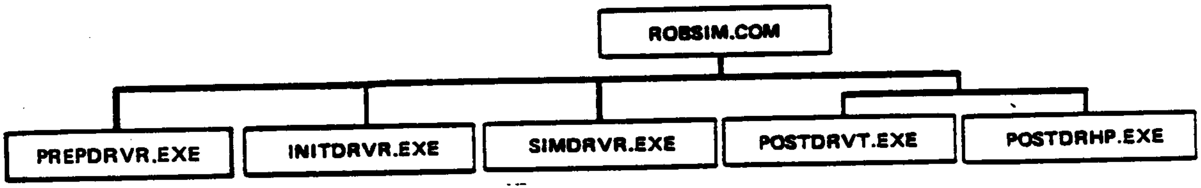


Figure B-3.- ROBSIM executive command file.

Linking the programs. - Each executable image contains an executive routine having the same name as the executable (POSTDRVR for the postprocessor images) and a large number of supporting routines. To facilitate linking, the compiled object modules are included in object libraries. The programs are linked by executing command files that reference these libraries. Figure B-4 shows the linker command files and Table B-I lists the programs in the object libraries.

The bulk of the libraries are contained in the main ROBSIM directory (ROBSIM_DIR:) but some reside in different directories or devices. This is especially convenient for implementations on multiple-disk systems. Table B-II lists the alternate device specifications; these logicals must be assigned to appropriate physical devices, possibly during the log-in procedure.

---

* Full-page figures can be found at the end of this section.

TABLE B-I. MODULES IN ROBSIM OBJECT LIBRARIES

CNTLLIB.OLB OBJECT LIBRARY MODULES:

- CMPCTRL
- CNTRSIG
- CONTROL
- FORREF
- FORTOR
- ICVTATD
- PIDCON
- PIDFOR
- PIDINIT
- POSSENS

CRLIB.OLB OBJECT LIBRARY MODULES:

- BLDARM
- BLDDAT
- BLDENV
- BLDLOD
- BLDTRG
- BLDSYS
- CREATARM
- DEFSPJT
- ENVIR
- LOAD
- RDARM
- RDARMS
- RDENV
- RDENVS
- RDLOAD
- RDLODS
- RDTARG
- RDTRGS
- TARGET
- TOTMAS
- WRTARM
- WRTENV
- WRTLOD
- WRTSYS
- WRTTRG

EANDSLIB.OLB OBJECT LIBRARY MODULES:

- DATOUT
- DIALS
- ESCNTRL
- ESPAUS
- FORM
- GRAFIX
- ISBIT1
- LOGO
- POSTGRAF
- ROTMAT

GEOMLIB.OLB OBJECT LIBRARY MODULES:

- ACTUATOR
- BASE
- BASELK
- BASES
- JOINT
- LINK
- LOCMOD
- LOCTMOD
- OBJECT
- SPAN
- TLDMAS
- TOOLJT
- TOOLLK

GRAFLIB.OLB OBJECT LIBRARY MODULES:

- CADOBJ
- CYL
- DATATAB
- DBAS
- DRAW
- DRWENV
- DRWLOD
- DRWTRG
- ESMAT
- FILLET
- GRAPH
- GRTERM
- MAT
- MATVEC
- OBSTCL
- ORIENT
- RCTSTR
- RECT
- SYSGRAF
- TARG
- TRISTR

MATHLIB.OLB OBJECT LIBRARY MODULES:

- CETM
- CRPD
- DOT2
- GAUSS
- MATMPY
- REPCOL
- SLVLIN
- SLVLIN2
- SOLVE

TABLE B-I. (cont)

ESCADLIB.OLB OBJECT LIBRARY MODULES:

GRAFCAD

POSTLIB.OLB OBJECT LIBRARY MODULES:

AXES
HDWMOTIN
LDTHET
MINMAX
ROBPLT
SCAL
SIMOTION
TICMRK

REQLIB.OLB OBJECT LIBRARY MODULES:

ACTORQ
BASGMNT
BASINIT
BCNTRLR
BORERR
BPCNTRL
BRCNTRL
CABSM
CHKLMT
CNSTFOR
CVTIN
DEBUG
DYNAM
ENDREQ
FORCE
FTIN
JTPOS
LODMOV
ORERR
OUTREQ
PCNTRL
POSGRDJT
POSSPJT
PTACC
PVASPJT
RATEPRO
RCNTRL
REQOPT
REQPLT
REQPRT
REQSOF
REQTRQ
SPRGFOR
SPRGINC
TORQUE
VAGRDJT

SETLIB.OLB OBJECT LIBRARY MODULES:

ADDMAS
ADDMAS2
BASPUT
GRASP
RCICR
RDSYS
RELEAS
SETUP
SETUP2

SIMLIB.OLB OBJECT LIBRARY MODULES:

ACTIVPIH
BDRTORQ
CALCI
DEFCNST
DERIV
DOT
DRTORQ
EFINRT
EFINRT2
ENDSIM
INITCO
INTGRT
LDVOLT
NLINK
OUTSIM
PRTARM
RESPON
SETCNST
SIMLMT
SIMOPT
SIMPLT
SIMPRT
SLVMBAS
SLVTHDD
SLV2ARM
STOPFR

UTILLIB.OLB OBJECT LIBRARY MODULES:

CVTUNIT
DEFUNIT
ERRMSG
JACOB
LININT
OUTUN
SETLU
ZERCOM

TABLE B-I. (concl)

PREPLIB.OLB OBJECT LIBRARY MODULES:

- BLDCAD

CADLIB.OLB OBJECT LIBRARY MODULES:

- CURVE
- LINE
- POINT
- TRANSF
- SPLINE

TASKLIB.OLB OBJECT LIBRARY MODULES:

- ANGLES
- CNTRLR
- HARALICKR
- INITTAR
- NEWFRAME
- PERSPECT
- REQUIR
- SEGINIT
- SEGTASK
- SGMNT
- TASK
- TRACKING

TABLE B-II. - DEVICE-DIRECTORY SPECIFICATIONS IN ROBSIM

Logical	Modules contained in directory
ROBSIM_DIR:	Basic ROBSIM modules
MPS_DIR:	Evans and Sutherland graphics modules
HELP_DIR:	Help utility modules
DI3000_DIR:	Display modules (video-terminal and hardcopy)
HARDCOPY_DIR:	Modules for creating meta-files from picture files

Fortran files and object files. - Each Fortran routine is included in its own file; the name of the file is that of the routine it contains and the file type is ".FOR". An object file with the same name and type ".OBJ" holds the compiled version of each Fortran file. After a Fortran module is modified, an executable image containing the updated version can be obtained by issuing the following commands:

```
FORTRAN MODULENAME
LIBRARY/REPLACE LIBNAME MODULENAME
@LNKNAME
```

Command files FORROB.COM and REPLIB.COM exist for compiling the entire set of routines in the main directory and updating the object libraries. PRTROB.COM provides for printing all of the Fortran modules. Each of these command files should be updated when routines are added to or deleted from the program.

Fortran COMMON blocks. - The variables used by several routines are arranged into COMMON blocks. The text file ROBCOM.DOC lists and briefly describes the variables included in each COMMON block. A Fortran COMMON statement for each block resides in a file of type ".CMN" that has the same name as the COMMON block. The COMMON blocks are included during compilation of the Fortran modules using the INCLUDE statement. This allows a block to be modified by changing only the ".CMN" file, instead of all the Fortran modules that use this block.

During compilation of the Fortran modules, maximum values must be specified for some of the array dimensions. These maximum dimensions are often defined by PARAMETER statements, and most of these statements are included in the file MXPRMS.TXT. Figure B-5 shows a listing of this file. To change the maximum dimension of some variables (e.g., to increase the number of arms possible in a system), the programmer must only change the appropriate parameter (MXARMS) and recompile the programs.

```
MXPRMS.TXT

  THE PARAMETERS IN THIS INCLUDE FILE ARE CONSTANT VALUES REQUIRED
  BY THE PROGRAM.

INTEGER*2 MAXSPN, IFACTCAD, ISEGCAD

PARAMETER (MXLNKS=10,MXARMS=5)
PARAMETER (MAXORD=3,MAXSEG=20,MXPLTS=31)
PARAMETER (MXENCMPS=30,MXGRCMP=40,MXLDCMPS=10)
PARAMETER (MXPTS=10,MXLODS=10)
PARAMETER (MXTRGCMPS=10,MXTRGS=10)
PARAMETER (MXGRAFPT=5000)
PARAMETER (MAXTRAN=50,MAXLIN=20000,MAXPNT=40)
PARAMETER (MAXARC=300,MAXSPL=200)
PARAMETER (IFLGEND=5557)
PARAMETER (IDIV=10,ISEGCAD=1,IFACTCAD=10)
PARAMETER (ITLNGTH=4,MAXFLD=30000,MAXSPN=500,MAXBRK=4)

  DEFINITIONS

   SYMBOL    TYPE  DIMENSION  DEFINITION

   MXARMS     I*4   1          MAXIMUM NUMBER OF ARMS
   MXLNKS     I*4   1          MAXIMUM NUMBER LINKS ALLOWABLE
   MXPLTS     I*4   1          MAXIMUM NUMBER OF Y ARRAY DATA
                                PARAMETERS WHICH MAY BE
                                WRITTEN TO PLOT FILE
   MAXORD     I*4   1          ORDER OF THE POLYNOMIAL DESCRIBING
                                THE MOTION TIME HISTORY
   MAXSEG     I*4   1          MAXIMUM NUMBER OF TIME SEGMENTS
                                ALLOWED TO DESCRIBE THE MOTION
                                TIME HISTORY
   MXPTS      I*4   1          MAXIMUM NUMBER OF POINT MASSES
                                IN EACH LINK OR LOAD
   MXGRCMP    I*4   1          MAXIMUM NUMBER OF GRAPHICS COMPONENTS
                                ALLOWED PER LINK
   MXENCMPS   I*4   1          MAXIMUM NUMBER OF GRAPHICS COMPONENTS
                                IN ENVIRONMENT
   MXLDCMPS   I*4   1          MAXIMUM NUMBER OF GRAPHICS COMPONENTS
                                IN EACH LOAD OBJECT
   MXLODS     I*4   1          MAXIMUM NUMBER OF LOAD OBJECTS ALLOWED
   MXTTRCMPS I*4    1          MAXIMUM NUMBER OF GRAPHICS COMPONENTS
                                IN EACH TARGET OBJECT
   MXTRGS     I*4   1          MAXIMUM NUMBER OF TARGET OBJECTS
                                ALLOWED
   MXGRAFPT   I*4   1          MAXIMUM NUMBER OF GRAFIX POINTS ALLOWED
                                IN EACH COMPONENT
   ISEGCAD    I*2   1          NUMBER OF SEGMENTS FOR THE CAD/CAM
                                GRAPHICS
   IFACTCAD   I*2   1          SCALE FACTOR FOR THE CAD/CAM GRAPHICS
   MAXSPN     I*2   1          MAXIMUM SPAN OF THE ARM DURING CAD/CAM
                                GRAPHICS
```

ITLNGTH	I*4	1	LENGTH OF THE CAD/CAM FILE TITLE
IFLGEND	I*4	1	CAD/CAM FILE FLAG SPECIFYING END OF DIRECTORY DATA SECTION IN FILE
MAXFLD	I*4	1	MAXIMUM NUMBER OF LINES IN THE CAD/CAM DATA FILE
MAXARC	I*4	1	MAXIMUM NUMBER ALLOWABLE CAD/CAM ARC ENTITIES
IDIV	I*4	1	NUMBER OF STRAIGHT LINE SEGMENTS INTO WHICH CURVE ENTITY IS DIVIDED FOR CAD/CAM GRAPHICS DISPLAY
MAXLIN	I*4	1	MAXIMUM NUMBER ALLOWABLE CAD/CAM LINE ENTITIES
MAXPNT	I*4	1	MAXIMUM NUMBER ALLOWABLE CAD/CAM POINT ENTITIES
MAXSPL	I*4	1	MAXIMUM NUMBER ALLOWABLE CAD/CAM B-SPLINE ENTITIES
MAXBRK	I*4	1	MAXIMUM ORDER ALLOWED FOR B-SPLINE DEFINING EQUATION DURING CAD/CAM
MAXTRAN	I*4	1	MAXIMUM NUMBER ALLOWABLE CAD/CAM TRANSFORMATION ENTITIES

Figure B-5. - Listing of MXPRMS.TXT.

Interactive help utility. - An interactive help utility is implemented in ROBSIM to provide online assistance to the user for answering some of the program prompts. The utility provides the user with information on the function and form of the routine and its arguments. The utility is implemented using a mixture of custom software and the VMS help utility. Information for the help library is included in the in-code documentation in the FORTRAN modules under the heading "CDX". The command file MAINHLP.COM is executed to set up a help library ROBLIB.HLB from this documentation. The executable image MNEXTRACT.EXE is run to extract the help library information from the FORTRAN modules; it selects all program lines beginning with "CDX" and deletes the "CDX" headings. The formatted file MAINHLP.DOC lists the FORTRAN modules (type ".FOR" implied) to be searched for help library information. All segments that are extracted must follow the conventions for creating help libraries as described in VAX/VMS Volume 4A Program Development Tools Utilities Reference Manual, Section 10.3.2. They are temporarily stored in a file of type ".HLP".

(Warning - all ".HLP" routines are deleted by the command file execution!)

As an example, Figure B-6 shows the help documentation extracted from program POSTDRVR. The help utility is accessed within the ROBSIM program modules by a call to the subroutine LBR_HLP. This module is included in the object library HELP_DIR:QESTLIB.OLB along with the other routines needed for the help utility. Table B-III summarizes the main files employed by the help utility.

```
1 POSTDRVR
  THIS MODULE IS EXECUTED BY THE POST PROCESSOR

2 PARAMETERS
   Qualifiers:
     /IMODE
3 /IMODE
       TYPE   DIM DEFINITION
        I*4     1  Select flag for mode of operation
                     = 1, Replay simulation graphic motion
                          only
                     = 2, Replay simulation versus hardware
                          motion
                     = 3, Parameter versus parameter plots
                     = 4, Return to ROBSIM executive
2 FUNCTION
     The result of executing option 1, is to call subroutine
  SIMOTION which provides a replay of the robotic system motion
  produced from a simulation run.  Option 2 provides a
  comparison of motion resultant from direct hardware theta value
  read and motion resultant from simulation execution, through
  subroutine HDWMOTIN.
  If option 3 is selected, subroutine ROBPLT is called to
  provide parameter versus parameter plots of any of the
  data computed and written to a plot file during the
  Requirements Analysis Tools Function.
  Option 4 returns execution to the primary ROBSIM level.
```

Figure B-6. - Listing of help documentation extracted from POSTDRVR.

TABLE B-III. - FILES USED FOR INTERACTIVE HELP UTILITY

MAINHLP.COM	Executive command file for extracting help library documentation from FORTRAN code
MAINHLP.DOC	Names of FORTRAN modules containing help information
MODULENAME.HLP	Temporary file of help documentation extracted from routine MODULENAME.FOR
ROBLIB.HLB	Data file used for help utility
LIB_HELP.FOR	Module containing program which reads ROBLIB.HLB
HELP_MAC.MAR	Macro routine used to access help facility

Hardcopy utility. - The ROBSIM program provides the capability for interactive display of the manipulator system on an Evans and Sutherland graphics workstation during system creation or analysis. In addition, plots of this display can be generated on a hardcopy plotter for future reference. Generation of the hardcopy plot entails three steps: (1) creation during program execution of a picture file, (2) conversion of this file into a graphics meta-file, and (3) translation of this meta-file into a display or plot.

The first step is initiated by a call to the routine HARD_COP at the points in the program where a hardcopy of the E&S display may be desired. If the user selects to keep a hardcopy of the current display, a picture file named by the user is created. The routines for this procedure are in object libraries HCPIC.OLB and HCMFL.OLB in directory HARDCOPY_DIR: and are linked with the ROBSIM executable images (Fig. B-4). Program execution continues after the meta-file is completed.

After the ROBSIM run terminates, the user can activate programs that convert the picture files into meta-files by executing HCMFL.EXE. The resulting picture file can be translated into a display on the video-terminal or hardcopy plotter using DI3000 software. The images TRANSLATE.EXE and then VTMETTRNS.EXE or HPMETTRNS.EXE in device-directory DI3000_DIR: perform this translation. Activating these images is made easier by assignments in the log-in command file:

```
HCMFL      := RUN HARDCOPY_DIR:HCMFL.EXE

TRANSLATE  := RUN DI3000_DIR:TRANSLATE.EXE

HPMETTRNS  := RUN DI3000_DIR:HPMETTRNS.EXE

VTMETTRNS  := RUN DI3000_DIR:VTMETTRNS.EXE
```

The user need only type the keyword to start execution of these programs.

File "type" conventions. - The different types of files used in creating the ROBSIM program are designated by individual file-type suffixes in their file specifications. It is recommended that the programmer and user maintain these conventions in the files they create. Table B-IV lists the suggested type specifications.

TABLE B-IV. - FILENAME CONVENTIONS USED IN ROBSIM

APPENDAGE FOR FILENAME	DEFINITION
.ARM	ARM GEOMETRY FILE CREATED DURING SYSTEM DEFINITION
.SYS	SYSTEM GEOMETRY FILE CREATED DURING SYSTEM DEFINITION
.LOD	LOAD GEOMETRY FILE CREATED DURING SYSTEM DEFINITION
.ENV	ENVIRONMENT GEOMETRY FILE CREATED DURING SYSTEM DEFINITION
.OBS	OBSTACLE FILE (NONPLANARX,Y,Z COORDINATES) READ FOR DETAILED GEOMETRY INPUT
.ACT	ACTUATOR DEFINITION INPUT FILE READ BY MODULE ACTUATOR DURING SYSTEM DEFINITION
.CON	RESPONSE ANALYSIS CONTROL OPTIONS INPUT FILE READ BY CONTRL MODULE
.THT	HARDWARE THETA ANGLE INPUT FILE CREATED FROM HARDWARE CONVERSION ROUTINE, AND INPUT DURING POST PROCESSING
.VLT	HARDWARE VOLTAGE CONTROL SIGNAL INPUT FILE CREATED FROM HARDWARE CONVERSION ROUTINE, AND INPUT DURING RESPONSE ANALYSIS EXECUTION
.THP	TIME HISTORY PROFILE FILE CREATED BY AN INPUT TO REQUIREMENTS ANALYSIS
.DAT	REQUIRMENTS OR RESPONSE SIMULATION OPTIONS INPUT FILES; ALSO SOME OUTPUT FILES
.CMN	COMMON BLOCKS INCLUDED THROUGHOUT PROGRAM
.OLB	PROGRAM LIBRARY FILES
.LIS	LISTINGS OF SUBROUTINES IN EACH LIBRARY
.FOR	FORTRAN CODE

TABLE B-IV (cont)

.OBJ	FORTRAN OBJECT MODULES
.EXE	ROBSIM PROGRAM AND UTILITIES EXECUTABLES
.COM	COMMAND FILES FOR COMPILING, REPLACING MODULES IN APPROPRIATE LIBRARIES, LINKING THE DRIVERS, PRINTING ALL MODULES, AND RUNNING THE PROGRAMS
.TXT	PARAMETER FILES INCLUDED IN MODULES THROUGHOUT PROGRAM
.DOC	DOCUMENTATION FILES
.HLP	USER HELP FILES GENERATED WITH THE MNEXTRACT UTILITY IN HELPER DIRECTORY ACCESSIBLE WITH THE LBR HELP UTILITY
.PRT	SIMULATION PRINT OUTPUT FILES
.PLT	PLOT OUTPUT FILES FOR HEWLETT PACKARD X-Y PLOTTER OR VT125 GRAPHICS TERMINALS
.AGF	ARM GEOMETRY PRINT OUTPUT FILES CREATED DURING SYSTEM DEFINITION
.PIC	PICTURE FILES OF EVANS AND SUTHERLAND DISPLAYS, GENERATED WITH HARD COP ROUTINE; MAY BE REPRODUCED ON THE HEWLETT PACKARD PLOTTER AFTER CONVERSION TO META-FILE FORMAT
.SOF	SIMULATION OUTPUT FILE FOR POST PROCESSING
.AVT	ACCELERATION-VELOCITY-THETA OUTPUT FILE
.TRQ	TORQUE OUTPUT FILE
.OUT	ACTUAL HARDWARE OUTPUT FILES FOR VOLTAGE CONTROL SIGNALS AND CORRESPONDING THETA ANGLE VALUES
.BMP	BASE MOTION PROFILE CREATED BY AN INPUT TO REQUIREMENTS ANALYSIS
.BTQ	BASE REACTION TORQUES AND FORCES OUTPUT FILE
.NPT	PRINTOUT FILE OF DETAILED GEOMETRY DATA INPUT BY USER

TABLE B-IV (concl)

.CAD	DETAILED GRAPHICS COMPONENT DATA GENERATED FROM CAD/CAM FILE INTERFACE IN PREPROCESSOR
.TRG	TARGET GEOMETRY FILE CREATED DURING SYSTEM DEFINITION
.SGF	SYSTEM GEOMETRY PRINT OUTPUT FILES CREATED WITH UTILITY RDWRTSYS

```
!ROBSIM.COM
$SET NOVERIFY
$SET TERM/NOBROAD
$COUNT=0
$LOOPS:
$COUNT=COUNT+1
$IF COUNT.GT.1 THEN GOTO ASKNEXT
$ASKWICH:
$WRITE SYS$OUTPUT "INPUT (PREPDRVR)-- TO RUN ROBSIM PREPROCESSOR
                                       FUNCTION"
$WRITE SYS$OUTPUT "INPUT (INITDRVR)-- TO RUN ROBSIM SYSTEM
                                       DEFINITION FUNCTION"
$WRITE SYS$OUTPUT "      (SIMDRVR) -- TO RUN ROBSIM
                                       SIMULATION ANALYSIS
                                       TOOLS FUNCTION"
$WRITE SYS$OUTPUT "      (POSTDRVR)-- TO RUN ROBSIM POST
                                       PROCESSOR FUNCTION"
$PROMPT:=WHICH:
$READ/PROMPT="''PROMPT'" SYS$COMMAND WHICH
$IF WHICH.EQS."INITDRVR" THEN GOTO INIT
$IF WHICH.EQS."SIMDRVR" THEN GOTO SIM
$IF WHICH.EQS."POSTDRVR" THEN GOTO POST
$PREP
$ASSIGN TT SYS$INPUT
$ASSIGN TT SYS$OUTPUT
$RUN [ROBSIM.WORK]PREPDRVR
$DEASSIGN SYS$INPUT
$DEASSIGN SYS$OUTPUT
$INQUIRR
$PROMPT:=INPUT(Y) TO RUN PREPROCESSOR FUNCTION AGAIN,-
 (OTHERWISE, RETURN)
$READ/PROMPT="''PROMPT'" SYS$COMMAND WHICH
$IF WHICH.EQS."Y" THEN GOTO PREP
$GOTO LOOPS
$INIT:
$ASSIGN TT SYS$INPUT
$ASSIGN TT SYS$OUTPUT
$RUN [ROBSIM.WORK]INITDRVR
$DEASSIGN SYS$INPUT
$DEASSIGN SYS$OUTPUT
$INQUIRI:
$PROMPT:=INPUT (Y) TO RUN SYSTEM DEFINITION FUNCTION AGAIN, -
 (OTHERWISE, RETURN)
$READ/PROMPT="''PROMPT'" SYS$COMMAND WHICH
$IF WHICH.EQS."Y" THEN GOTO INIT
$GOTO LOOPS
$SIM:
$ASSIGN TT SYS$INPUT
$ASSIGN TT SYS$OUTPUT
```

Figure B-2. - The ROBSIM executive command file.

```
$RUN [ROBSIM.WORK]SIMDRVR
$DEASSIGN SYS$INPUT
$DEASSIGN SYS$OUTPUT
$INQUIRS:
$PROMPT:=INPUT (Y) TO RUN SIMULATION ANALYSIS TOOLS -
 FUNCTION AGAIN, (OTHERWISE, RETURN)
$READ/PROMPT="''PROMPT'" SYS$COMMAND WHICH
$IF WHICH.EQS."Y" THEN GOTO SIM
$GOTO LOOPS
$POST:
$WRITE SYS$OUTPUT "DO YOU WISH (1) TERMINAL OR
                               (2) HARDCOPY PLOTTING?"
$PROMPT:=   ENTER INTEGER:
$READ/PROMPT="''PROMPT'" SYS$COMMAND WHICH
$ASSIGN TT SYS$INPUT
$ASSIGN TT SYS$OUTPUT
$IF WHICH.EQS."1" THEN RUN [ROBSIM.WORK]POSTDRVT
$IF WHICH.EQS."2" THEN RUN [ROBSIM.WORK]POSTDRHP
$DEASSIGN SYS$INPUT
$DEASSIGN SYS$OUTPUT
$INQUIRP:
$PROMPT:=INPUT (Y) TO RUN POST PROCESSOR FUNCTION AGAIN, -
 (OTHERWISE, RETURN)
$READ/PROMPT="''PROMPT'" SYS$COMMAND WHICH
$IF WHICH.EQS."Y" THEN GOTO POST
$GOTO LOOPS
$ASKNEXT:
$PROMPT:=INPUT (Q) IF YOU WISH TO EXIT THE PROGRAM
                                       (OTHERWISE, RETURN)
$READ/PROMPT="''PROMPT'" SYS$COMMAND QUIT
$IF QUIT.EQS."" THEN GOTO ASKWICH
$EXIT
$STOP
```

Figure B-2. (concl)

LNKPREP.COM

```
$LINK/EXECUTABLE=PREPDRVR   PREPDRVR,-
        PREPLIB/LIB,-
        CADLIB/LIB,-
        ESCADLIB/LIB,-
        UTILLIB/LIB,-
        MATHLIB/LIB,-
        HCPIC/LIB,-
        HCMFL/LIB,-
        DISK$USER1:[ROBSIM.HELPER]QESTLIB/LIB,-
        SYS$SYSDEVICE:[MPSGSP]MPLIB/L
```

LNKINIT.COM

```
$LINK/EXECUTABLE=INITDRVR   INITDRVR,-
        CRLIB/LIB,-
        GEOMLIB/LIB,-
        GRAFLIB/LIB,-
        SETLIB/LIB,-
        EANDSLIB/LIB,-
        UTILLIB/LIB,-
        MATHLIB/LIB,-
        HCPIC/LIB,-
        HCMFL/LIB,-
        DISK$USER1:[ROBSIM.HELPER]QESTLIB/LIB,-
        SYS$SYSDEVICE:[MPSGSP]MPLIB/L
```

LNKSIM.COM

```
$LINK/EXECUTABLE=SIMDRVR   SIMDRVR,-
        SIMLIB/LIB,-
        CNTLLIB/LIB,-
        TASKLIB/LIB,-
        REQLIB/LIB,-
        EANDSLIB/LIB,-
        UTILLIB/LIB,-
        SETLIB/LIB,-
        MATHLIB/LIB,-
        HCPIC/LIB,-
        HCMFL/LIB,-
        DISK$USER1:[ROBSIM.HELPER]QESTLIB/LIB,-
        SYS$SYSDEVICE:[MPSGSP]MPLIB/L
```

Figure B-4 - ROBSIM linker command files.

LNKPOSTVT.COM

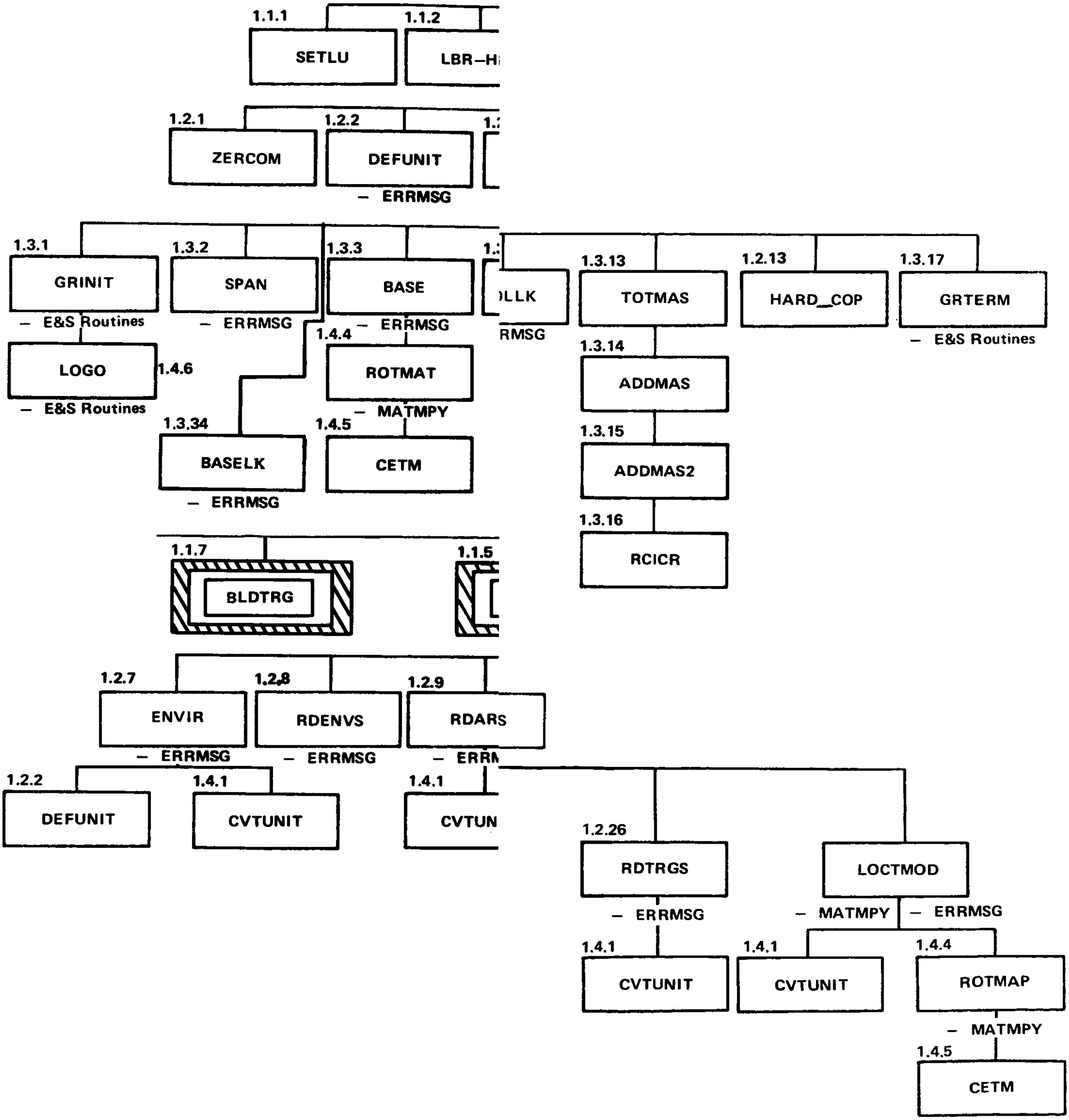
```
$LINK/EXECUTABLE=POSTDRVT   POSTDRVR,-
        POSTLIB/LIB,-
        SETLIB/LIB,-
        UTILLIB/LIB,-
        MATHLIB/LIB,-
        EANDSLIB/LIB,-
        HCPIC/LIB,-
        HCMFL/LIB,-
        DISK$USER1:[ROBSIM.HELPER]QESTLIB/LIB,-
        SYS$SYSDEVICE:[MPSGSP]MPLIB/L
        di3_link:DILIB/LIB,MFNODE/OPT, LVLC/OPT,-
        DI3_DDR:DDR125,-
        DI3_LINK:UTILLIB/LIB
```

LNKPOSTHP.COM

```
$LINK/EXECUTABLE=POSTDRHP   POSTDRVR,-
        POSTLIB/LIB,-
        SETLIB/LIB,-
        UTILLIB/LIB,-
        MATHLIB/LIB,-
        EANDSLIB/LIB,-
        HCPIC/LIB,-
        HCMFL/LIB,-
        DISK$USER1:[ROBSIM.HELPER]QESTLIB/LIB
        SYS$SYSDEVICE:[MPSGSP]MPLIB/L
        DI3_CS:MGRAIN,Q3ATOC,-
        di3_link:DILIB/LIB,MFNODE/OPT,LVLC/OPT,-
        DI3_DDR:DDR721,-
        DI3_LINK:UTILLIB/LIB
```

Figure B-4. (Concl)

The program INITDRVR is the system
shows the program modules employed in I
modules. The set of functional descrip
following pages describe these routines



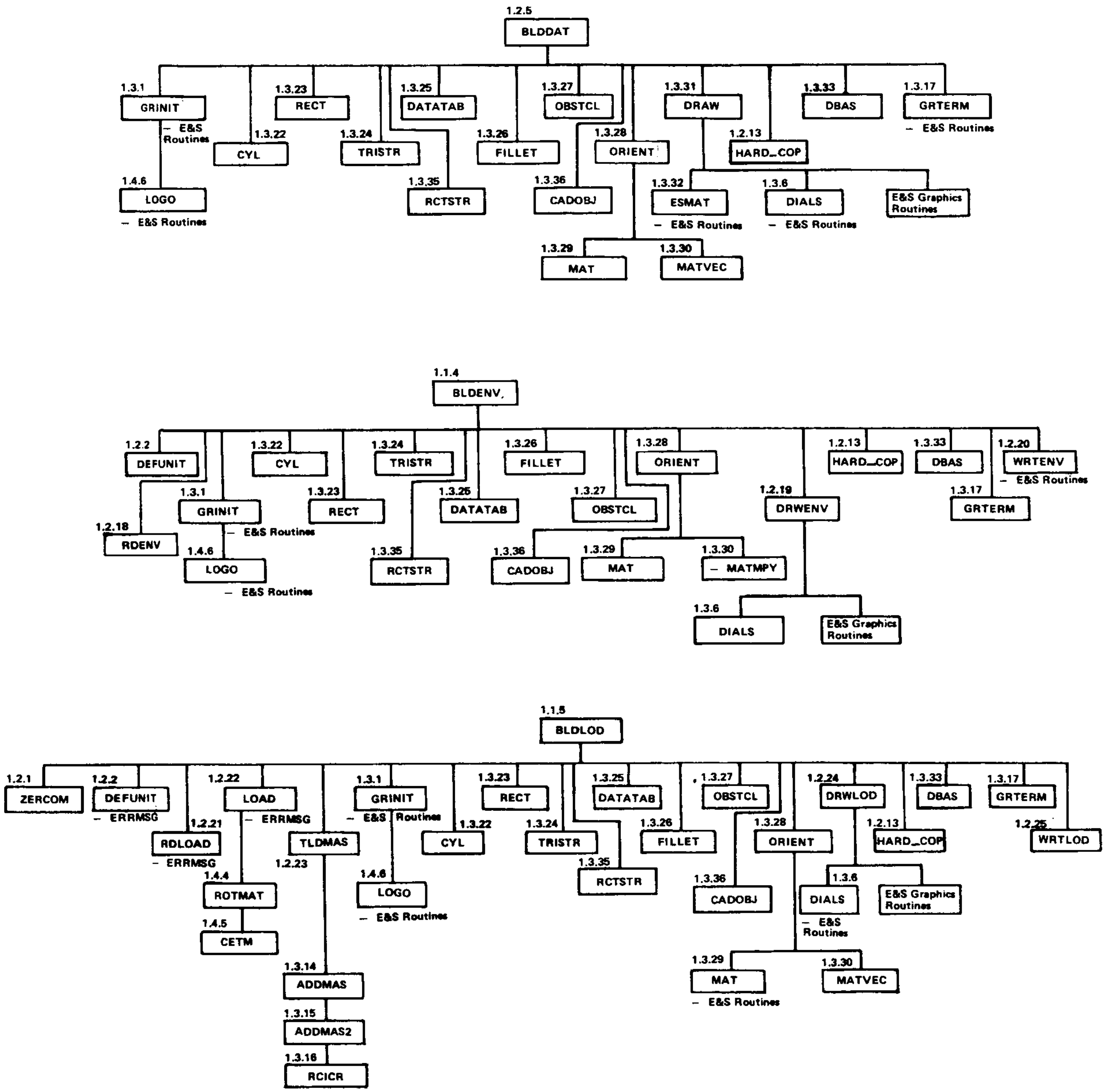


Figure B-7. (cont)

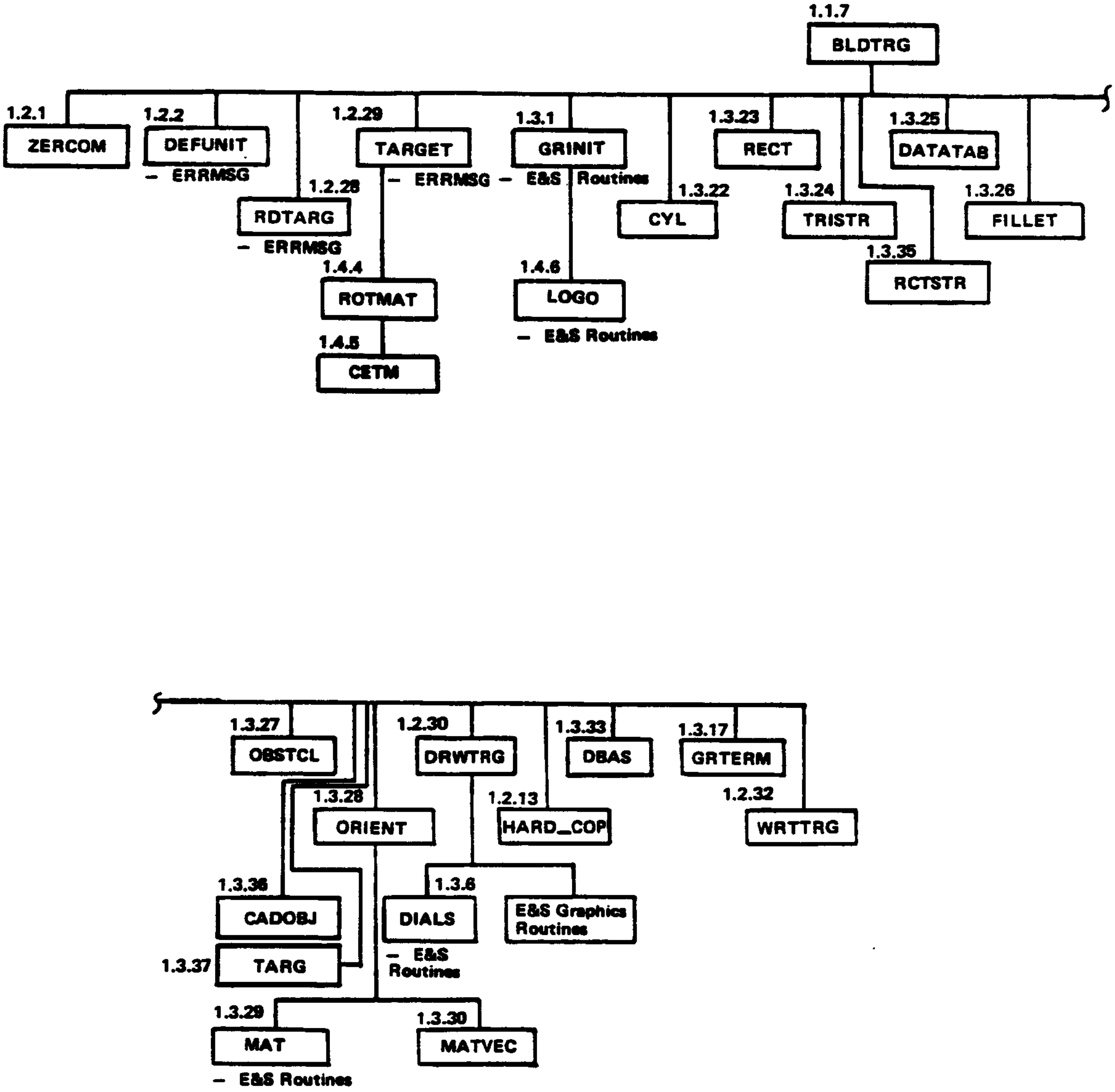


Figure B-7. (concl)

TABLE B-V. - PROGRAMS EMPLOYED IN INITDRVR

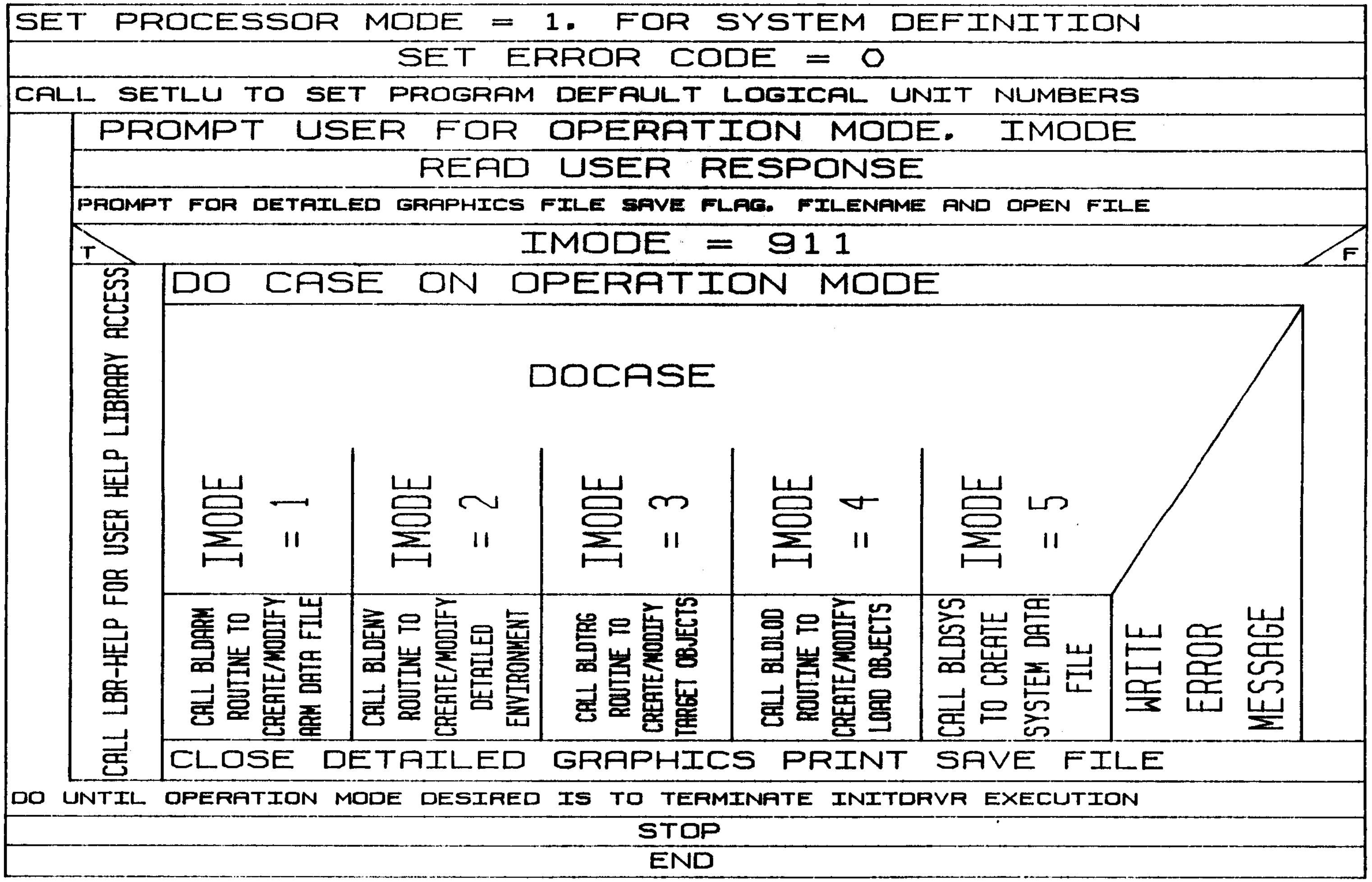
1.0	INITDRVR
1.1.1	SETLU
1.1.2	LBR_HELP
1.1.3	BLDARM
1.1.4	BLDENV
1.1.5	BLDLOD
1.1.6	BLDSYS
1.1.7	BLDTRG
1.2.1	ZERCOM
1.2.2	DEFUNIT
1.2.3	CREATARM
1.2.4	RDARM
1.2.5	BLDDAT
1.2.6	WRTARM
1.2.7	ENVIR
1.2.8	RDENVS
1.2.9	RDARMS
1.2.10	BASES
1.2.11	SETUP
1.2.12	SETUP2
1.2.13	HARD_COP
1.2.14	SYSGRAF
1.2.15	RDLODS
1.2.16	LOCMOD
1.2.17	WRTSYS
1.2.18	RDENV
1.2.19	DRWENV
1.2.20	WRTENV
1.2.21	RDLOAD
1.2.22	LOAD
1.2.23	TLDMAS
1.2.24	DRWLOD
1.2.25	WRTLOD
1.2.26	RDTRGS
1.2.27	LOCTMOD
1.2.28	RDTARG
1.2.29	TARGET
1.2.30	DRWTRG
1.2.31	WRTTRG
1.3.1	GRINIT
1.3.2	SPAN
1.3.3	BASE
1.3.4	OBJECT
1.3.5	GRAPH
1.3.6	DIALS
1.3.7	JOINT
1.3.8	ACTUATOR
1.3.9	LINK
1.3.10	DEFSPJT
1.3.11	TOOLJT
1.3.12	TOOLLK
1.3.13	TOTMAS
1.3.14	ADDMAS
1.3.15	ADDMAS2
1.3.16	RCICR
1.3.17	GRTERM
1.3.18	BASPUT
1.3.19	JACOB
1.3.20	DATOUT
1.3.21	FORM
1.3.22	CYL
1.3.23	RECT
1.3.24	TRISTR
1.3.25	DATATAB
1.3.26	FILLET
1.3.27	OBSTCL
1.3.28	ORIENT
1.3.29	MAT
1.3.30	MATVEC
1.3.31	DRAW
1.3.32	ESMAT
1.3.33	DBAS
1.3.34	BASELK
1.3.35	RCTSTR
1.3.36	CADOBJ
1.3.37	TARG
1.4.1	CVTUNIT
1.4.2	MATMPY
1.4.3	ERRMSG
1.4.4	ROTMAT
1.4.5	CETM
1.4.6	LOGO
1.4.7	CRPD

1.0 INITDRVR

The program INITDRVR is the system definition function driver. It operates in an interactive mode, prompting the user for the system definition option desired--create or modify an arm data file, create or modify a detailed environment file, create or modify a target objects file, create or modify a load objects file, create a system data file, or terminate INITDRVR execution. Subroutine SETLU is called to set the Fortran logical units. The necessary simple cylinder or detailed single arm file must exist prior to building a system. A detailed graphics save file is opened if requested.

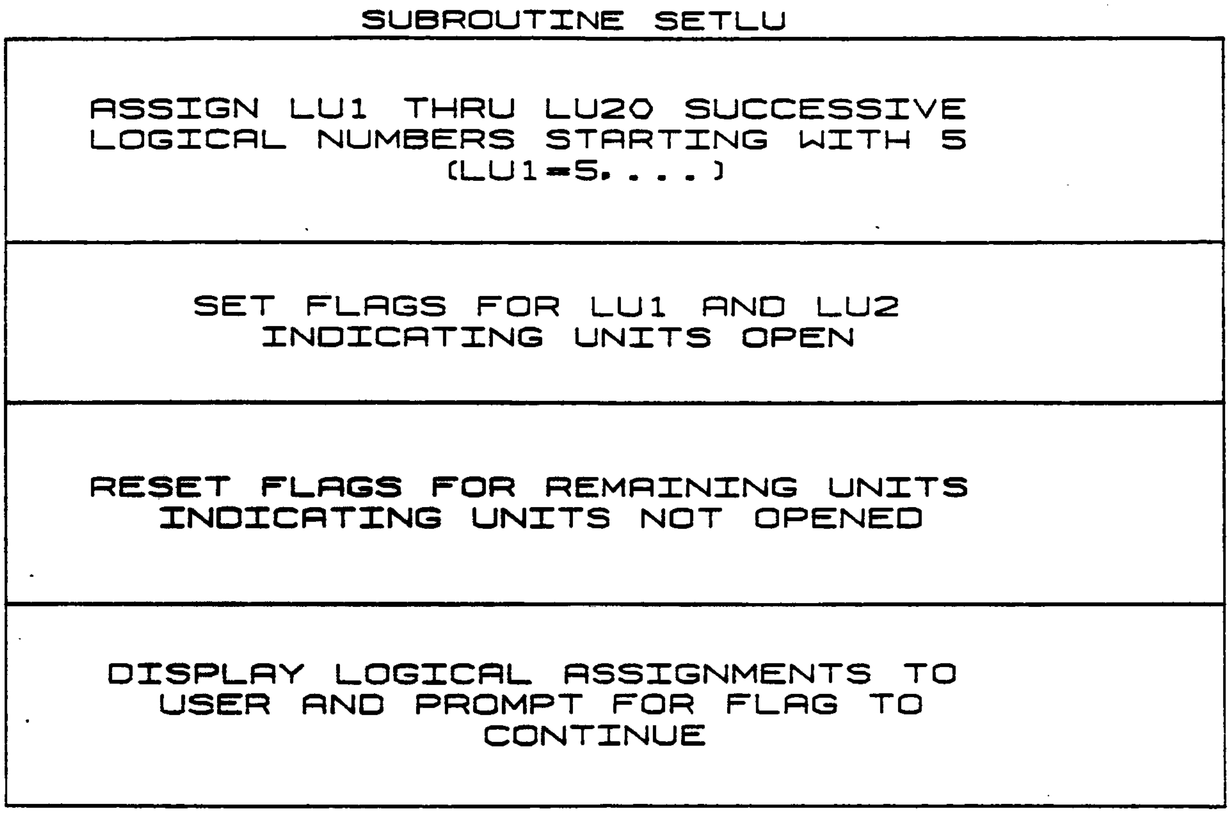
ORIGINAL PAGE IS
OF POOR QUALITY

PROGRAM INITDRVR



1.1.1 SETLU

SETLU is called from the various executive drivers to set the Fortran logical unit number to be stored in COMMON block LUNITBK for reference by the rest of the ROBSIM program. After assigning the variables to consecutive unit numbers, the "unit open" flags are reset to indicate the units are not open (except the terminal read and write units).



SUBROUTINE SETLU

ASSIGN LU1 THRU LU20 SUCCESSIVE LOGICAL NUMBERS STARTING WITH 5 (LU1=5, . . .)

SET FLAGS FOR LU1 AND LU2 INDICATING UNITS OPEN

RESET FLAGS FOR REMAINING UNITS INDICATING UNITS NOT OPENED

DISPLAY LOGICAL ASSIGNMENTS TO USER AND PROMPT FOR FLAG TO CONTINUE

1.1.2 LBR_HELP

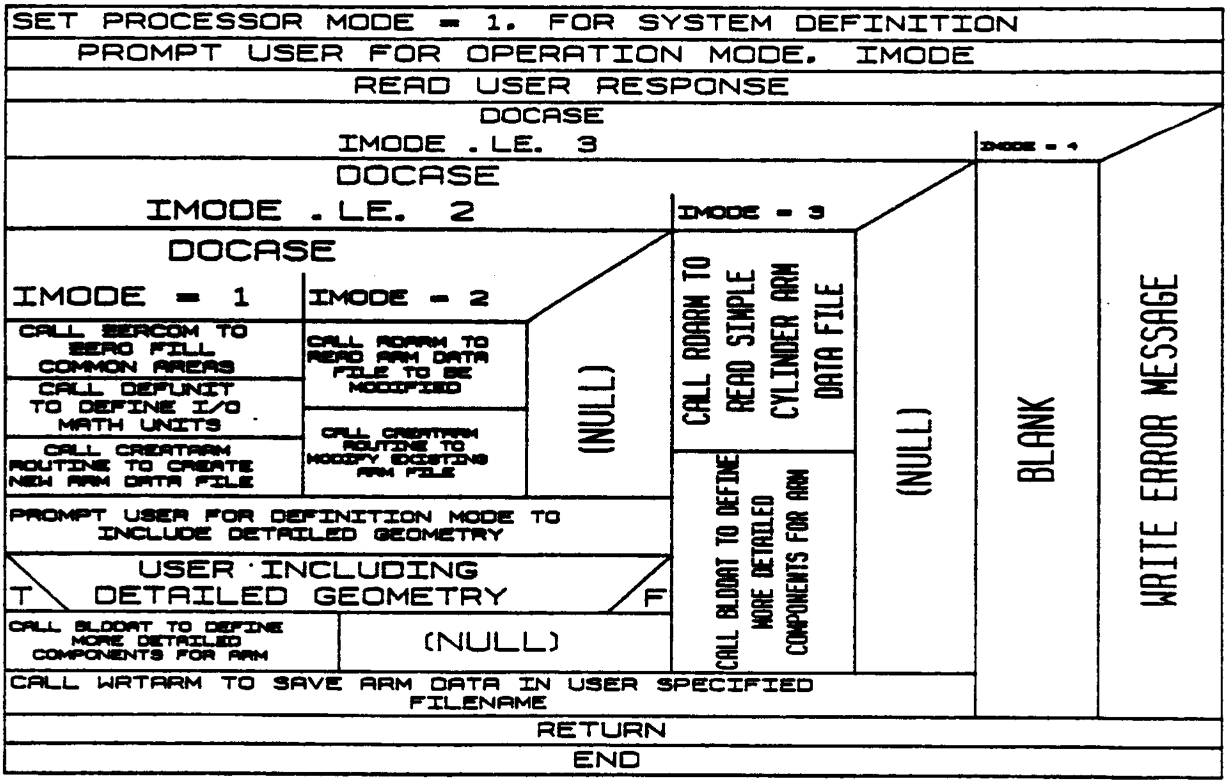
Subroutine LBR_HELP is called to execute the help utility during a ROBSIM run. It uses the object file created from the macro HELPMAC.MAR and runs the system help utilities as required.

(VCLR for LBR_HELP not available.)

1.1.3 BLDARM

BLDARM is met when a selection of 1, to create or modify an arm data file, is entered from INITDRVR. The user choices for mode of operation are (1) create a simple cylinder arm data file, (2) modify existing arm data file, (3) enter detailed graphics data for arm (a simple cylinder file must already exist), or (4) terminate arm definition and return to the INITDRVR. For initial creation, option (1), subroutine ZERCOM is called to zero the COMMON locations and then CREATARM is called to build the new data file. For modification, RDARM and CREATARM are called when option (2) is requested. BLDDAT is responsible for the invention of detailed arm geometry. In all cases, WRTARM will be called to write the arm data COMMON information.

SUBROUTINE BLDARM



1.1.4 BLDENV

The user has the capability with routine BLDENV to specify a detailed physical representation for the robotic environment. Components for the environment are defined as basic geometric shapes (cylinders, cones, rectangular solids, symmetric or nonsymmetric trapezoidal figures, triangular cross-sectional beams, rectangular beams, fillet components, data tablet-defined entities, obstacles, and CAD/CAM objects. The component type is written to the detailed graphics save file if requested.

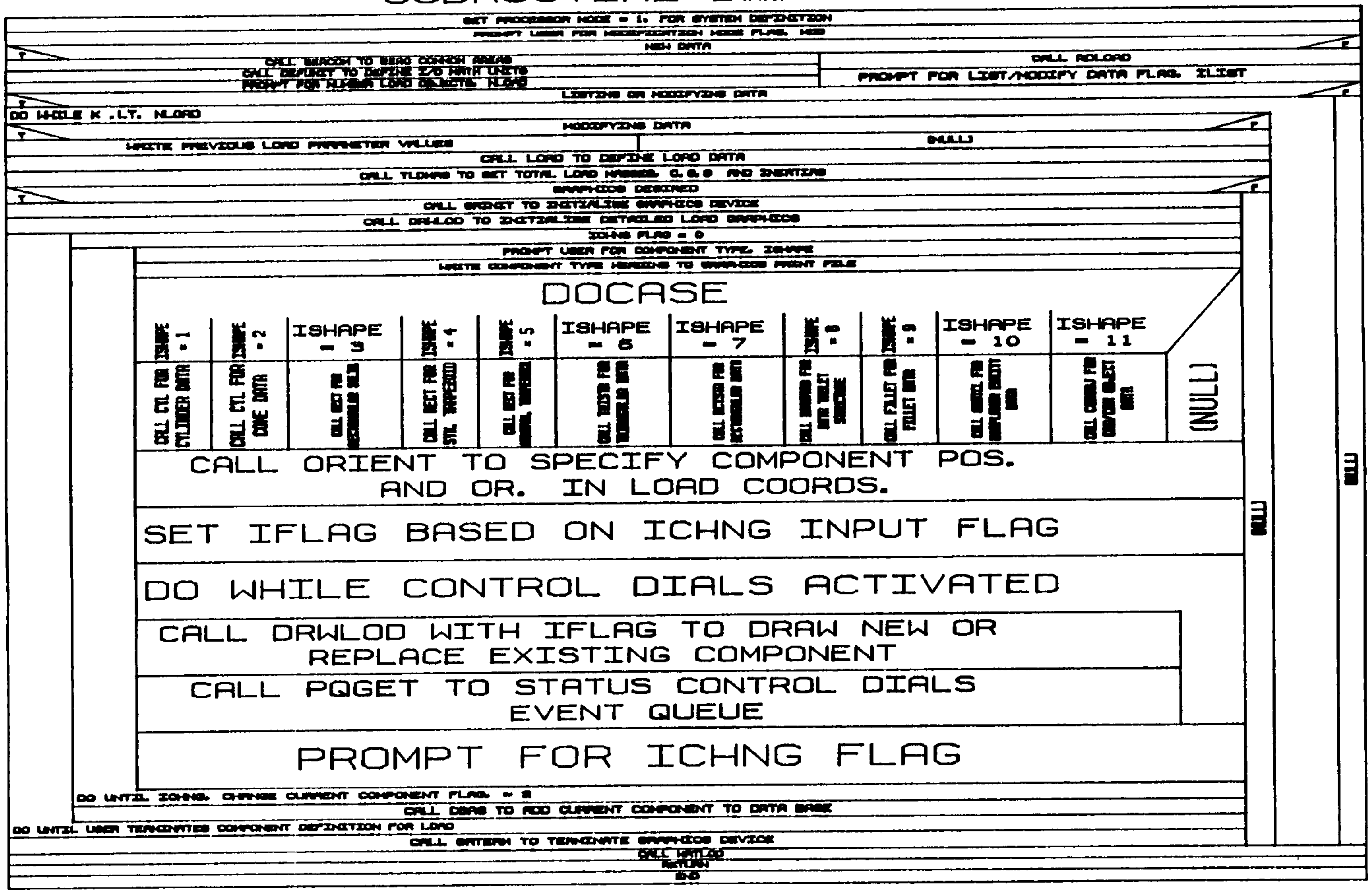
SUBROUTINE BLDENV

```
SET PROCESSOR MODE = 1, FOR SYSTEM DEFINITION
SET IFLAG = 1
N = 1
CALL DEFUNIT TO DEFINE I/O MATH UNITS
CALL GRINIT TO INITIALIZE GRAPHICS DEVICE
CALL DRWENV TO INITIALIZE DETAILED ENVIRONMENT GRAPHICS
NS = 0
DO
    NS = NS + 1
    ICHNG FLAG = 0
    DO
        PROMPT USER FOR COMPONENT TYPE, ISHAPE
        WRITE COMPONENT TYPE HEADING TO GRAPHICS PRINT FILE
        DOCASE
            ISHAPE = 1:  CALL CYL FOR CYLINDER DATA
            ISHAPE = 2:  CALL CYL FOR CONE DATA
            ISHAPE = 3:  CALL RECT FOR [illegible]
            ISHAPE = 4:  CALL RECT FOR STL TRAPEZOID
            ISHAPE = 5:  CALL RECT FOR [illegible]
            ISHAPE = 6:  CALL TRISTR FOR TRIANGULAR DATA
            ISHAPE = 7:  CALL [illegible]
            ISHAPE = 8:  CALL [illegible] STRUCTURE
            ISHAPE = 9:  CALL FILLET FOR FILLET DATA
            ISHAPE = 10: CALL OBSTCL FOR NONPLANAR ENTITY DATA
            ISHAPE = 11: CALL CBOOBJ FOR CBO/CON OBJECT DATA
            (LEFT FOR ADDITIONS)
        CALL ORIENT TO SPECIFY COMPONENT POS. AND OR.
            IN WORLD COORDS.
        SET IFLAG BASED ON ICHNG INPUT FLAG
        DO WHILE CONTROL DIALS ACTIVATED
            CALL DRWENV WITH IFLAG TO DRAW NEW OR
                REPLACE EXISTING COMPONENT
            IFLAG = 2
            CALL PQGET TO STATUS CONTROL DIALS EVENT
                QUEUE
        PROMPT FOR ICHNG FLAG
    DO UNTIL ICHNG, CHANGE CURRENT COMPONENT FLAG, = 2
    CALL DBMS TO ADD CURRENT COMPONENT TO DATA BASE
DO UNTIL USER TERMINATES COMPONENT DEFINITION FOR ENVIRONMENT
CALL GRTERM TO TERMINATE GRAPHICS DEVICE
CALL WRTNEW TO WRITE NEW ENVIRONMENT DATA FILE
RETURN
END
```

1.1.5 BLDLOD

Through routine BLDLOD, the user has the capability to specify a detailed physical representation for the robotic load objects to be used. Components for the load objects are defined as basic geometric shapes (cylinders, cones, rectangular solids, symmetric or nonsymmetric trapezoidal figures, triangular cross-sectional beams, rectangular beams, fillet components, data tablet-defined entities, nonplanar entities, and CAD/CAM objects). This subroutine creates a new file, or modifies an existing file of load objects, and includes the capability to specify the detail at the first creation session for the load objects. The component type is written to the detailed graphics save file if requested.

SUBROUTINE BLDLOD



1.1.6 BLDSYS

BLDSYS prompts the user for the moving base information and then reads individual arm data files into the appropriate system COMMON blocks. It desired, the locations of the fixed bases can be modified. BLDSYS then sets up the environment, load objects, target data, and stores the system file.

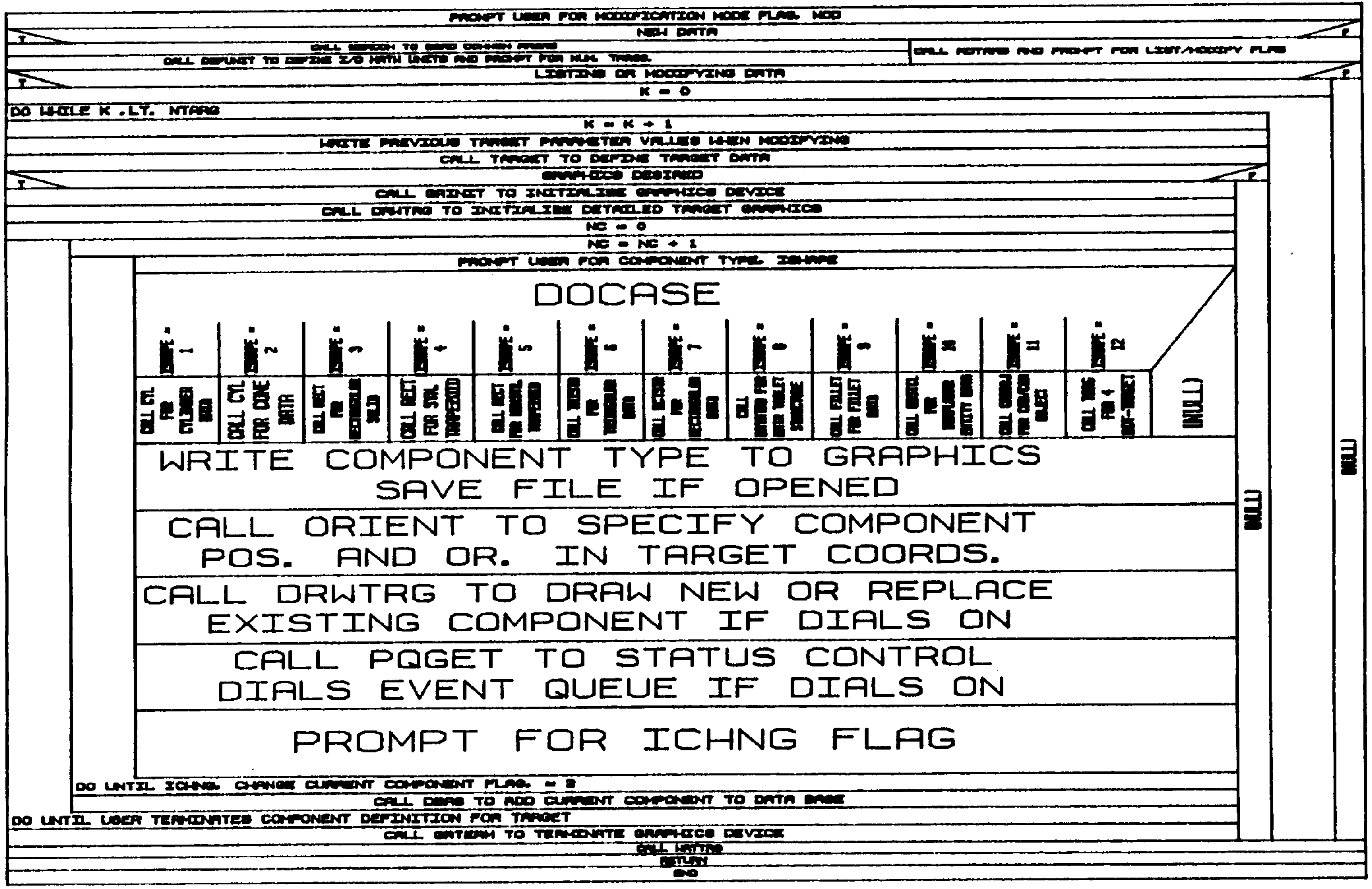
SUBROUTINE BLDSYS

```
PROMPT FOR GRAPHICS DISPLAY DURING SYSTEM DEFINITION
CALL ENVIR FOR USER INPUT OF ENVIRONMENT SET PROPERTIES
CALL RDENVS TO READ ENVIRONMENT DATA IF REQUESTED AND GRAPHICS OPTED
CALL SYSGRAF TO DRAW ENVIRONMENT WHEN GRAPHICS IS DESIRED
PROMPT FOR NUMBER OF MOVING BASES, NBAS, IF TO BE INCLUDED
PROMPT FOR NUMBER OF ROBOTIC ARMS IN SYSTEM, NARM
DO WHILE KARM .LT. NARM
    CALL RDARMS TO READ ARM DATA INTO SYSTEM COMMON BLOCKS
    INCLUDING MOVING BASES
    T:
        PROMPT FOR WHICH MOVING BASE ARM IS ATTACHED TO, KBASNUM (KARM)
    F:
        MODIFY BASE LOCATION OR ORIENTATION IF REQUESTED
        CALL BASES TO PROMPT FOR CHANGES
        GRAPHICS DESIRED
        T:
            CALL SETUP FOR POS./ROT. AND CALL SYSGRAF TO DRAW ARM WITH DIALS
        F:
            (NULL)
PROMPT USER FOR DEFINITION MODE TO INCLUDE LOAD OBJECTS
CALL RDLODS TO READ LOAD OBJECTS DATA IF INCLUDING LOADS
DO WHILE K .LT. NLOAD
    CHANGE CURRENT LOAD LOC. AND OR. IF REQUESTED
    GRAPHICS DESIRED
    T:
        CALL SYSGRAF TO DRAW CURRENT LOAD WITH DIALS
    F:
        (NULL)
    CALL LOCMOD
PROMPT USER FOR DEFINITION MODE TO INCLUDE TARGETS
CALL RDTRGS TO READ TARGET DATA IF INCLUDING TARGETS
DO WHILE K .LT. NTARG
    CHANGE CURRENT TARGET LOC. AND OR. IF REQUESTED
    GRAPHICS DESIRED
    T:
        CALL SYSGRAF TO DRAW CURRENT TARGET WITH DIALS
    F:
        (NULL)
    CALL LOCTMOD
CALL SYSGRAF TO TERMINATE GRAPHICS IF NECESSARY
CALL WRTSYS TO WRITE ROBOTIC SYSTEM FILE IN USER SPECIFIED FILENAME
RETURN
END
```

1.1.7 BLDTRG

Through routine BLDTRG, the user can specify a detailed physical representation for the robotic target objects to be used. Components for the target objects are defined as basic geometric shapes (cylinders, cones, rectangular solids, symmetric or nonsymmetric trapezoidal figures, triangular cross-sectional beams, rectangular beams, fillet components, data tablet-defined entities, obstacles, CAD/CAM objects and four-dot target patterns). This subroutine creates a new file or modifies an existing file of target objects, and includes the capability to specify the detail at the first creation session for the target objects.

SUBROUTINE BLDTRG



```
PROMPT USER FOR MODIFICATION MODE FLAG, MOD
IF NEW DATA
  T: CALL SEARCH TO READ COMMON AREAS
     CALL DEFUNIT TO DEFINE I/O MATH UNITS AND PROMPT FOR NUM. TARGS.
  F: CALL ROTARG AND PROMPT FOR LIST/MODIFY FLAG
IF LISTING OR MODIFYING DATA
  T: K = 0
     DO WHILE K .LT. NTARG
        K = K + 1
        WRITE PREVIOUS TARGET PARAMETER VALUES WHEN MODIFYING
        CALL TARGET TO DEFINE TARGET DATA
        IF GRAPHICS DESIRED
          T: CALL GRINIT TO INITIALIZE GRAPHICS DEVICE
             CALL DRWTRG TO INITIALIZE DETAILED TARGET GRAPHICS
             NC = 0
             DO UNTIL USER TERMINATES COMPONENT DEFINITION FOR TARGET
                NC = NC + 1
                DO UNTIL ICHNG, CHANGE CURRENT COMPONENT FLAG, = 2
                   PROMPT USER FOR COMPONENT TYPE, ISHAPE
                   DOCASE
                     ISHAPE = 1:  CALL CYL FOR CYLINDER DATA
                     ISHAPE = 2:  CALL CYL FOR CONE DATA
                     ISHAPE = 3:  CALL RECT FOR RECTANGULAR SOLID
                     ISHAPE = 4:  CALL RECT FOR SYM. TRAPEZOID
                     ISHAPE = 5:  CALL RECT FOR [illegible] TRAPEZOID
                     ISHAPE = 6:  CALL [illegible] FOR TRIANGULAR DATA
                     ISHAPE = 7:  CALL [illegible] FOR RECTANGULAR DATA
                     ISHAPE = 8:  CALL [illegible] FOR [illegible] STRUCTURE
                     ISHAPE = 9:  CALL FILLET FOR FILLET DATA
                     ISHAPE = 10: CALL [illegible] FOR [illegible] ENTITY DATA
                     ISHAPE = 11: CALL [illegible] FOR [illegible] OBJECT
                     ISHAPE = 12: CALL TORG FOR 4 DOT-TARGET
                     (NULL)
                   WRITE COMPONENT TYPE TO GRAPHICS
                   SAVE FILE IF OPENED
                   CALL ORIENT TO SPECIFY COMPONENT
                   POS. AND OR. IN TARGET COORDS.
                   CALL DRWTRG TO DRAW NEW OR REPLACE
                   EXISTING COMPONENT IF DIALS ON
                   CALL PQGET TO STATUS CONTROL
                   DIALS EVENT QUEUE IF DIALS ON
                   PROMPT FOR ICHNG FLAG
                CALL DBAS TO ADD CURRENT COMPONENT TO DATA BASE
             CALL GRTERM TO TERMINATE GRAPHICS DEVICE
          F: (NULL)
  F: (NULL)
CALL WRTTRG
RETURN
END
```

1.2.1 ZERCOM

Subroutine ZERCOM is called from BLDARM, BLDLOD, and BLDTRG to initialize the arm, load, and target data COMMON blocks prior to creating new system files. The COMMON blocks initialized to zero include:

1) BLDGBK - arm geometric properties;

2) BLDMBK - arm mass properties;

3) GRAFBK - arm graphics data;

4) BLDABK - arm actuator parameters;

5) BLDSJBK - special joint flags;

6) LOADBK - load geometry and mass properties;

7) LGRAFBK - load graphics data;

8) TARGBK - target geometry and mass properties;

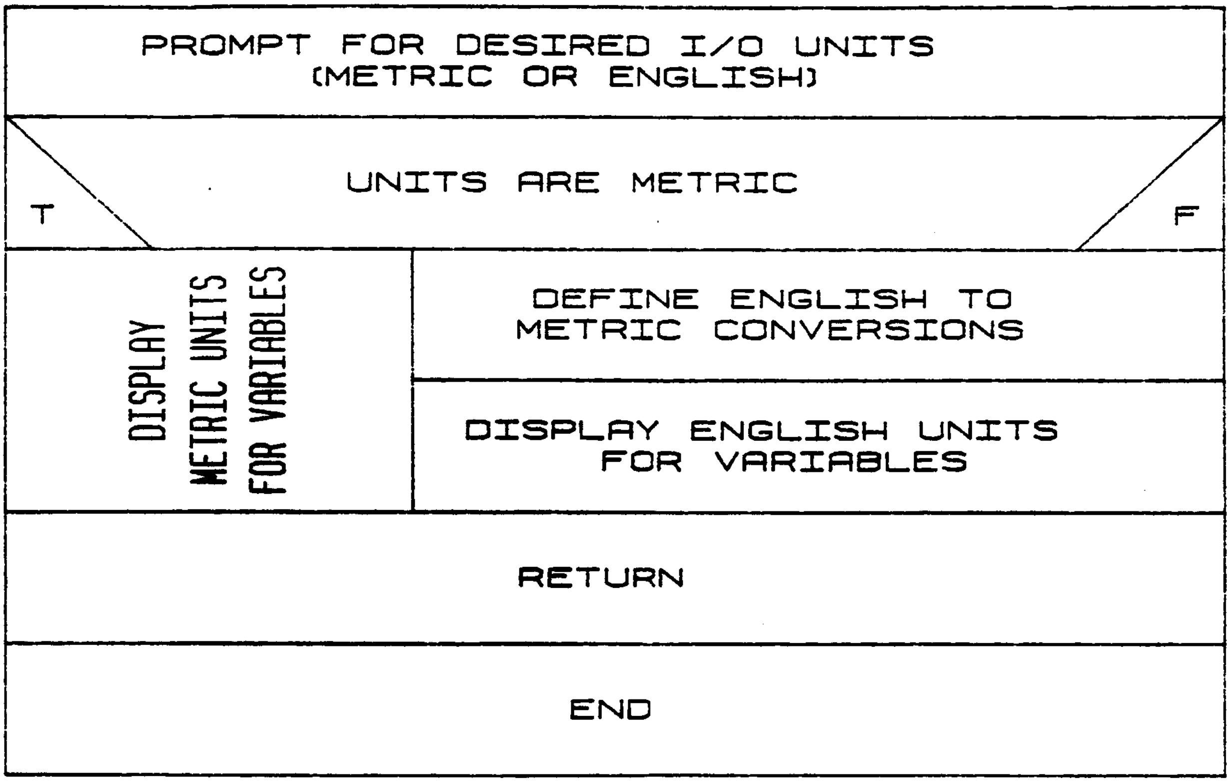
9) TGRAFBK - target graphics data.

SUBROUTINE ZERCOM

```
NJ = MAXIMUM NUMBER OF LINKS
    ZERO VARIABLES IN GEOMETRIC PROPERTIES COMMON BLOCK BLDGBK
DO UNTIL N = NUMBER OF LINKS IN CURRENT ARM
    ZERO VARIABLES IN MASS PROPERTIES COMMON BLOCK BLDMBK
DO UNTIL N = NUMBER OF LINKS IN CURRENT ARM
ZERO VARIABLES IN ARM GRAPHICS COMMON BLOCK GRAFBK
    ZERO VARIABLES IN ACTUATOR PARAMETERS COMMON BLOCK BLDABK
DO UNTIL N = NUMBER OF JOINTS IN CURRENT ARM
    ZERO VARIABLES IN SPECIAL JOINTS COMMON BLOCK BLDSJBK
DO UNTIL N = NUMBER OF SPECIAL JOINTS IN CURRENT ARM
NJ = 0
    ZERO VARIABLES IN LOAD GEOMETRY AND MASS COMMON BLOCK LOADBK
DO UNTIL N = NUMBER OF LOADS IN LOAD OBJECT FILE
ZERO VARIABLES IN LOAD GRAPHICS COMMON BLOCK LGRAFBK
    ZERO VARIABLES IN TARGET GEOMETRY COMMON BLOCK TARGBK
DO UNTIL N = NUMBER OF TARGETS IN TARGET FILE
ZERO VARIABLES IN TARGET GRAPHICS COMMON BLOCK TGRAFBK
RETURN
END
```

1.2.2 DEFUNIT

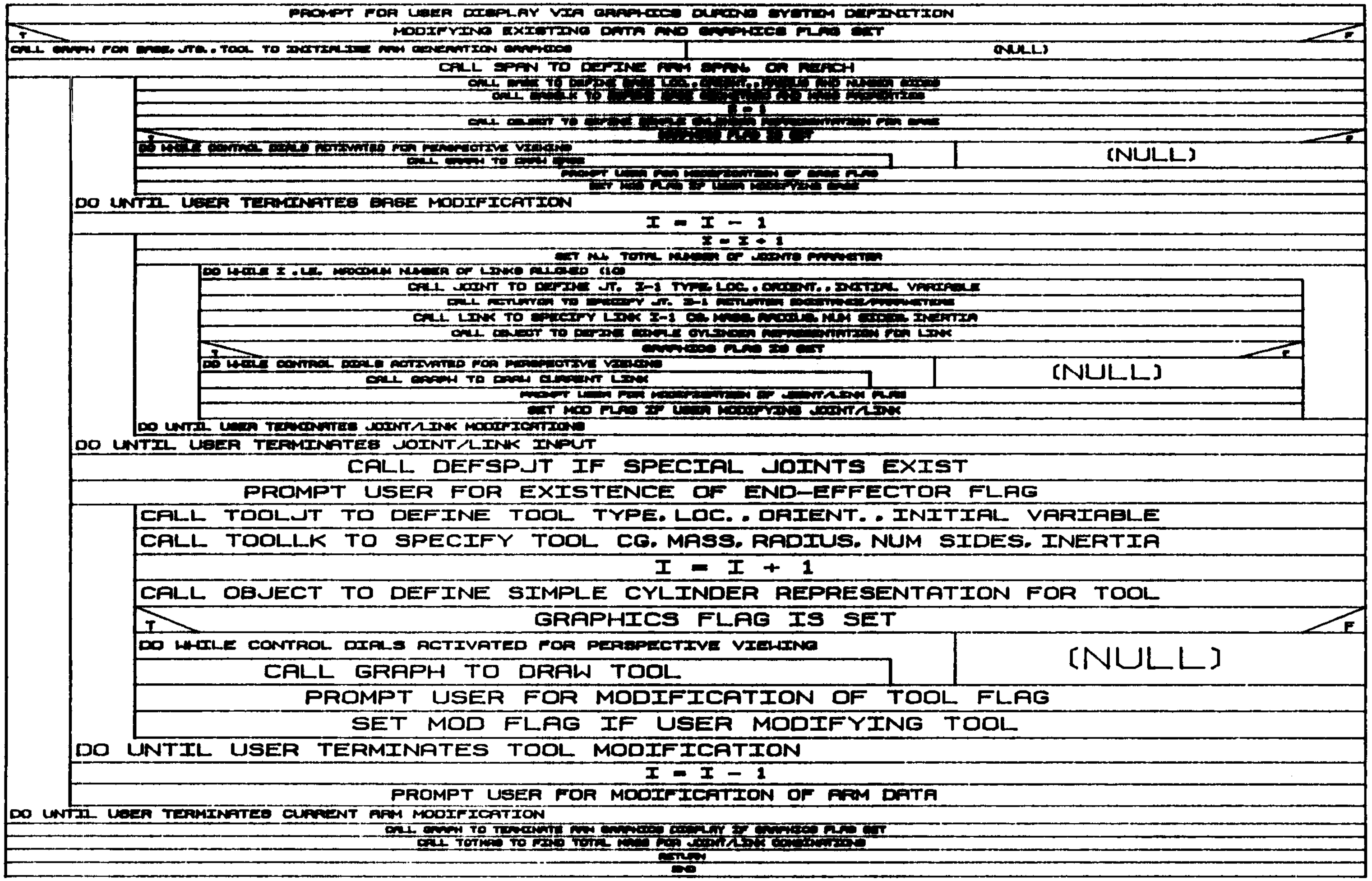
Subroutine DEFUNIT is called during system definition to set up input and output units specified by the user. If these I/O units are not metric, the routine establishes conversion factors between the I/O units and internal (metric) units. The conversion factors are stored in variable CONUNIT, and LISUNIT contains a character string listing the I/O units employed.


SUBROUTINE DEFUNIT

1.2.3 CREATARM

Subroutine CREATARM is called within the system definition function to provide control of the creation or modification modes for the simple cylinder arm data file. The basic routines called for either option are SPAN (define arm span), BASE (define base geometric properties), BASELK (define base mass properties), JOINT (define joint), ACTUATOR (optional, to define motor properties), LINK (define link properties), and DEFSPJT (optional, to define special joints). If the user opts for an end-effector, TOOLJT (define tool-joint properties) and TOOLLK (define tool-link properties) are called. Graphics may be requested during CREATARM.

SUBROUTINE CREATARM



```
PROMPT FOR USER DISPLAY VIA GRAPHICS DURING SYSTEM DEFINITION
MODIFYING EXISTING DATA AND GRAPHICS FLAG SET
  T: CALL GRAPH FOR BASE, JTS., TOOL TO INITIALIZE ARM GENERATION GRAPHICS
  F: (NULL)
CALL SPAN TO DEFINE ARM SPAN, OR REACH
    DO UNTIL USER TERMINATES BASE MODIFICATION
        CALL BASE TO DEFINE BASE LOC., ORIENT., RADIUS AND NUMBER SIDES
        CALL BASELK TO DEFINE BASE GEOMETRY AND MASS PROPERTIES
        I = 1
        CALL OBJECT TO DEFINE SIMPLE CYLINDER REPRESENTATION FOR BASE
        GRAPHICS FLAG IS SET
          T: DO WHILE CONTROL DIALS ACTIVATED FOR PERSPECTIVE VIEWING
                 CALL GRAPH TO DRAW BASE
          F: (NULL)
        PROMPT USER FOR MODIFICATION OF BASE FLAG
        SET MOD FLAG IF USER MODIFYING BASE
    I = I - 1
    DO UNTIL USER TERMINATES JOINT/LINK INPUT
        I = I + 1
        SET NJ, TOTAL NUMBER OF JOINTS PARAMETER
        DO UNTIL USER TERMINATES JOINT/LINK MODIFICATIONS
            DO WHILE I .LE. MAXIMUM NUMBER OF LINKS ALLOWED (10)
            CALL JOINT TO DEFINE JT. I-1 TYPE, LOC., ORIENT., INITIAL VARIABLE
            CALL ACTUATOR TO SPECIFY JT. I-1 ACTUATOR EXISTANCE/PARAMETERS
            CALL LINK TO SPECIFY LINK I-1 CG, MASS, RADIUS, NUM SIDES, INERTIA
            CALL OBJECT TO DEFINE SIMPLE CYLINDER REPRESENTATION FOR LINK
            GRAPHICS FLAG IS SET
              T: DO WHILE CONTROL DIALS ACTIVATED FOR PERSPECTIVE VIEWING
                     CALL GRAPH TO DRAW CURRENT LINK
              F: (NULL)
            PROMPT USER FOR MODIFICATION OF JOINT/LINK FLAG
            SET MOD FLAG IF USER MODIFYING JOINT/LINK
    CALL DEFSPJT IF SPECIAL JOINTS EXIST
    PROMPT USER FOR EXISTENCE OF END-EFFECTOR FLAG
    DO UNTIL USER TERMINATES TOOL MODIFICATION
        CALL TOOLJT TO DEFINE TOOL TYPE, LOC., ORIENT., INITIAL VARIABLE
        CALL TOOLLK TO SPECIFY TOOL CG, MASS, RADIUS, NUM SIDES, INERTIA
        I = I + 1
        CALL OBJECT TO DEFINE SIMPLE CYLINDER REPRESENTATION FOR TOOL
        GRAPHICS FLAG IS SET
          T: DO WHILE CONTROL DIALS ACTIVATED FOR PERSPECTIVE VIEWING
                 CALL GRAPH TO DRAW TOOL
          F: (NULL)
        PROMPT USER FOR MODIFICATION OF TOOL FLAG
        SET MOD FLAG IF USER MODIFYING TOOL
    I = I - 1
    PROMPT USER FOR MODIFICATION OF ARM DATA
DO UNTIL USER TERMINATES CURRENT ARM MODIFICATION
CALL GRAPH TO TERMINATE ARM GRAPHICS DISPLAY IF GRAPHICS FLAG SET
CALL TOTMAS TO FIND TOTAL MASS FOR JOINT/LINK COMBINATIONS
RETURN
END
```

1.2.4 RDARM

Subroutine RDARM is called from BLDARM to read from an unformatted arm data file the data describing a single arm. Routines called by BLDARM can then modify the data. The user is prompted for the name of the arm data file to be modified. The following data are read from it:

1) Input/output units;

2) Geometric properties;

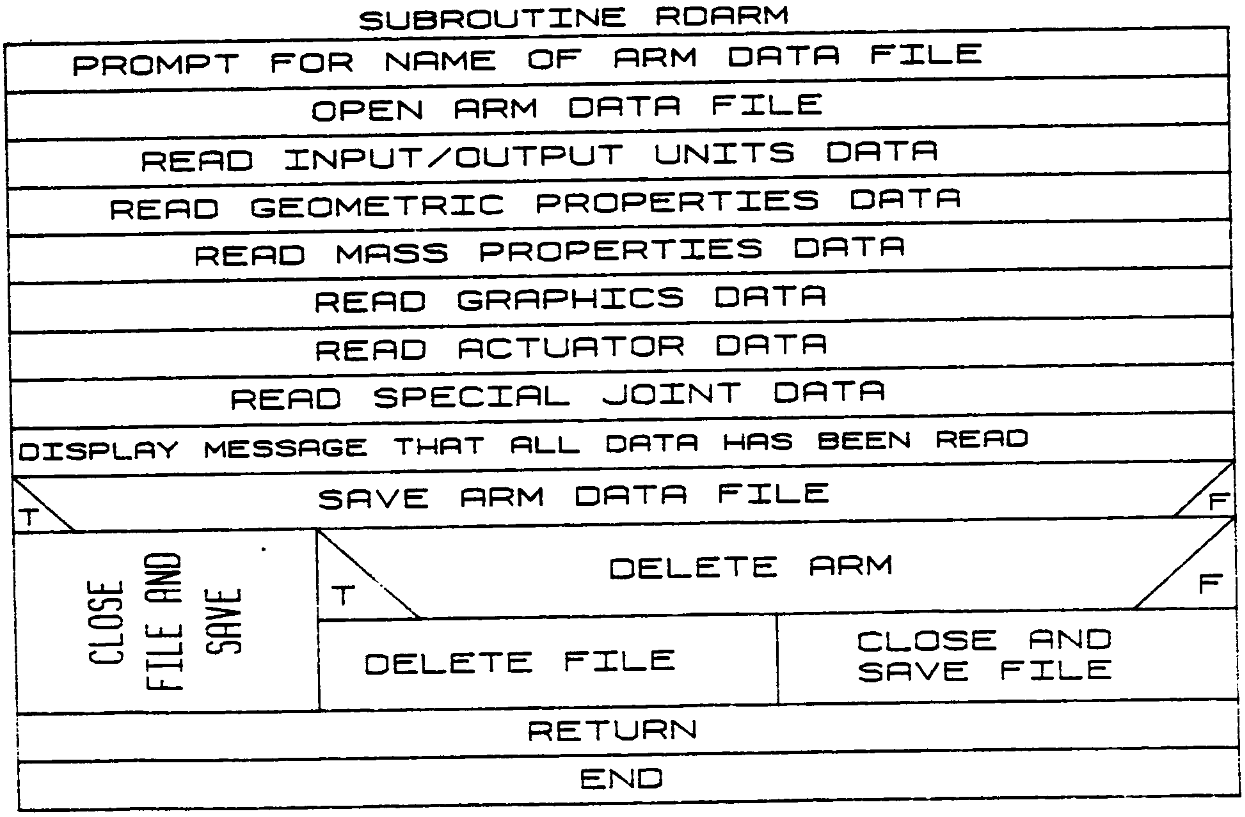
3) Mass properties;

4) Graphics data;

5) Actuator data;

6) Information on special joints.

The user has the option of saving or deleting the old data file.



1.2.5 BLDDAT

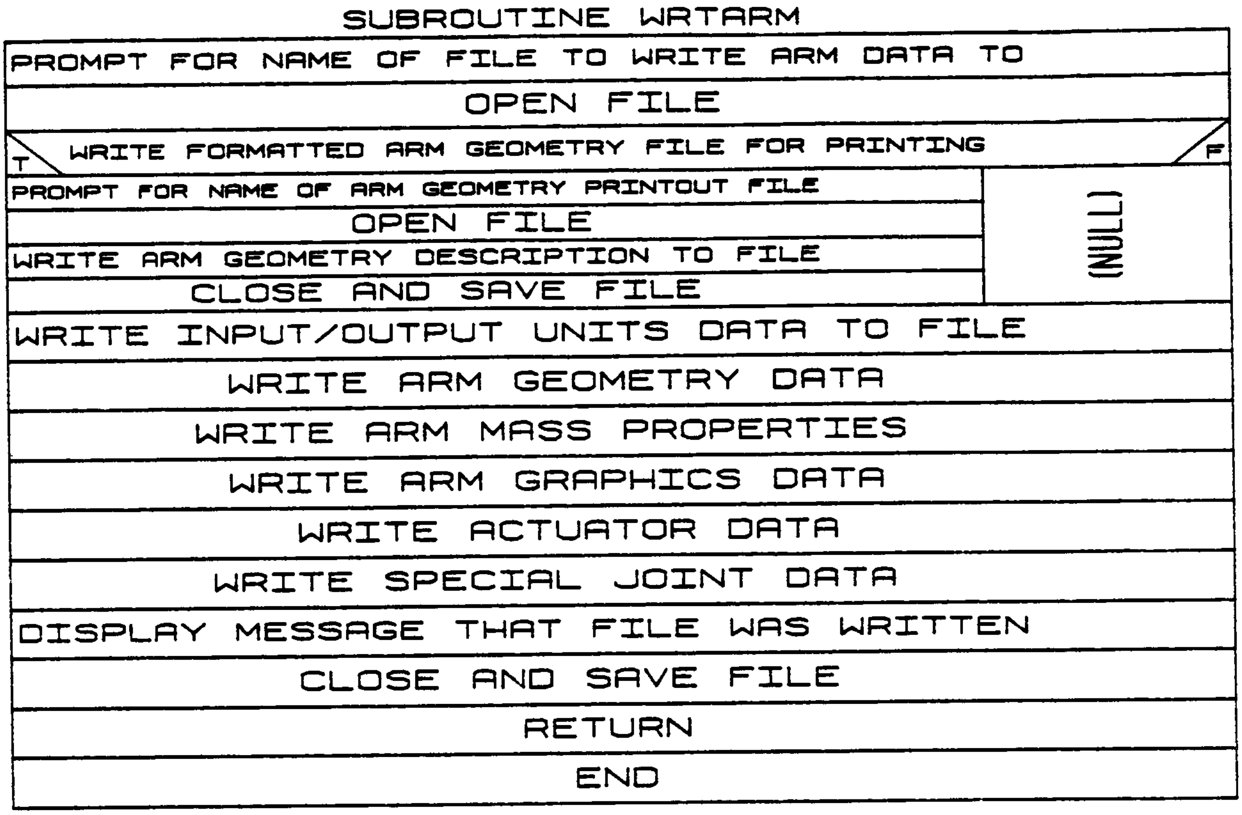
Subroutine BLDDAT provides the user the capability to specify a more detailed physical representation for the links of the robotic arm. Components of the robotic arm system are defined by combinations of geometric primitives. A number of detailed components can be included for the base, each link extension and the tool definitions. The components are simple three-dimensional shapes: the cylinders, cones, rectangular solids, symmetric trapezoids, nonsymmetric trapezoids, triangular cross-sectional beams, rectangular beams, data tablet structures, fillet components, nonplanar entities, and CAD/CAM objects. Unique subroutines are called to handle loading the graphics object data for the shapes chosen to represent a detailed arm. Additional shapes can be added as required. The component type is written to the detailed graphics save file if requested.

ORIGINAL PAGE IS
OF POOR QUALITY

```
SUBROUTINE BLDDAT
SET PROCESSOR MODE = 1. FOR SYSTEM DEFINITION
CALL GRINIT TO INITIALIZE GRAPHICS DEVICE
SET IFLAG = 1
CALL DRAW TO INITIALIZE DETAILED GEOMETRY GRAPHICS
N = 0
DO WHILE N .LT. NJ + 2
    N = N + 1
    NS = 0
    NS = NS + 1
    ICHNG FLAG = 0
    PROMPT USER FOR COMPONENT TYPE, ISHAPE
    WRITE COMPONENT TYPE HEADING TO GRAPHICS PRINT FILE
    DOCASE
        ISHAPE = 1:  CALL CTL FOR CYLINDER DATA
        ISHAPE = 2:  CALL CTL FOR CONE DATA
        ISHAPE = 3:  CALL RECT FOR [illegible]
        ISHAPE = 4:  CALL RECT FOR SYM. TRAPEZOID
        ISHAPE = 5:  CALL RECT FOR [illegible] TRAPEZOID
        ISHAPE = 6:  CALL [illegible] FOR [illegible]
        ISHAPE = 7:  CALL [illegible] FOR [illegible]
        ISHAPE = 8:  CALL [illegible] FOR [illegible] FILLET [illegible]
        ISHAPE = 9:  CALL FILLET FOR FILLET DATA
        ISHAPE = 10: CALL [illegible] FOR [illegible] ENTITY DATA
        ISHAPE = 11: CALL [illegible] FOR [illegible] OBJECT DATA
        (NULL)
    CALL ORIENT TO SPECIFY COMPONENT POS. AND
        OR. IN LINK COORDS.
    SET IFLAG BASED ON ICHNG INPUT FLAG
    DO WHILE CONTROL DIALS ACTIVATED
        CALL DRAW WITH IFLAG TO DRAW NEW OR
            REPLACE EXISTING COMPONENT
        IFLAG = 2
        CALL PQGET TO STATUS CONTROL DIALS EVENT
            QUEUE
    PROMPT FOR ICHNG FLAG
    DO UNTIL ICHNG. CHANGE CURRENT COMPONENT FLAG. = 2
DO UNTIL USER TERMINATES COMPONENT DEFINITION FOR LINK
CALL DBAS TO ADD CURRENT COMPONENT TO DATA BASE
CALL GRTERM TO TERMINATE GRAPHICS DEVICE
RETURN
END
```

1.2.6 WRTARM

Subroutine WRTARM is called from BLDARM to save, in a user-specified file, the data generated when creating or modifying an arm description. The user is prompted for the name of this file and is also given the option of storing a formatted file containing the arm description for later printing.

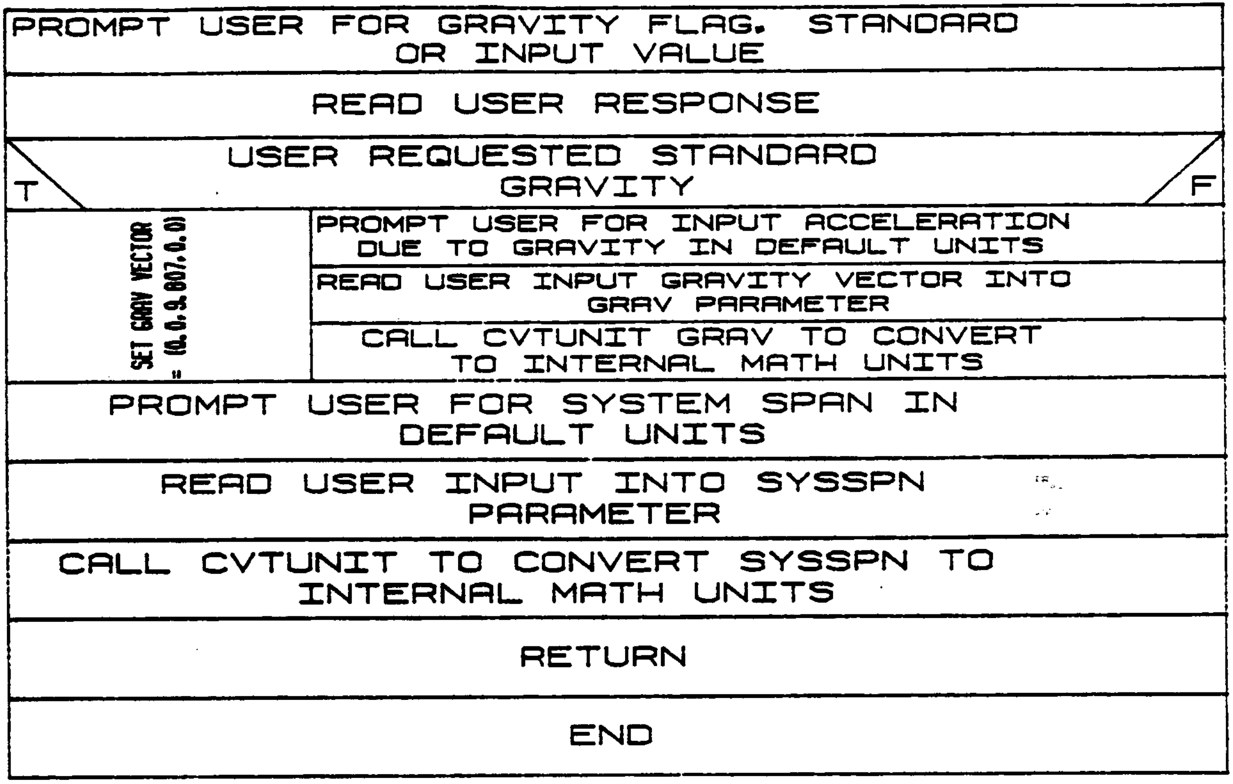


```
SUBROUTINE WRTARM
PROMPT FOR NAME OF FILE TO WRITE ARM DATA TO
OPEN FILE
WRITE FORMATTED ARM GEOMETRY FILE FOR PRINTING
  T:
    PROMPT FOR NAME OF ARM GEOMETRY PRINTOUT FILE
    OPEN FILE
    WRITE ARM GEOMETRY DESCRIPTION TO FILE
    CLOSE AND SAVE FILE
  F:
    (NULL)
WRITE INPUT/OUTPUT UNITS DATA TO FILE
WRITE ARM GEOMETRY DATA
WRITE ARM MASS PROPERTIES
WRITE ARM GRAPHICS DATA
WRITE ACTUATOR DATA
WRITE SPECIAL JOINT DATA
DISPLAY MESSAGE THAT FILE WAS WRITTEN
CLOSE AND SAVE FILE
RETURN
END
```

1.2.7 ENVIR

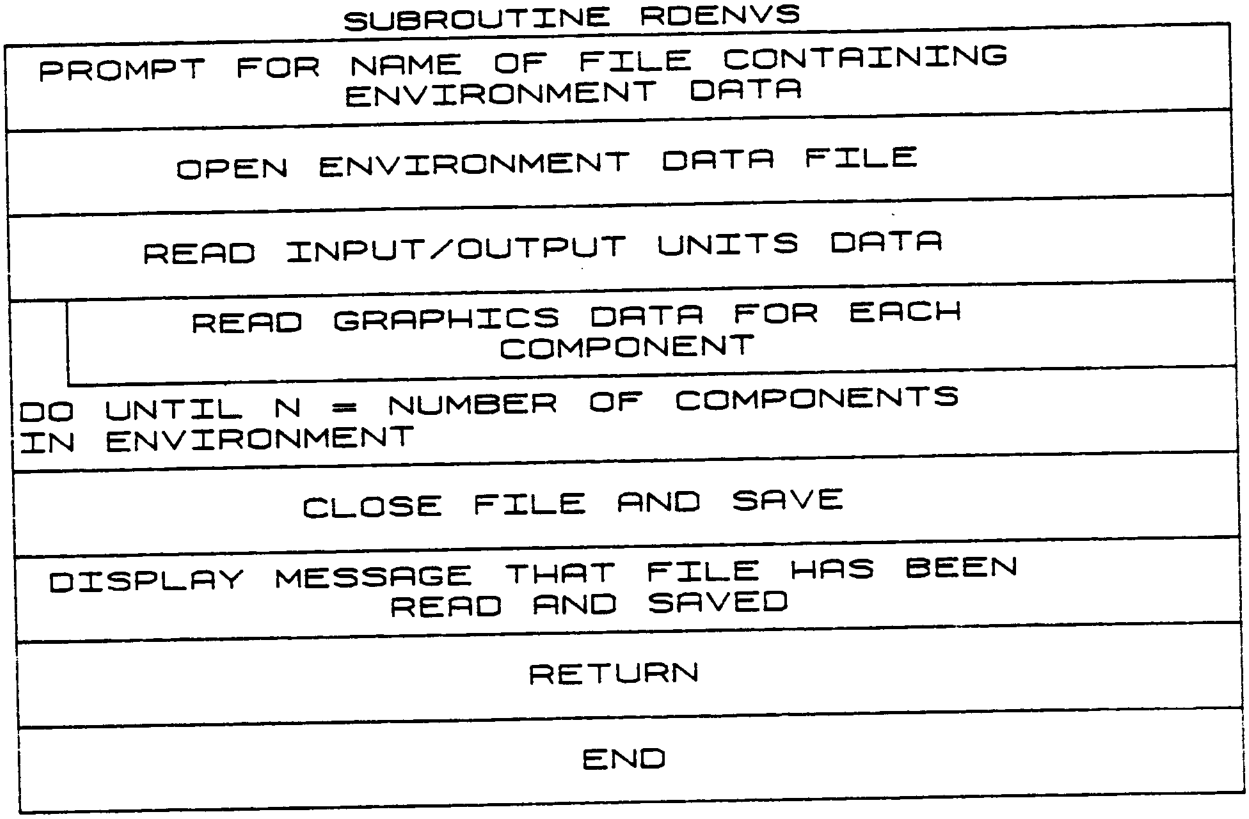
Subroutine ENVIR interactively establishes the basic properties of the system environment during system definition. This includes the input/output units, the gravity vector and the system span.

SUBROUTINE ENVIR



1.2.8 RDENVS

The subroutine RDENVS is called from BLDSYS if the user wishes to include an environment in the system being created. This routine reads the unformatted environment data file created by the system definition function for the multiarm system. The user is prompted for the name of the data file under which the environment data have been stored. The file is opened and COMMON block ENVTBK loaded from the data file during system creation. The file is closed and saved.



```
SUBROUTINE RDENVS
PROMPT FOR NAME OF FILE CONTAINING
    ENVIRONMENT DATA
OPEN ENVIRONMENT DATA FILE
READ INPUT/OUTPUT UNITS DATA
    READ GRAPHICS DATA FOR EACH
        COMPONENT
DO UNTIL N = NUMBER OF COMPONENTS
IN ENVIRONMENT
CLOSE FILE AND SAVE
DISPLAY MESSAGE THAT FILE HAS BEEN
    READ AND SAVED
RETURN
END
```

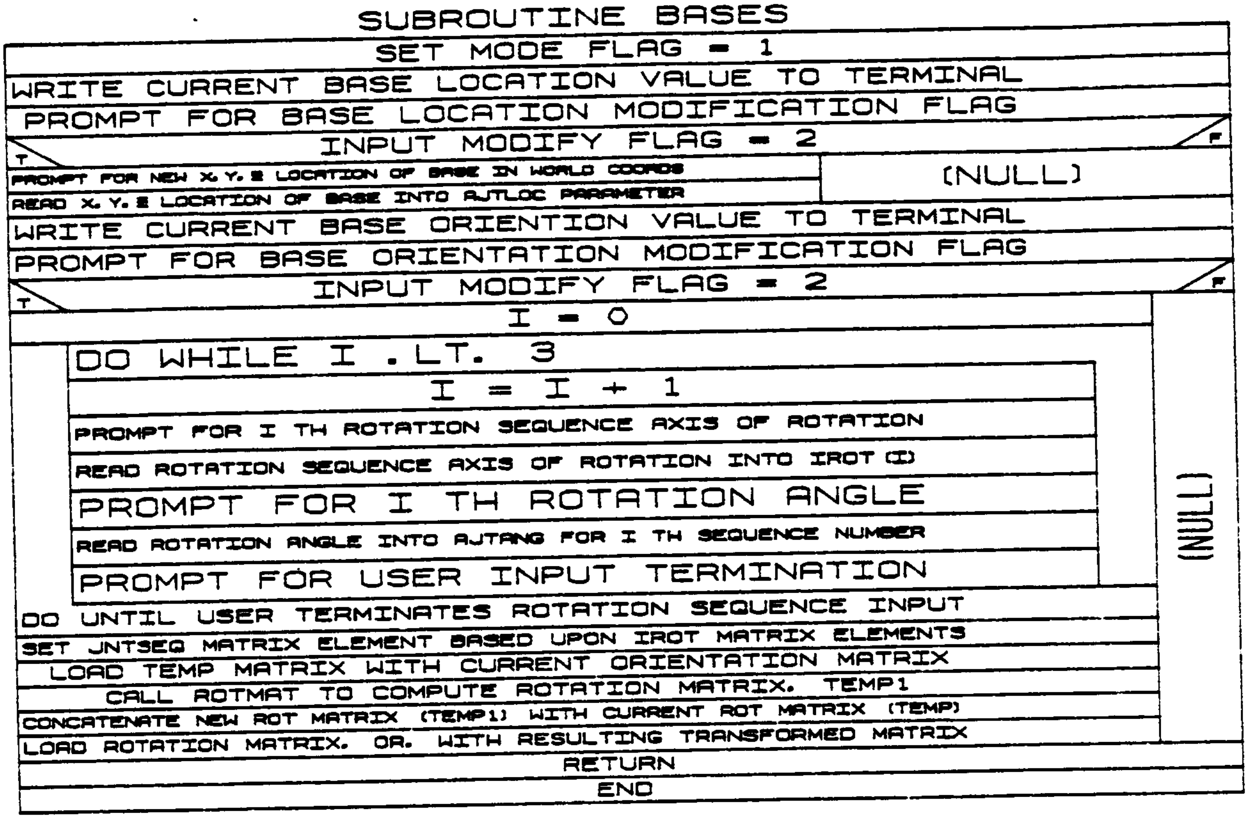
1.2.9 RDARMS

Routine RDARMS is called during the total robotic system creation for each of the arms desired for inclusion in the system setup. The subroutine RDARMS reads the unformatted data file created by the system definition function containing any one arm file. The user is prompted for the name of the data file under which the arm data have been stored. The file is opened and read into the following COMMON blocks: GEOMBK, AMASBK, IOBJBK, TOOLBK, FORCBK, MOTORBK and SPJTBK.

```
SUBROUTINE RDARMS
SET PROCESSSOR MODE = 1. FOR SYSTEM DEFINITION
PROMPT USER FOR FILENAME OF SINGLE ARM FILE TO READ
OPEN ARM DATA FILE
STORE SYSTEM UNITS IN TEMPORARY ARRAYS
READ UNITS COMMON BLOCK INTO SYSTEM COMMON
READ GEOMETRY COMMON BLOCK FOR BASE. JTS. AND TOOL INTO SYSTEM COMMON
READ MASS PROPERTIES COMMON BLOCK FOR BASE. JTS. AND TOOL INTO SYSTEM COMMON
CONVERT PROPERTIES TO INTERNAL UNITS FOR SLIDING AND ROTATING JTS.
PUT TOOL MASS PROPERTIES INTO SYSTEM TOOL COMMON BLOCK
READ GRAPHICS DATA COMMON BLOCK INTO SYSTEM COMMON
CONVERT ARM SPAN TO INTERNAL UNITS
SCALE GRAPHICS OBJECT DATA BY (ARM SPAN / SYSTEM SPAN)
READ ACTUATOR DATA COMMON BLOCK INTO SYSTEM COMMON
CONVERT ACTUATOR DATA TO INTERNAL UNITS
READ SPECIAL JOINT DATA COMMON BLOCK INTO SYSTEM COMMON
CLOSE SINGLE ARM DATA FILE
REWRITE SYSTEM UNITS INTO SYSTEM UNITS COMMON BLOCK
RETURN
END
```

1.2.10 BASES

BASES modifies the base location or orientation when including an arm in a system; it is called from BLDSYS.



```
SUBROUTINE BASES
SET MODE FLAG = 1
WRITE CURRENT BASE LOCATION VALUE TO TERMINAL
PROMPT FOR BASE LOCATION MODIFICATION FLAG
IF INPUT MODIFY FLAG = 2
  T:
    PROMPT FOR NEW X. Y. Z LOCATION OF BASE IN WORLD COORDS
    READ X. Y. Z LOCATION OF BASE INTO AJTLOC PARAMETER
  F:
    (NULL)
WRITE CURRENT BASE ORIENTION VALUE TO TERMINAL
PROMPT FOR BASE ORIENTATION MODIFICATION FLAG
IF INPUT MODIFY FLAG = 2
  T:
    I = 0
    DO
      DO WHILE I .LT. 3
        I = I + 1
        PROMPT FOR I TH ROTATION SEQUENCE AXIS OF ROTATION
        READ ROTATION SEQUENCE AXIS OF ROTATION INTO IROT (I)
        PROMPT FOR I TH ROTATION ANGLE
        READ ROTATION ANGLE INTO AJTANG FOR I TH SEQUENCE NUMBER
        PROMPT FOR USER INPUT TERMINATION
    DO UNTIL USER TERMINATES ROTATION SEQUENCE INPUT
    SET JNTSEQ MATRIX ELEMENT BASED UPON IROT MATRIX ELEMENTS
    LOAD TEMP MATRIX WITH CURRENT ORIENTATION MATRIX
    CALL ROTMAT TO COMPUTE ROTATION MATRIX. TEMP1
    CONCATENATE NEW ROT MATRIX (TEMP1) WITH CURRENT ROT MATRIX (TEMP)
    LOAD ROTATION MATRIX. OR. WITH RESULTING TRANSFORMED MATRIX
  F:
    (NULL)
RETURN
END
```

1.2.11 SETUP

Subroutine SETUP calls SETUP2 for each arm in the manipulator system to calculate the positions of all arm components in terms of world coordinates.

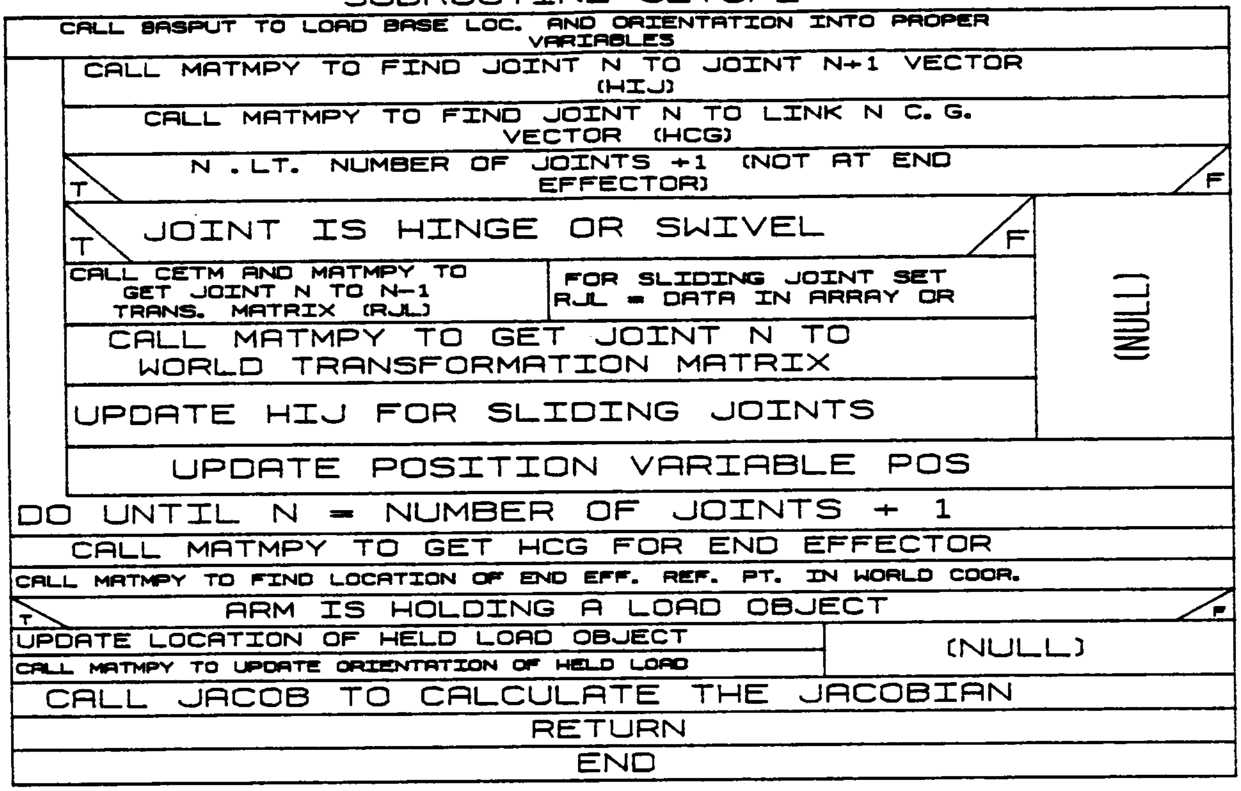
SUBROUTINE SETUP

```
    CALL SETUP2 TO CALCULATE ALL
    POSITIONS IN WORLD COORDINATES
DO UNTIL KARM = NUMBER OF ARMS IN
THE SYSTEM
RETURN
END
```

1.2.12 SETUP2

SETUP2 works every increment. It calculates the positions of all links (including base, tool, and any held loads) and transforms link and centroid vectors to world coordinates. The recursive positioning method described in the main text is used. Finally, subroutine JACOB is called to compute the Jacobian for the current position.

SUBROUTINE SETUP2



```
CALL BASPUT TO LOAD BASE LOC. AND ORIENTATION INTO PROPER VARIABLES
    CALL MATMPY TO FIND JOINT N TO JOINT N+1 VECTOR (HIJ)
    CALL MATMPY TO FIND JOINT N TO LINK N C. G. VECTOR (HCG)
    N .LT. NUMBER OF JOINTS +1 (NOT AT END EFFECTOR)
    T
        JOINT IS HINGE OR SWIVEL
        T
            CALL CETM AND MATMPY TO GET JOINT N TO N-1 TRANS. MATRIX (RJL)
        F
            FOR SLIDING JOINT SET RJL = DATA IN ARRAY OR
        CALL MATMPY TO GET JOINT N TO WORLD TRANSFORMATION MATRIX
        UPDATE HIJ FOR SLIDING JOINTS
    F
        (NULL)
    UPDATE POSITION VARIABLE POS
DO UNTIL N = NUMBER OF JOINTS + 1
CALL MATMPY TO GET HCG FOR END EFFECTOR
CALL MATMPY TO FIND LOCATION OF END EFF. REF. PT. IN WORLD COOR.
ARM IS HOLDING A LOAD OBJECT
T
    UPDATE LOCATION OF HELD LOAD OBJECT
    CALL MATMPY TO UPDATE ORIENTATION OF HELD LOAD
F
    (NULL)
CALL JACOB TO CALCULATE THE JACOBIAN
RETURN
END
```

1.2.13 HARD_COP

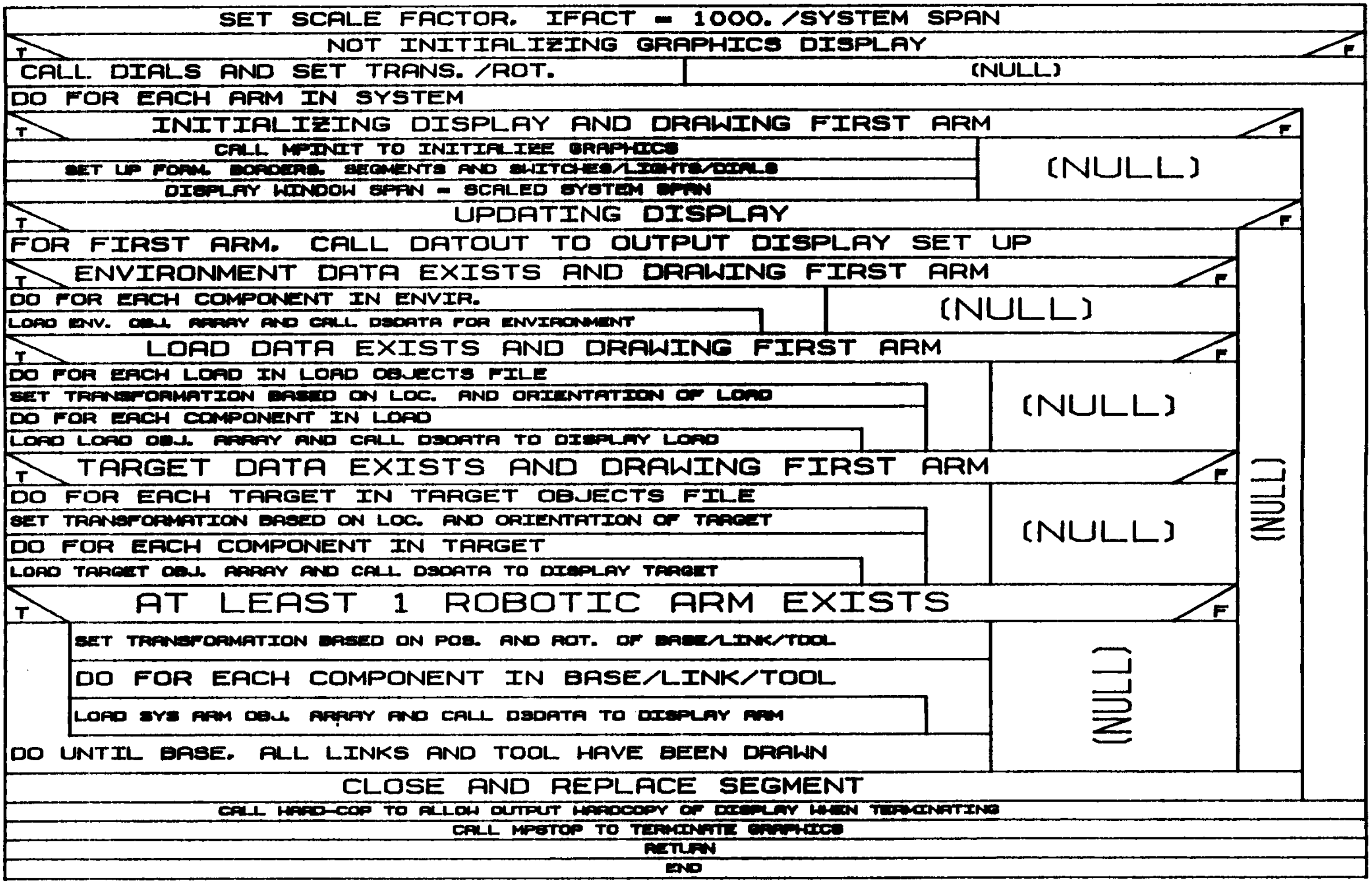
Subroutine HARD_COP is executed when a hardcopy record of the current Evans and Sutherland display may be desired. This routine queries the user to determine if a hardcopy is desired and runs the appropriate routines to create a picture file for later translation into a hardcopy plot.

(VCLR for HARD_COP is not available.)

1.2.14 SYSGRAF

Subroutine SYSGRAF provides the system definition graphics capability in the system definition function. SYSGRAF displays the environment, target, load and robotic arm choices for building a robotic system scenario. It takes as input through the calling sequence, the number of arms in the system, a flag indicating the existence of an environment file for the system, a target file, and a load objects file inclusion indicator. It uses the system span input by the user to scale the graphics picture. IFLAG controls the logical flow in the subroutine. If IFLAG=1, the graphics system is initialized and displayed in the initial condition; if IFLAG =2, the robotic system, targets, loads and environment are displayed; if IFLAG=3, the graphics display is terminated. In the update mode, the environment is constant and therefore not updated. As before, the Evans and Sutherland graphics routines are used to provide all graphic capabilities.

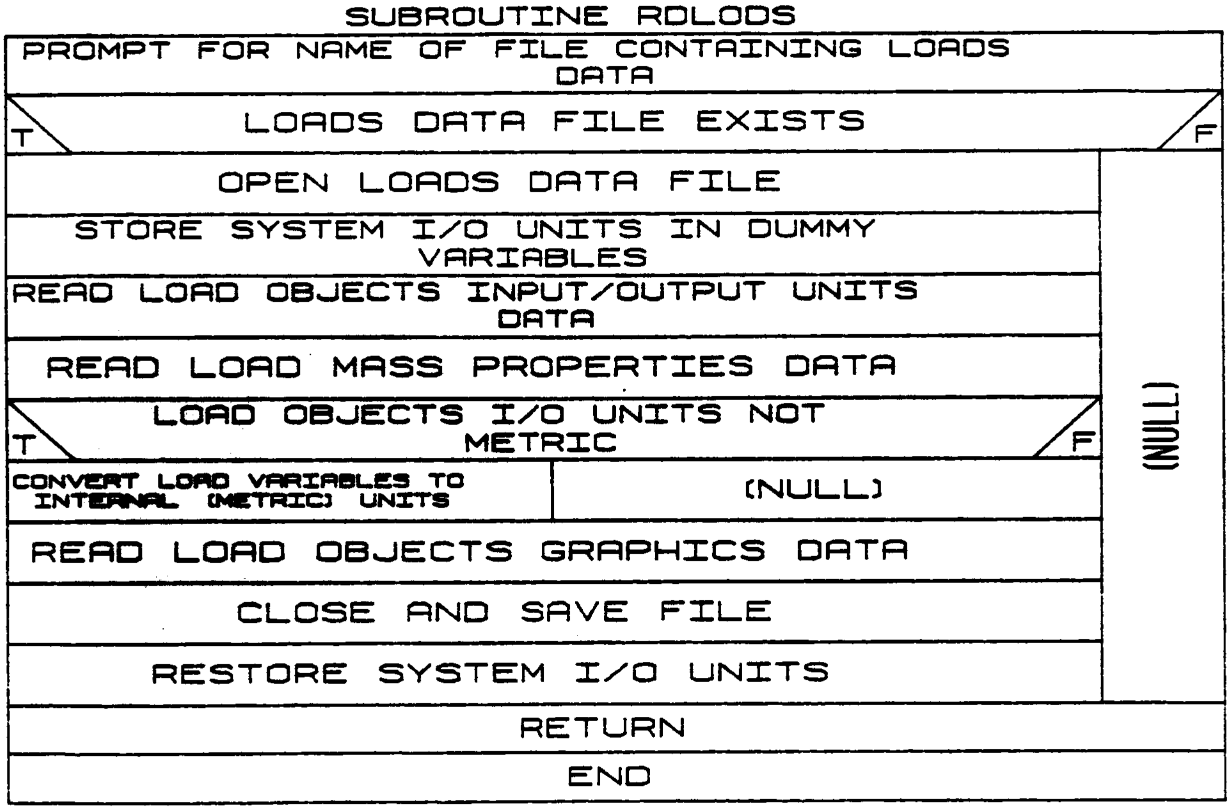
SUBROUTINE SYSGRAF



```
SET SCALE FACTOR. IFACT = 1000./SYSTEM SPAN
IF NOT INITIALIZING GRAPHICS DISPLAY
  T: CALL DIALS AND SET TRANS./ROT.
  F: (NULL)
DO FOR EACH ARM IN SYSTEM
  IF INITIALIZING DISPLAY AND DRAWING FIRST ARM
    T: CALL MPINIT TO INITIALIZE GRAPHICS
       SET UP FORM, BORDERS, SEGMENTS AND SWITCHES/LIGHTS/DIALS
       DISPLAY WINDOW SPAN = SCALED SYSTEM SPAN
    F: (NULL)
  IF UPDATING DISPLAY
    T: FOR FIRST ARM, CALL DATOUT TO OUTPUT DISPLAY SET UP
       IF ENVIRONMENT DATA EXISTS AND DRAWING FIRST ARM
         T: DO FOR EACH COMPONENT IN ENVIR.
              LOAD ENV. OBJ. ARRAY AND CALL DSDATA FOR ENVIRONMENT
         F: (NULL)
       IF LOAD DATA EXISTS AND DRAWING FIRST ARM
         T: DO FOR EACH LOAD IN LOAD OBJECTS FILE
              SET TRANSFORMATION BASED ON LOC. AND ORIENTATION OF LOAD
              DO FOR EACH COMPONENT IN LOAD
                LOAD LOAD OBJ. ARRAY AND CALL DSDATA TO DISPLAY LOAD
         F: (NULL)
       IF TARGET DATA EXISTS AND DRAWING FIRST ARM
         T: DO FOR EACH TARGET IN TARGET OBJECTS FILE
              SET TRANSFORMATION BASED ON LOC. AND ORIENTATION OF TARGET
              DO FOR EACH COMPONENT IN TARGET
                LOAD TARGET OBJ. ARRAY AND CALL DSDATA TO DISPLAY TARGET
         F: (NULL)
       IF AT LEAST 1 ROBOTIC ARM EXISTS
         T: DO
              SET TRANSFORMATION BASED ON POS. AND ROT. OF BASE/LINK/TOOL
              DO FOR EACH COMPONENT IN BASE/LINK/TOOL
                LOAD SYS ARM OBJ. ARRAY AND CALL DSDATA TO DISPLAY ARM
            DO UNTIL BASE, ALL LINKS AND TOOL HAVE BEEN DRAWN
         F: (NULL)
    F: (NULL)
  CLOSE AND REPLACE SEGMENT
CALL HARD-COP TO ALLOW OUTPUT HARDCOPY OF DISPLAY WHEN TERMINATING
CALL MPSTOP TO TERMINATE GRAPHICS
RETURN
END
```

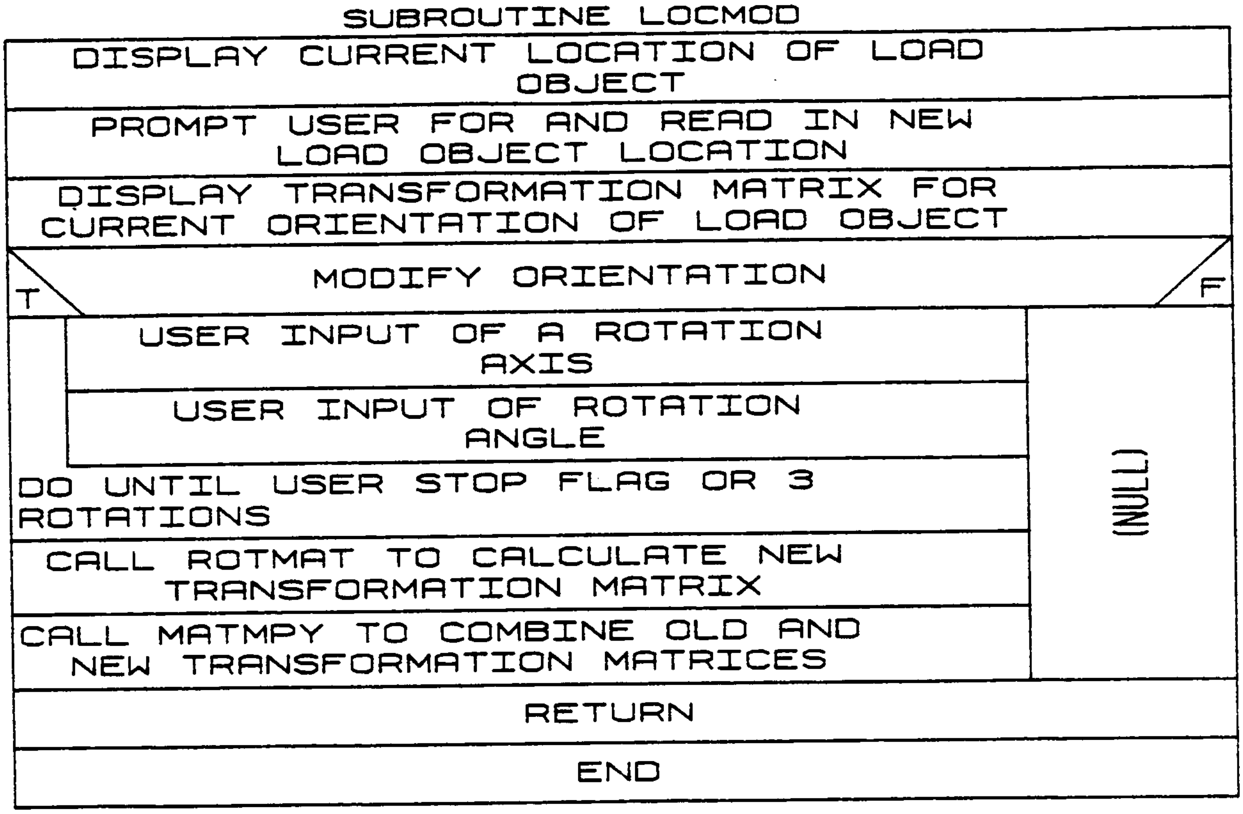
1.2.15 RDLODS

RDLODS reads in load data if the user requests that loads be included in the robotic system under construction. The file read is the unformatted load file created by the system definition function. Subroutine RDLODS prompts the user for the name of the file containing load data, and then reads those data into COMMON blocks LGRAFBK and LOADBK during system creation. The load file is scaled from load units to internal system units, closed, and saved.



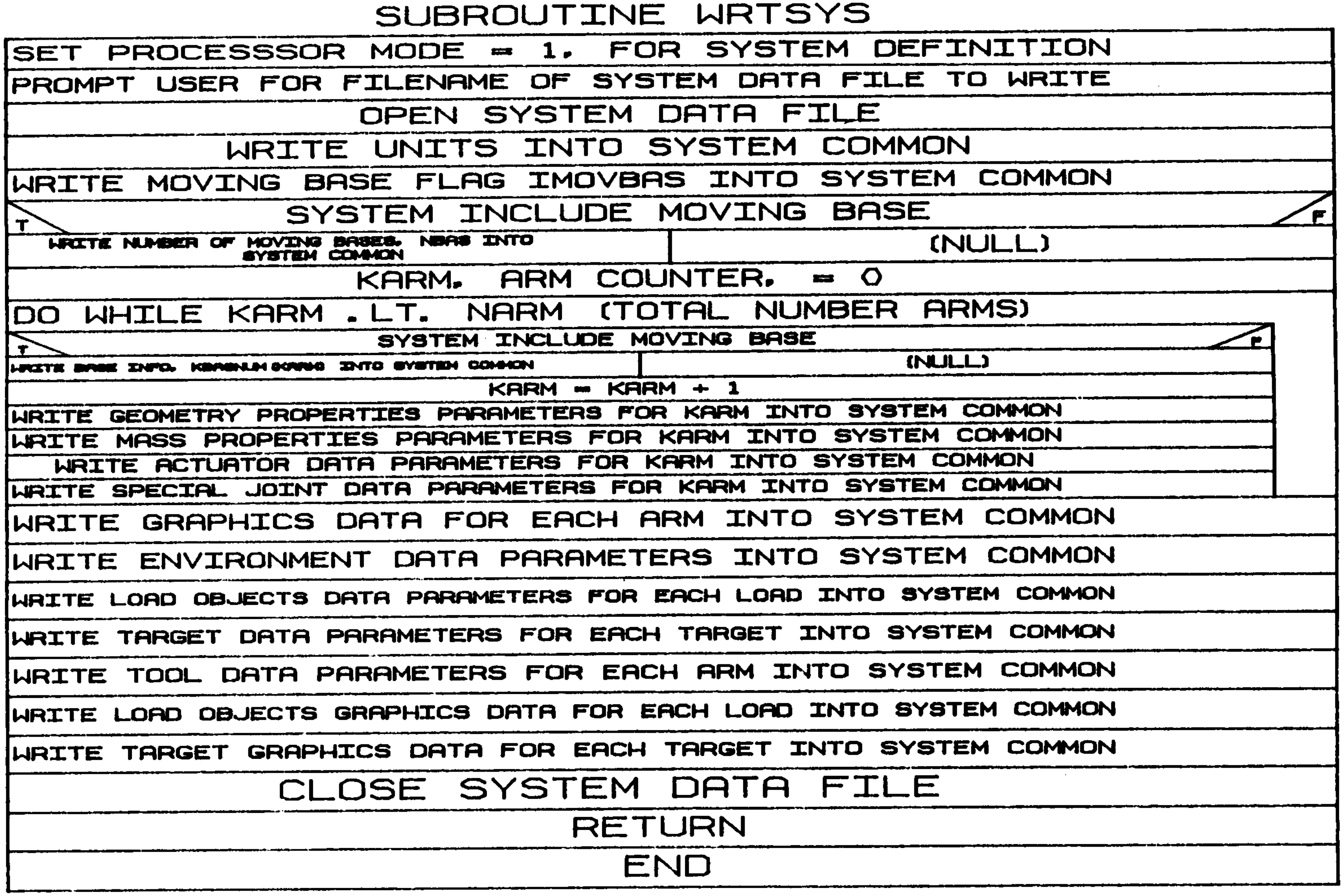
1.2.16 LOCMOD

Subroutine LOCMOD is called from BLDSYS to allow the user to modify the locations and orientations of load objects when building a system. The current location is displayed and then the user is prompted for a new location. The subroutine also displays the transformation matrix for the current orientation of the load object and prompts the user for a sequence of rotation axes and angles that define a change in orientation. ROTMAT is called to calculate the transformation matrix from the user input, and MATMPY combines this new transformation matrix with the old one.



1.2.17 WRTSYS

Subroutine WRTSYS is called from BLDSYS to write an unformatted file containing the data needed to describe a system. These date include user units, moving base flags, arm geometry, mass and actuator properties, special joint data, arm graphics, environment, load object and target properties, tool data, and load object and target graphics information.



```
SUBROUTINE WRTSYS
SET PROCESSSOR MODE = 1. FOR SYSTEM DEFINITION
PROMPT USER FOR FILENAME OF SYSTEM DATA FILE TO WRITE
OPEN SYSTEM DATA FILE
WRITE UNITS INTO SYSTEM COMMON
WRITE MOVING BASE FLAG IMOVBAS INTO SYSTEM COMMON
SYSTEM INCLUDE MOVING BASE
  T: WRITE NUMBER OF MOVING BASES, NBAS INTO SYSTEM COMMON
  F: (NULL)
KARM, ARM COUNTER, = 0
DO WHILE KARM .LT. NARM (TOTAL NUMBER ARMS)
    SYSTEM INCLUDE MOVING BASE
      T: WRITE BASE INFO. KBASNUM(KARM) INTO SYSTEM COMMON
      F: (NULL)
    KARM = KARM + 1
    WRITE GEOMETRY PROPERTIES PARAMETERS FOR KARM INTO SYSTEM COMMON
    WRITE MASS PROPERTIES PARAMETERS FOR KARM INTO SYSTEM COMMON
    WRITE ACTUATOR DATA PARAMETERS FOR KARM INTO SYSTEM COMMON
    WRITE SPECIAL JOINT DATA PARAMETERS FOR KARM INTO SYSTEM COMMON
WRITE GRAPHICS DATA FOR EACH ARM INTO SYSTEM COMMON
WRITE ENVIRONMENT DATA PARAMETERS INTO SYSTEM COMMON
WRITE LOAD OBJECTS DATA PARAMETERS FOR EACH LOAD INTO SYSTEM COMMON
WRITE TARGET DATA PARAMETERS FOR EACH TARGET INTO SYSTEM COMMON
WRITE TOOL DATA PARAMETERS FOR EACH ARM INTO SYSTEM COMMON
WRITE LOAD OBJECTS GRAPHICS DATA FOR EACH LOAD INTO SYSTEM COMMON
WRITE TARGET GRAPHICS DATA FOR EACH TARGET INTO SYSTEM COMMON
CLOSE SYSTEM DATA FILE
RETURN
END
```

1.2.18 RDENV

The subroutine RDENV reads an unformatted environment data file during the system definition function. The content of the file is the pertinent COMMON block defining an environment for the robotic system. The user is prompted for the file name from which the file is to be read.

```
SUBROUTINE RDENV
PROMPT USER FOR FILENAME OF
ENVIRONMENT FILE TO READ
OPEN ENVIRONMENT DATA FILE
READ UNITS COMMON BLOCK
READ ENVIRONMENT GRAPHICS DATA
COMMON BLOCK
CLOSE ENVIRONMENT DATA FILE
RETURN
END
```

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1.2.19 DRWENV

DRWENV is called within the system definition function from BLDENV to provide graphics display during the generation of detailed environment graphics representations. It is called to display each successive environment component as it is defined.

```
SUBROUTINE DRWENV
SET PROCESSOR MODE = 1. FOR SYSTEM DEFINITION
IF INITIALIZING
  T:
    PROMPT USER FOR ENVIRONMENT SPAN
  F:
    (NULL)
SET SCALE FACTOR. IFACT = 1000./ENVIR. SPAN
IF INITIALIZING DISPLAY
  T:
    ZERO INTEGER TRANSLATION AND ROTATION VALUES
    SET WINDOW BOUNDARIES
    DRAW COLOR COORDINATED AXES SYSTEM (RED-X, WHT-Y, BLU-Z)
  F:
    SET PICTURE PROCESSOR TRANS. TO IDENTITY
    CALL DIALS TO STATUS ANALOG CONTROL DIALS
    SET CURRENT INTEGER TRANSLATION AND ROT. VALUES
IF DRAWING OR REPLACING COMPONENT
  T:
    SET WINDOW BOUNDARIES
    SET CURRENT INTEGER TRANSLATION AND ROT. VALUES
    SET NUMBER OF COMPONENTS IN ENVIR. PARAMETER
    DO FOR ALL COMPONENTS BEFORE CURRENT COMP.
      SET GRAPHICS FLAGS FOR SEQUENTIAL AND ALTERNATING PTS.
      CALL D3DATA TO DISPLAY COMPONENT
      SET COUNTER FOR LAST ENV. OBJECT ARRAY LOCATION USED
    SET GRAPHICS FLAGS FOR SEQUENTIAL AND ALTERNATING PTS.
    CALL D3DATA TO DISPLAY COMPONENT
    SET COUNTER FOR LAST ENV. OBJECT ARRAY LOCATION USED
    CLOSE AND REPLACE SEGMENT
  F:
    (NULL)
RETURN
END
```

1.2.20 WRTENV

Subroutine WRTENV writes an unformatted environment data file during the system definition function. The content of the file is the pertinent COMMON block defining an environment.

```
SUBROUTINE WRTENV
PROMPT USER FOR FILENAME OF ENVIRONMENT FILE TO WRITE
OPEN ENVIRONMENT DATA FILE
WRITE UNITS COMMON BLOCK
WRITE ENVIRONMENT GRAPHICS DATA COMMON BLOCK
CLOSE ENVIRONMENT DATA FILE
RETURN
END
```

1.2.21 RDLOAD

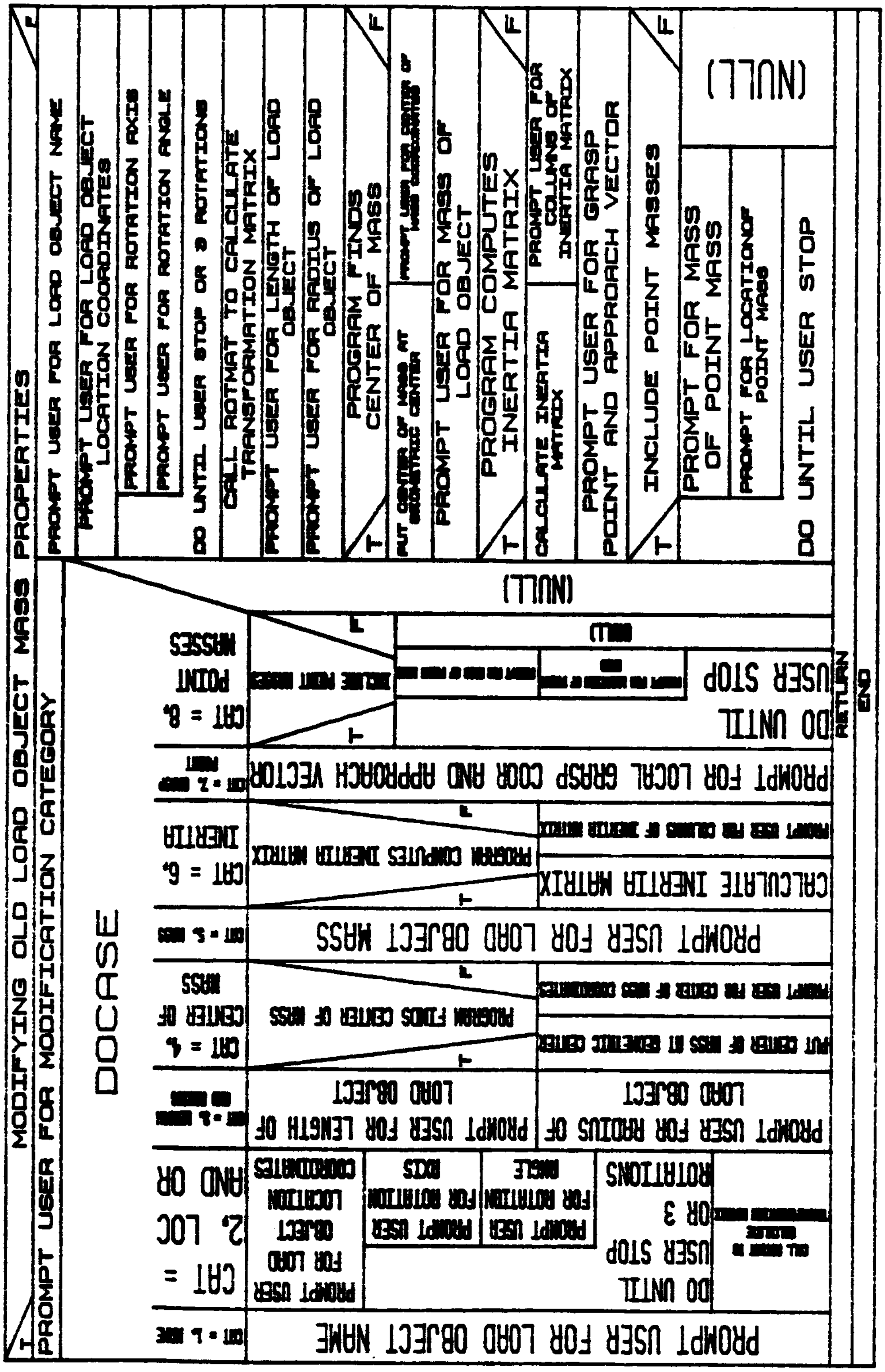
The subroutine RDLOAD reads an unformatted load objects data file during the system definition function. The contents of the file are the pertinent COMMON blocks defining a load file for the robotic system. The user is prompted for the file name from which the file is to be read.

```
SUBROUTINE RDLOAD
    PROMPT USER FOR FILENAME OF LOAD OBJECTS FILE TO READ
    OPEN LOAD OBJECTS DATA FILE
    READ UNITS COMMON BLOCK
    READ LOAD OBJECTS MASS PROPERTIES COMMON BLOCK
    READ LOAD OBJECTS GRAPHICS DATA COMMON BLOCK
    CLOSE LOAD OBJECTS DATA FILE
    RETURN
END
```

1.2.22 LOAD

Subroutine LOAD is called during the BLDLOD option of INITDRVR. It allows the user to create and define the mass properties of one or more load objects. If a file of load object data already exists, this subroutine may be used to modify portions of those data. The load parameters for which the user is prompted are listed:

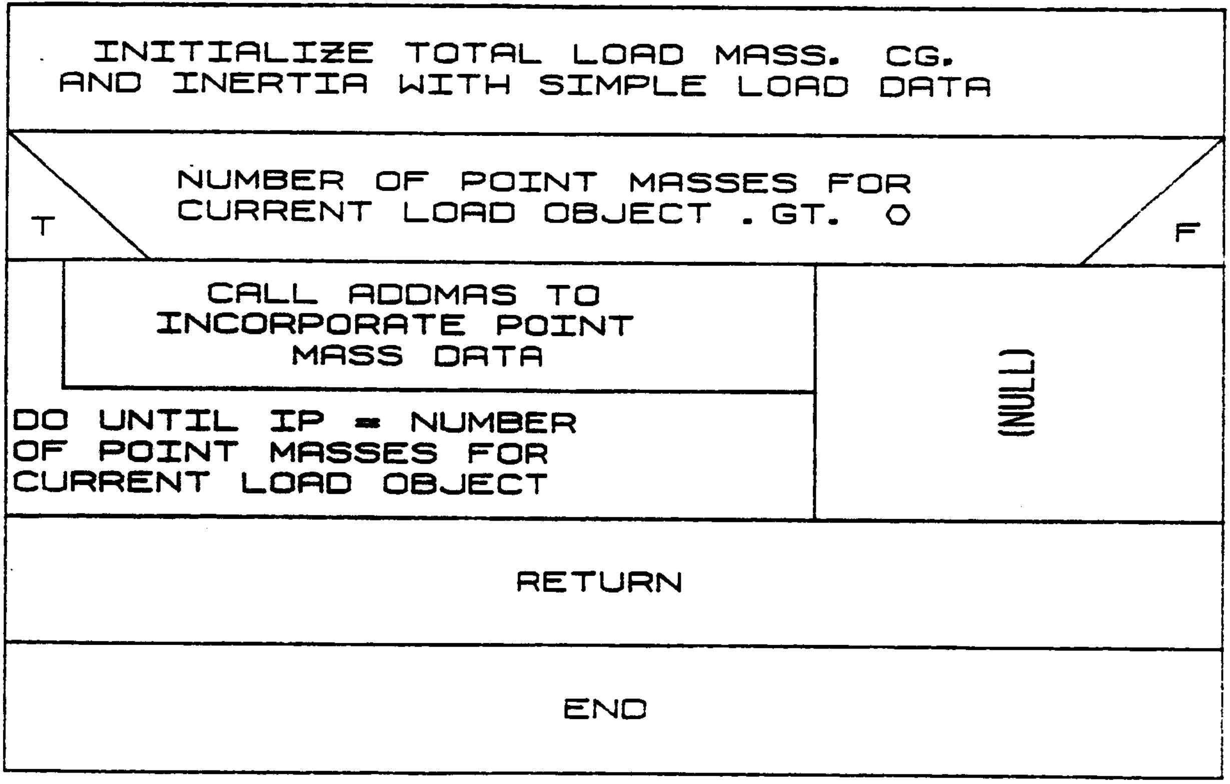
1) Load object name (up to 8 characters);
2) Location and orientation with respect to the world coordinate system;
3) Length and radius;
4) Center of mass;
5) Mass;
6) Inertia distribution;
7) Grasp point and approach vector in load local coordinates;
8) Mass and location of any point masses included.


SUBROUTINE LOAD
MODIFYING OLD LOAD OBJECT MASS PROPERTIES
PROMPT USER FOR MODIFICATION CATEGORY
DOCASE
T
F
CAT = 1. NAME
PROMPT USER FOR LOAD OBJECT NAME
CAT = 2. LOC AND OR
PROMPT USER FOR LOAD OBJECT LOCATION COORDINATES
PROMPT USER FOR ROTATION AXIS
PROMPT USER FOR ROTATION ANGLE
DO UNTIL USER STOP OR 3 ROTATIONS
CALL ROTMAT TO CALCULATE TRANSFORMATION MATRIX
PROMPT USER FOR LENGTH OF LOAD OBJECT
PROMPT USER FOR RADIUS OF LOAD OBJECT
CAT = 4. CENTER OF MASS
PROGRAM FINDS CENTER OF MASS
PUT CENTER OF MASS AT GEOMETRIC CENTER
PROMPT USER FOR CENTER OF MASS COORDINATES
CAT = 5. MASS
PROMPT USER FOR LOAD OBJECT MASS
CAT = 6. INERTIA
PROGRAM COMPUTES INERTIA MATRIX
CALCULATE INERTIA MATRIX
PROMPT USER FOR COLUMNS OF INERTIA MATRIX
CAT = 7. GRASP POINT
PROMPT FOR LOCAL GRASP COOR AND APPROACH VECTOR
PROMPT USER FOR GRASP POINT AND APPROACH VECTOR
CAT = 8. POINT MASSES
INCLUDE POINT MASSES
PROMPT FOR MASS OF POINT MASS
PROMPT FOR LOCATION OF POINT MASS
DO UNTIL USER STOP
(NULL)
RETURN
END

1.2.23 TLDMAS

Subroutine TLDMAS is called from BLDLOD to add the effects of point masses included in a load object. Variables for total mass, centroid location, and rotary inertia are initialized with the values for the simple load object. If point masses are included, ADDMAS is called to calculate new values for these variables that include the point mass effects.

SUBROUTINE TLDMAS



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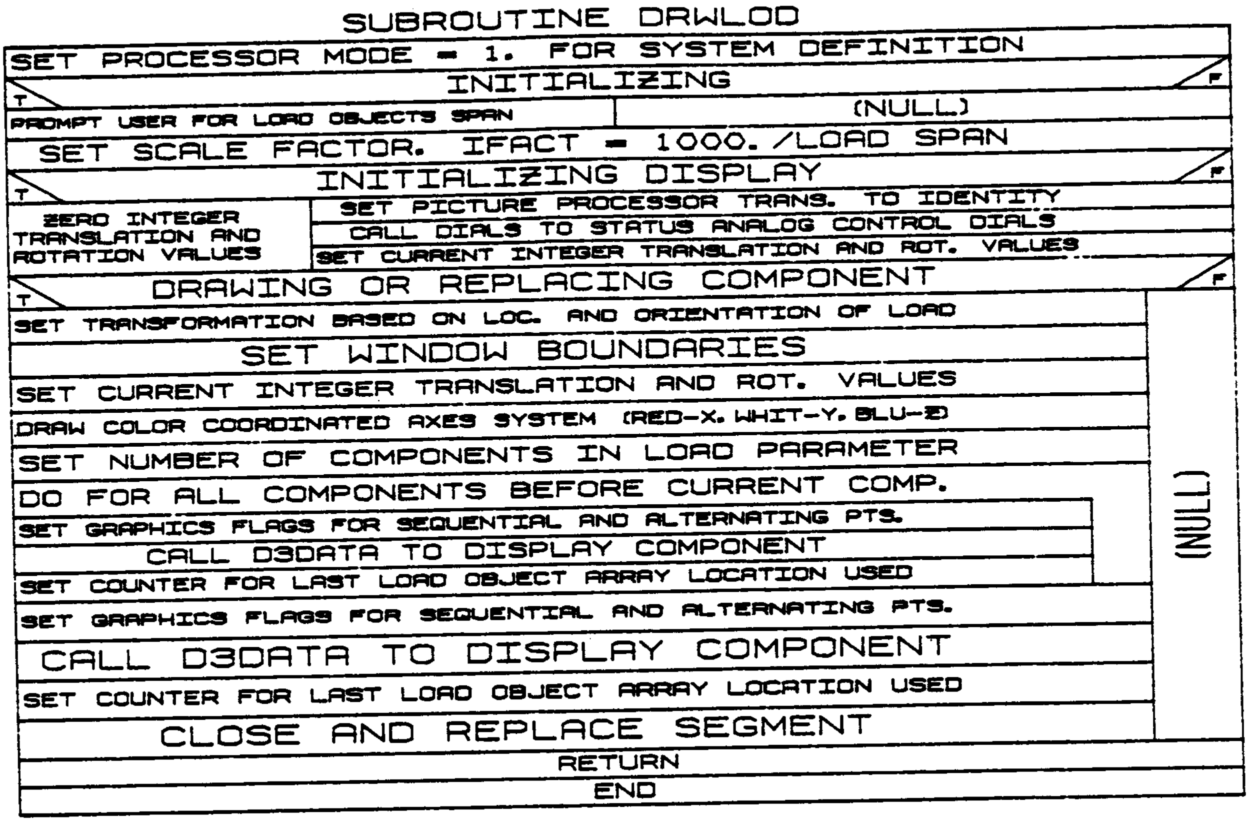
1.2.24 DRWLOD

DRWLOD is called within the system definition function from BLDLOD to provide graphics display during the generation of a detailed load objects file. It is called to display each successive load object component as it is defined.



1.2.25 WRTLOD

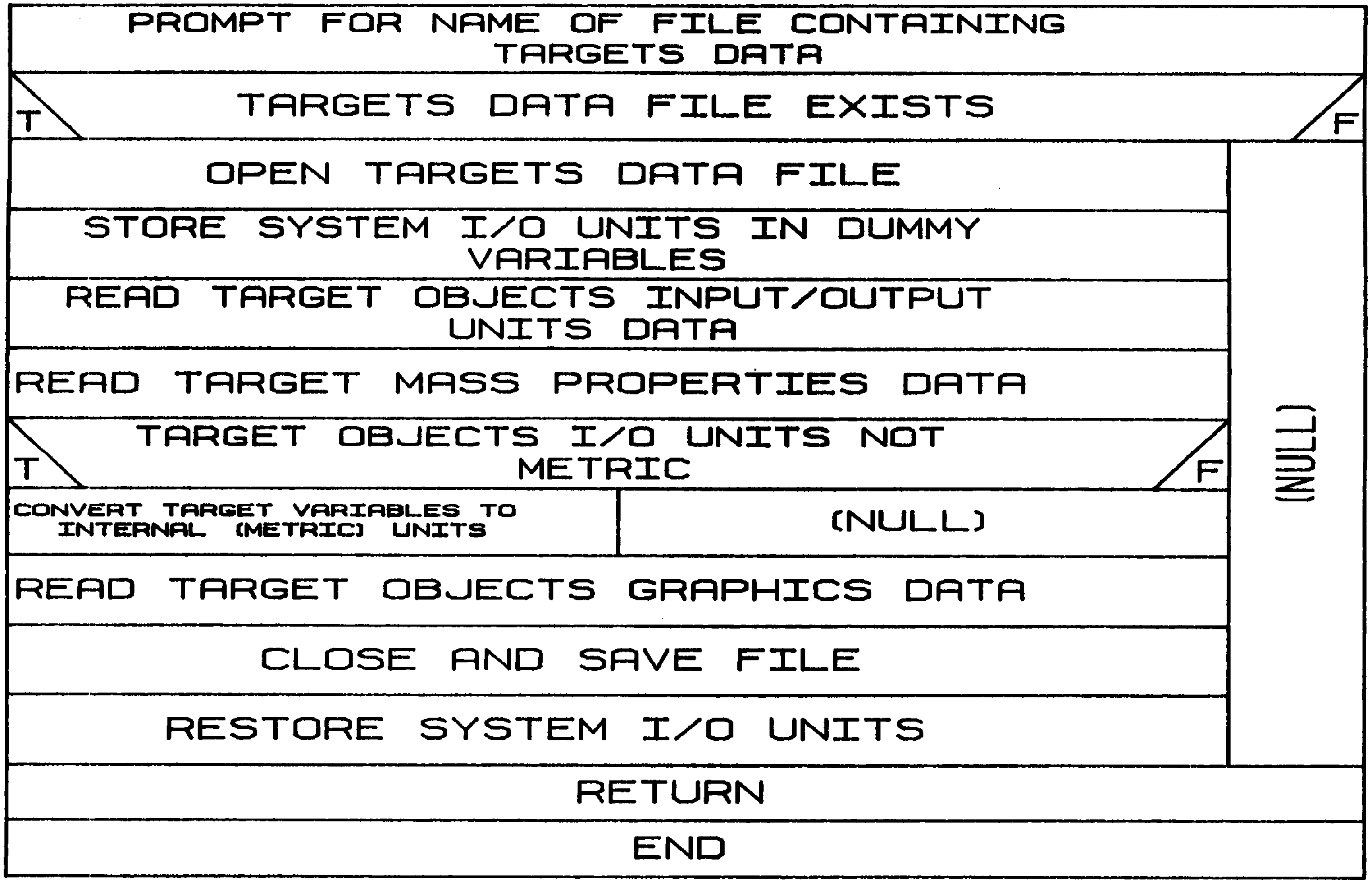
Subroutine WRTLOD writes the unformatted load objects data file during the system definition function. The contents of the file are the pertinent COMMON blocks defining the mass properties and graphics of the loads for a system.

```
SUBROUTINE WRTLOD
PROMPT USER FOR FILENAME OF LOAD OBJECTS FILE TO WRITE
OPEN LOAD OBJECTS DATA FILE
WRITE UNITS COMMON BLOCK
WRITE LOAD OBJECTS MASS PROPERTIES COMMON BLOCK
WRITE LOAD OBJECTS GRAPHICS DATA COMMON BLOCK
CLOSE LOAD OBJECTS DATA FILE
RETURN
END
```

1.2.26 RDTRGS

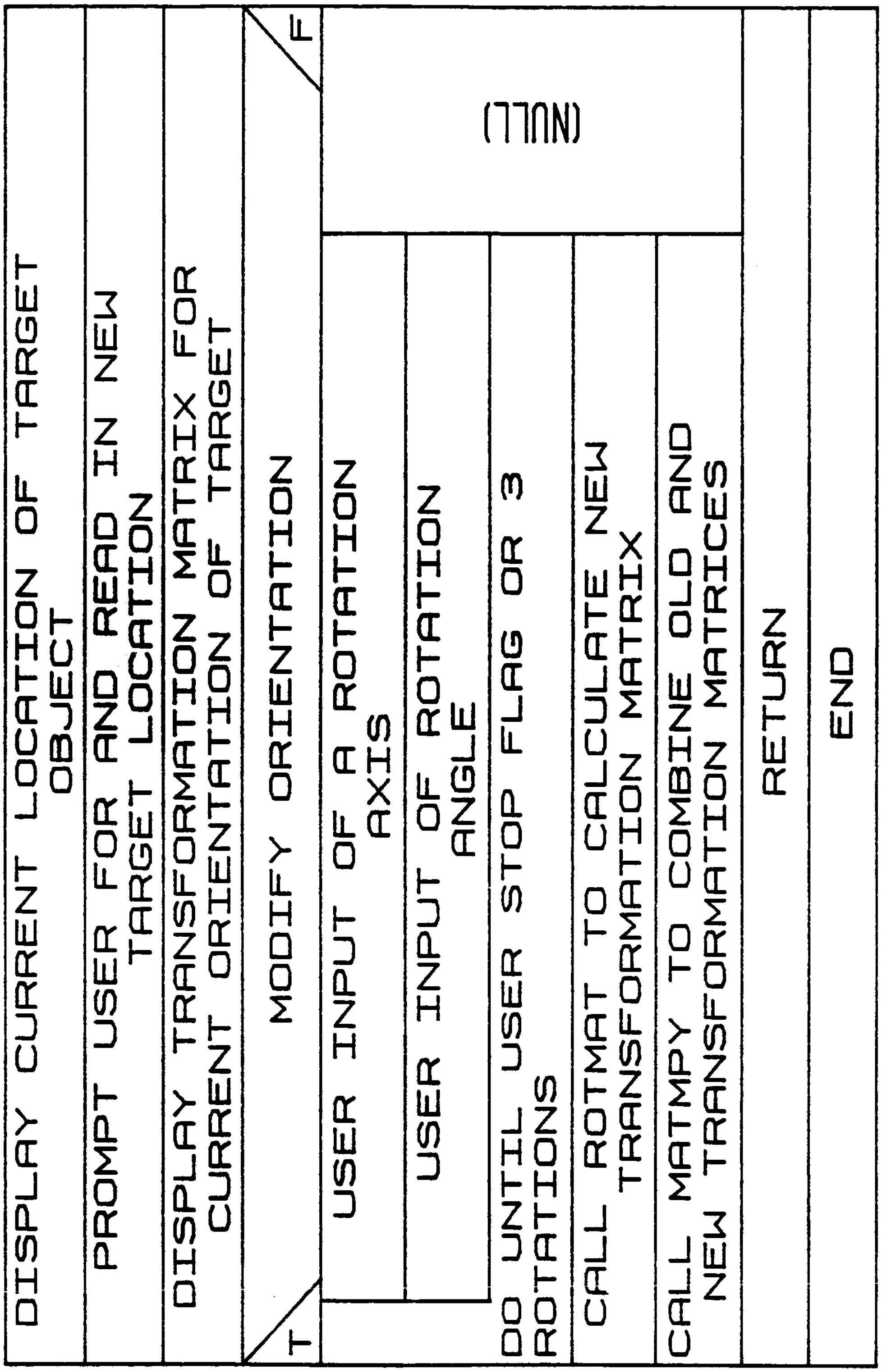
RDTRGS reads in target data if the user requests that targets be included in the robotic system under construction. The file read is the unformatted target file created by the system definition function. Subroutine RDTRGS prompts the user for the name of the file containing target data, and then reads those data into common blocks TGRAFBK and TARGBK during system creation. The target file is scaled from target units to internal system units, closed, and saved.

SUBROUTINE RDTRGS



1.2.27 LOCTMOD

Subroutine LOCTMOD is called from BLDSYS to allow the user to modify the locations and orientations of target objects when building a system. The current location is displayed, and then the user is prompted for a new location. The subroutine also displays the transformation matrix for the current orientation of the target object and prompts the user for a sequence of rotation axes and angles that define a change in orientation. ROTMAT is called to calculate the transformation matrix from the user input, and MATMPY combines this new transformation matrix with the old one.


SUBROUTINE LOCTMOD
DISPLAY CURRENT LOCATION OF TARGET OBJECT
PROMPT USER FOR AND READ IN NEW TARGET LOCATION
DISPLAY TRANSFORMATION MATRIX FOR CURRENT ORIENTATION OF TARGET
MODIFY ORIENTATION
T
F
USER INPUT OF A ROTATION AXIS
USER INPUT OF ROTATION ANGLE
DO UNTIL USER STOP FLAG OR 3 ROTATIONS
(NULL)
CALL ROTMAT TO CALCULATE NEW TRANSFORMATION MATRIX
CALL MATMPY TO COMBINE OLD AND NEW TRANSFORMATION MATRICES
RETURN
END

1.2.28 RDTARG

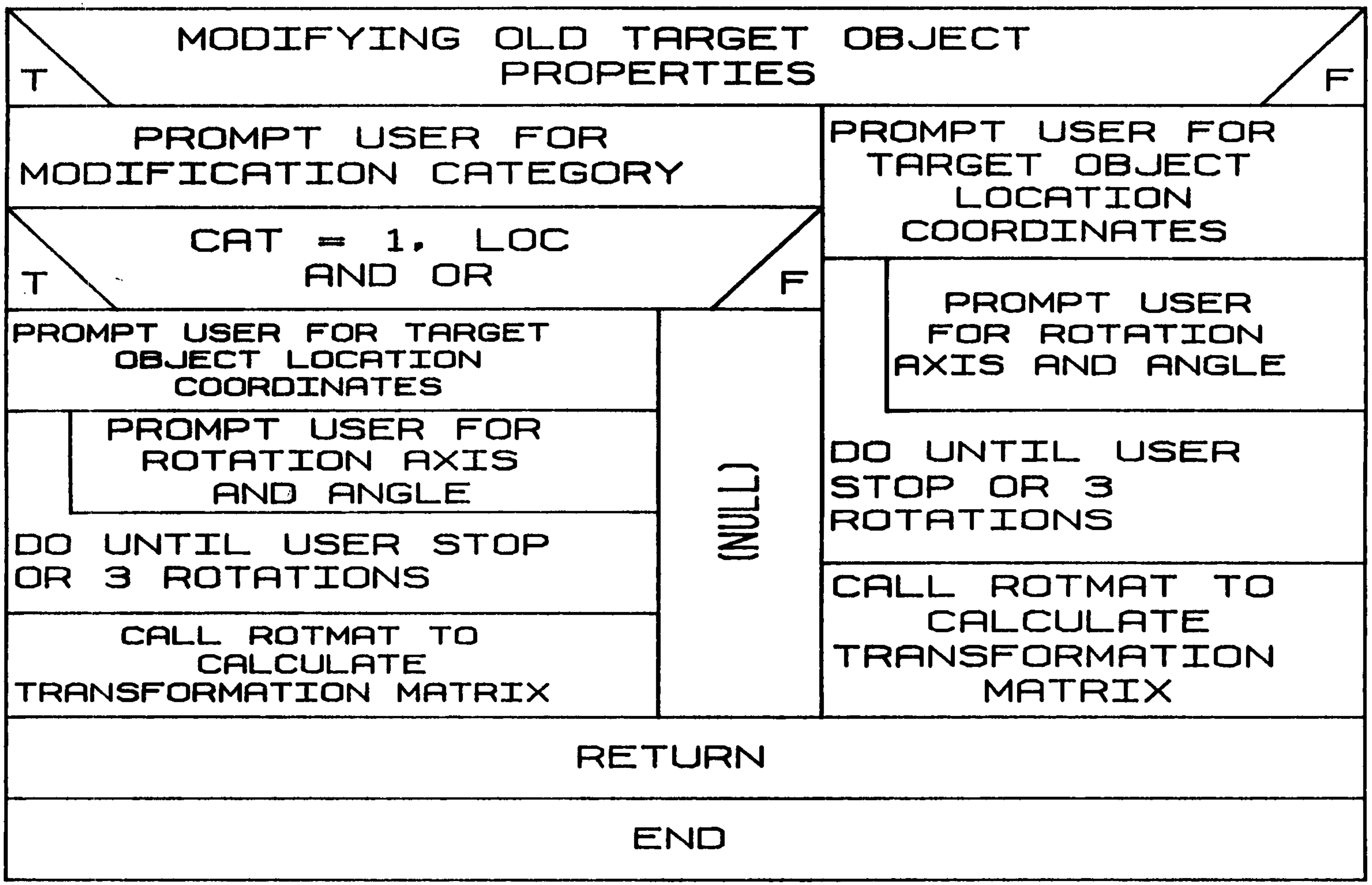
The subroutine RDTARG reads an unformatted target object data file during the system definition function. The contents of the file are the pertinent common blocks defining a target file for the robotic system. The user is prompted for the file name from which the file is to be read.

```
SUBROUTINE RDTARG
PROMPT USER FOR FILENAME OF TARGET OBJECTS FILE TO READ
OPEN TARGET OBJECTS DATA FILE
READ UNITS COMMON BLOCK
READ TARGET OBJECTS MASS PROPERTIES COMMON BLOCK
READ TARGET OBJECTS GRAPHICS DATA COMMON BLOCK
CLOSE TARGET OBJECTS DATA FILE
RETURN
END
```

1.2.29 TARGET

Subroutine TARGET is called during the BLDTRG option of INITDRVR. It allows the user to create and define the properties of one or more target objects. If a file of target object data already exists, this subroutine may be used to modify portions of these data. The target parameters for which the user is prompted are the location and orientation with respect to the world coordinates.

SUBROUTINE TARGET



1.2.30 DRWTRG

DRWTRG is called within the system definition function from BLDTRG to provide graphics display during the generation of a detailed target object file. It is called to display each successive target object component as it is defined.

SUBROUTINE DRWTRG

```
SET PROCESSOR MODE = 1, FOR SYSTEM DEFINITION
INITIALIZING
  T: PROMPT USER FOR TARGET OBJECTS SPAN
  F: (NULL)
SET SCALE FACTOR, IFACT = 1000./TARGET SPAN
INITIALIZING DISPLAY
  T: ZERO INTEGER TRANSLATION AND ROTATION VALUES
  F: SET PICTURE PROCESSOR TRANS. TO IDENTITY
     CALL DIALS TO STATUS ANALOG CONTROL DIALS
     SET CURRENT INTEGER TRANSLATION AND ROT. VALUES
DRAWING OR REPLACING COMPONENT
  T: SET TRANSFORMATION BASED ON LOC. AND ORIENTATION OF TARGET
     SET WINDOW BOUNDARIES
     SET CURRENT INTEGER TRANSLATION AND ROT. VALUES
     DRAW COLOR COORDINATED AXES SYSTEM (RED-X, WHIT-Y, BLU-Z)
     SET NUMBER OF COMPONENTS IN TARGET PARAMETER
     DO FOR ALL COMPONENTS BEFORE CURRENT COMP.
        SET GRAPHICS FLAGS FOR SEQUENTIAL AND ALTERNATING PTS.
        CALL D3DATA TO DISPLAY COMPONENT
        SET COUNTER FOR LAST TARGET OBJECT ARRAY LOCATION USED
     SET GRAPHICS FLAGS FOR SEQUENTIAL AND ALTERNATING PTS.
     CALL D3DATA TO DISPLAY COMPONENT
     SET COUNTER FOR LAST TARGET OBJECT ARRAY LOCATION USED
     CLOSE AND REPLACE SEGMENT
  F: (NULL)
RETURN
END
```

1.2.31 WRTTRG

Subroutine WRTTRG writes the unformatted target object data file during the system definition function. The contents of the file are the pertinent common blocks defining the mass properties and graphics of the targets for the system.

SUBROUTINE WRTTRG

```
PROMPT USER FOR FILENAME OF TARGET
  OBJECTS FILE TO WRITE
OPEN TARGET OBJECTS DATA FILE
WRITE UNITS COMMON BLOCK
WRITE TARGET OBJECTS MASS
  PROPERTIES COMMON BLOCK
WRITE TARGET OBJECTS GRAPHICS DATA
  COMMON BLOCK
CLOSE TARGET OBJECTS DATA FILE
RETURN
END
```

1.3.1 GRINIT

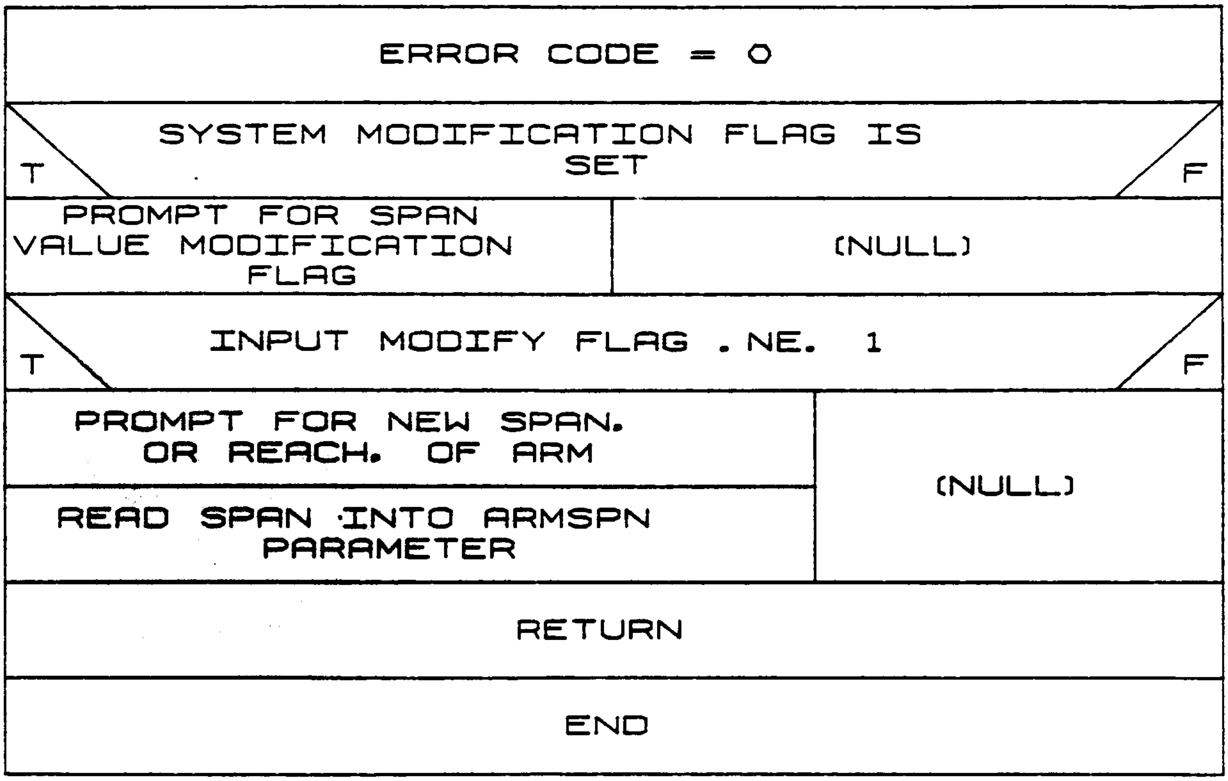
For building an environment, simple arm, detailed arm, targets or loads with graphics, routine GRINIT initializes the E&S display, extended switches/lights, and analog control dials, and draws the graphics display border. Working from the input flag IFLAG, the type heading of the general display is chosen, either simple cylinder, detailed geometry, environment, target or load. The graphics segments are opened and the title for the system definition function driver currently under execution is output.

```
SUBROUTINE GRINIT
CALL MPINIT TO INITIALIZE GRAPHICS SYSTEM
INITIALIZE EXTENDED FUNCTION KEY SWITCHES
INITIALIZE EXTENDED FUNCTION KEY LIGHTS
INITIALIZE ANALOG CONTROL DIALS
INITIALIZE EVENT QUEUE
DRAW GRAPHICS DISPLAY BORDER
OUTPUT GRAPHICS DISPLAY TITLE
OUTPUT MARTIN MARIETTA COMPANY LOGO
TRANSFER INITIAL READINGS OF CONTROL DIALS FROM DEVICE QUEUE
RETURN
END
```

1.3.2 SPAN

The manipulator arm span is requested as input from the user during initial creation of simple cylinder arm data; modification of the ARMSPN value is also allowed through a call to SPAN during the CREATARM modification mode.

SUBROUTINE SPAN



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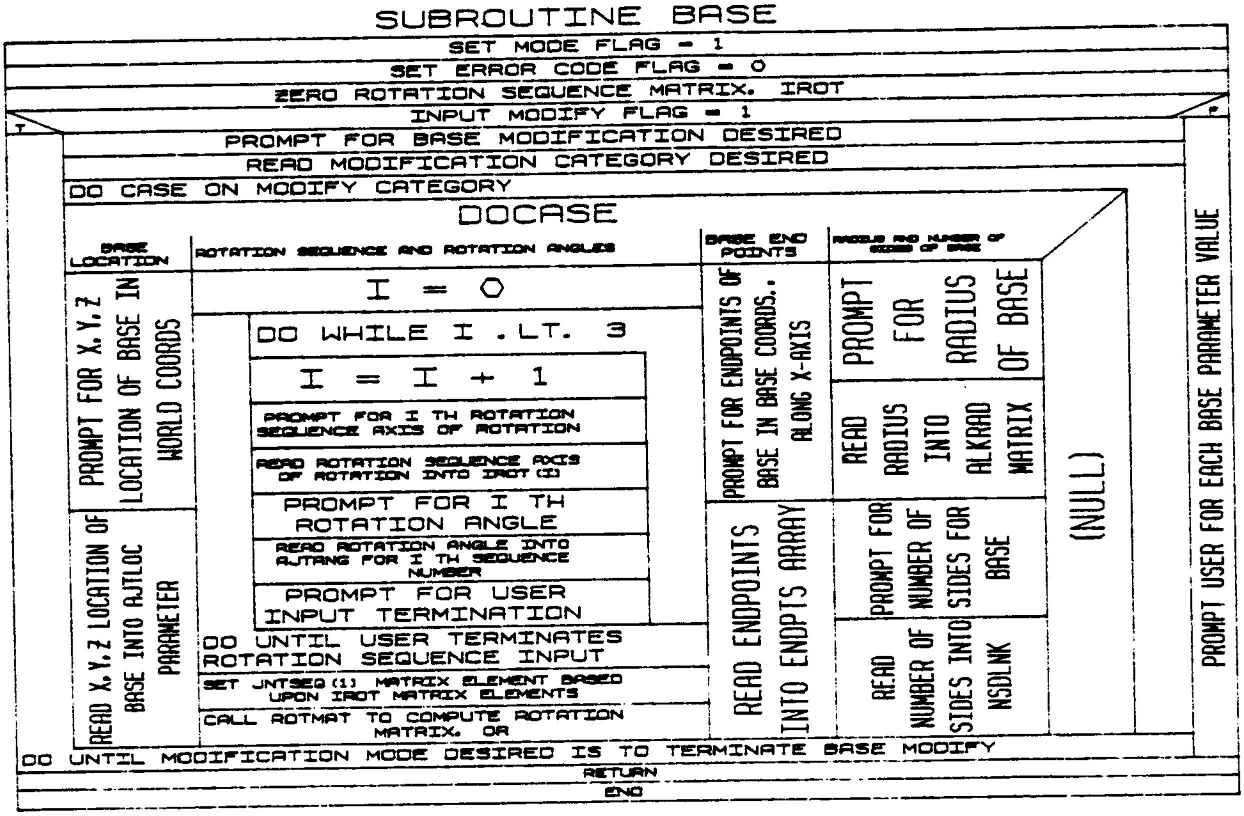
1.3.3 BASE

Subroutine BASE is called within the system definition function during definition or modification of the simple cylinder arm or detailed arm geometry file. The purpose of subroutine BASE is to provide the input of the robotic base position, orientation, and physical dimensions (radius of base, endpoints and number of sides), and to load these values into COMMON blocks.

SUBROUTINE BASE



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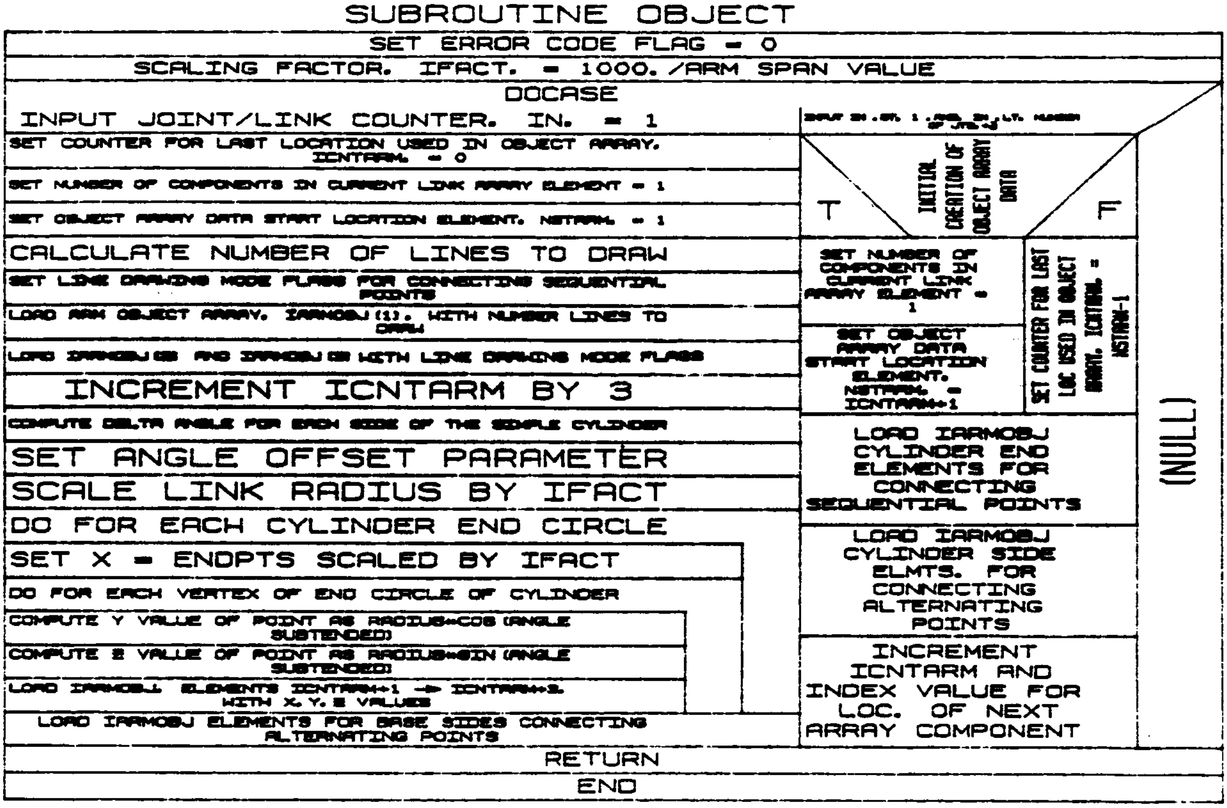
1.3.4 OBJECT

Subroutine OBJECT creates simple cylinder graphics data used by the graphics package to draw the robotic arm during the system definition function. The data created in OBJECT are stored in COMMON block IARMOBJ, and represent a right circular cylinder of the specified size for each system component (the base, each link and the tool). It is called for generation of each of these components in turn.



1.3.5 GRAPH

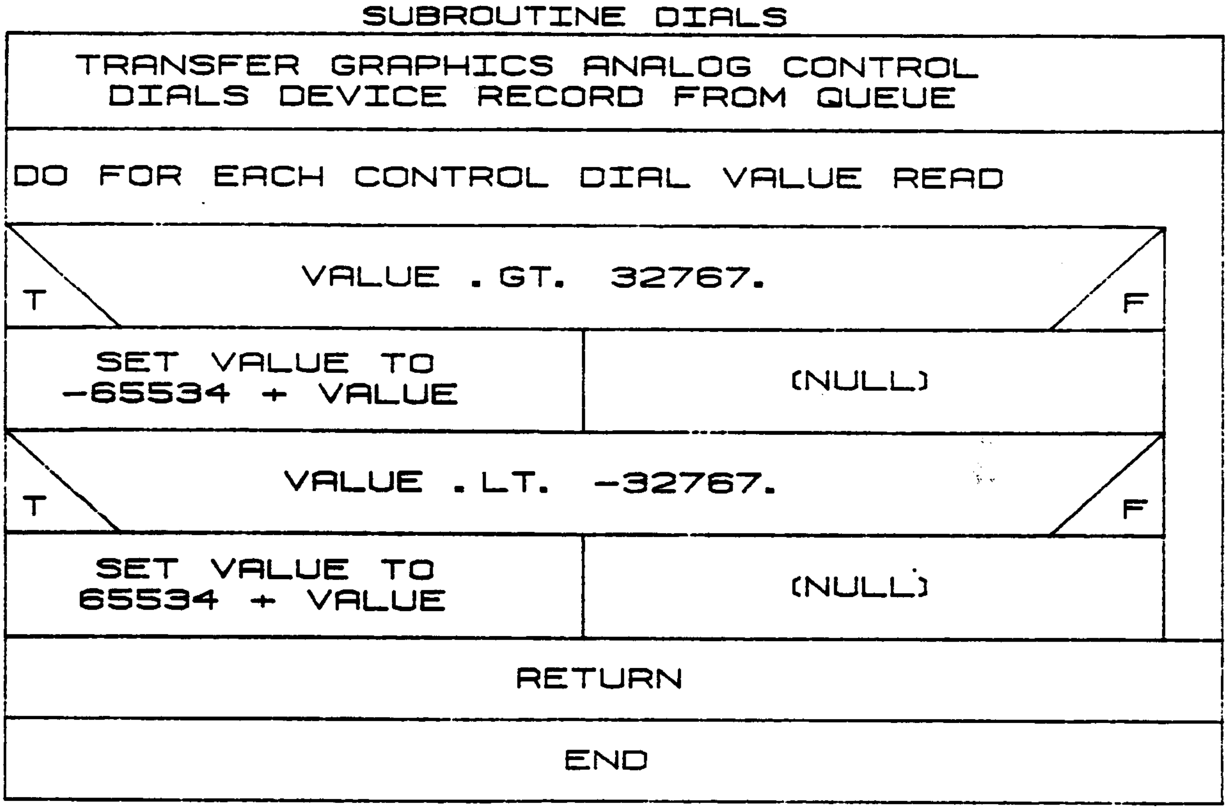
If the graphics are initiated during the simple single arm creation or modification, subroutine GRAPH provides the graphics capability for the simple cylinder representation of the robotic manipulator. GRAPH displays each base, joint/link combination and tool as they are defined. Graphics during the modification mode is handled with calling arguments input to GRAPH; appropriate deletions, additions and changes to the links are visually depicted. GRAPH provides only the simplified robotic arm definition display.

SUBROUTINE GRAPH

```
SET PROCESSOR MODE = 1. FOR SYSTEM DEFINITION
SET SCALE FACTOR. IFACT = 1000./ARM SPAN
SET PICTURE PROCESSOR TRANS. TO IDENTITY
CALL DIALS TO STATUS ANALOG CONTROL DIALS
SET INTEGER TRANSLATION AND ROTATION VALUES
DISPLAY WINDOW SPAN = SCALED ARM SPAN
SET WINDOW BOUNDARIES
SET CURRENT PICTURE PROCESSOR TRANSFORMATION
SCALE BASE LOCATION BY IFACT AND LOAD INTO INTEGER ARRAY
SET UP PICTURE PROCESSOR ROTATION MATRIX FOR BASE
SET NUMBER OF COMPONENTS IN BASE PARAMETER
DO FOR EACH COMPONENT IN BASE
    LOAD ARM OBJ. ARRAY FOR GRAPHICS FLAGS
    CALL D3DATA TO DISPLAY BASE
    SET COUNTER FOR LAST ARM OBJECT ARRAY LOCATION USED
    SCALE JT. LOCATION BY IFACT AND LOAD INTO INTEGER ARRAY
    CALL TTRAN FOR PICTURE PROCESSOR TRANSFORMATION MATRIX
    EXTRACT OFFSET JT. ANG. FROM JOINT VARIABLE ARRAY
    CALL TROTX OR -Y WITH JT. ANG. TO ROTATE TRANSFORMATION
    EXTRACT ROTATION AXES USED IN ORIENTING. FROM JOINT SEQUENCE ARRAY
    EXTRACT X. Y. Z ROT. ANGLES USED IN ORIENTING. FROM JT. ANGLE ARRAY
    CALL TROTX. -Y OR -Z WITH INTEGER ANG. TO ROTATE TRANSFORMATION
    SET NUMBER OF COMPONENTS IN LINK PARAMETER
    DO FOR EACH COMPONENT IN LINK
        SET START LOCATION IN ARM OBJECT ARRAY FOR CURRENT COMPONENT
        LOAD ARM OBJ. ARRAY FOR GRAPHICS FLAGS
        LOAD ARM OBJ. ARRAY FOR SEQUENTIAL POINTS
        LOAD ARM OBJ. ARRAY FOR ALTERNATING POINTS
        CALL D3DATA TO DISPLAY LINK
        SET COUNTER FOR LAST ARM OBJECT ARRAY LOCATION USED
DO UNTIL ALL EXISTING LINKS HAVE BEEN DRAWN
SCALE TOOL LOCATION BY IFACT AND LOAD INTO INTEGER ARRAY
SET UP PICTURE PROCESSOR ROTATION MATRIX FOR TOOL
SET NUMBER OF COMPONENTS IN TOOL PARAMETER
DO FOR EACH COMPONENT IN TOOL
    LOAD ARM OBJ. ARRAY FOR GRAPHICS FLAGS
    CALL D3DATA TO DISPLAY TOOL
    SET COUNTER FOR LAST ARM OBJECT ARRAY LOCATION USED
RETURN
END
```

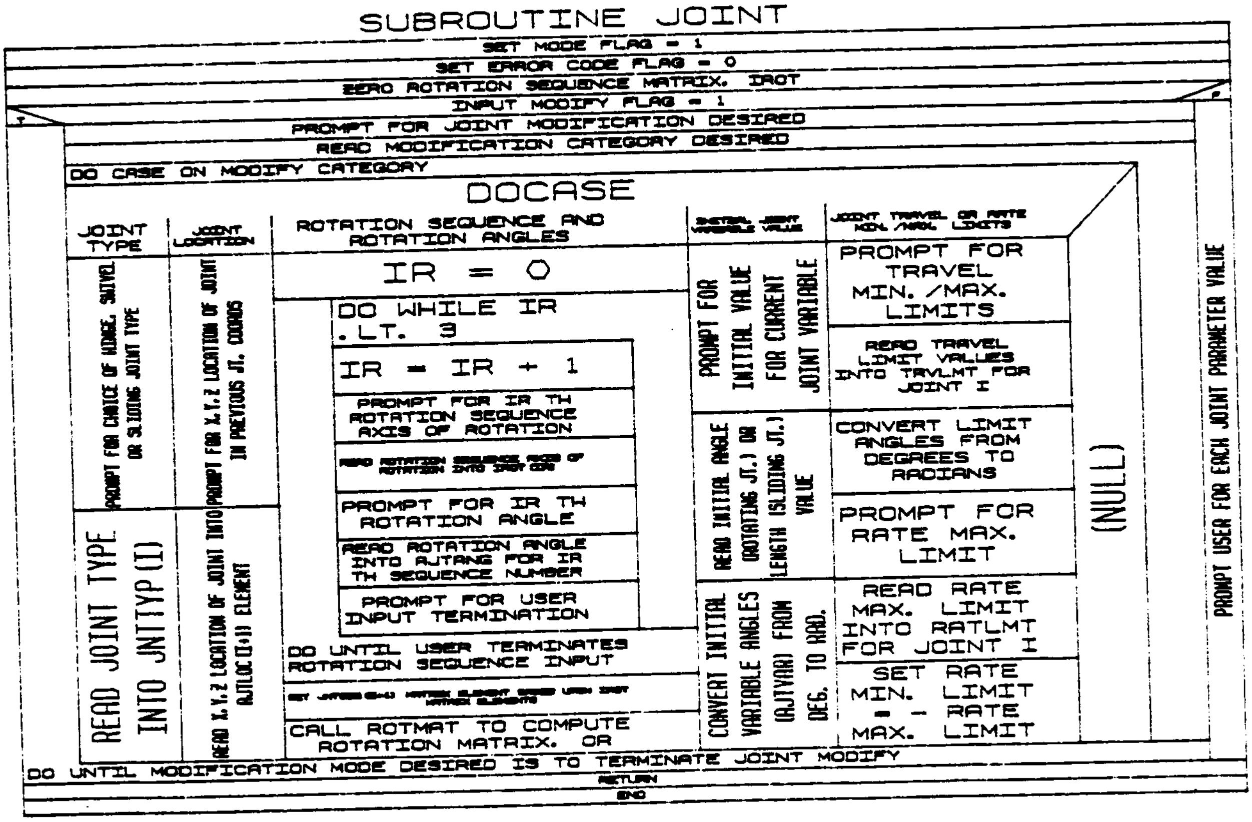
1.3.6 DIALS

DIALS is called to scale the Evans and Sutherland analog control dials values read during camera perspective changes via the extended E&S dials. The values are scaled to integers between -32767 and +32767.



1.3.7 JOINT

For JOINT, the user inputs joint type, joint location as Cartesian coordinates in terms of the coordinate system of the previous joint (or base, if the current joint is joint 1), joint orientation as a rotation sequence of axes and corresponding angles with respect to the previous joint coordinate system (or base, if joint 1), and initial joint state (initial angle for hinge or swivel, or initial length for sliding joints). The x-axis of a joint coordinate system is directed along the centerline of the link between joint i and joint i+1 (or end-effector if the current joint is the final joint in the system). JOINT is called by CREATARM during initial creation or modification of arm data.

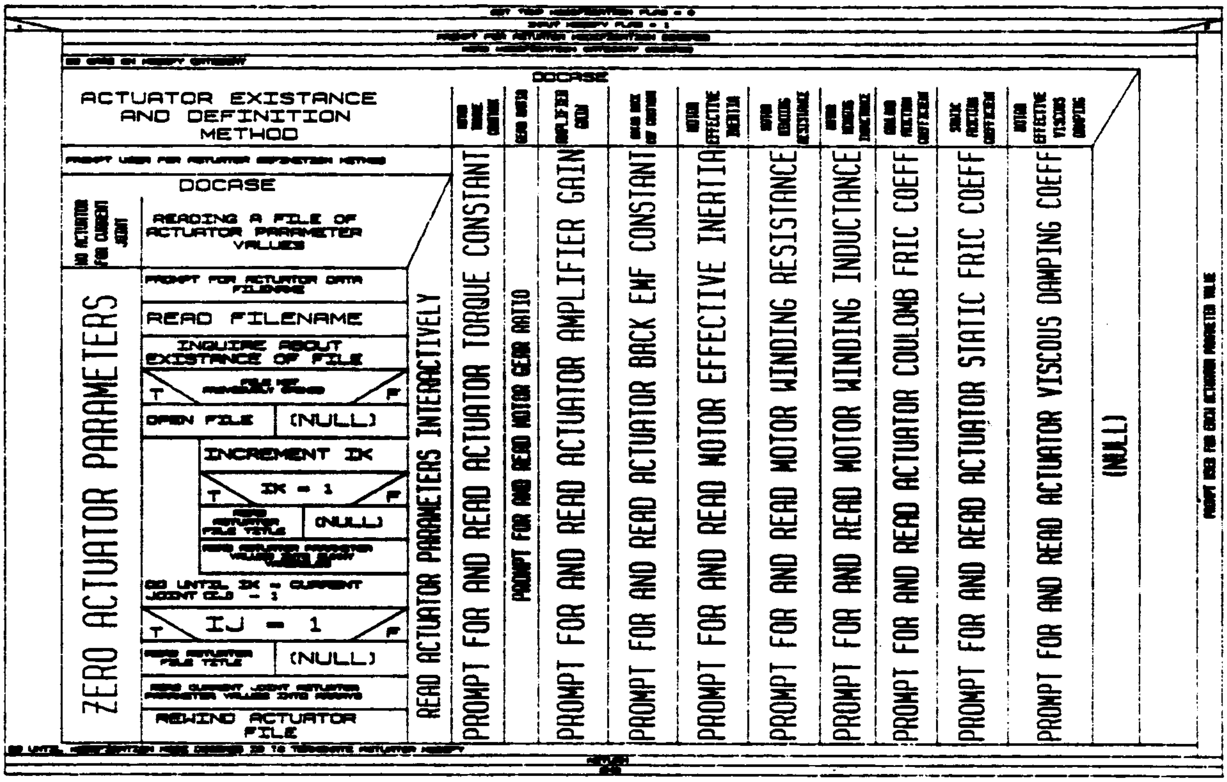


```
SUBROUTINE JOINT
SET MODE FLAG = 1
SET ERROR CODE FLAG = 0
ZERO ROTATION SEQUENCE MATRIX, IROT
INPUT MODIFY FLAG = 1
    PROMPT FOR JOINT MODIFICATION DESIRED
    READ MODIFICATION CATEGORY DESIRED
    DO CASE ON MODIFY CATEGORY
    DOCASE
        JOINT TYPE:
            PROMPT FOR CHOICE OF HINGE, SWIVEL OR SLIDING JOINT TYPE
            READ JOINT TYPE INTO JNTTYP(I)
        JOINT LOCATION:
            PROMPT FOR X,Y,Z LOCATION OF JOINT IN PREVIOUS JT. COORDS
            READ X,Y,Z LOCATION OF JOINT INTO AJTLOC(I+1) ELEMENT
        ROTATION SEQUENCE AND ROTATION ANGLES:
            IR = 0
            DO WHILE IR .LT. 3
                IR = IR + 1
                PROMPT FOR IR TH ROTATION SEQUENCE AXIS OF ROTATION
                READ ROTATION SEQUENCE AXES OF ROTATION INTO IROT COR
                PROMPT FOR IR TH ROTATION ANGLE
                READ ROTATION ANGLE INTO AJTANG FOR IR TH SEQUENCE NUMBER
                PROMPT FOR USER INPUT TERMINATION
            DO UNTIL USER TERMINATES ROTATION SEQUENCE INPUT
            SET AJTROT(3+1) MATRIX ELEMENT BASED UPON IROT MATRIX ELEMENTS
            CALL ROTMAT TO COMPUTE ROTATION MATRIX. OR
        INITIAL JOINT VARIABLE VALUE:
            PROMPT FOR INITIAL VALUE FOR CURRENT JOINT VARIABLE
            READ INITIAL ANGLE (ROTATING JT.) OR LENGTH (SLIDING JT.) VALUE
            CONVERT INITIAL VARIABLE ANGLES (AJTVAR) FROM DEG. TO RAD.
        JOINT TRAVEL OR RATE MIN./MAX. LIMITS:
            PROMPT FOR TRAVEL MIN./MAX. LIMITS
            READ TRAVEL LIMIT VALUES INTO TRVLMT FOR JOINT I
            CONVERT LIMIT ANGLES FROM DEGREES TO RADIANS
            PROMPT FOR RATE MAX. LIMIT
            READ RATE MAX. LIMIT INTO RATLMT FOR JOINT I
            SET RATE MIN. LIMIT = - RATE MAX. LIMIT
        (NULL)
    PROMPT USER FOR EACH JOINT PARAMETER VALUE
DO UNTIL MODIFICATION MODE DESIRED IS TO TERMINATE JOINT MODIFY
RETURN
END
```

1.3.8 ACTUATOR

ACTUATOR allows the user to define or modify the COMMON blocks defining actuator properties for the arm by interactively prompting for actuator parameter values or by reading a previously constructed file of actuator parameter values. The user can opt for no actuator definition if desired.

SUBROUTINE ACTUATOR



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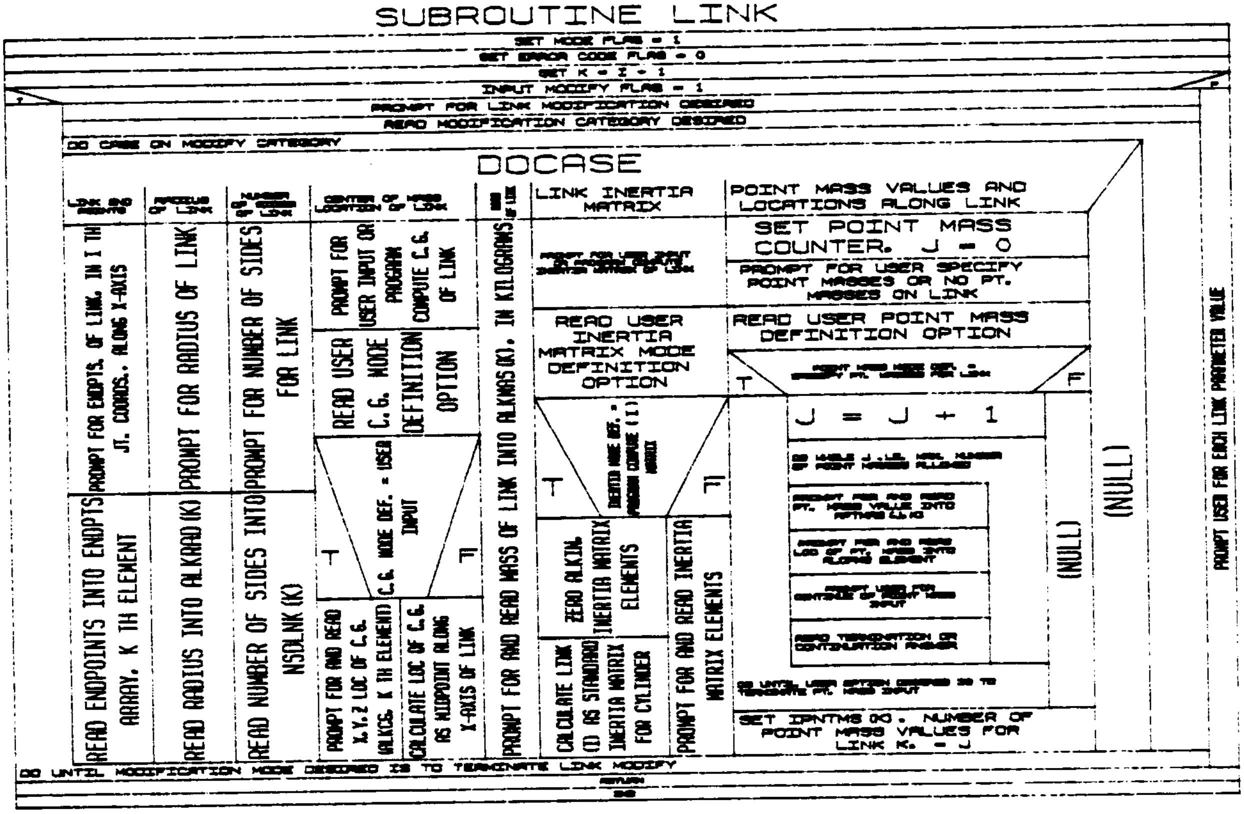
1.3.9 LINK

In the create mode of LINK, the user is prompted for link endpoints in coordinates along the x-axis, link radius, the location of center of mass as the Cartesian coordinates of the center of gravity in the coordinate system of the joint at the "base" end of the link, link mass and inertia matrix relative to the centroid and the number of sides for the desired simple cylinder.



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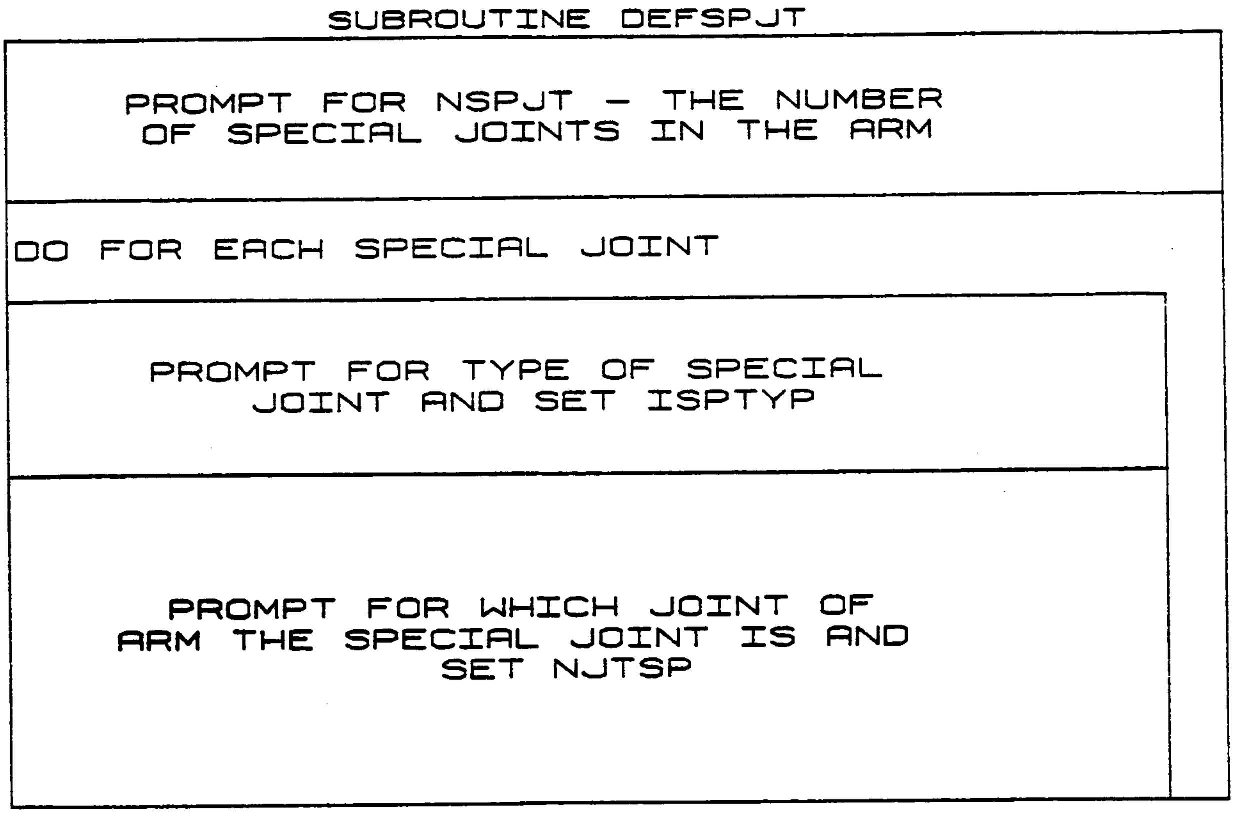
1.3.10 DEFSPJT

This routine interactively establishes the number, type and location of "special joints." These are joints for which a constraint is placed on the relative joint displacements.



```
SUBROUTINE DEFSPJT
PROMPT FOR NSPJT - THE NUMBER
OF SPECIAL JOINTS IN THE ARM
DO FOR EACH SPECIAL JOINT
    PROMPT FOR TYPE OF SPECIAL
    JOINT AND SET ISPTYP
    PROMPT FOR WHICH JOINT OF
    ARM THE SPECIAL JOINT IS AND
    SET NJTSP
```

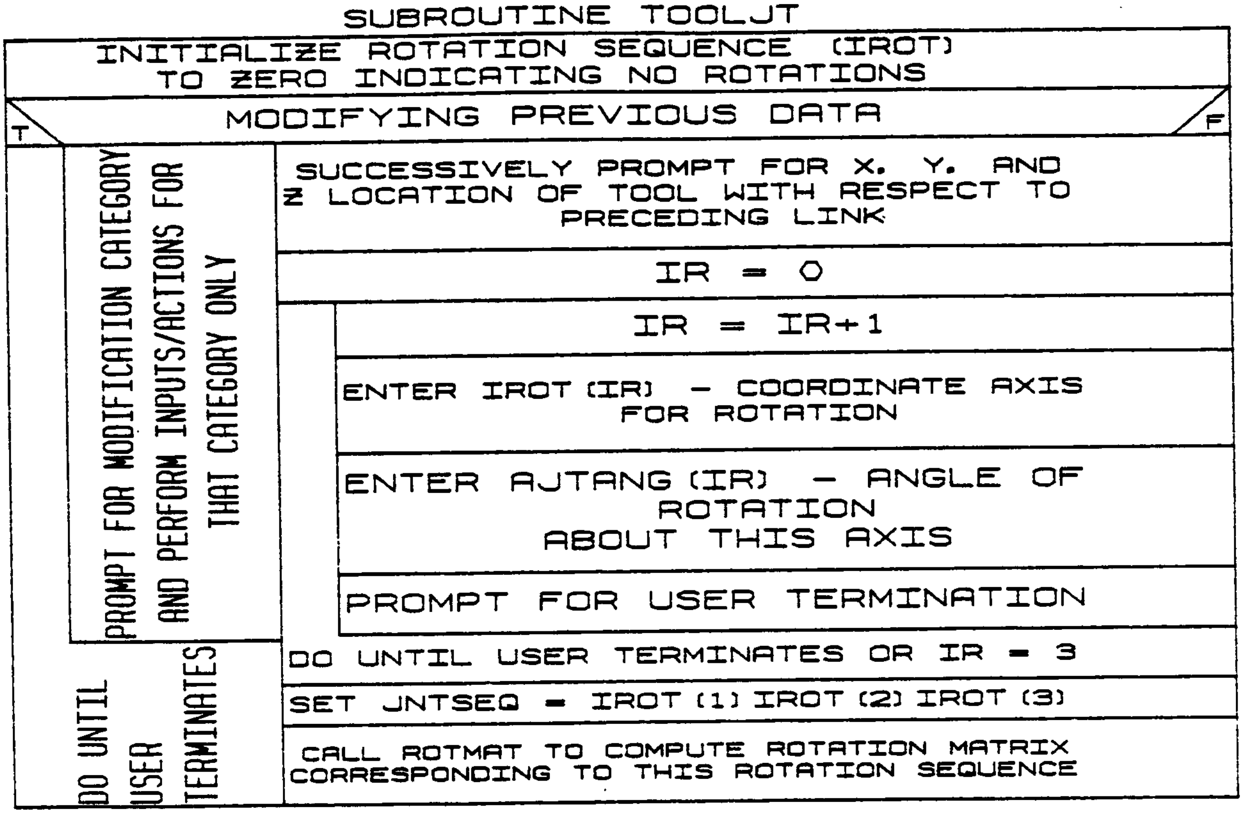
1.3.11 TOOLJT

Subroutine TOOLJT is called by CREATARM to interactively define or modify the geometry properties of the manipulator end-effector. The data for which the user is prompted include:

1) Location of tool with respect to final link;

2) Orientation of tool with respect to final link.

The orientation data are input as a sequence of rotations about coordinate axes and ROTMAT is called to compute the corresponding rotation matrix.



```
SUBROUTINE TOOLJT
INITIALIZE ROTATION SEQUENCE (IROT) TO ZERO INDICATING NO ROTATIONS
MODIFYING PREVIOUS DATA
T:
    DO UNTIL USER TERMINATES
        PROMPT FOR MODIFICATION CATEGORY AND PERFORM INPUTS/ACTIONS FOR THAT CATEGORY ONLY
F:
    SUCCESSIVELY PROMPT FOR X. Y. AND Z LOCATION OF TOOL WITH RESPECT TO PRECEDING LINK
    IR = 0
    DO UNTIL USER TERMINATES OR IR = 3
        IR = IR+1
        ENTER IROT (IR) - COORDINATE AXIS FOR ROTATION
        ENTER AJTANG (IR) - ANGLE OF ROTATION ABOUT THIS AXIS
        PROMPT FOR USER TERMINATION
    SET JNTSEQ = IROT (1) IROT (2) IROT (3)
    CALL ROTMAT TO COMPUTE ROTATION MATRIX CORRESPONDING TO THIS ROTATION SEQUENCE
```

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1.3.12 TOOLLK

Subroutine TOOLLK is called by CREATARM to interactively define or modify the mass and graphics properties of the manipulator end-effector. The data for which the user is prompted include:

1) Endpoints for cylinder representation;

2) Radius of cylinder;

3) Number of sides of cylinder;

4) Center of mass of end-effector;

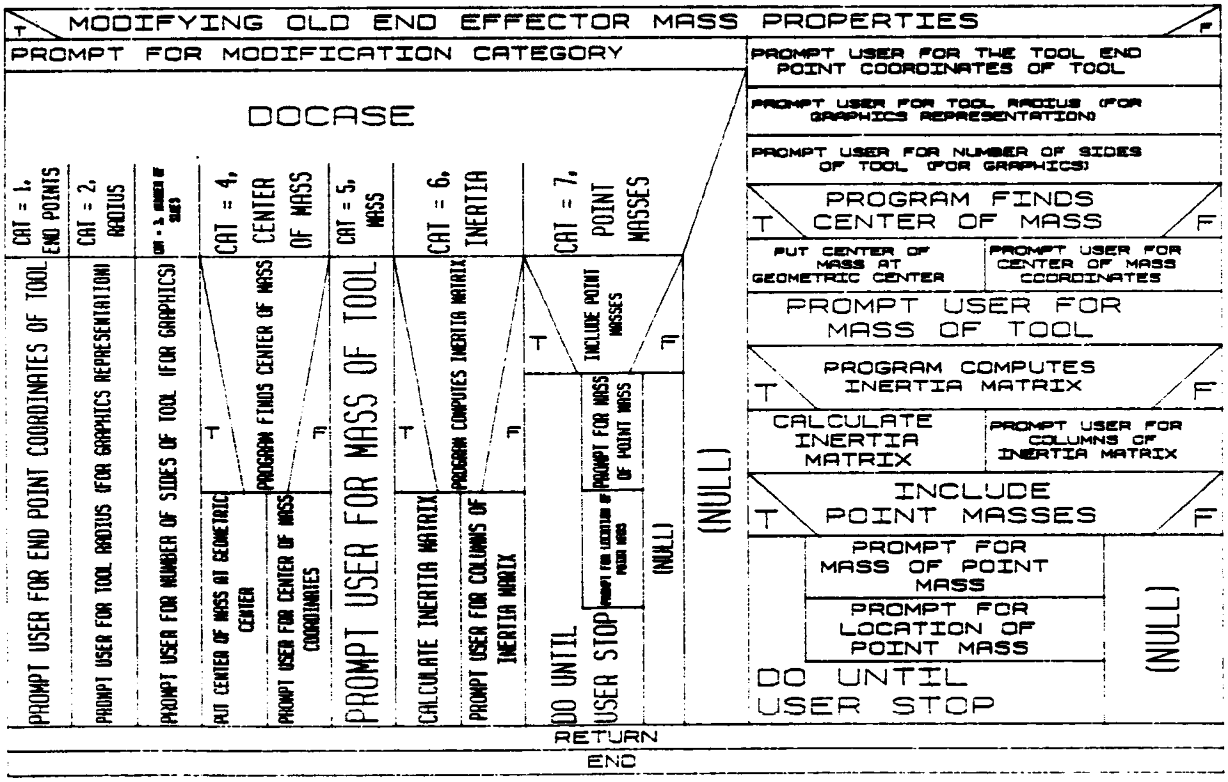
5) Mass;

6) Inertia distribution;

7) Location and mass of point masses.

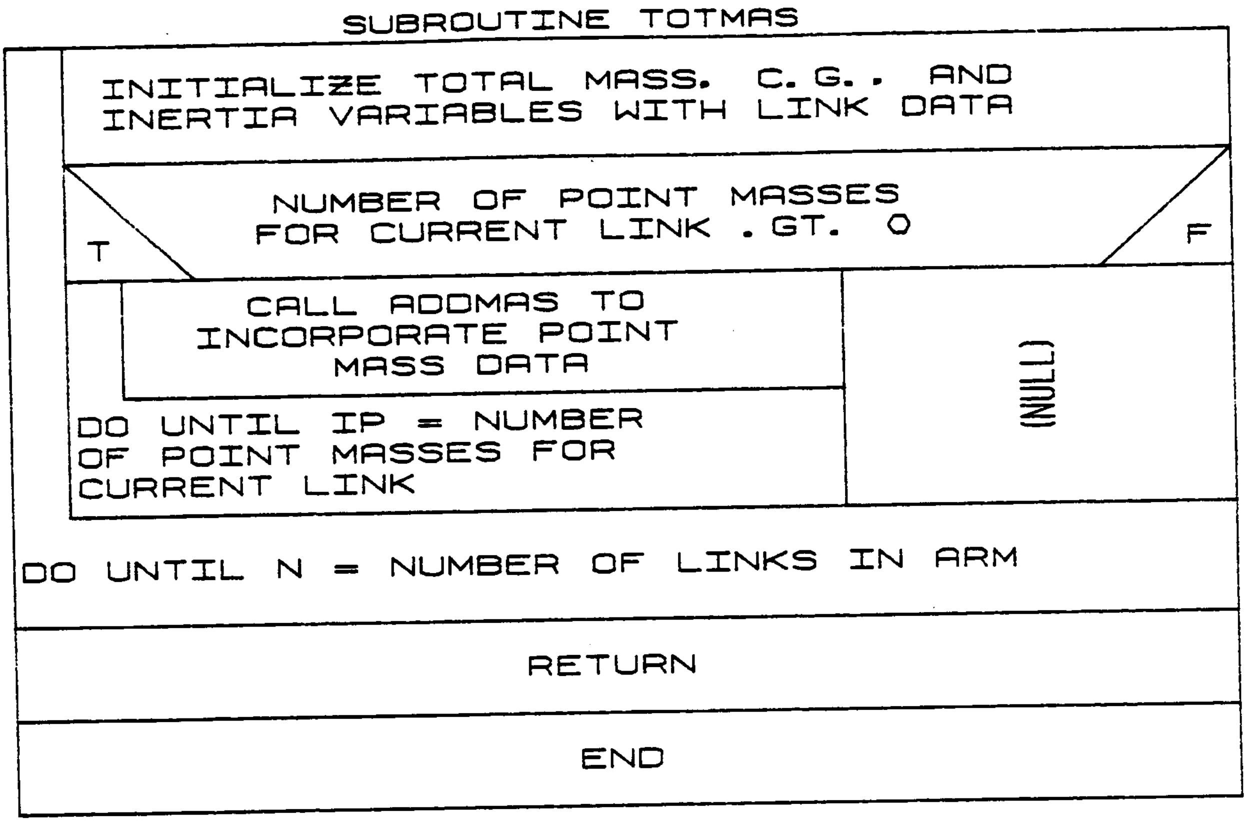
When modifying existing data, the user has the option of which categories to modify.

SUBROUTINE TOOLLK



1.3.13 TOTMAS

Routine TOTMAS combines individual components of each link's contributions (e.g., link mass, point masses) to obtain a total mass distribution for the joint/link combinations and tool during robot arm creation. Variables for the total mass, centroid location, and inertia distribution are initialized with the values from the simple link. If point masses are included, ADDMAS is called to add the effects of these additional terms.



1.3.14 ADDMAS

Subroutine ADDMAS combines the mass properties of two objects to obtain composite values for the mass, centroid location, and inertia distribution. ADDMAS calls ADDMAS2 to perform the computations. ADDMAS then loads the results into the first object's mass property variables.

SUBROUTINE ADDMAS

```
CALL ADDMAS2 FOR COMPOSITE INERTIA AND PUT IN TEMP VARIABLES
PUT MASS RESULTS INTO MASS OF BODY 1
PUT C. G. RESULTS INTO C. G. OF BODY 1
PUT INERTIA MATRIX INTO INERTIA MATRIX OF BODY 1
RETURN
END
```

1.3.15 ADDMAS2

ADDMAS2 calculates the composite mass properties of two rigid bodies joined together. The mass, centroid location, and inertia matrix for the composite body are returned as results.

```
SUBROUTINE ADDMAS2
TOTAL MASS = MASS OF BODY 1 + MASS OF BODY 2
COMPOSITE CENTROID = (MASS 1 * CG 1 + MASS 2 * CG 2) / TOTAL MASS
R1 = CG 1 - COMPOSITE CENTROID
R2 = CG 2 - COMPOSITE CENTROID
CALL RCICR FOR R1 SQUARED MATRIX (R1SQ) USED TO FIND COMPOSITE INERTIA
CALL RCICR FOR R2 SQUARED MATRIX (R2SQ) USED TO FIND COMPOSITE INERTIA
COMPOSITE INERTIA = AIN1 + AIN2 + (MASS 1 * R1SQ + MASS 2 * R2SQ)
RETURN
END
```

1.3.16 RCICR

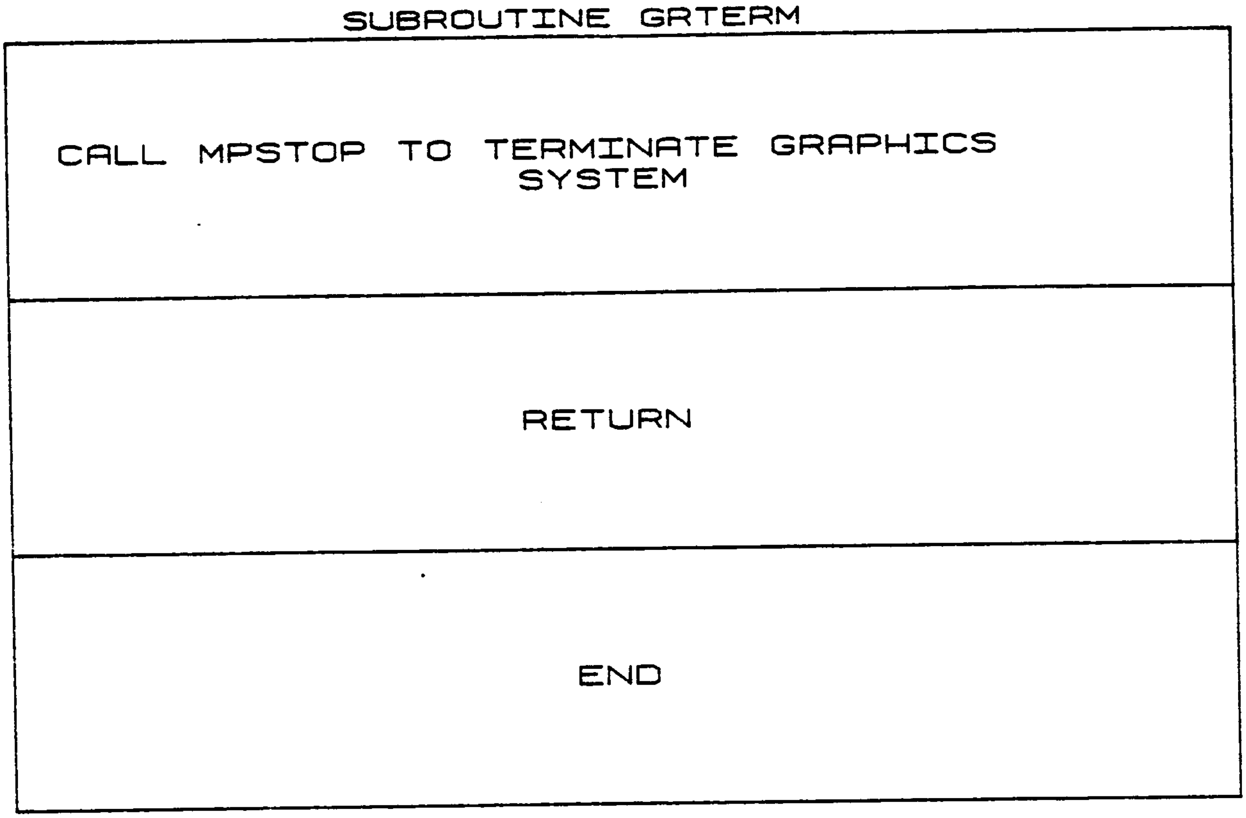
Subroutine RCICR is called by ADDMAS2 to set up the inertia matrix corresponding to a point mass displaced from the body centroid. This inertia matrix forms one component of the inertia distribution for the composite body.

SUBROUTINE RCICR

```
TR = 0.0
    INCREMENT I
        INCREMENT J
        R SQUARED MATRIX ELEMENT. (RSQ (I. J) )
            = -R (I) * R (J)
    DO UNTIL J = 3
    TR = TR - RSQ (I. I)
DO UNTIL I = 3
    INCREMENT I
    DIAGONAL ELEMENT. RSQ (I. I) = RSQ (I. I)
        + TR
DO UNTIL I = 3
RETURN
END
```

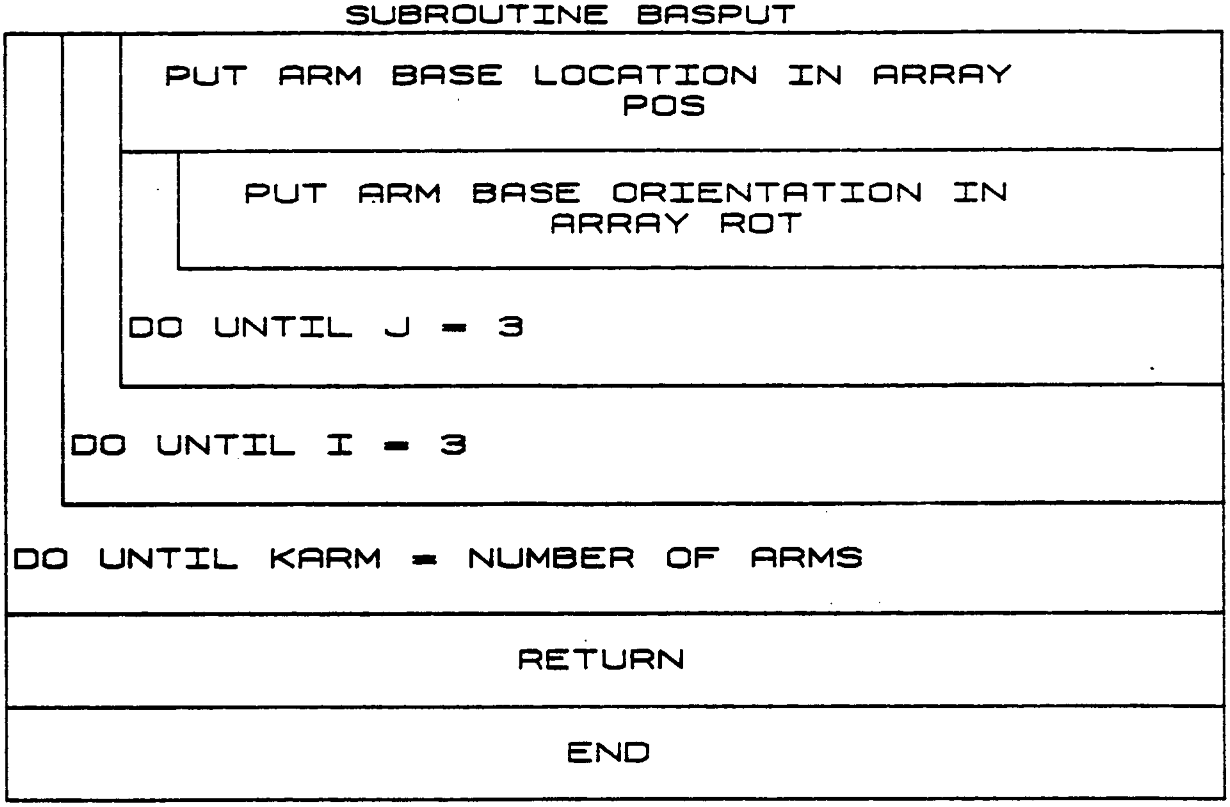
1.3.17 GRTERM

GRTERM is called to terminate the Evans and Sutherland device processor display unit. It calls MPSTOP to terminate the multi-picture processor display unit graphics.



1.3.18 BASPUT

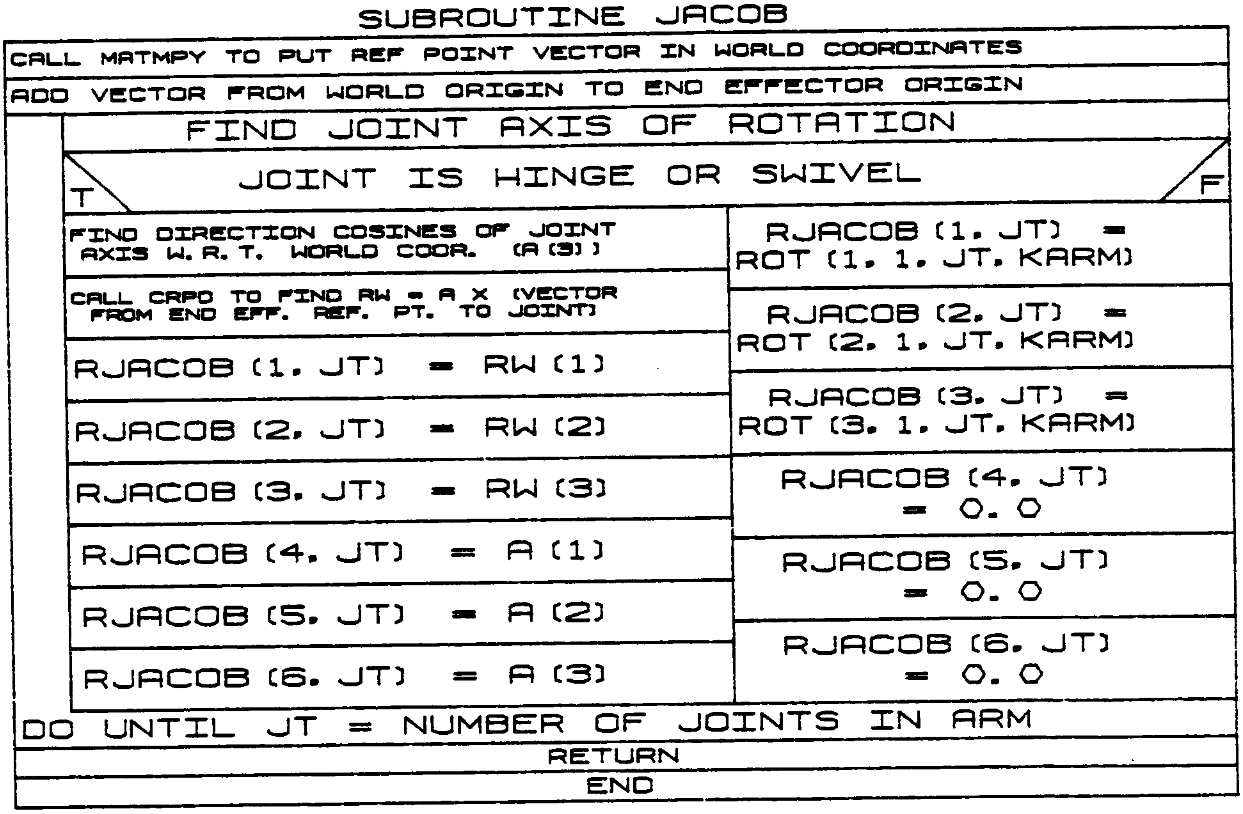
Subroutine BASPUT is called from subroutine SETUP2 during position calculations for the manipulator. This subroutine takes the position and orientation of the base of each arm (with respect to the world coordinate system) and loads these data into the arrays POS and ROT.



```
SUBROUTINE BASPUT
      PUT ARM BASE LOCATION IN ARRAY POS
         PUT ARM BASE ORIENTATION IN ARRAY ROT
      DO UNTIL J = 3
   DO UNTIL I = 3
DO UNTIL KARM = NUMBER OF ARMS
RETURN
END
```

1.3.19 JACOB

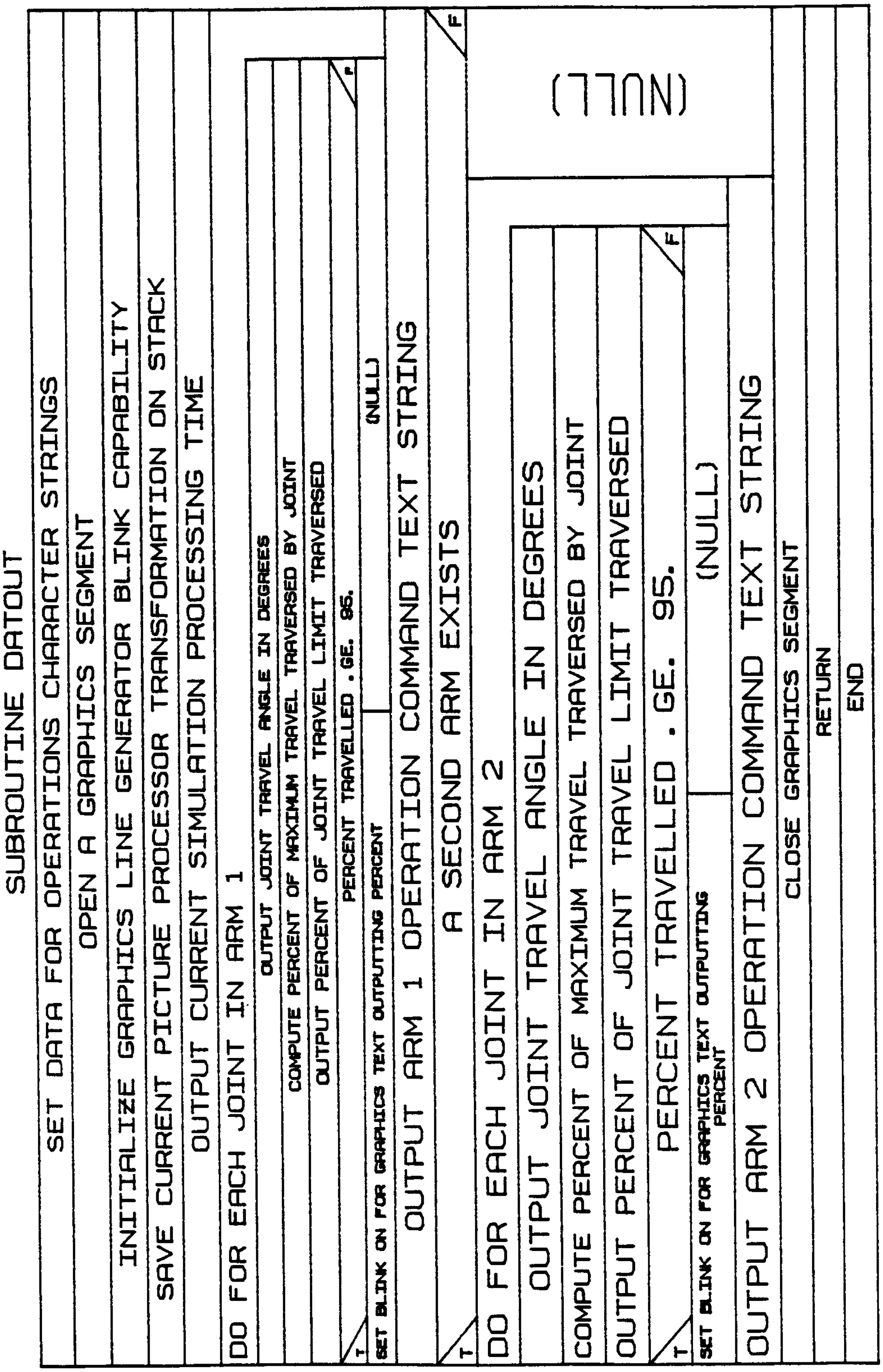
Subroutine JACOB sets up the Jacobian matrix that will later be used to solve for individual joint velocities for each arm given the end effector velocity. This subroutine uses end-effector position and joint to world transformation matrices to determine the entries of the Jacobian as described in a previous section. The result is a 6xN matrix for each arm.



```
SUBROUTINE JACOB
CALL MATMPY TO PUT REF POINT VECTOR IN WORLD COORDINATES
ADD VECTOR FROM WORLD ORIGIN TO END EFFECTOR ORIGIN
    FIND JOINT AXIS OF ROTATION
    JOINT IS HINGE OR SWIVEL
    T:
        FIND DIRECTION COSINES OF JOINT AXIS W.R.T. WORLD COOR. (A (3))
        CALL CRPD TO FIND RW = A X (VECTOR FROM END EFF. REF. PT. TO JOINT)
        RJACOB (1. JT) = RW (1)
        RJACOB (2. JT) = RW (2)
        RJACOB (3. JT) = RW (3)
        RJACOB (4. JT) = A (1)
        RJACOB (5. JT) = A (2)
        RJACOB (6. JT) = A (3)
    F:
        RJACOB (1. JT) = ROT (1. 1. JT. KARM)
        RJACOB (2. JT) = ROT (2. 1. JT. KARM)
        RJACOB (3. JT) = ROT (3. 1. JT. KARM)
        RJACOB (4. JT) = 0. 0
        RJACOB (5. JT) = 0. 0
        RJACOB (6. JT) = 0. 0
DO UNTIL JT = NUMBER OF JOINTS IN ARM
RETURN
END
```

1.3.20 DATOUT

DATOUT is responsible for the data output in the columns set up by subroutine FORM of the E&S robotic simulation display. It includes the current simulation time, joint travel angles, percent of the maximum traveled for each joint and task commands. DATOUT has provisions for only two arms.

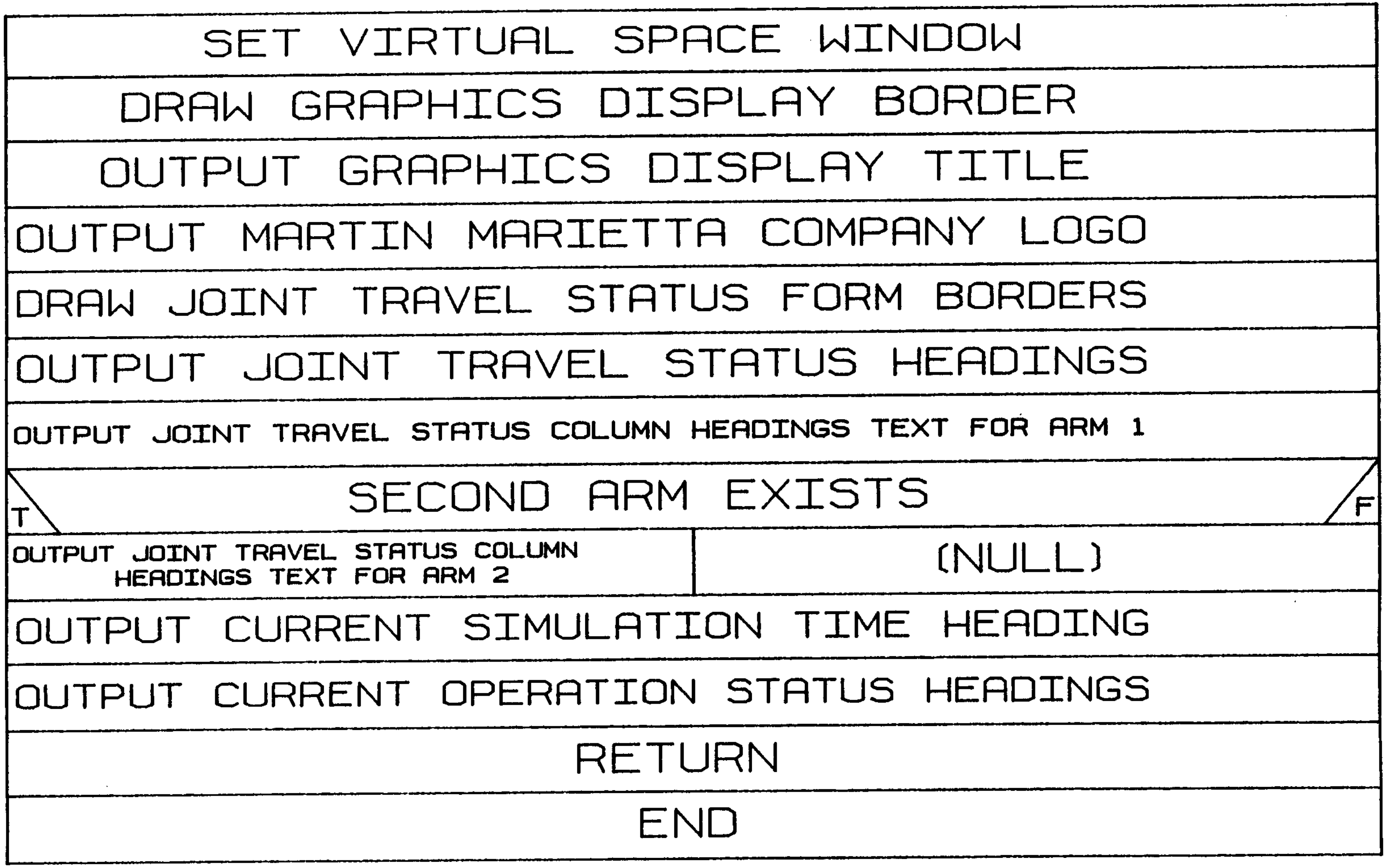


```
SUBROUTINE DATOUT
SET DATA FOR OPERATIONS CHARACTER STRINGS
OPEN A GRAPHICS SEGMENT
INITIALIZE GRAPHICS LINE GENERATOR BLINK CAPABILITY
SAVE CURRENT PICTURE PROCESSOR TRANSFORMATION ON STACK
OUTPUT CURRENT SIMULATION PROCESSING TIME
DO FOR EACH JOINT IN ARM 1
    OUTPUT JOINT TRAVEL ANGLE IN DEGREES
    COMPUTE PERCENT OF MAXIMUM TRAVEL TRAVERSED BY JOINT
    OUTPUT PERCENT OF JOINT TRAVEL LIMIT TRAVERSED
    PERCENT TRAVELLED .GE. 95.
        T: SET BLINK ON FOR GRAPHICS TEXT OUTPUTTING PERCENT
        F: (NULL)
OUTPUT ARM 1 OPERATION COMMAND TEXT STRING
A SECOND ARM EXISTS
    T: DO FOR EACH JOINT IN ARM 2
           OUTPUT JOINT TRAVEL ANGLE IN DEGREES
           COMPUTE PERCENT OF MAXIMUM TRAVEL TRAVERSED BY JOINT
           OUTPUT PERCENT OF JOINT TRAVEL LIMIT TRAVERSED
           PERCENT TRAVELLED .GE. 95.
               T: SET BLINK ON FOR GRAPHICS TEXT OUTPUTTING PERCENT
               F: (NULL)
       OUTPUT ARM 2 OPERATION COMMAND TEXT STRING
    F: (NULL)
CLOSE GRAPHICS SEGMENT
RETURN
END
```

1.3.21 FORM

The FORM routine sets up the borders and the text output locations for the manipulator display on the E&S graphics unit. It sets up the Evans and Sutherland graphics display borders and outputs the robotic simulation title, current simulation time text title, joint travel status data column and task command headings. FORM has provisions for only two arms.

SUBROUTINE FORM



```
SET VIRTUAL SPACE WINDOW
DRAW GRAPHICS DISPLAY BORDER
OUTPUT GRAPHICS DISPLAY TITLE
OUTPUT MARTIN MARIETTA COMPANY LOGO
DRAW JOINT TRAVEL STATUS FORM BORDERS
OUTPUT JOINT TRAVEL STATUS HEADINGS
OUTPUT JOINT TRAVEL STATUS COLUMN HEADINGS TEXT FOR ARM 1
SECOND ARM EXISTS
  T: OUTPUT JOINT TRAVEL STATUS COLUMN HEADINGS TEXT FOR ARM 2
  F: (NULL)
OUTPUT CURRENT SIMULATION TIME HEADING
OUTPUT CURRENT OPERATION STATUS HEADINGS
RETURN
END
```

1.3.22 CYL

Subroutine CYL is called within the system definition function during detailed graphic representation generation for the robotic system constituents (environment, arms, targets, loads). If the requested component is a cylinder or cone, it is called to compute data points for the graphic routines. The controlling argument in the call, ISHAPE, determines which geometric shape has been chosen in calling routine BLDENV, BLDDAT, BLDTRG or BLDENV. The detailed graphic component dimensions are written to a print/save file for archiving the program interaction.

SUBROUTINE CYL

```
PROMPT FOR CYLINDER DIAMETER. USED AS BOTTOM DIAMETER OF CONE
IF ISHAPE = 2. FOR CONE
  T: PROMPT FOR TOP DIAMETER OF CONE
  F: (NULL)
PROMPT FOR LENGTH OF CYLINDER OR CONE
WRITE TO GRAPHICS SAVE FILE IF OPTED
SET NUMBER OF SIDES = 8
CALCULATE NUMBER OF LINES TO DRAW SEQUENTIALLY
SET LINE DRAWING MODE FLAG FOR CONNECTING SEQUENTIAL POINTS
COMPUTE DELTA ANGLE FOR EACH SIDE OF THE CYLINDER
SET ANGLE OFFSET PARAMETER
ICOUNT = 0
DO FOR EACH CYLINDER END CIRCLE
    CYLINDER RADIUS = DIAMETER/2.
    IF ISHAPE = 2. FOR CONE
      T: CYLINDER RADIUS = TOP DIAMETER/2.
      F: (NULL)
    SET NL = NUMBER LINES IN END CIRCLE
    DO FOR EACH VERTEX OF END CIRCLE OF CYLINDER
        ICOUNT = ICOUNT + 1
        COMPUTE ANGLE SUBTENDED USING ANG. OFFSET VALUE
        COMPUTE Y VALUE OF POINT AS RADIUS*COS(ANGLE SUBTENDED)
        COMPUTE Z VALUE OF POINT AS RADIUS*SIN(ANGLE SUBTENDED)
        SET X VALUE = 0.
        IF SECOND CYL. END CIRCLE
          T: X = CYLINDER LENGTH VALUE
          F: (NULL)
        LOAD ARRAY. ELEMENT ICOUNT. WITH X. Y. Z
CALCULATE NUMBER OF LINES TO DRAW ALTERNATELY
SET LINE DRAWING MODE FLAG FOR CONNECTING ALTERNATING POINTS
SET ANGLE OFFSET PARAMETER TO NUM. SIDES + 1
DO FOR EACH CYLINDER SIDE FROM 2 TO NUM. SIDES
    INCREMENT I
    ICOUNT = ICOUNT + 1
    LOAD ARRAY. ELEMENT ICOUNT. WITH X. Y. Z FROM ARRAY ELEMENT I
    ICOUNT = ICOUNT + 1
    LOAD ARRAY.ELEMENT ICOUNT. WITH X. Y. Z FROM ARRAY ELEMENT I+OFFSET
RETURN
END
```

1.3.23 RECT

Subroutine RECT is called within the system definition function during generation of detailed graphic representations for environment, arm, target, or load objects file. It is called if the requested component is a rectangular solid (ISHAPE = 3), a symmetric trapezoidal solid (ISHAPE = 4), or a nonsymmetric trapezoidal solid (ISHAPE = 5) to compute data points for the graphic routines. The detailed graphic component dimensions are written to a print/save file for archiving the program interaction.

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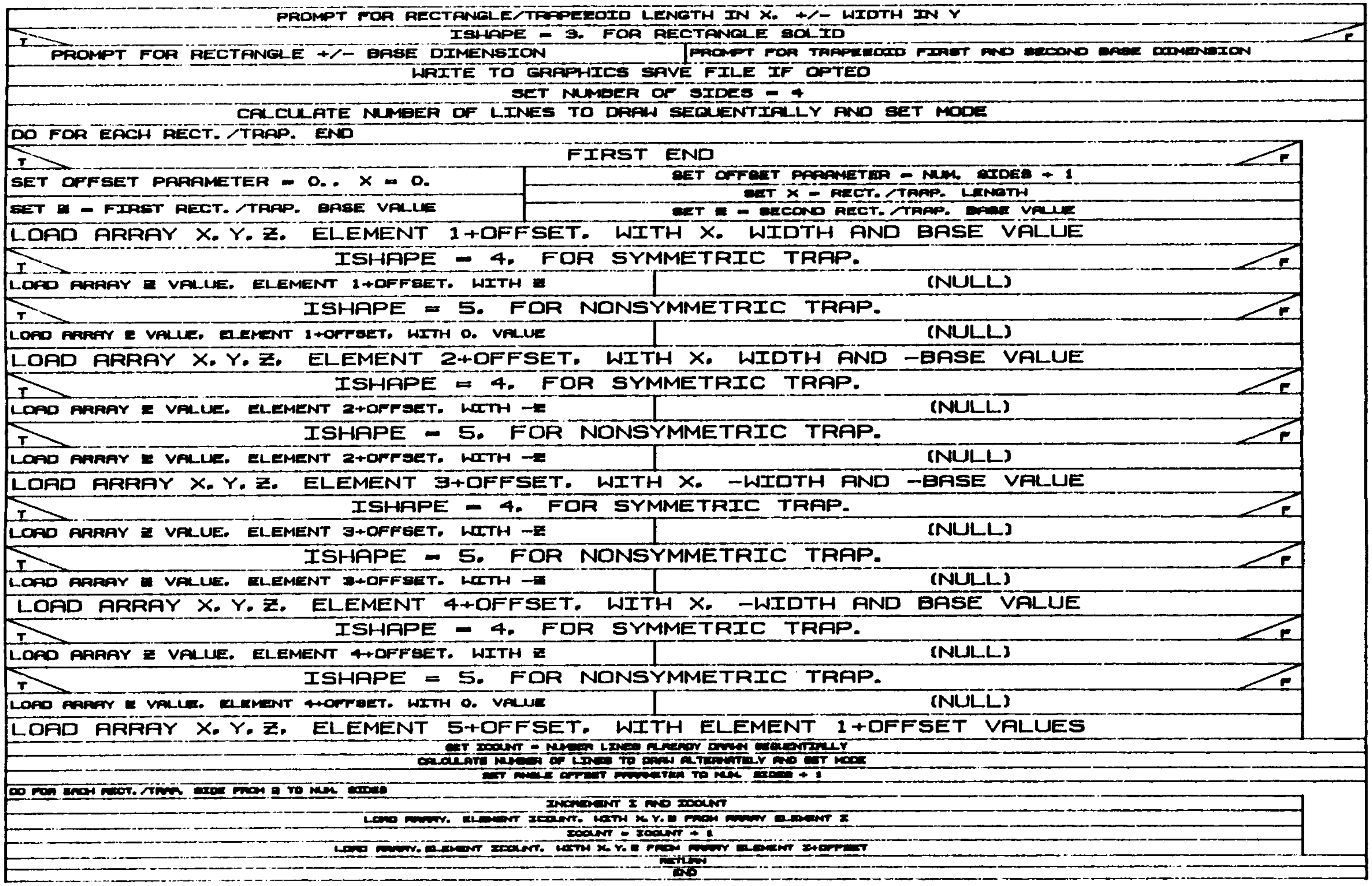
SUBROUTINE RECT



```
PROMPT FOR RECTANGLE/TRAPEZOID LENGTH IN X, +/- WIDTH IN Y
IF ISHAPE = 3, FOR RECTANGLE SOLID
  T: PROMPT FOR RECTANGLE +/- BASE DIMENSION
  F: PROMPT FOR TRAPEZOID FIRST AND SECOND BASE DIMENSION
WRITE TO GRAPHICS SAVE FILE IF OPTED
SET NUMBER OF SIDES = 4
CALCULATE NUMBER OF LINES TO DRAW SEQUENTIALLY AND SET MODE
DO FOR EACH RECT./TRAP. END
    IF FIRST END
      T: SET OFFSET PARAMETER = 0., X = 0.
         SET Z = FIRST RECT./TRAP. BASE VALUE
      F: SET OFFSET PARAMETER = NUM. SIDES + 1
         SET X = RECT./TRAP. LENGTH
         SET Z = SECOND RECT./TRAP. BASE VALUE
    LOAD ARRAY X, Y, Z, ELEMENT 1+OFFSET, WITH X, WIDTH AND BASE VALUE
    IF ISHAPE = 4, FOR SYMMETRIC TRAP.
      T: LOAD ARRAY Z VALUE, ELEMENT 1+OFFSET, WITH Z
      F: (NULL)
    IF ISHAPE = 5, FOR NONSYMMETRIC TRAP.
      T: LOAD ARRAY Z VALUE, ELEMENT 1+OFFSET, WITH 0. VALUE
      F: (NULL)
    LOAD ARRAY X, Y, Z, ELEMENT 2+OFFSET, WITH X, WIDTH AND -BASE VALUE
    IF ISHAPE = 4, FOR SYMMETRIC TRAP.
      T: LOAD ARRAY Z VALUE, ELEMENT 2+OFFSET, WITH -Z
      F: (NULL)
    IF ISHAPE = 5, FOR NONSYMMETRIC TRAP.
      T: LOAD ARRAY Z VALUE, ELEMENT 2+OFFSET, WITH -Z
      F: (NULL)
    LOAD ARRAY X, Y, Z, ELEMENT 3+OFFSET, WITH X, -WIDTH AND -BASE VALUE
    IF ISHAPE = 4, FOR SYMMETRIC TRAP.
      T: LOAD ARRAY Z VALUE, ELEMENT 3+OFFSET, WITH -Z
      F: (NULL)
    IF ISHAPE = 5, FOR NONSYMMETRIC TRAP.
      T: LOAD ARRAY Z VALUE, ELEMENT 3+OFFSET, WITH -Z
      F: (NULL)
    LOAD ARRAY X, Y, Z, ELEMENT 4+OFFSET, WITH X, -WIDTH AND BASE VALUE
    IF ISHAPE = 4, FOR SYMMETRIC TRAP.
      T: LOAD ARRAY Z VALUE, ELEMENT 4+OFFSET, WITH Z
      F: (NULL)
    IF ISHAPE = 5, FOR NONSYMMETRIC TRAP.
      T: LOAD ARRAY Z VALUE, ELEMENT 4+OFFSET, WITH 0. VALUE
      F: (NULL)
    LOAD ARRAY X, Y, Z, ELEMENT 5+OFFSET, WITH ELEMENT 1+OFFSET VALUES
SET ICOUNT = NUMBER LINES ALREADY DRAWN SEQUENTIALLY
CALCULATE NUMBER OF LINES TO DRAW ALTERNATELY AND SET MODE
SET ANGLE OFFSET PARAMETER TO NUM. SIDES + 1
DO FOR EACH RECT./TRAP. SIDE FROM 2 TO NUM. SIDES
    INCREMENT I AND ICOUNT
    LOAD ARRAY, ELEMENT ICOUNT, WITH X, Y, Z FROM ARRAY ELEMENT I
    ICOUNT = ICOUNT + 1
    LOAD ARRAY, ELEMENT ICOUNT, WITH X, Y, Z FROM ARRAY ELEMENT I+OFFSET
RETURN
END
```

1.3.24 TRISTR

Subroutine TRISTR is called within the system definition function during detailed graphics representation generation for the environment, manipulator, target, or load objects. If the requested component is a triangular cross-section beam (ISHAPE = 6), it is called to compute data points for the graphics routine. The detailed graphic component dimensions are written to a print/save file for archiving the program interaction.

SUBROUTINE TRISTR

```
PROMPT FOR TRIANGLE SIDE LENGTH
PROMPT FOR SEGMENT LENGTH
PROMPT FOR NUMBER OF SEGMENTS
WRITE TO GRAPHICS SAVE FILE IF OPTED
SET NUMBER OF SIDES = 3
CALCULATE NUMBER OF LINES TO DRAW
SET LINE DRAWING MODE FLAG FOR CONNECTING SEQUENTIAL POINTS
DO FOR EACH SEGMENT OF TRI. STRUCTURE, FROM 1 TO NUM. SIDES + 1
    CALCULATE OFFSET BASED ON CURRENT SEGMENT NUMBER
    X = (CURRENT SEG. NUM. - 1) * (NUM. SIDES + 1)
    LOAD ARRAY X VALUE, ELEMENT 1+OFFSET, WITH X
    LOAD ARRAY Y VALUE, ELEMENT 1+OFFSET, WITH TRI. LENGTH/2.
    LOAD ARRAY Z VALUE, ELEMENT 1+OFFSET, WITH 0.
    LOAD ARRAY X VALUE, ELEMENT 2+OFFSET, WITH X
    LOAD ARRAY Y VALUE, ELEMENT 2+OFFSET, WITH -TRI. LENGTH/2.
    LOAD ARRAY Z VALUE, ELEMENT 2+OFFSET, WITH 0.
    LOAD ARRAY X VALUE, ELEMENT 3+OFFSET, WITH X
    LOAD ARRAY Y VALUE, ELEMENT 3+OFFSET, WITH 0.
    LOAD ARRAY Z VALUE, ELEMENT 3+OFFSET, WITH -TRI. LENGTH
    LOAD ARRAY X,Y,Z VALUES, ELEMENT 4+OFFSET, WITH ELEMT. 1+OFFSET VALUES
SET ICOUNT = NUMBER LINES ALREADY DRAWN SEQUENTIALLY
CALCULATE NUMBER OF LINES TO DRAW ALTERNATELY
SET LINE DRAWING MODE FLAG FOR CONNECTING ALTERNATING POINTS
SET ANGLE OFFSET PARAMETER TO (SEG. NUM.) * (NUM. SIDES + 1)
DO FOR EACH TRIANGLE SIDE FROM 2 TO NUM. SIDES
    INCREMENT I
    ICOUNT = ICOUNT + 1
    LOAD ARRAY, ELEMENT ICOUNT, WITH X,Y,Z FROM ARRAY ELEMENT I
    ICOUNT = ICOUNT + 1
    LOAD ARRAY, ELEMENT ICOUNT, WITH X,Y,Z FROM ARRAY ELEMENT I+OFFSET
RETURN
END
```

1.3.25 DATATAB

Subroutine DATATAB is called within the system definition function during detailed graphics representation generation for the environment, the robotic arm, target, or load. If the requested component is a data tablet structure, it is called to compute data points for the graphic routines when the input ISHAPE flag = 8. The detailed graphic component dimensions are written to a print/save file for archiving the program interaction.

SUBROUTINE DATATAB

```
PROMPT FOR NUMBER OF POINTS TO BE INPUT VIA DATA TABLET
INITIALIZE DATA TABLET DEVICE
INITIALIZE EVENT QUEUE
KOUNT = 0
    READ DIGITIZED X AND Y INTEGER VALUES INPUT ON DATA TABLET
    KOUNT = KOUNT + 1
    SET IDATA ARRAY. ELEMENT KOUNT. TO INTEGER X AND Y READ
    PLOT POINT INPUT AND REFRESH GRAPHICS SCREEN
DO UNTIL ALL POINTS HAVE BEEN INPUT
PLOT LAST POINT
READ 2 POINTS FROM DATA TAB. BETWEEN WHICH THERE IS A KNOWN DISTANCE
PROMPT USER FOR KNOWN DIMENSION BETWN. 2 PTS., USED FOR SCALING
COMPUTE INTERNAL DATA TAB. DISTANCE BETWEEN 2 POINTS
SCALE FACTOR = DIMENSION/DATA TAB. INTERNAL DISTANCE
READ POINT FROM DATA TAB. TO BE USED AS ORIGIN
PROMPT FOR SHAPE DEPTH VALUE
WRITE TO GRAPHICS SAVE FILE
SET NUMBER OF SIDES = KOUNT
CALCULATE NUMBER OF LINES TO DRAW SEQUENTIALLY
SET LINE DRAWING MODE FLAG FOR CONNECTING SEQUENTIAL POINTS
ICOUNT = 0
DO FOR EACH FIGURE END DIAMETER
    SET NL = NUMBER LINES IN END DIAMETER
    DO FOR EACH VERTEX OF END PERIMETER
        ICOUNT = ICOUNT + 1
        FIRST END
        T:
            Z = DEPTH INPUT
        F:
            Z = -DEPTH INPUT
        LOAD ARRAY X. ELEMENT ICOUNT. WITH (X DATA - X ORG.) * SCAL. FACT
        LOAD ARRAY Y. ELEMENT ICOUNT. WITH (Y DATA - Y ORG.) * SCAL. FACT
        LOAD ARRAY Z. ELEMENT ICOUNT. WITH Z
CALCULATE NUMBER OF LINES TO DRAW ALTERNATELY
SET LINE DRAWING MODE FLAG FOR CONNECTING ALTERNATING POINTS
SET ANGLE OFFSET PARAMETER TO NUM. SIDES + 1
DO FOR EACH FIGURE SIDE FROM 2 TO NUM. SIDES
    INCREMENT I
    ICOUNT = ICOUNT + 1
    LOAD ARRAY. ELEMENT ICOUNT. WITH X. Y. Z FROM ARRAY ELEMENT I
    ICOUNT = ICOUNT + 1
    LOAD ARRAY. ELEMENT ICOUNT. WITH X. Y. Z FROM ARRAY ELEMENT I+OFFSET
RETURN
END
```

1.3.26 FILLET

Subroutine FILLET is called within the system definition function during detailed graphics representation generation for the environment, the robotic arm, target, or load. If the requested component is a fillet part, it is called to compute the data points for the graphic routines. For a concave fillet, the input ISHAPE flag is 9. The detailed graphic component dimensions are written to a print/save file for archiving the program interaction.

SUBROUTINE FILLET

```
PROMPT FOR FILLET RADIUS
PROMPT FOR FILLET LENGTH
WRITE TO GRAPHICS SAVE FILE IF OPTED
SET NUMBER OF SIDES = 8
CALCULATE NUMBER OF LINES TO DRAW SEQUENTIALLY
SET LINE DRAWING MODE FLAG FOR CONNECTING SEQUENTIAL POINTS
COMPUTE DELTA ANGLE FOR EACH SIDE OF THE FILLET
ICOUNT = 0
DO FOR EACH FILLET END DIAMETER
    SET FILLET RADIUS = RADIUS INPUT
    SET NL = NUMBER LINES IN END DIAMETER
    DO FOR EACH VERTEX END PERIMETER, FROM 1 TO NUM. SIDES - 1
        ICOUNT = ICOUNT + 1
        COMPUTE ANGLE SUBTENDED USING DELTA ANG. VALUE
        COMPUTE Y VALUE OF POINT AS RAD. - RAD. *COS (ANGLE SUBTENDED)
        COMPUTE Z VALUE OF POINT AS RAD. - RAD. *SIN (ANGLE SUBTENDED)
        SET X VALUE = 0.
        SECOND FILLET END PERIMETER
        T:
            X = FILLET LENGTH
        F:
            (NULL)
        LOAD ARRAY, ELEMENT ICOUNT, WITH X, Y, Z
    ICOUNT = ICOUNT + 1
    LOAD ARRAY X VALUE, ELEMENT ICOUNT, WITH X
    LOAD ARRAY Y, Z VALUES, ELEMENT ICOUNT, WITH 0.
    ICOUNT = ICOUNT + 1
    LOAD LAST ARRAY ELEMENT, WITH X, Y, Z FROM ELEMENT 1
CALCULATE NUMBER OF LINES TO DRAW ALTERNATELY
SET LINE DRAWING MODE FLAG FOR CONNECTING ALTERNATING POINTS
SET ANGLE OFFSET PARAMETER TO NUM. SIDES + 1
DO FOR EACH FILLET SIDE FROM 2 TO NUM. SIDES
    INCREMENT I
    ICOUNT = ICOUNT + 1
    LOAD ARRAY, ELEMENT ICOUNT, WITH X, Y, Z FROM ARRAY ELEMENT I
    ICOUNT = ICOUNT + 1
    LOAD ARRAY, ELEMENT ICOUNT, WITH X, Y, Z FROM ARRAY ELEMENT I+OFFSET
RETURN
END
```

1.3.27 OBSTCL

Subroutine OBSTCL is called within the system definition function during graphics representation generation with option ISHAPE equal 10 for the environment, detailed robotic arm, target, or load. It is called if a requested component is an obstacle entity (a choice option from BLDENV) or nonplanar structure (for BLDLOD, BLDTRG or BLDDAT). It computes data points for the graphic routines. The detailed graphic component dimensions are written to a print/save file for archiving the program interaction.

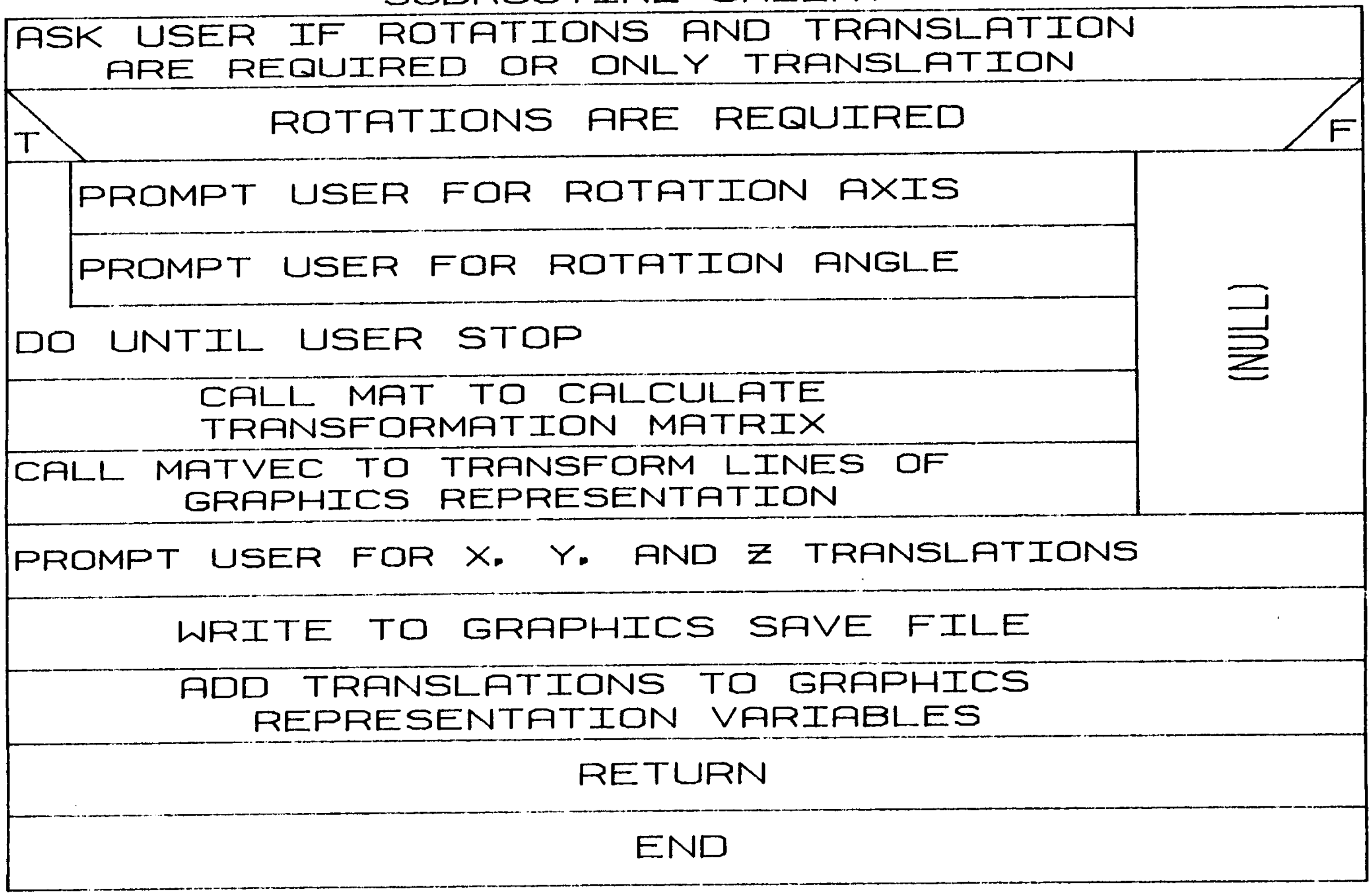
SUBROUTINE OBSTCL

```
PROMPT USER FOR CHOICE TO READ COMPONENT FILE OR INPUT INTERACTIVELY
READING FILE
T
    PROMPT USER FOR COMPONENT FILENAME
    OPEN COMPONENT FILE
    READ NUMBER OF DATA POINTS VALUE FROM FILE
        READ RECORD FROM FILE CONTAINING X. Y. Z VALUES OF PT. INTO DATA
    DO UNTIL ALL POINTS HAVE BEEN READ
    CLOSE COMPONENT FILE
F
    PROMPT FOR NUMBER OF POINTS TO BE INPUT FOR OBSTCL PERIMETER
    SET NUM. SIDES = NUM. PTS. TO BE INPUT
    KOUNT = 0
        READ USER INPUT X. Y AND Z REAL VALUES FOR CURRENT POINT INTO DATA
        KOUNT = KOUNT + 1
    DO UNTIL ALL POINTS HAVE BEEN INPUT
    KOUNT = NUMBER PTS. READ + 1
    SET LAST DATA ARRAY ELEMENT. WITH X. Y. Z VALUES READ FOR ELEMENT 1
    PROMPT USER FOR SCALE FACTOR TO BE USED
    WRITE TO GRAPHICS SAVE FILE
    SET LINE DRAWING MODE FLAG FOR CONNECTING SEQUENTIAL POINTS = KOUNT
    SET LINE DRAWING MODE FLAG FOR CONNECTING ALTERNATING POINTS = 0
    DO FOR EACH POINT TO BE CONNECTED SEQUENTIALLY
        LOAD ARRAY X. Y. Z. ELEMENT KOUNT. WITH DATA X. Y. Z* SCAL. FACT
RETURN
END
```

1.3.28 ORIENT

ORIENT is called from most of the build options in INITDRVR, allowing the user to reposition components. The user can input a rotation sequence consisting of rotation axes and angles, and a translation vector to position the origin of the component within the reference coordinate system. MAT is called to compute the total rotation transformation matrix, and MATVEC to transform vectors from the new coordinate system to the reference system. The translation vector is then added to each set of coordinates. The translation and orientation of detailed graphic components are written to a print/save file for archiving the program interaction.

SUBROUTINE ORIENT



1.3.29 MAT

Subroutine MAT is called during the system definition function to compute the total rotation transformation matrix defined by the input rotation sequence and angles. MAT is called from subroutine ORIENT. The rotation sequence passed to it determines the transformation matrix from the component system to the reference system it calculates. The transpose (inverse) of the normal X,Y and Z-axis rotation matrices are used. For each rotation in the input sequence, the axis rotation matrix is loaded and premultiplied with the current total transformation matrix.

```
SUBROUTINE MAT
I = 0
    I = I + 1
    ANG = USER INPUT ROTATION ANG TO ORIENT LINK IN CURRENT COORD. SYS.
    ZERO RMAT INTERMEDIATE ROTATION MATRIX
    ROTATION AXIS IS X-AXIS
    T:
        RMAT (1, 1) = 1.
        RMAT (2, 2) = COS (ANG)
        RMAT (2, 3) = -SIN (ANG)
        RMAT (3, 2) = SIN (ANG)
        RMAT (3, 3) = COS (ANG)
    F:
        (NULL)
    ROTATION AXIS IS Y-AXIS
    T:
        RMAT (1, 1) = COS (ANG)
        RMAT (1, 3) = SIN (ANG)
        RMAT (2, 2) = 1.
        RMAT (3, 1) = -SIN (ANG)
        RMAT (3, 3) = COS (ANG)
    F:
        (NULL)
    ROTATION AXIS IS Z-AXIS
    T:
        RMAT (1, 1) = COS (ANG)
        RMAT (1, 2) = -SIN (ANG)
        RMAT (2, 1) = SIN (ANG)
        RMAT (2, 2) = COS (ANG)
        RMAT (3, 3) = 1.
    F:
        (NULL)
    CONCATENATE TRANS MATRIX WITH RMAT AND LOAD INTO TRANS
DO UNTIL I .EQ. 3
OUTPUT TRANS MATRIX PRODUCT
RETURN
END
```

1.3.30 MATVEC

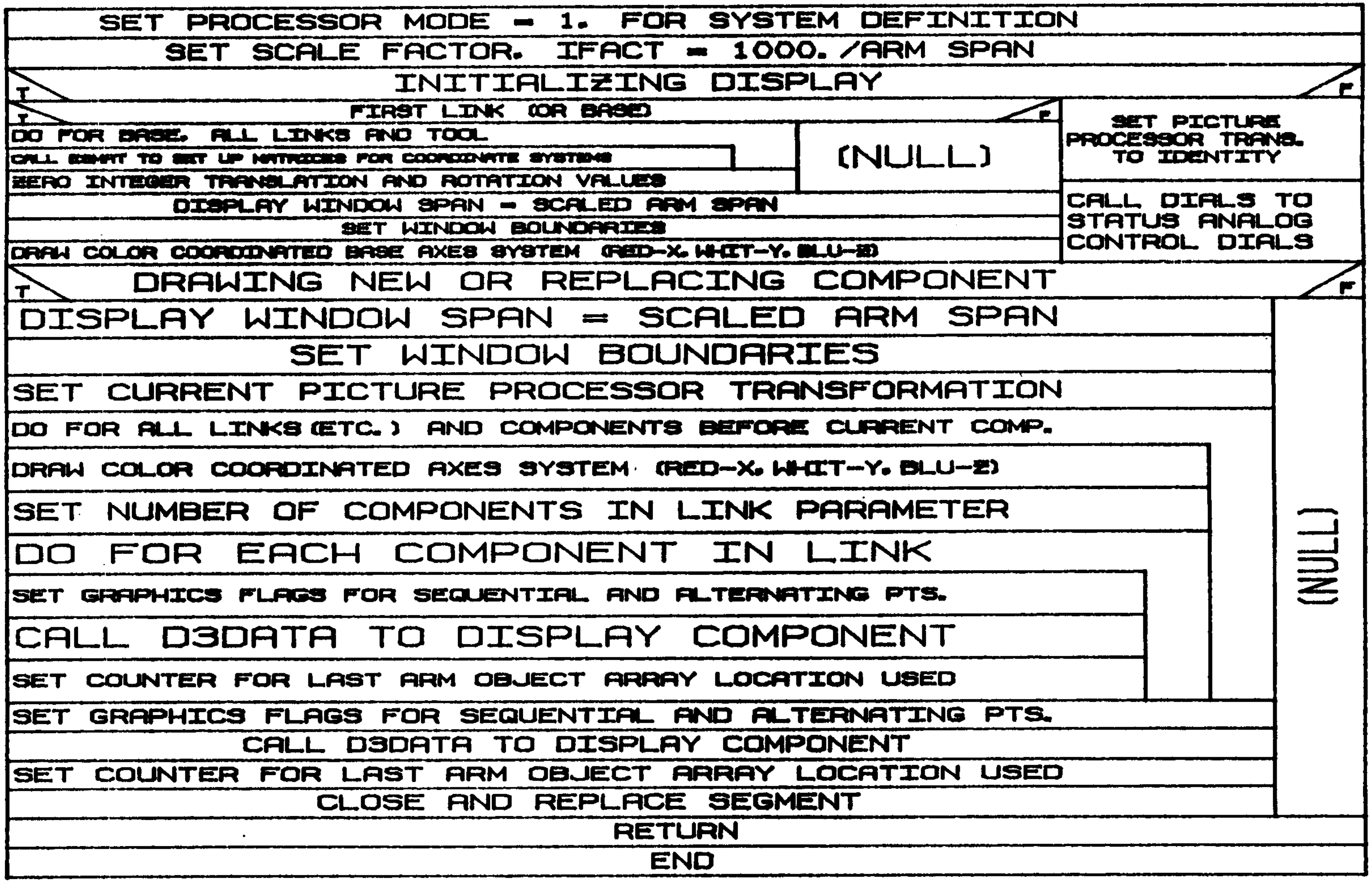
Subroutine MATVEC is called during the system definition function to provide matrix/vector multiplication. The routine is called from ORIENT. The vector A is multiplied by the matrix TRANS to produce output vector B. Note that this matrix/vector multiplication is 3-D only.

```
SUBROUTINE MATVEC
I = 0
    I = I + 1
    J = 0
        B (I) = PRODUCT OF MATRIX TRANS.
        ELMT. (I, J) * VECTOR A. ELMT. (J)
    DO UNTIL J .EQ. 3
DO UNTIL I .EQ. 3
RETURN
END
```

1.3.31 DRAW

Subroutine DRAW is called within the system definition function to provide the graphics display during the generation of arm detailed representations. It is called to display each successive component as it is defined. The routine logic is controlled by flag inputs specifying initialization (at which time base/link/tool transformation matrix concatenations to the system are performed), component drawing, or component modification world.

SUBROUTINE DRAW



```
SET PROCESSOR MODE = 1. FOR SYSTEM DEFINITION
SET SCALE FACTOR. IFACT = 1000./ARM SPAN
INITIALIZING DISPLAY
  T:
    FIRST LINK (OR BASE)
      T:
        DO FOR BASE. ALL LINKS AND TOOL
          CALL D3MAT TO SET UP MATRICES FOR COORDINATE SYSTEMS
        ZERO INTEGER TRANSLATION AND ROTATION VALUES
      F:
        (NULL)
    DISPLAY WINDOW SPAN = SCALED ARM SPAN
    SET WINDOW BOUNDARIES
    DRAW COLOR COORDINATED BASE AXES SYSTEM (RED-X, WHIT-Y, BLU-Z)
  F:
    SET PICTURE PROCESSOR TRANS. TO IDENTITY
    CALL DIALS TO STATUS ANALOG CONTROL DIALS
DRAWING NEW OR REPLACING COMPONENT
  T:
    DISPLAY WINDOW SPAN = SCALED ARM SPAN
    SET WINDOW BOUNDARIES
    SET CURRENT PICTURE PROCESSOR TRANSFORMATION
    DO FOR ALL LINKS (ETC.) AND COMPONENTS BEFORE CURRENT COMP.
      DRAW COLOR COORDINATED AXES SYSTEM (RED-X, WHIT-Y, BLU-Z)
      SET NUMBER OF COMPONENTS IN LINK PARAMETER
      DO FOR EACH COMPONENT IN LINK
        SET GRAPHICS FLAGS FOR SEQUENTIAL AND ALTERNATING PTS.
        CALL D3DATA TO DISPLAY COMPONENT
        SET COUNTER FOR LAST ARM OBJECT ARRAY LOCATION USED
    SET GRAPHICS FLAGS FOR SEQUENTIAL AND ALTERNATING PTS.
    CALL D3DATA TO DISPLAY COMPONENT
    SET COUNTER FOR LAST ARM OBJECT ARRAY LOCATION USED
    CLOSE AND REPLACE SEGMENT
  F:
    (NULL)
RETURN
END
```

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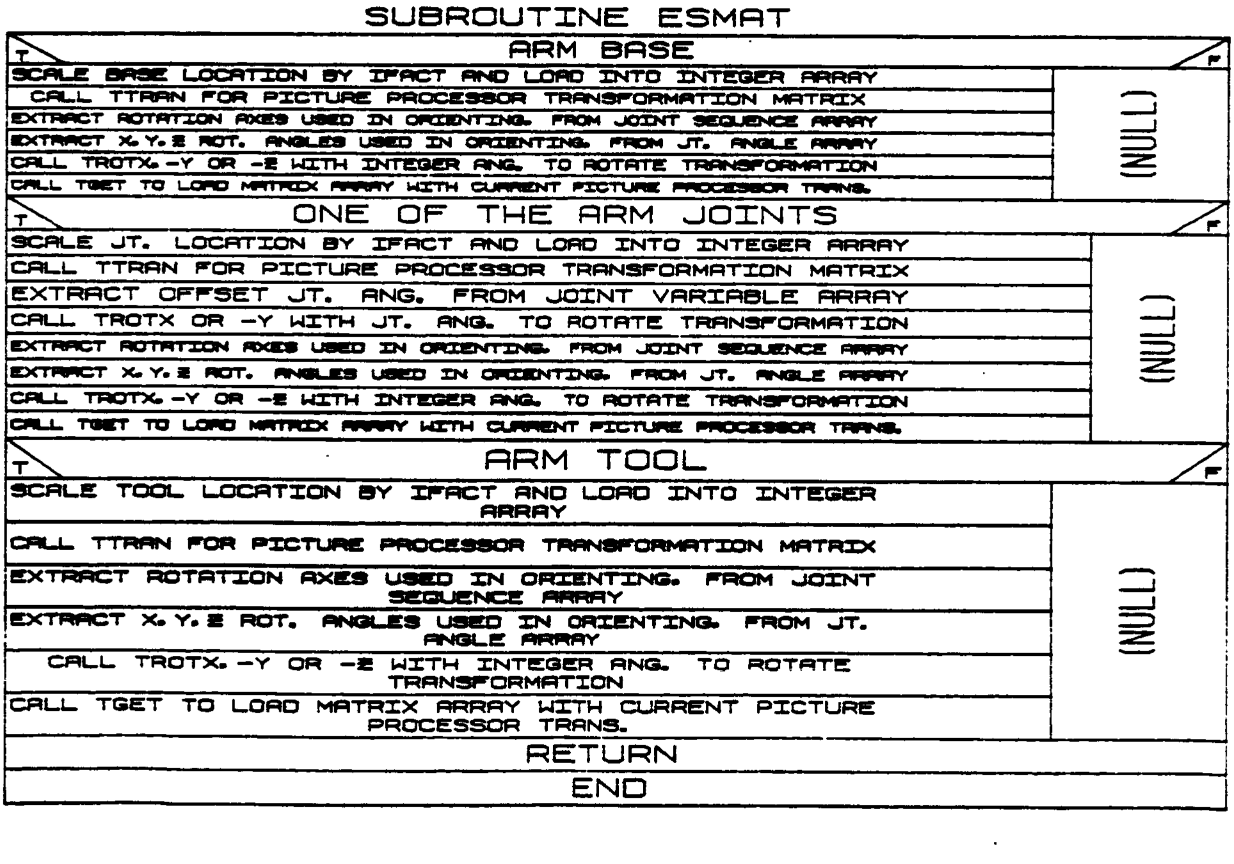
1.3.32 ESMAT

Subroutine ESMAT uses Evans and Sutherland graphics routines to construct the required transformation matrices from each system section coordinate system to the graphics coordinate system. Input argument K specifies which system section is under consideration. It is called during execution of the system definition function. It is called from subroutine DRAW to compute the required transformation matrices for each system section. The robotic system has section coordinate systems for the base, each joint/link, and the end-effector. An input value of K=1 indicates the robotic system base. The transformation matrix is composed of a translation matrix based on the base location and rotation matrices constructed using the base orientation parameters. A value of K from 2 to the number of links plus 1 (NJ+1) indicates the (K-1)th joint/link. All transformation matrices from each of the sections to the previous joint (or base, if the current joint is the first joint) are concatenated to form the total transformation matrix to the graphics coordinate system. Each joint transformation matrix is composed of a translation matrix based on the joint position, a rotation matrix based on the initial joint angular displacement, and rotation matrices for joint orientation. A value of K=NJ+2 indicates the end-effector system. The transformation matrix for the end-effector is composed of a translation matrix, and rotation matrices for end-effector orientation. The end-effector location and orientation are specified relative to the coordinate system of the final joint in the system.

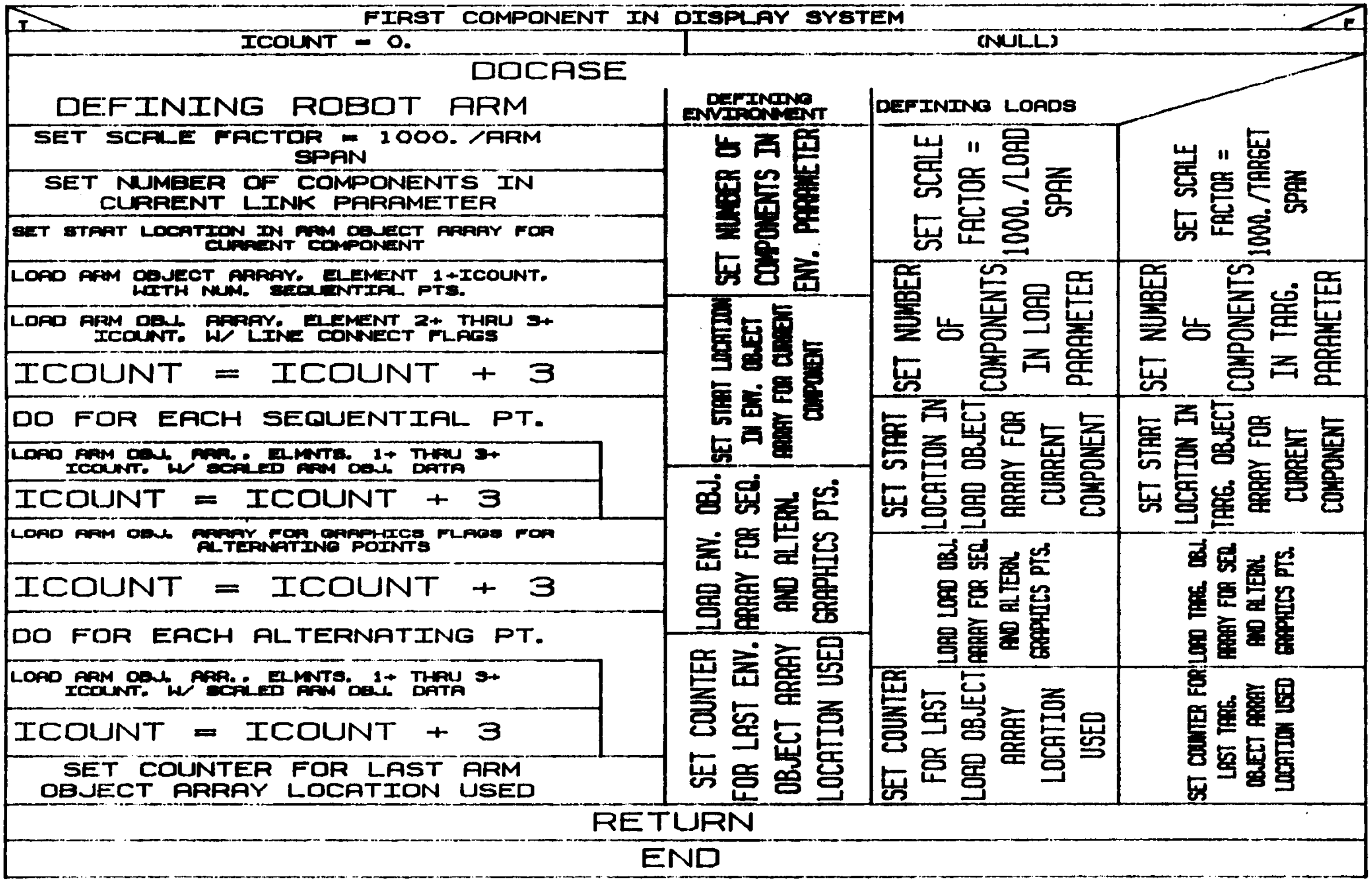


```
SUBROUTINE ESMAT
ARM BASE
  T:
    SCALE BASE LOCATION BY IFACT AND LOAD INTO INTEGER ARRAY
    CALL TTRAN FOR PICTURE PROCESSOR TRANSFORMATION MATRIX
    EXTRACT ROTATION AXES USED IN ORIENTING. FROM JOINT SEQUENCE ARRAY
    EXTRACT X. Y. Z ROT. ANGLES USED IN ORIENTING. FROM JT. ANGLE ARRAY
    CALL TROTX. -Y OR -Z WITH INTEGER ANG. TO ROTATE TRANSFORMATION
    CALL TGET TO LOAD MATRIX ARRAY WITH CURRENT PICTURE PROCESSOR TRANS.
  F:
    (NULL)
ONE OF THE ARM JOINTS
  T:
    SCALE JT. LOCATION BY IFACT AND LOAD INTO INTEGER ARRAY
    CALL TTRAN FOR PICTURE PROCESSOR TRANSFORMATION MATRIX
    EXTRACT OFFSET JT. ANG. FROM JOINT VARIABLE ARRAY
    CALL TROTX OR -Y WITH JT. ANG. TO ROTATE TRANSFORMATION
    EXTRACT ROTATION AXES USED IN ORIENTING. FROM JOINT SEQUENCE ARRAY
    EXTRACT X. Y. Z ROT. ANGLES USED IN ORIENTING. FROM JT. ANGLE ARRAY
    CALL TROTX. -Y OR -Z WITH INTEGER ANG. TO ROTATE TRANSFORMATION
    CALL TGET TO LOAD MATRIX ARRAY WITH CURRENT PICTURE PROCESSOR TRANS.
  F:
    (NULL)
ARM TOOL
  T:
    SCALE TOOL LOCATION BY IFACT AND LOAD INTO INTEGER ARRAY
    CALL TTRAN FOR PICTURE PROCESSOR TRANSFORMATION MATRIX
    EXTRACT ROTATION AXES USED IN ORIENTING. FROM JOINT SEQUENCE ARRAY
    EXTRACT X. Y. Z ROT. ANGLES USED IN ORIENTING. FROM JT. ANGLE ARRAY
    CALL TROTX. -Y OR -Z WITH INTEGER ANG. TO ROTATE TRANSFORMATION
    CALL TGET TO LOAD MATRIX ARRAY WITH CURRENT PICTURE PROCESSOR TRANS.
  F:
    (NULL)
RETURN
END
```

1.3.33 DBAS

Subroutine DBAS is called within the system definition function during detailed graphics representation generation. For the subroutine, input calling argument IMAN specifies environment, robotic system component, target, or load objects file consideration. Graphics object data IOBJBK are loaded for robotic system components, TGRAFBK is loaded for target components, LGRAFBK is loaded for load components, and ENVTBK is loaded for environment components. The manner in which the data are stored in the COMMON blocks is dictated by the data format used in Evans and Sutherland graphics routine D3DATA.

SUBROUTINE DBAS



```
FIRST COMPONENT IN DISPLAY SYSTEM
  T:
    ICOUNT = 0.
  F:
    (NULL)
DOCASE
  DEFINING ROBOT ARM
    SET SCALE FACTOR = 1000./ARM SPAN
    SET NUMBER OF COMPONENTS IN CURRENT LINK PARAMETER
    SET START LOCATION IN ARM OBJECT ARRAY FOR CURRENT COMPONENT
    LOAD ARM OBJECT ARRAY, ELEMENT 1+ICOUNT, WITH NUM. SEQUENTIAL PTS.
    LOAD ARM OBJ. ARRAY, ELEMENT 2+ THRU 3+ ICOUNT, W/ LINE CONNECT FLAGS
    ICOUNT = ICOUNT + 3
    DO FOR EACH SEQUENTIAL PT.
      LOAD ARM OBJ. ARR., ELMNTS. 1+ THRU 3+ ICOUNT, W/ SCALED ARM OBJ. DATA
      ICOUNT = ICOUNT + 3
    LOAD ARM OBJ. ARRAY FOR GRAPHICS FLAGS FOR ALTERNATING POINTS
    ICOUNT = ICOUNT + 3
    DO FOR EACH ALTERNATING PT.
      LOAD ARM OBJ. ARR., ELMNTS. 1+ THRU 3+ ICOUNT, W/ SCALED ARM OBJ. DATA
      ICOUNT = ICOUNT + 3
    SET COUNTER FOR LAST ARM OBJECT ARRAY LOCATION USED
  DEFINING ENVIRONMENT
    SET NUMBER OF COMPONENTS IN ENV. PARAMETER
    SET START LOCATION IN ENV. OBJECT ARRAY FOR CURRENT COMPONENT
    LOAD ENV. OBJ. ARRAY FOR SEQ. AND ALTERN. GRAPHICS PTS.
    SET COUNTER FOR LAST ENV. OBJECT ARRAY LOCATION USED
  DEFINING LOADS
    SET SCALE FACTOR = 1000./LOAD SPAN
    SET NUMBER OF COMPONENTS IN LOAD PARAMETER
    SET START LOCATION IN LOAD OBJECT ARRAY FOR CURRENT COMPONENT
    LOAD LOAD OBJ. ARRAY FOR SEQ. AND ALTERN. GRAPHICS PTS.
    SET COUNTER FOR LAST LOAD OBJECT ARRAY LOCATION USED
  
    SET SCALE FACTOR = 1000./TARGET SPAN
    SET NUMBER OF COMPONENTS IN TARG. PARAMETER
    SET START LOCATION IN TARG. OBJECT ARRAY FOR CURRENT COMPONENT
    LOAD TARG. OBJ. ARRAY FOR SEQ. AND ALTERN. GRAPHICS PTS.
    SET COUNTER FOR LAST TARG. OBJECT ARRAY LOCATION USED
RETURN
END
```

1.3.34 BASELK

In the create mode of BASELK, the user is prompted for the base mass, the location of the base center of mass in the base coordinate system, the base inertia matrix relative to the centroid, the point mass values and locations if desired.

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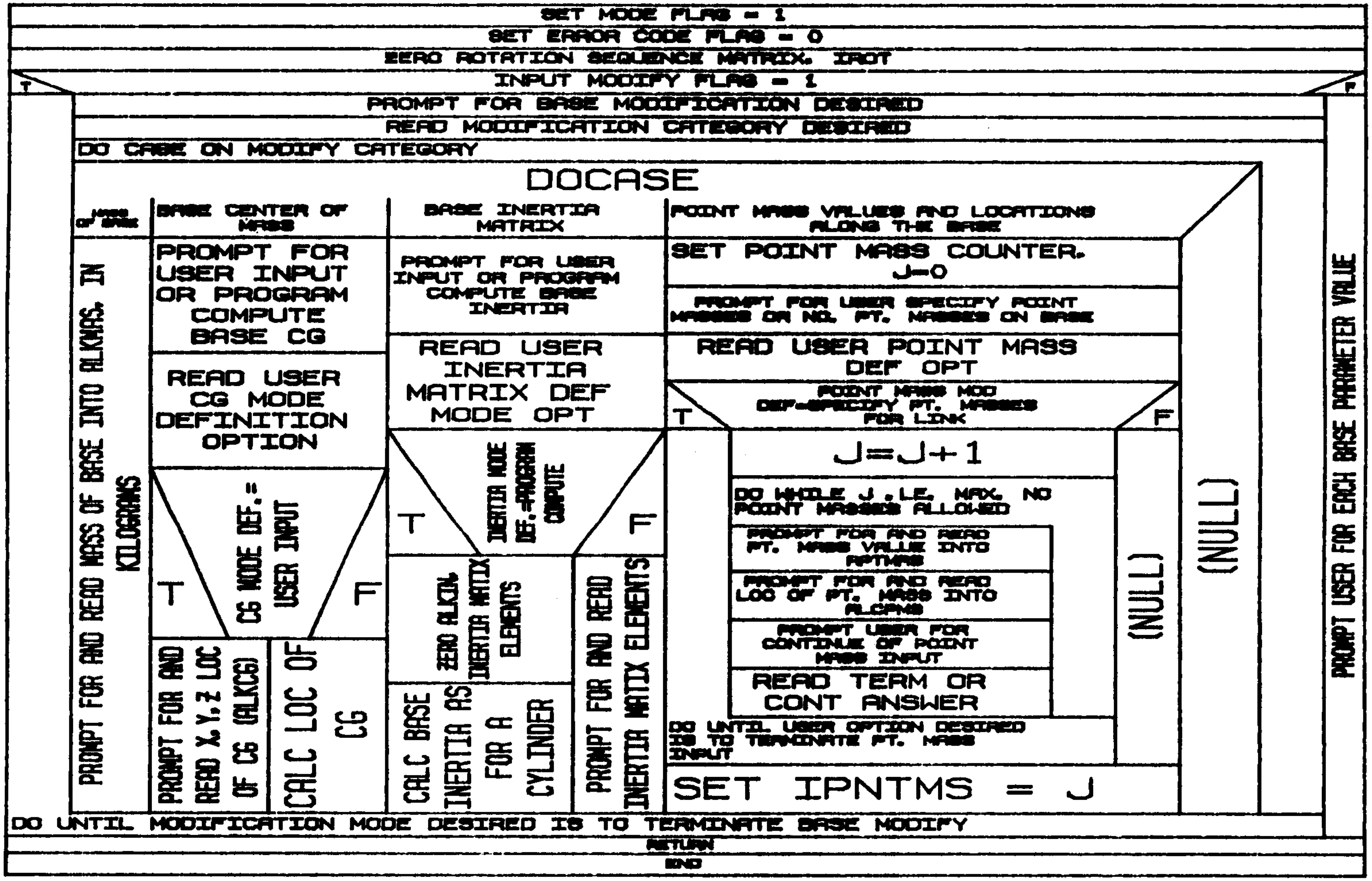
SUBROUTINE BASELK



1.3.35 RCTSTR

Subroutine RCTSTR is called within the system definition function during detailed graphics representation generation for the environment, manipulator, load, or target objects. If the requested component is a rectangular cross-section beam (ISHAPE=7), it is called to compute data points for the graphics routine.

SUBROUTINE RCTSTR

```
PROMPT FOR RECTANGLE +/-Y SIDE LENGTH, RCTL
PROMPT FOR RECTANGLE +/-Z SIDE LENGTH, RCTL1
PROMPT FOR SEGMENT LENGTH AND NUM. SEGS.
WRITE TO GRAPHICS SAVE FILE IF OPTED
SET NUMBER OF SIDES = 4
SET NUM. LINES AND MODE DRAWING FLAG FOR CONNECTING SEQ. PTS.
DO FOR EACH SEGMENT OF RECT. STRUCTURE, FROM 1 TO NUM. SIDES + 1
    SET OFFSET AND X = (CURRENT SEG. NUM. - 1) * (SEGM. LENGTH)
    LOAD ARRAY X, Y, Z VALUE, ELEMENT 1+OFFSET, WITH X, RCTL, RCTL1
    LOAD ARRAY X, Y, Z VALUE, ELEMENT 2+OFFSET, WITH X, -RCTL, RCTL1
    LOAD ARRAY X, Y, Z VALUE, ELEMENT 3+OFFSET, WITH X, -RCTL, -RCTL1
    LOAD ARRAY X, Y, Z VALUE, ELEMENT 4+OFFSET, WITH X, RCTL, -RCTL1
    LOAD ARRAY X, Y, Z VALUES, ELEMENT 5+OFFSET, WITH ELEMT. 1+OFFSET VALUES
SET ICOUNT = NUMBER LINES ALREADY DRAWN SEQ.
SET NUM. LINES LINE DRAWING MODE FLAG FOR CONNECTING ALT. PTS.
SET ANGLE OFFSET PARAMETER TO (SEG. NUM.) * (NUM. SIDES + 1)
DO FOR EACH RECTANGLE SIDE FROM 2 TO NUM. SIDES
    INCREMENT I
    ICOUNT = ICOUNT + 1
    LOAD ARRAY, ELEMENT ICOUNT, WITH X, Y, Z FROM ARRAY ELEMENT I
    ICOUNT = ICOUNT + 1
    LOAD ARRAY, ELEMENT ICOUNT, WITH X, Y, Z FROM ARRAY ELEMENT I+OFFSET
RETURN
END
```

1.3.36 CADOBJ

Subroutine CADOBJ is called within the system definition function during detailed graphics representation generation for the environment, manipulator, load, or target objects. If the requested component is a CAD/CAM object (ISHAPE=11), it is called to compute data points for the graphics routine.

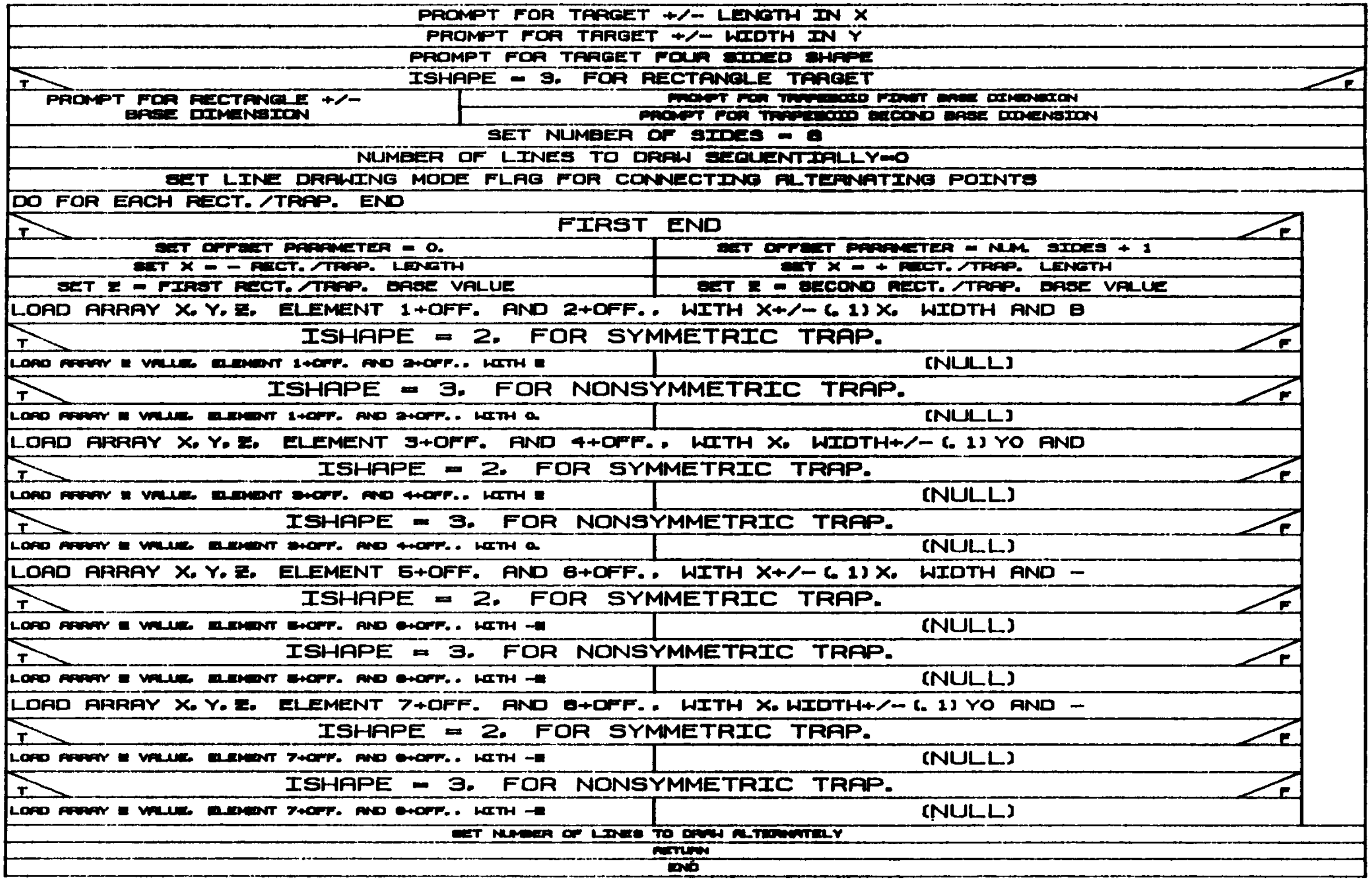
SUBROUTINE CADOBJ

```
PROMPT USER FOR CHOICE TO READ COMPONENT FILE OR INPUT INTERACTIVELY
READING FILE
  T:
    PROMPT USER FOR COMPONENT FILENAME
    OPEN COMPONENT FILE
    READ NUMBER OF DATA POINTS VALUE FROM FILE
    DO UNTIL ALL POINTS HAVE BEEN READ
        READ RECORD FROM FILE CONTAINING X, Y, Z VALUES OF PT. INTO DATA
    CLOSE COMPONENT FILE
  F:
    PROMPT FOR NUMBER OF POINTS TO BE INPUT FOR OBSTCL PERIMETER
    SET NUM. SIDES = NUM. PTS. TO BE INPUT
    KOUNT = 0
    DO UNTIL ALL POINTS HAVE BEEN INPUT
        READ USER INPUT X, Y AND Z REAL VALUES FOR CURRENT POINT INTO DATA
        KOUNT = KOUNT + 1
    KOUNT = NUMBER PTS. READ + 1
    SET LAST DATA ARRAY ELEMENT, WITH X, Y, Z VALUES READ FOR ELEMENT 1
    PROMPT USER FOR SCALE FACTOR TO BE USED
    SET LINE DRAWING MODE FLAG FOR CONNECTING SEQUENTIAL POINTS = KOUNT
    SET LINE DRAWING MODE FLAG FOR CONNECTING ALTERNATING POINTS = 0
    DO FOR EACH POINT TO BE CONNECTED SEQUENTIALLY
        LOAD ARRAY X, Y, Z, ELEMENT KOUNT, WITH DATA X, Y, Z* SCAL.FACT
RETURN
END
```

1.3.37 TARG

Subroutine TARG is called within the system definition function during detailed graphics representation generation for target objects. If the requested component is a 4-dot target object (ISHAPE=12), it is called to compute data points for the graphics routine.

SUBROUTINE TARG



```
PROMPT FOR TARGET +/- LENGTH IN X
PROMPT FOR TARGET +/- WIDTH IN Y
PROMPT FOR TARGET FOUR SIDED SHAPE
ISHAPE = 3. FOR RECTANGLE TARGET
  T: PROMPT FOR RECTANGLE +/- BASE DIMENSION
  F: PROMPT FOR TRAPEZOID FIRST BASE DIMENSION
     PROMPT FOR TRAPEZOID SECOND BASE DIMENSION
SET NUMBER OF SIDES = 8
NUMBER OF LINES TO DRAW SEQUENTIALLY=0
SET LINE DRAWING MODE FLAG FOR CONNECTING ALTERNATING POINTS
DO FOR EACH RECT./TRAP. END
    FIRST END
      T: SET OFFSET PARAMETER = 0.
         SET X = - RECT./TRAP. LENGTH
         SET Z = FIRST RECT./TRAP. BASE VALUE
      F: SET OFFSET PARAMETER = NUM. SIDES + 1
         SET X = + RECT./TRAP. LENGTH
         SET Z = SECOND RECT./TRAP. BASE VALUE
    LOAD ARRAY X, Y, Z, ELEMENT 1+OFF. AND 2+OFF., WITH X+/-(.1)X, WIDTH AND B
    ISHAPE = 2. FOR SYMMETRIC TRAP.
      T: LOAD ARRAY Z VALUE, ELEMENT 1+OFF. AND 2+OFF., WITH B
      F: (NULL)
    ISHAPE = 3. FOR NONSYMMETRIC TRAP.
      T: LOAD ARRAY Z VALUE, ELEMENT 1+OFF. AND 2+OFF., WITH 0.
      F: (NULL)
    LOAD ARRAY X, Y, Z, ELEMENT 3+OFF. AND 4+OFF., WITH X, WIDTH+/-(.1)YO AND
    ISHAPE = 2. FOR SYMMETRIC TRAP.
      T: LOAD ARRAY Z VALUE, ELEMENT 3+OFF. AND 4+OFF., WITH B
      F: (NULL)
    ISHAPE = 3. FOR NONSYMMETRIC TRAP.
      T: LOAD ARRAY Z VALUE, ELEMENT 3+OFF. AND 4+OFF., WITH 0.
      F: (NULL)
    LOAD ARRAY X, Y, Z, ELEMENT 5+OFF. AND 6+OFF., WITH X+/-(.1)X, WIDTH AND -
    ISHAPE = 2. FOR SYMMETRIC TRAP.
      T: LOAD ARRAY Z VALUE, ELEMENT 5+OFF. AND 6+OFF., WITH -B
      F: (NULL)
    ISHAPE = 3. FOR NONSYMMETRIC TRAP.
      T: LOAD ARRAY Z VALUE, ELEMENT 5+OFF. AND 6+OFF., WITH -B
      F: (NULL)
    LOAD ARRAY X, Y, Z, ELEMENT 7+OFF. AND 8+OFF., WITH X, WIDTH+/-(.1)YO AND -
    ISHAPE = 2. FOR SYMMETRIC TRAP.
      T: LOAD ARRAY Z VALUE, ELEMENT 7+OFF. AND 8+OFF., WITH -B
      F: (NULL)
    ISHAPE = 3. FOR NONSYMMETRIC TRAP.
      T: LOAD ARRAY Z VALUE, ELEMENT 7+OFF. AND 8+OFF., WITH -B
      F: (NULL)
SET NUMBER OF LINES TO DRAW ALTERNATELY
RETURN
END
```

1.4.1 CVTUNIT

Subroutine CVTUNIT is responsible for the conversion of input data from I/O units to internal mathematical units. Each data value VAL is multiplied by CONUNIT(IDIM) and replaced in VAL.

```
SUBROUTINE CVTUNIT
DO FOR EACH VALUE TO BE CONVERTED
    VALUE = VALUE TIMES APPROPRIATE
            COMPONENT OF CONUNIT
```

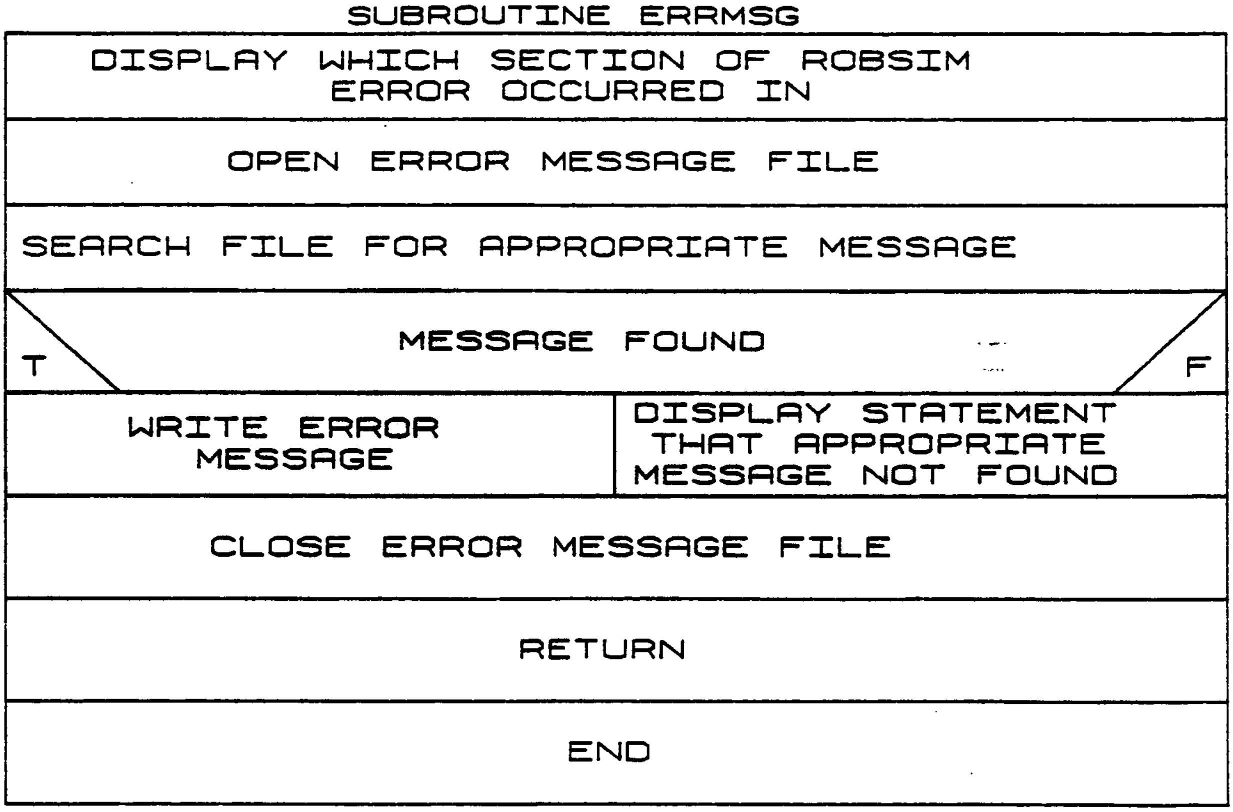
1.4.2 MATMPY

Subroutine MATMPY performs the multiplication of two matrices, AB=C, where A has I rows and J columns, the dimension of B is JxK and C is IxK. The matrices and their sizes are passed to subroutine as calling arguments.

```
SUBROUTINE MATMPY
            C (IROW. ICOL) = 0. 0
                R = A (IROW. ICNT) *B (ICNT. ICOL)
                C (IROW. ICOL) = C (IROW. ICOL) +R
            DO UNTIL ICNT = NUMBER OF
            COLUMNS IN MATRIX A (ROWS IN B)
        DO UNTIL ICOL = NUMBER OF
        COLUMNS IN SECOND MATRIX B
    DO UNTIL IROW = NUMBER OF ROWS IN
    FIRST MATRIX A
RETURN
END
```

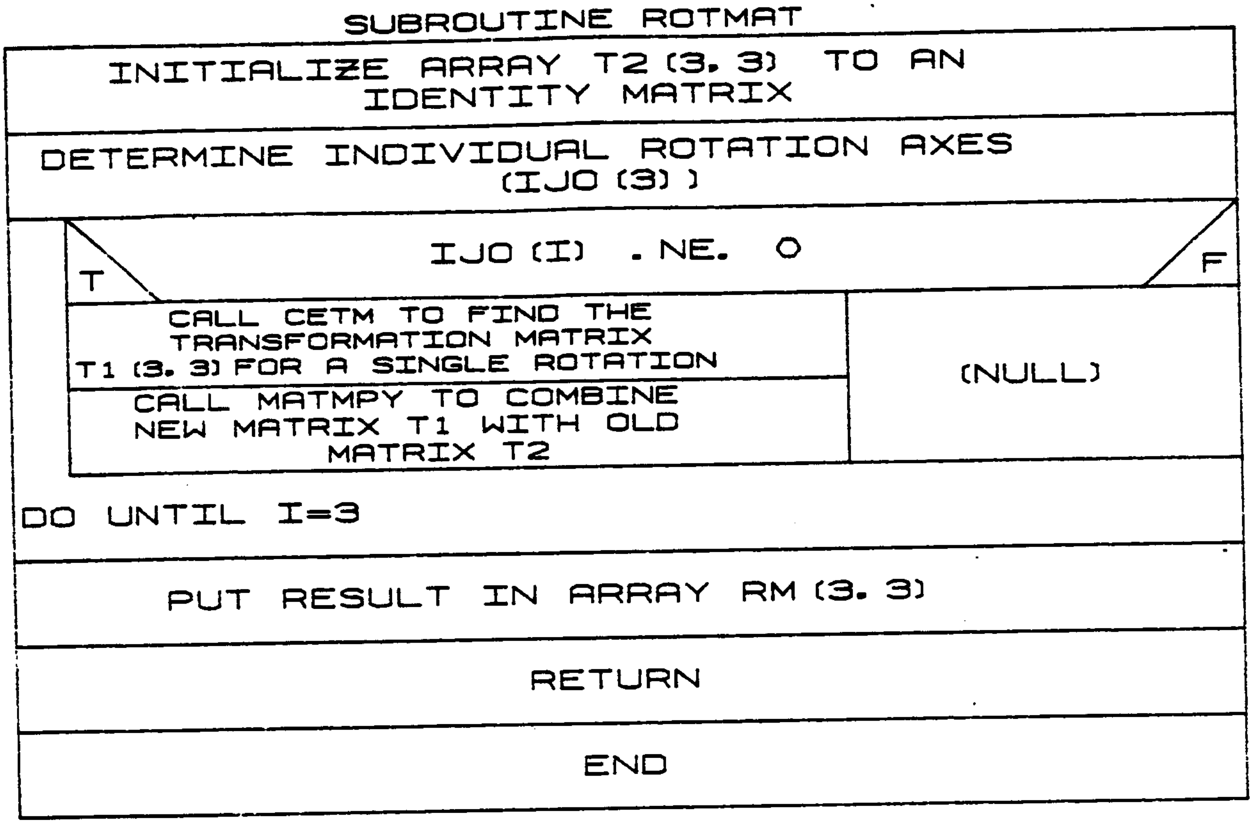
1.4.3 ERRMSG

Subroutine ERRMSG is called when certain errors occur during ROBSIM execution. The routine first displays the current operating mode (i.e., system definition, analysis, or postprocessing). The routine searches the file ERROR.DAT for an error message corresponding to the error number passed to it. The message is typed at the terminal and execution returns to the calling routine, from which it continues or terminates depending on whether the error is fatal.



1.4.4 ROTMAT

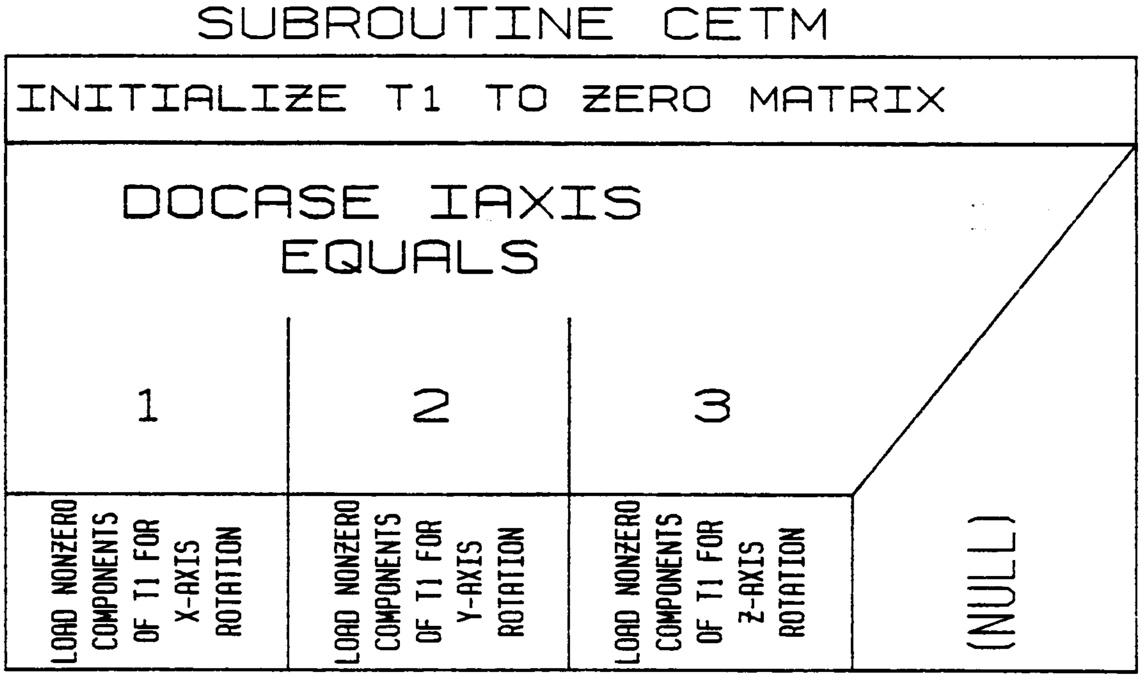
ROTMAT computes a rotation matrix from a sequence of up to three rotations about coordinate axes. It decomposes the input calling argument JSEQ into three successive rotation axes, computes each corresponding rotation matrix from the specified angles of rotation and combines these successively to find the overall rotation matrix.



1.4.5 CETM

Subroutine CETM calculates a transformation matrix for a specific input axis of rotation and rotation angle by the use of appropriate direction cosines matrix. The calling argument input is:

Symbol	Type	Dim.	Definition
IAXIS	I*4	1	Rotation axis for joint orientation = 1, Rotation about x-axis = 2, Rotation about y-axis = 3, Rotation about z-axis
TH	R*4	1	Rotation angle for joint orientation



1.4.6 LOGO

The LOGO routine calculates data points required to output the Martin Marietta logo, and displays it on the robotic simulation E&S graphics display. It extracts from the data points file LOGO.DAT, the Martin Marietta company logo, scales and displays the logo for the robotic graphics simulation.

```
SUBROUTINE LOGO
OPEN LOGO DATA FILE
READ ALL OF LOGO DATA INTO INTEGER DATA ARRAY
CLOSE LOGO DATA FILE
SET INTEGER STEP VALUE TO 80/INPUT SIZE
DO FOR EACH DATA HORIZONTAL PIXEL
    L = 0
    INCREMENT I
    INTEGER X.Y VALUES - (DATA ARRAY ELMT.*INPUT SIZE) + INITIAL X.Y
    INTEGER Z VALUE = INITIAL Z
    L = L + 1
    SET OUTPUT LOGO ARRAY X.Y.Z. ELEMENT L. TO X.Y.Z
    SET START AND STOP POINTS LOOP PARAMETERS
    J = 0
    DO WHILE L. NUMBER OF POINTS IN LOGO. .LE. 500
        J = J + 1
        DETERMINE RATIO TO USE IN OUTPUTTING LOGO POINTS
        REWRITE INTEGER X VALUE - INTEGER X * RATIO
    DO UNTIL J .GT. STOP LOOP PARM. FROM START LOOP PARM. AT STEP VALUE
    SET LINE GENERATOR FLAGS FOR GRAPHICS DISPLAY ROUTINE
    DISPLAY CURRENT GRAPHICS DATA ARRAY- DRAW SCALED LOGO
RETURN
END
```

1.4.7 CRPD

Subroutine CRPD computes the cross-product of two vectors A and B, each containing three components. The result is put into the vector C.

SUBROUTINE CRPD

```
C (1)  =  A (2) *B (3) -A (3) *B (2)
C (2)  =  A (3) *B (1) -A (1) *B (3)
C (3)  =  A (1) *B (2) -A (2) *B (1)
RETURN
END
```

The Analysis Tools Function

The program SIMDRVR is the analysis tools function driver. The following set of routine functional descriptions and VCLRs (visual control logic representations) are the modules found in the analysis tools function of ROBSIM.

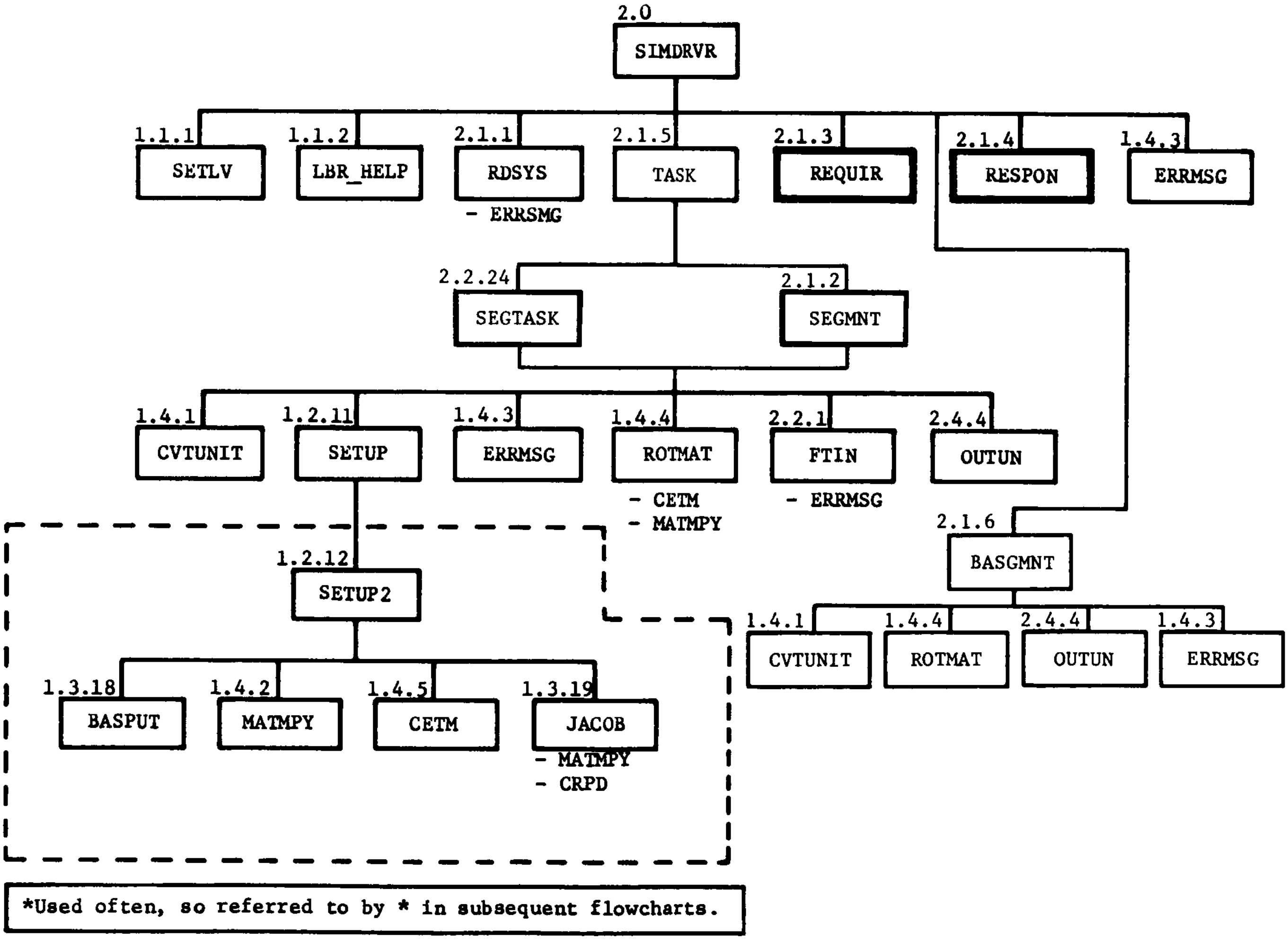


Figure B-8. - Functional block diagram for SIMDRVR.

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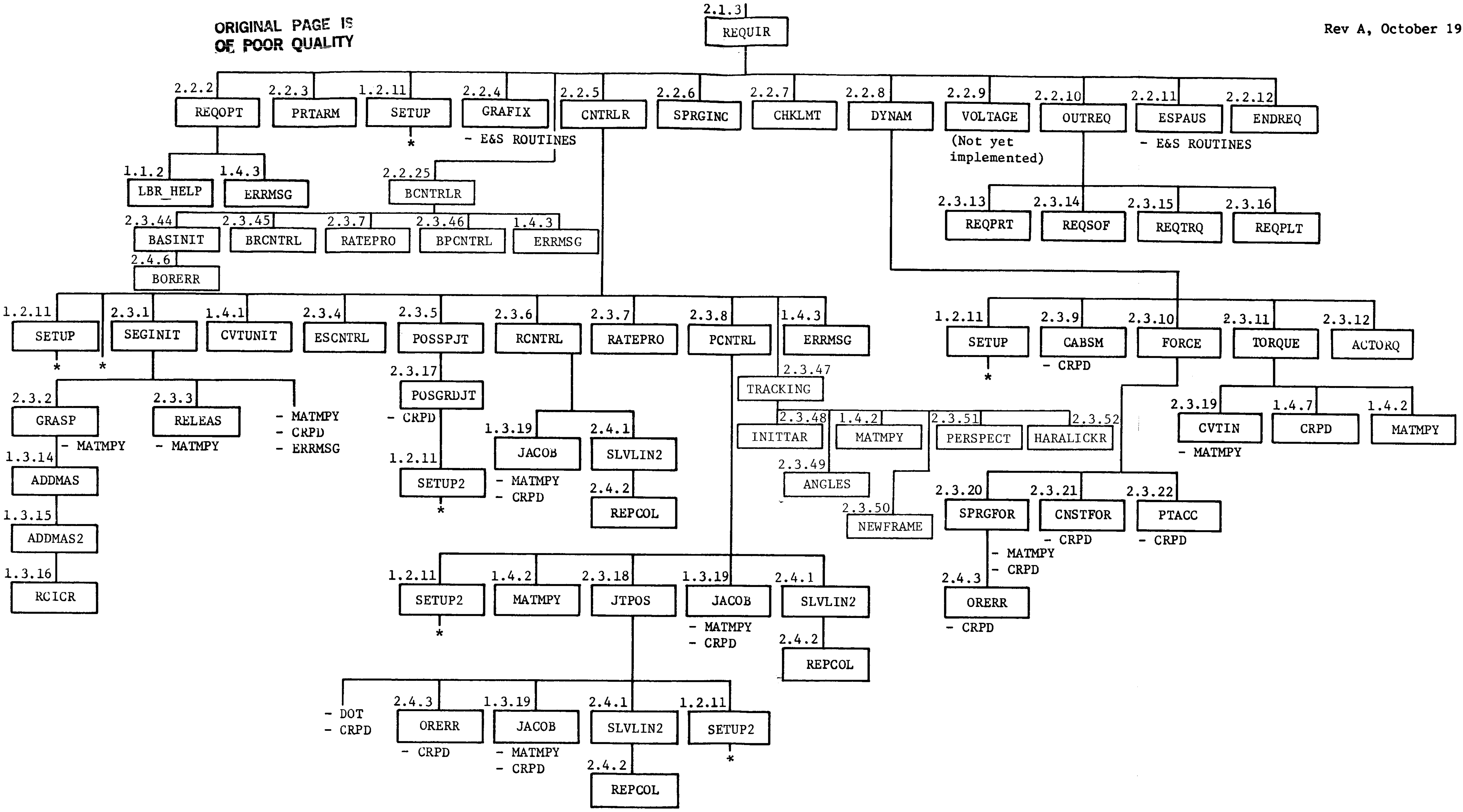

*Defined in previous flowchart SIMDRVR.

Figure B-8. - (cont)

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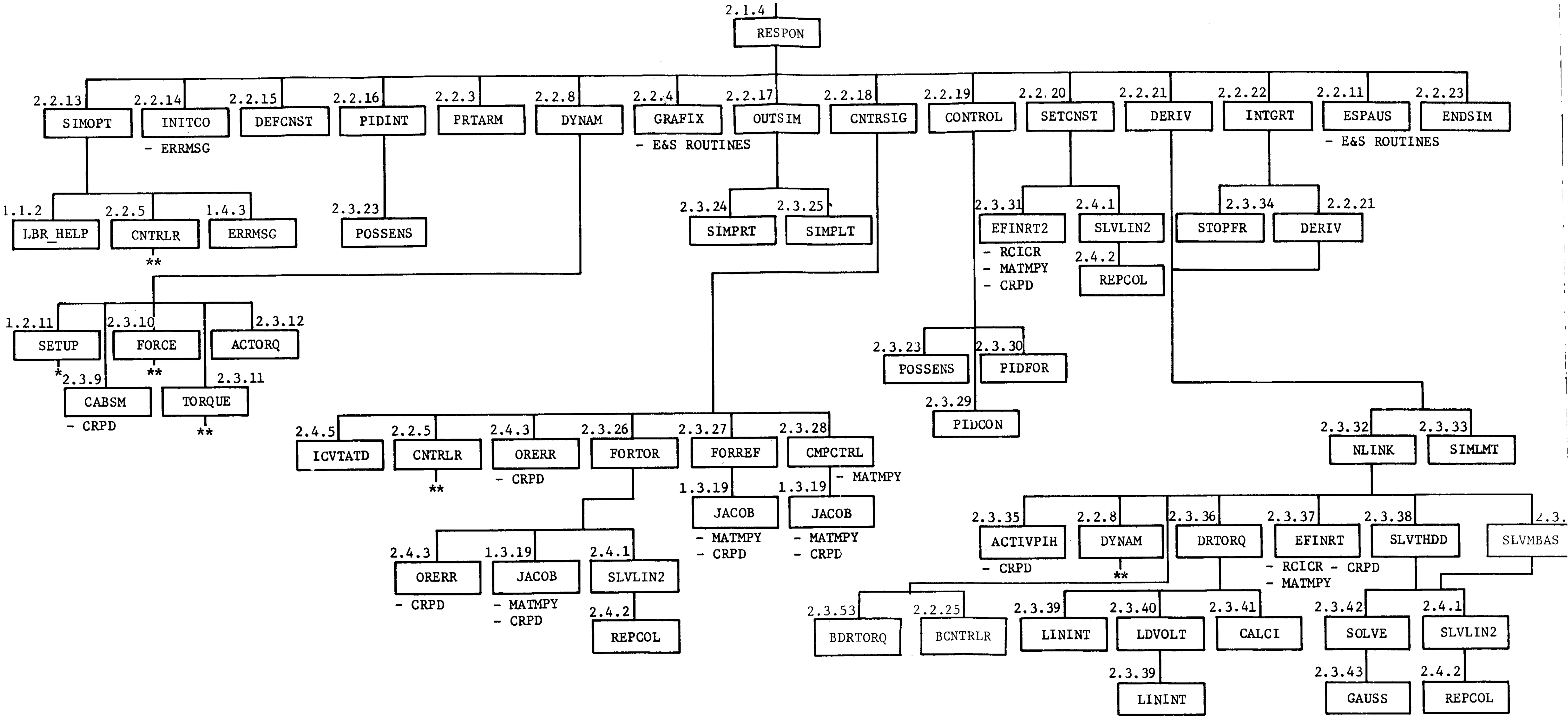


*Defined in flowchart SIMDRVR.

**These subroutines defined in previous flowchart under REQUIR.

FOLDOUT FRAME

Figure B-8. - (concl)

FOLDOUT FRAME

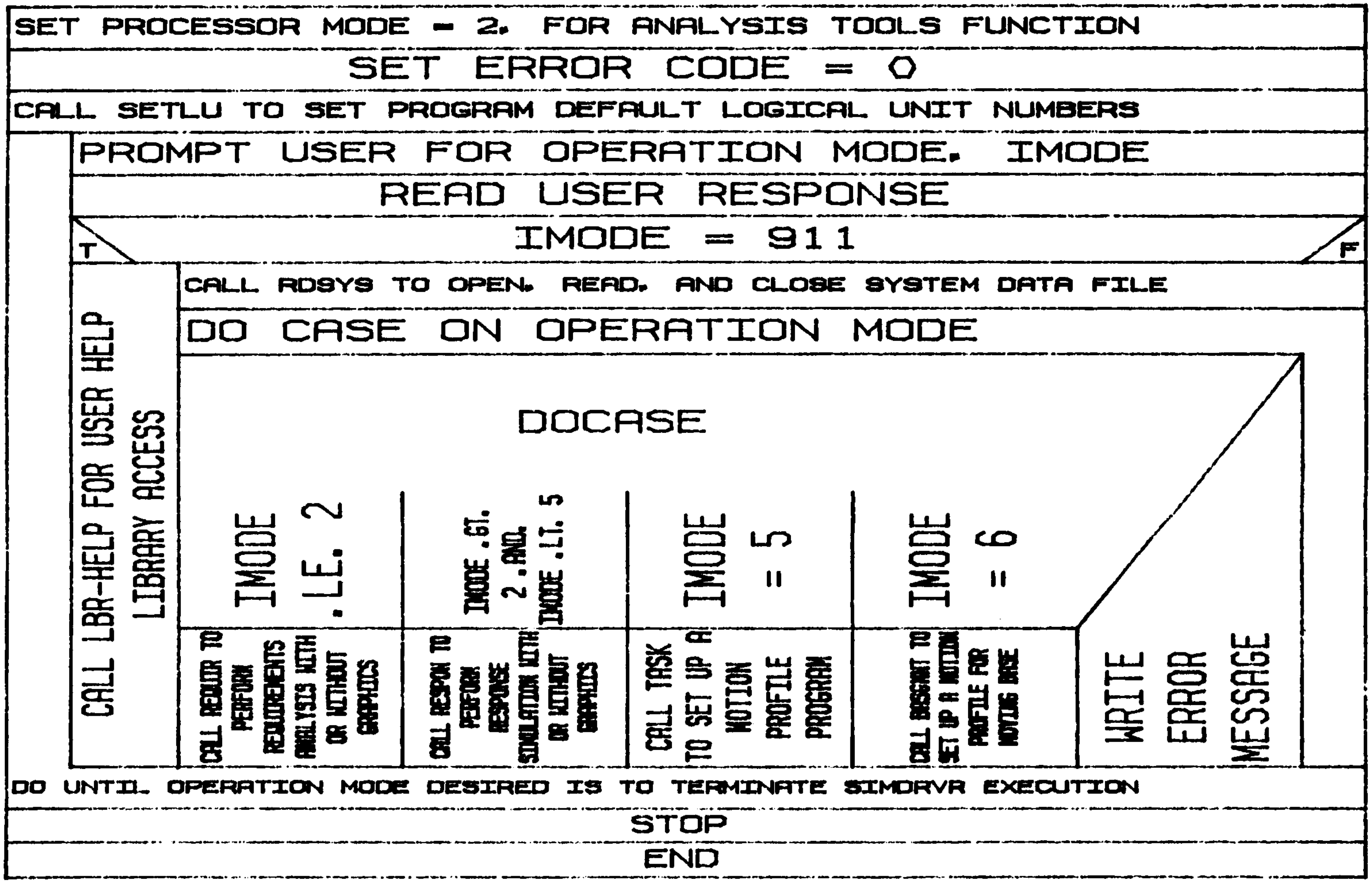
TABLE B-VI. - PROGRAMS EMPLOYED IN SIMDRVR

2.0	SIMDRVR
2.1.1	RDSYS
2.1.2	SGMNT
2.1.3	REQUIR
2.1.4	RESPON
2.1.5	TASK
2.1.6	BASGMNT
2.2.1	FTIN
2.2.2	REQOPT
2.2.3	PRTARM
2.2.4	GRAFIX
2.2.5	CNTRLR
2.2.6	SPRGINC
2.2.7	CHKLMT
2.2.8	DYNAM
2.2.9	VOLTAGE
2.2.10	OUTREQ
2.2.11	ESPAUS
2.2.12	ENDREQ
2.2.13	SIMOPT
2.2.14	INITCO
2.2.15	DEFCNST
2.2.16	PIDINIT
2.2.17	OUTSIM
2.2.18	CNTRSIG
2.2.19	CONTROL
2.2.20	SETCNST
2.2.21	DERIV
2.2.22	INTGRT
2.2.23	ENDSIN
2.2.24	SEGTASK
2.2.25	BCNTRLR
2.3.1	SEGINIT
2.3.2	GRASP
2.3.3	RELEAS
2.3.4	ESCNTRL
2.3.5	POSSPJT
2.3.6	RCNTRL
2.3.7	RATEPRO
2.3.8	PCNTRL
2.3.9	CABSIM
2.3.10	FORCE
2.3.11	TORQUE
2.3.12	ACTORQ
2.3.13	REQPRT
2.3.14	REQSOF
2.3.15	REQTRQ
2.3.16	REQPLT
2.3.17	POSGRDJT
2.3.18	JTPOS
2.3.19	CVTIN
2.3.20	SPRGFOR
2.3.21	CNSTFOR
2.3.22	PTACC
2.3.23	POSSENS
2.3.24	SIMPRT
2.3.25	SIMPLT
2.3.26	FORTOR
2.3.27	FORREF
2.3.28	CMPCTRL
2.3.29	PIDCON
2.3.30	PIDFOR
2.3.31	EFINRT2
2.3.32	NLINK
2.3.33	SIMLMT
2.3.34	STOPFR
2.3.35	ACTIVPIH
2.3.36	DRTORQ
2.3.37	EFINRT
2.3.38	SLVTHDD
2.3.39	LININT
2.3.40	LDVOLT
2.3.41	CALCI
2.3.42	SOLVE
2.3.43	GAUSS
2.3.44	BASINIT
2.3.45	BRCNTRL
2.3.46	BPCNTRL
2.3.47	TRACKING
2.3.48	INITTAR
2.3.49	ANGLES
2.3.50	NEWFRAME
2.3.51	PERSPECT
2.3.52	HARALICKR
2.3.53	BDRTORQ
2.3.54	SLVMBAS
2.4.1	SLVLIN2
2.4.2	REPCOL
2.4.3	ORERR
2.4.4	OUTUN
2.4.5	ICVTATD
2.4.6	BORERR

2.0 SIMDRVR

The program SIMDRVR is the analysis tools function driver. It operates in an interactive mode, prompting the user for the analysis option desired: requirements analysis without graphics, requirements analysis with graphics (a display of system motion during program execution), response simulation analysis without graphics, response simulation analysis with graphics, option to set up a base or arm motion program or terminate SIMDRVR execution.

PROGRAM SIMDRVR



```
SET PROCESSOR MODE = 2, FOR ANALYSIS TOOLS FUNCTION
SET ERROR CODE = 0
CALL SETLU TO SET PROGRAM DEFAULT LOGICAL UNIT NUMBERS
    PROMPT USER FOR OPERATION MODE, IMODE
    READ USER RESPONSE
    IMODE = 911
    T:
        CALL LBR-HELP FOR USER HELP LIBRARY ACCESS
    F:
        CALL RDSYS TO OPEN, READ, AND CLOSE SYSTEM DATA FILE
        DO CASE ON OPERATION MODE
            DOCASE
            IMODE .LE. 2:
                CALL REQUIR TO PERFORM REQUIREMENTS ANALYSIS WITH OR WITHOUT GRAPHICS
            IMODE .GT. 2 .AND. IMODE .LT. 5:
                CALL RESPON TO PERFORM RESPONSE SIMULATION WITH OR WITHOUT GRAPHICS
            IMODE = 5:
                CALL TASK TO SET UP A MOTION PROFILE PROGRAM
            IMODE = 6:
                CALL BASGNRT TO SET UP A MOTION PROFILE FOR MOVING BASE
            (other):
                WRITE ERROR MESSAGE
DO UNTIL OPERATION MODE DESIRED IS TO TERMINATE SIMDRVR EXECUTION
STOP
END
```

2.1.1 RDSYS

Subroutine RDSYS is called from SIMDRVR to read in the manipulator system definition data needed to run any of the SIMDRVR analysis options. The routine first prompts the user for the name of the file containing the system's data and then opens that file. If the system includes moving bases it reads the number of bases. Moving base numbers, geometric properties, mass properties, actuator properties and special joint data for each arm are read in, as well as system graphics data and the definition of gravity for the system. If the system contains an environment, the data describing it are read in. If load objects are also to be included, the data describing them are read in. End-effector data and target data are to be read next. After that, the file is closed and saved.

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SUBROUTINE RDSYS

```
PROMPT FOR NAME OF SYSTEM DATA FILE
OPEN SYSTEM DATA FILE
READ INPUT AND OUTPUT UNITS
READ MOVING BASE FLAG IMOVBAS
IMOVBAS=1
  T: READ NUMBER OF MOVING BASES NBAS
  F: (NULL)
READ NARM (NUMBER OF ARMS IN SYSTEM)
DO UNTIL KARM = NARM
    IMOVBAS=1
      T: READ KBASNUM (KARM)
      F: (NULL)
    READ ARM GEOMETRIC PROPERTIES
    READ ARM MASS PROPERTIES
    READ ACTUATOR PROPERTIES
    READ SPECIAL JOINT DATA
READ SYSTEM GRAPHICS DATA
READ GRAVITY
NUMBER OF ENVIRONMENT COMPONENTS .NE. 0
  T: READ ENVIRONMENT DATA
  F: (NULL)
NUMBER OF LOAD OBJECTS .NE. 0
  T: READ LOAD OBJECTS DATA
  F: (NULL)
NUMBER OF TARGETS OBJECTS .NE. 0
  T: READ TARGET DATA
  F: (NULL)
READ TOOL DATA FOR EACH ARM
NUMBER OF LOAD OBJECTS .NE. 0
  T: READ LOAD OBJECTS GRAPHICS DATA
  F: (NULL)
NUMBER OF TARGETS .NE. 0
  T: READ TARGET GRAPHICS DATA
  F: (NULL)
DISPLAY MESSAGE THAT FILE READ AND COMMON BLOCKS LOADED
CLOSE AND SAVE FILE
RETURN
END
```

2.1.2 SGMNT

Subroutine SGMNT allows the user to set up the desired motion profile for a requirements analysis or response simulation run. It is called from SIMDRVR. An existing motion profile file may be read in and modified or the profile may be defined interactively. Motion is specified in one of four ways:

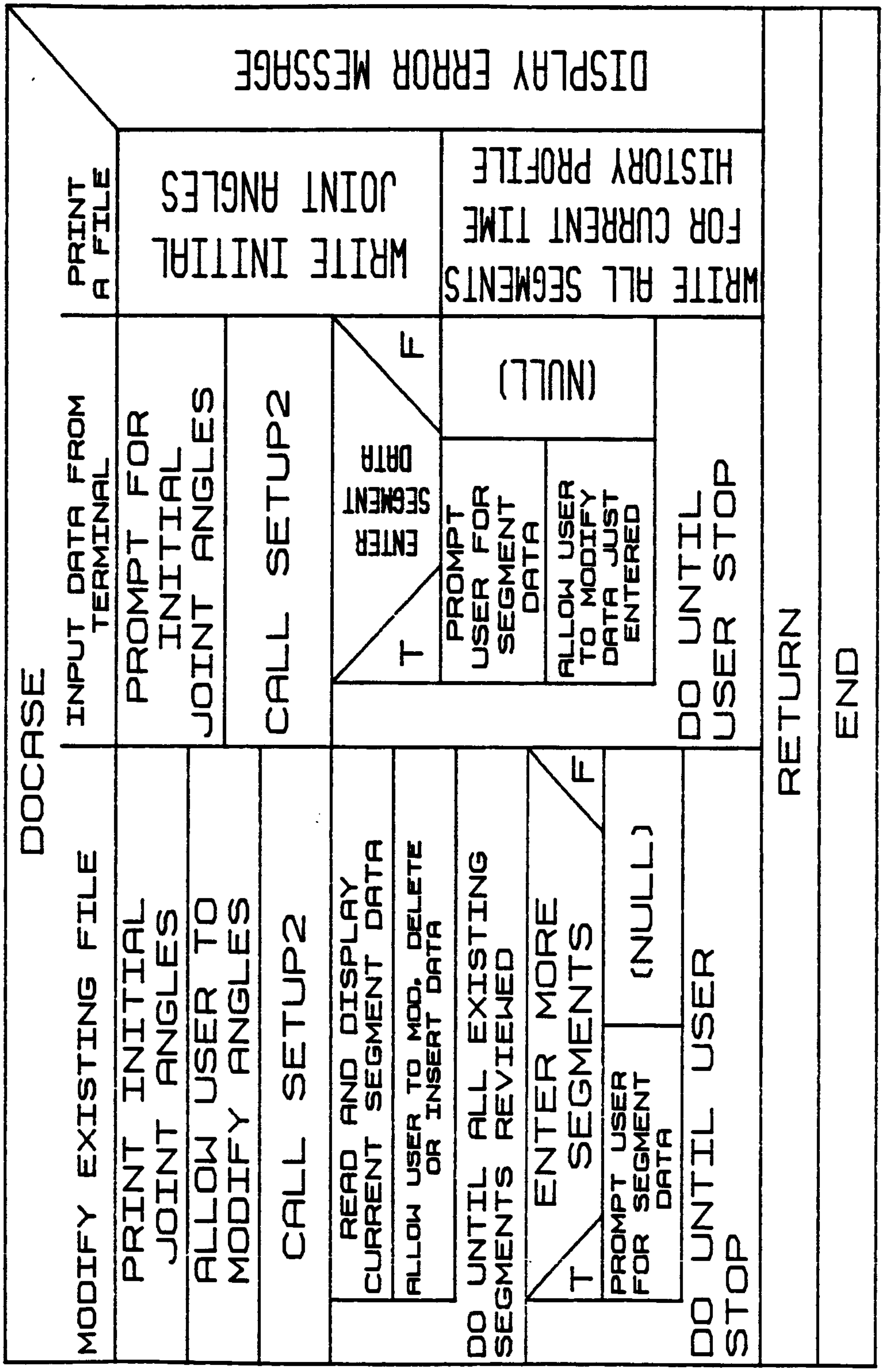
1) Desired position of end-effector;

2) Desired position of each joint;

3) Rate of end-effector movement;

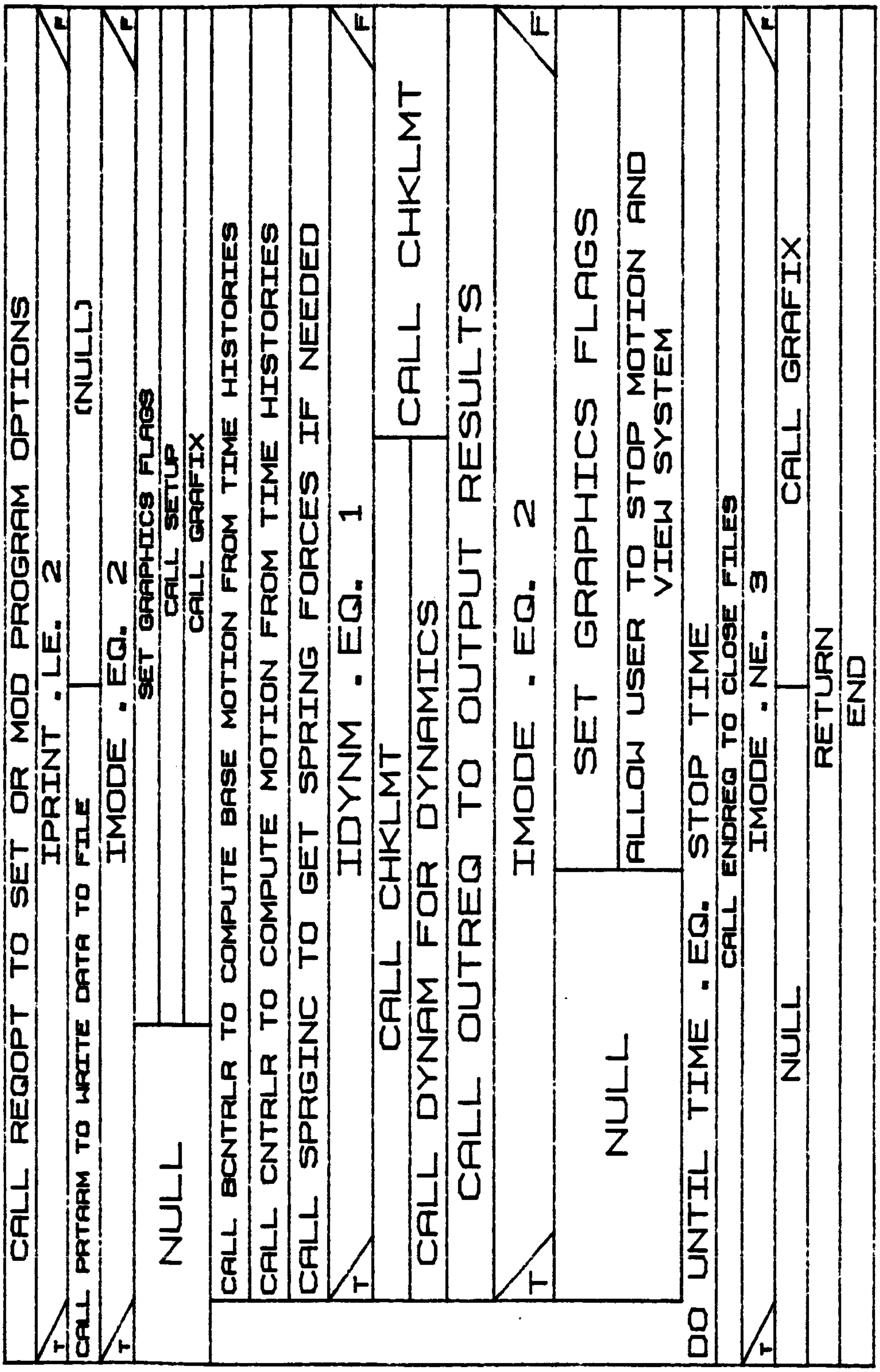
4) Rate of each joint.

In addition, motion may be specified by having an end-effector-mounted sensor move toward a target. Several nonmotion-type operations such as grasp a load object, release object and wait a given length of time may also be specified.


SUBROUTINE SGMNT
DOCASE
MODIFY EXISTING FILE
PRINT INITIAL JOINT ANGLES
ALLOW USER TO MODIFY ANGLES
CALL SETUP2
READ AND DISPLAY CURRENT SEGMENT DATA
ALLOW USER TO MOD, DELETE OR INSERT DATA
DO UNTIL ALL EXISTING SEGMENTS REVIEWED
ENTER MORE SEGMENTS
T
F
PROMPT USER FOR SEGMENT DATA
(NULL)
DO UNTIL USER STOP
INPUT DATA FROM TERMINAL
PROMPT FOR INITIAL JOINT ANGLES
CALL SETUP2
ENTER SEGMENT DATA
T
F
PROMPT USER FOR SEGMENT DATA
ALLOW USER TO MODIFY DATA JUST ENTERED
(NULL)
DO UNTIL USER STOP
PRINT A FILE
WRITE INITIAL JOINT ANGLES
WRITE ALL SEGMENTS FOR CURRENT TIME HISTORY PROFILE
DISPLAY ERROR MESSAGE
RETURN
END

2.1.3 REQUIR

Subroutine REQUIR is called from SIMDRVR and is the routine that controls the execution of any requirements analysis run. It first calls REQOPT to set up program run time options. If requested, PRTARM is called to write a description of the system to an output file. SETUP is called to calculate initial positions. GRAFIX is called if the run is to include graphic displays. The subroutines CNTRLR, SPRGINC, CHKLMT, DYNAM and OUTREQ are called at every increment of a user-defined time loop to calculate the manipulator system's motion, forces and torques, and write these data to an output file. ESPAUS is called when motion is temporarily halted during execution. When the stop time is reached, ENDREQ is called to close any open files.

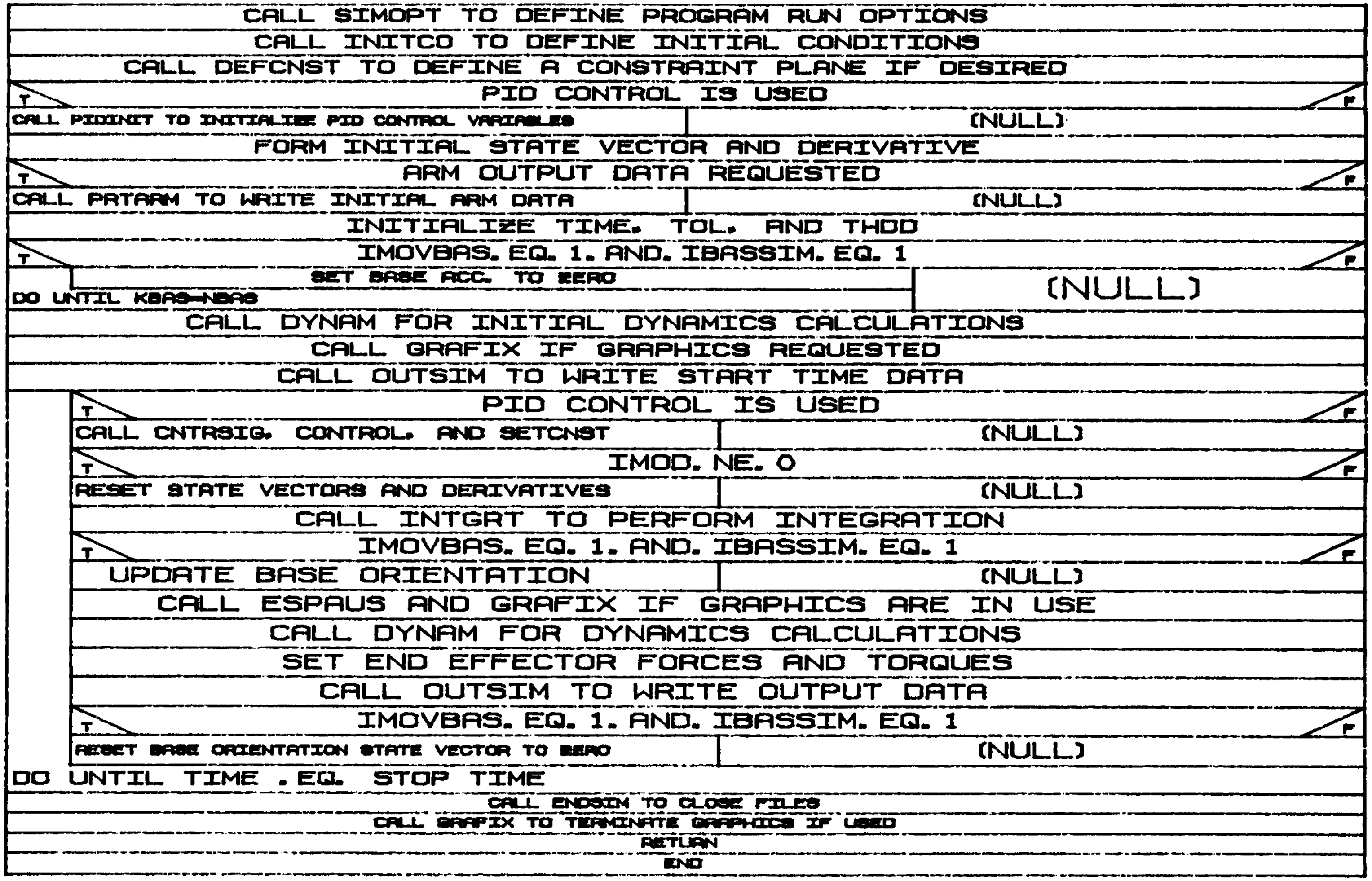


```
SUBROUTINE REQUIR
CALL REQOPT TO SET OR MOD PROGRAM OPTIONS
IPRINT .LE. 2
  T: CALL PRTARM TO WRITE DATA TO FILE
  F: (NULL)
IMODE .EQ. 2
  T: NULL
  F: SET GRAPHICS FLAGS
     CALL SETUP
     CALL GRAFIX
DO UNTIL TIME .EQ. STOP TIME
    CALL BCNTRLR TO COMPUTE BASE MOTION FROM TIME HISTORIES
    CALL CNTRLR TO COMPUTE MOTION FROM TIME HISTORIES
    CALL SPRGINC TO GET SPRING FORCES IF NEEDED
    IDYNM .EQ. 1
      T: CALL CHKLMT
         CALL DYNAM FOR DYNAMICS
      F: CALL CHKLMT
    CALL OUTREQ TO OUTPUT RESULTS
    IMODE .EQ. 2
      T: NULL
      F: SET GRAPHICS FLAGS
         ALLOW USER TO STOP MOTION AND
                VIEW SYSTEM
CALL ENDREQ TO CLOSE FILES
IMODE .NE. 3
  T: NULL
  F: CALL GRAFIX
RETURN
END
```

2.1.4 RESPON

Subroutine RESPON is called from SIMDRVR to control the execution of a response simulation run. Run time options and program variables are first initialized. A user-defined time loop is executed to call routines to carry out all the control functions. After execution is completed, ENDSIM is called to close the files.

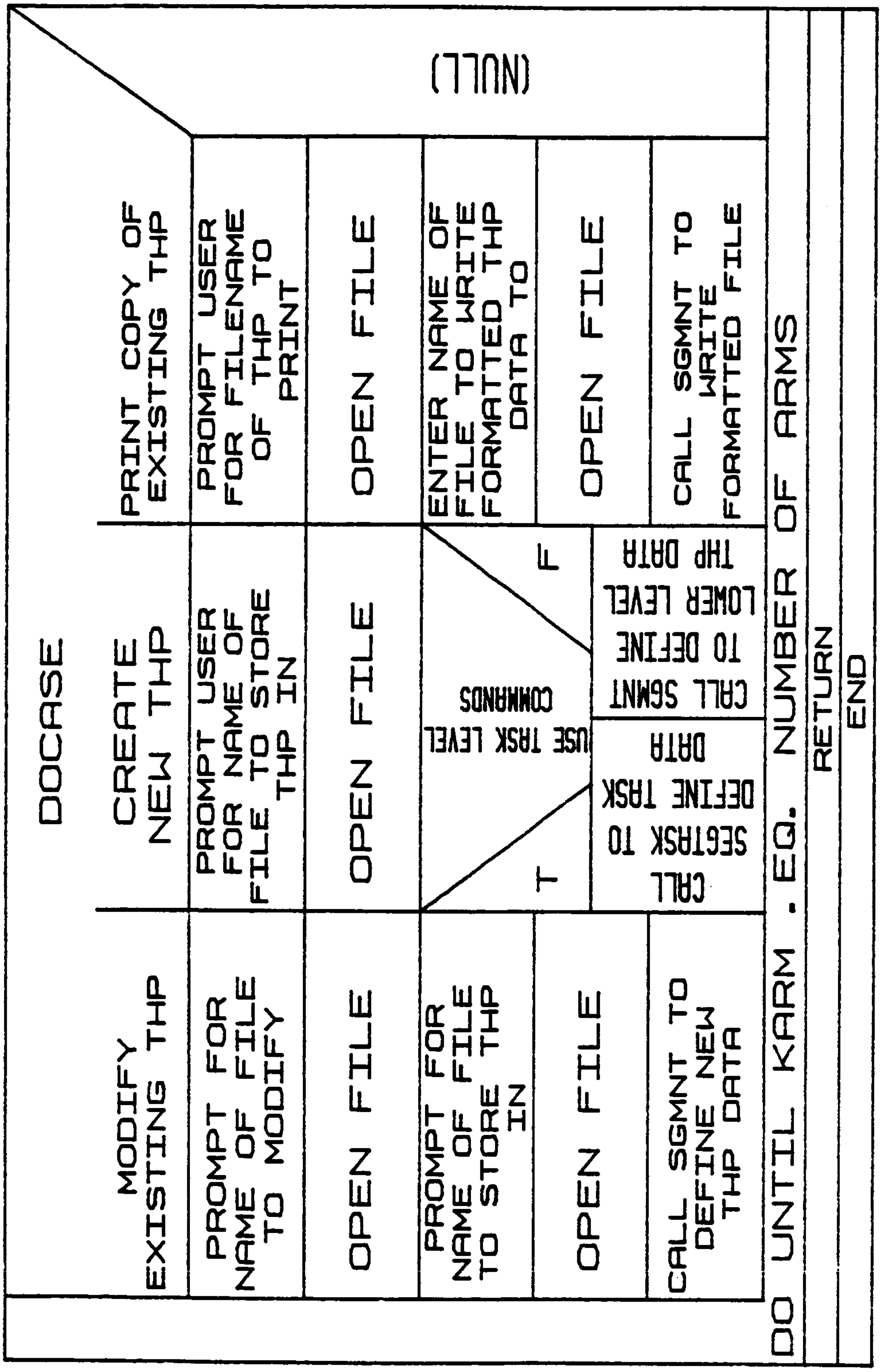
SUBROUTINE RESPON



```
CALL SIMOPT TO DEFINE PROGRAM RUN OPTIONS
CALL INITCO TO DEFINE INITIAL CONDITIONS
CALL DEFCNST TO DEFINE A CONSTRAINT PLANE IF DESIRED
PID CONTROL IS USED
  T: CALL PIDINIT TO INITIALIZE PID CONTROL VARIABLES
  F: (NULL)
FORM INITIAL STATE VECTOR AND DERIVATIVE
ARM OUTPUT DATA REQUESTED
  T: CALL PRTARM TO WRITE INITIAL ARM DATA
  F: (NULL)
INITIALIZE TIME. TOL. AND THDD
IMOVBAS. EQ. 1. AND. IBASSIM. EQ. 1
  T:   SET BASE ACC. TO ZERO
     DO UNTIL KBAS=NBAS
  F: (NULL)
CALL DYNAM FOR INITIAL DYNAMICS CALCULATIONS
CALL GRAFIX IF GRAPHICS REQUESTED
CALL OUTSIM TO WRITE START TIME DATA
  PID CONTROL IS USED
    T: CALL CNTRSIG. CONTROL. AND SETCNST
    F: (NULL)
  IMOD. NE. 0
    T: RESET STATE VECTORS AND DERIVATIVES
    F: (NULL)
  CALL INTGRT TO PERFORM INTEGRATION
  IMOVBAS. EQ. 1. AND. IBASSIM. EQ. 1
    T: UPDATE BASE ORIENTATION
    F: (NULL)
  CALL ESPAUS AND GRAFIX IF GRAPHICS ARE IN USE
  CALL DYNAM FOR DYNAMICS CALCULATIONS
  SET END EFFECTOR FORCES AND TORQUES
  CALL OUTSIM TO WRITE OUTPUT DATA
  IMOVBAS. EQ. 1. AND. IBASSIM. EQ. 1
    T: RESET BASE ORIENTATION STATE VECTOR TO ZERO
    F: (NULL)
DO UNTIL TIME .EQ. STOP TIME
CALL ENDSIM TO CLOSE FILES
CALL GRAFIX TO TERMINATE GRAPHICS IF USED
RETURN
END
```

2.1.5 TASK

Subroutine TASK is the preliminary routine called when defining manipulator motion. The user has the choice of modifying an existing time history (motion) profile, creating a new profile or writing a user readable, formatted file from an existing time history profile. The subroutine opens the appropriate files and then calls subroutine SGMNT if an existing file is being modified, a formatted file is to be written, or a new file is to be created using just lower level motion commands. If task level commands are used, TASK calls subroutine SEGTASK. For other options task calls SGMNT.

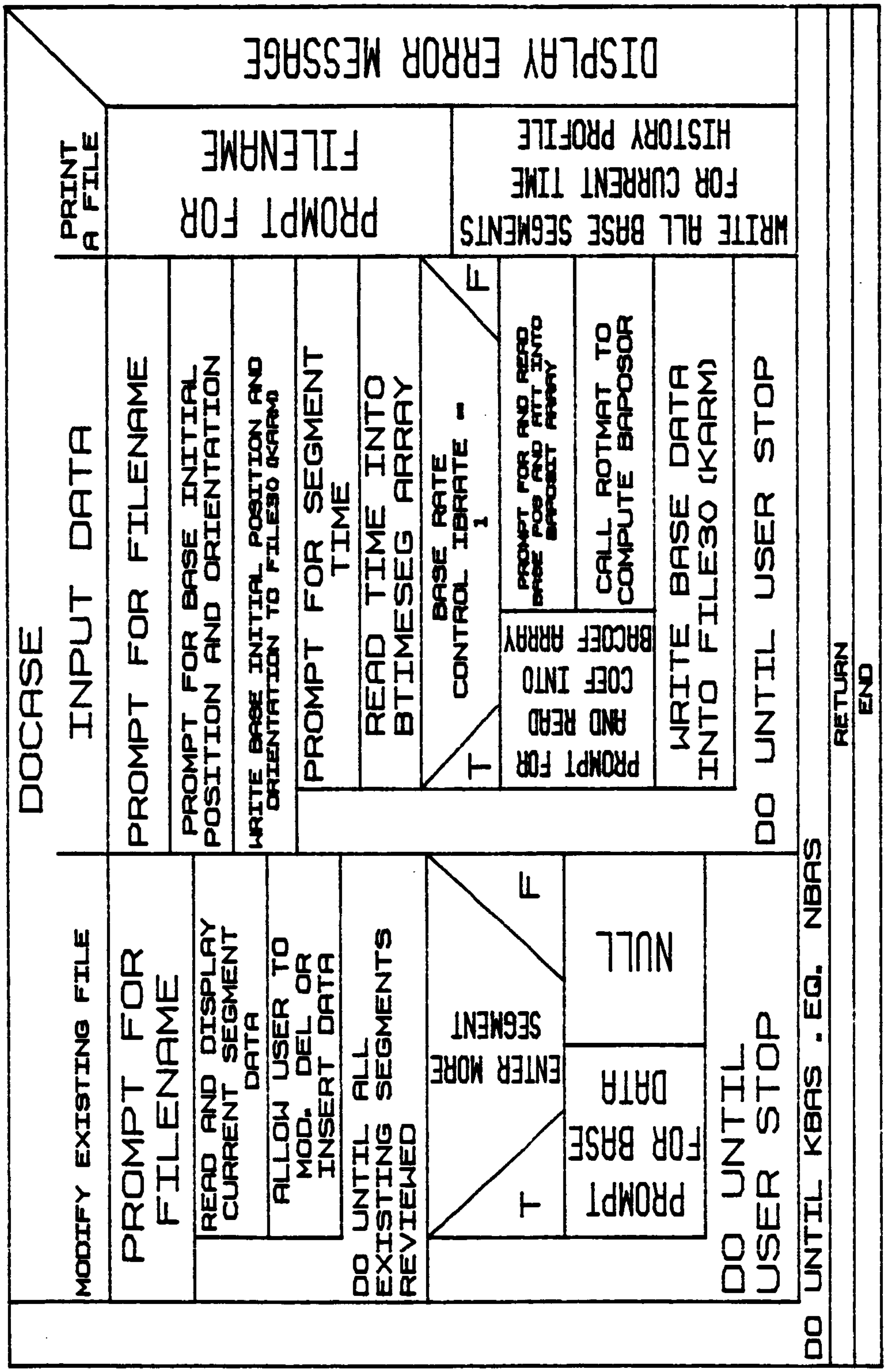


```
SUBROUTINE TASK
DO UNTIL KARM .EQ. NUMBER OF ARMS
    DOCASE
        MODIFY EXISTING THP
            PROMPT FOR NAME OF FILE TO MODIFY
            OPEN FILE
            PROMPT FOR NAME OF FILE TO STORE THP IN
            OPEN FILE
            CALL SGMNT TO DEFINE NEW THP DATA
        CREATE NEW THP
            PROMPT USER FOR NAME OF FILE TO STORE THP IN
            OPEN FILE
            USE TASK LEVEL COMMANDS
                T
                    CALL SEGTASK TO DEFINE TASK DATA
                F
                    CALL SGMNT TO DEFINE LOWER LEVEL THP DATA
        PRINT COPY OF EXISTING THP
            PROMPT USER FOR FILENAME OF THP TO PRINT
            OPEN FILE
            ENTER NAME OF FILE TO WRITE FORMATTED THP DATA TO
            OPEN FILE
            CALL SGMNT TO WRITE FORMATTED FILE
        (NULL)
RETURN
END
```

2.1.6 BASGMNT

Subroutine BASGMNT allows the user to set up the desired base motion profile for a requirements analysis or response simulation run. It is called from SIMDRVR. An existing base motion profile file may be read in and modified or the profile may be defined interactively. Base motion is specified in one of two ways:

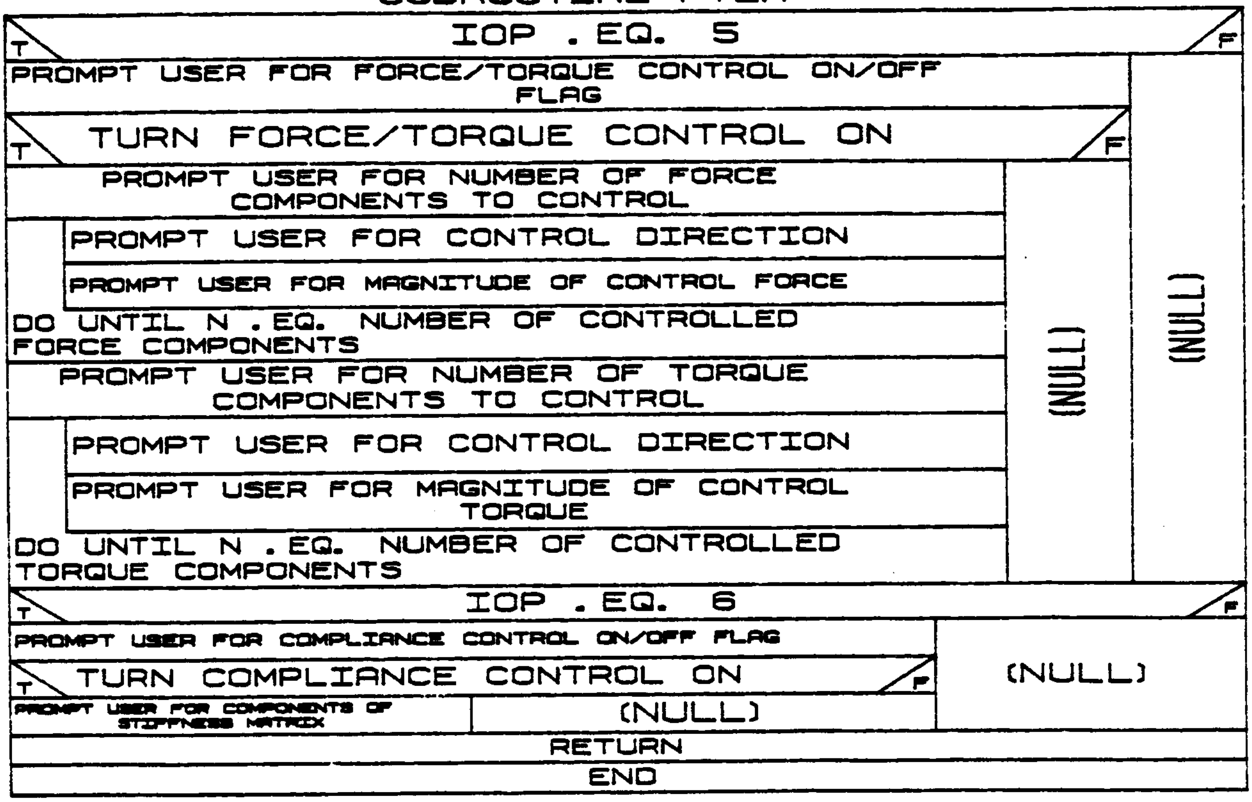
1) Desired position and orientation of the base;
2) Rate of base motion.


SUBROUTINE BASGMNT
DOCASE
MODIFY EXISTING FILE
PROMPT FOR FILENAME
DO UNTIL ALL EXISTING SEGMENTS REVIEWED
READ AND DISPLAY CURRENT SEGMENT DATA
ALLOW USER TO MOD. DEL OR INSERT DATA
DO UNTIL USER STOP
ENTER MORE SEGMENT
T
F
PROMPT FOR BASE DATA
NULL
INPUT DATA
PROMPT FOR FILENAME
PROMPT FOR BASE INITIAL POSITION AND ORIENTATION
WRITE BASE INITIAL POSITION AND ORIENTATION TO FILE30 (KARM)
DO UNTIL USER STOP
PROMPT FOR SEGMENT TIME
READ TIME INTO BTIMESEG ARRAY
BASE RATE CONTROL IBRATE = 1
T
F
PROMPT FOR AND READ COEF INTO BACOEF ARRAY
PROMPT FOR AND READ BASE POS AND ATT INTO BAPOSIT ARRAY
CALL ROTMAT TO COMPUTE BAPOSOR
WRITE BASE DATA INTO FILE30 (KARM)
PRINT A FILE
PROMPT FOR FILENAME
WRITE ALL BASE SEGMENTS FOR CURRENT TIME HISTORY PROFILE
DISPLAY ERROR MESSAGE
DO UNTIL KBAS .EQ. NBAS
RETURN
END

2.2.1 FTIN

Subroutine FTIN is called from SGMNT if force/torque or active compliance control was specified by the user. If force/torque control was specified, the user is prompted for the number of force and torque components to be controlled, the unit vectors in the directions to be controlled and the magnitude of the control force or torque. If active compliance control was specified, the user is prompted for the stiffness matrix at the end-effector reference point.

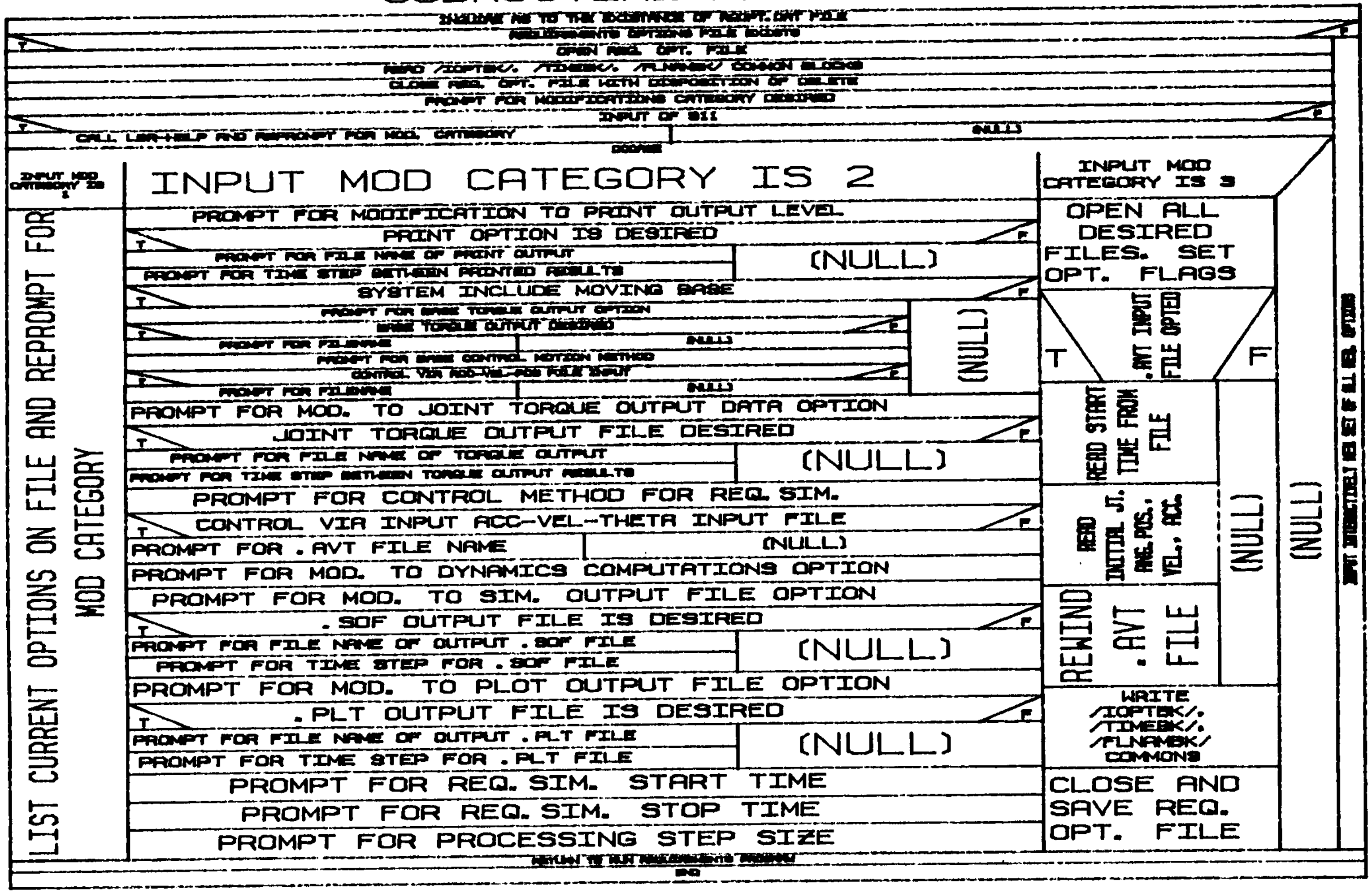
SUBROUTINE FTIN



2.2.2 REQOPT

Subroutine REQOPT is called from REQUIR to define requirements analysis run time options. The user may list currently defined options and use them or input a new set of options. Options the user may set include run time data file write, torque file write, control method to be used, control of robot base, dynamic calculations, playback file write, plot file write, and simulation start time, stop time, and processing step size.

SUBROUTINE REQOPT



2.2.3 PRTARM

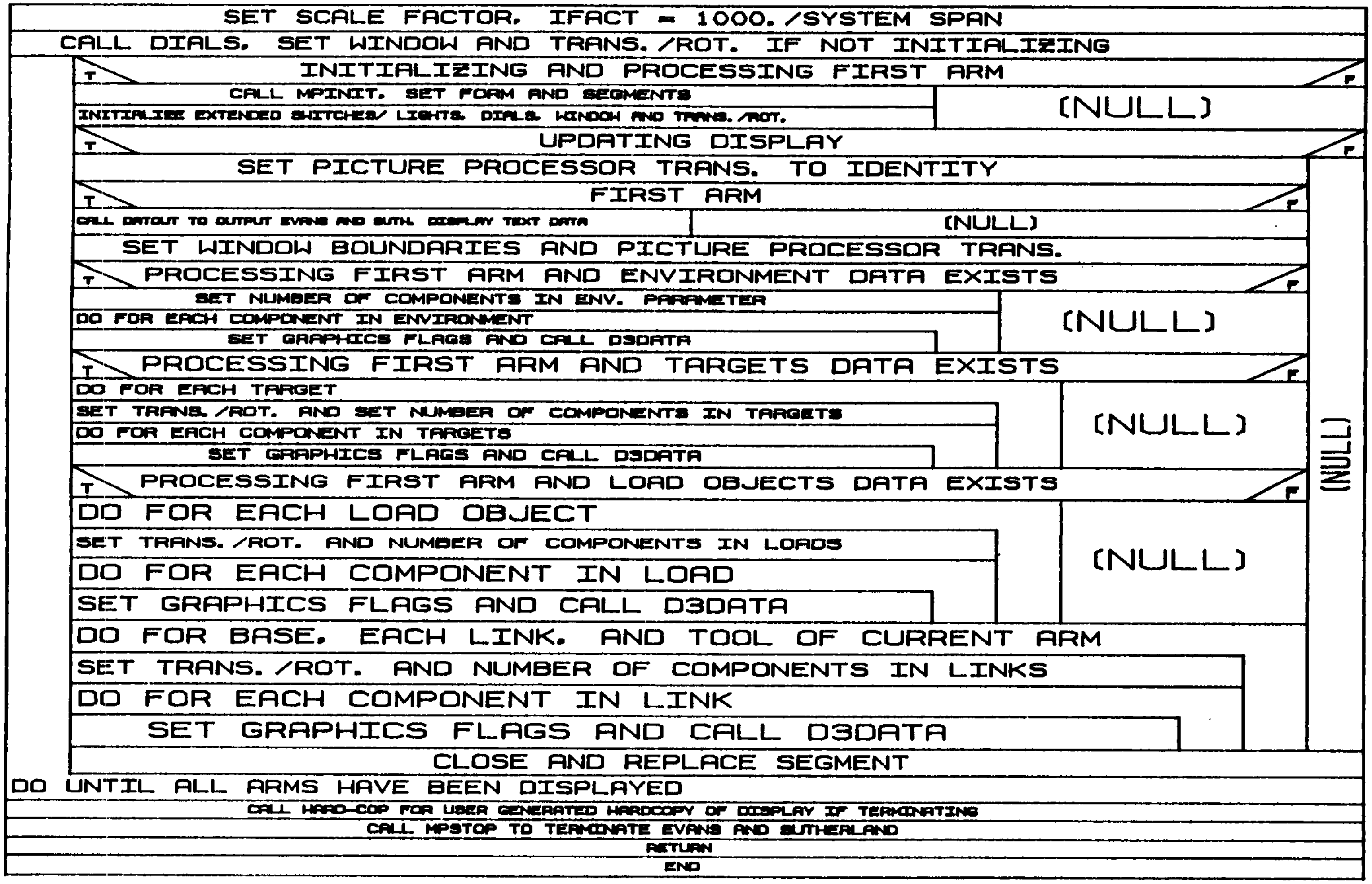
Subroutine PRTARM is called form either REQUIR or RESPON when the flag for printed output of that analysis is set. This routine prints a description of the manipulator system that includes the following variables: current arm number and number of joints per arm, type and mass of each joint, initial angular positions and velocities of each joint, joint travel and rate limits, joint/link centroid locations, joint location relative to previous joint, inertia matrix for each joint, orientation matrix for each joint relative to previous joint, span of the whole system, and the acceleration attributable to gravity.

```
SUBROUTINE PRTARM
    WRITE CURRENT ARM NUMBER AND THE NUMBER OF JOINTS PER ARM
    WRITE THE TYPE AND MASS OF EACH JOINT
    CONVERT DATA TO BE WRITTEN FROM INTERNAL TO INPUT/OUTPUT UNITS
    WRITE JOINT INITIAL ANGULAR POSITIONS AND VELOCITIES
    WRITE JOINT TRAVEL AND RATE LIMITS
    WRITE JOINT/LINK CENTROID LOCATIONS
    WRITE JOINT LOCATIONS RELATIVE TO PREVIOUS JOINT
    WRITE INERTIA MATRICES FOR JOINT/LINK COMBINATIONS
    WRITE ORIENTATION MATRICES FOR EACH JOINT RELATIVE TO PREVIOUS JOINT
DO UNTIL KARM = NUMBER OF ARMS IN THE SYSTEM
WRITE TOTAL SYSTEM SPAN
WRITE ACCELERATION DUE TO GRAVITY
RETURN
END
```

2.2.4 GRAFIX

Subroutine GRAFIX provides the motion graphics capability in the response simulation, requirements analysis and postprocessing functions. GRAFIX displays the environment, target, load and robotic system motion within the environment. If IFLAG=1, the graphics system is initialized and displayed in the initial condition; if IFLAG=2, the display is updated to the current time step condition; if IFLAG=3, the motion is complete and the graphics are terminated.

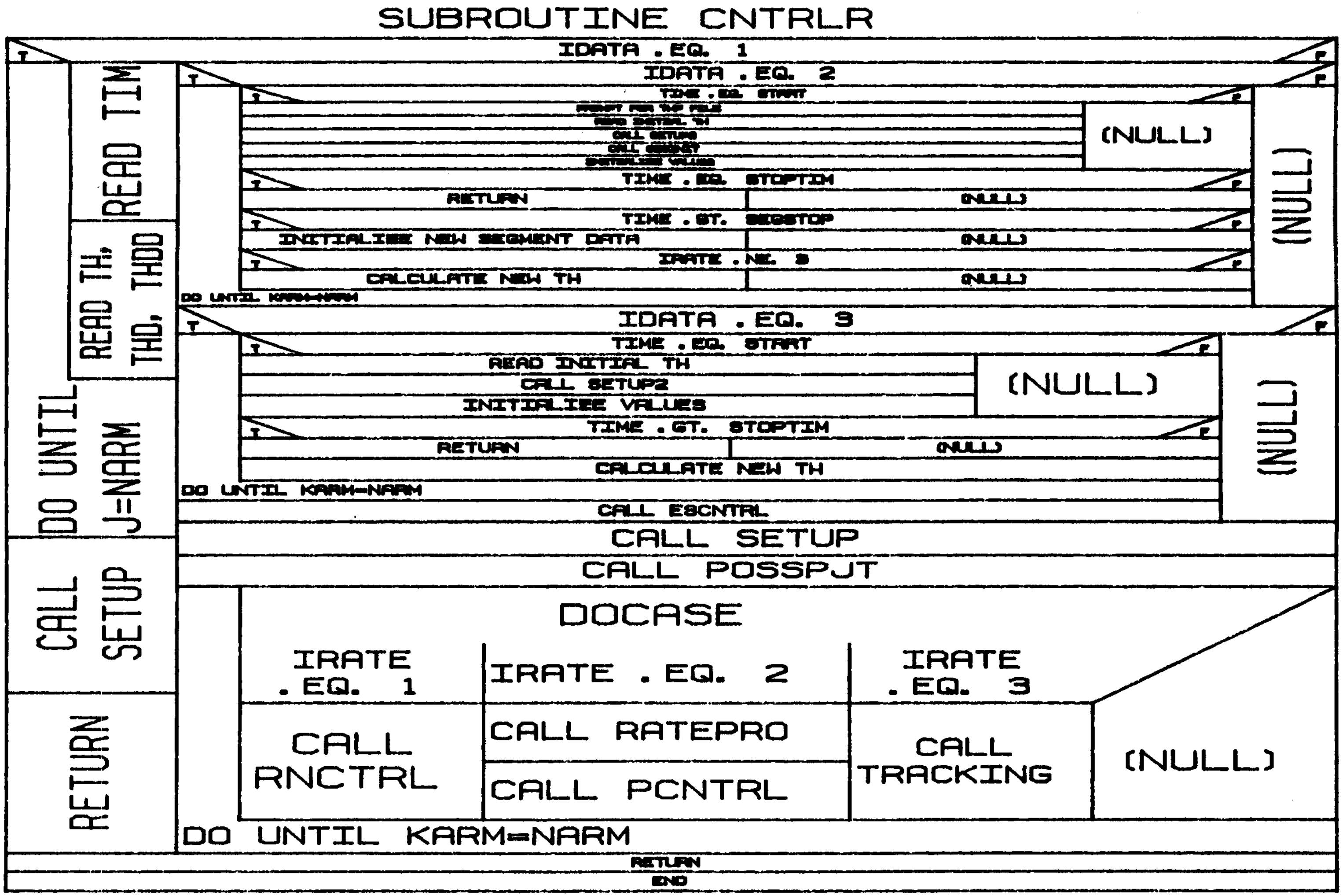
SUBROUTINE GRAFIX



```
SET SCALE FACTOR, IFACT = 1000./SYSTEM SPAN
DO
    CALL DIALS, SET WINDOW AND TRANS./ROT. IF NOT INITIALIZING
    INITIALIZING AND PROCESSING FIRST ARM
    T:
        CALL MPINIT, SET FORM AND SEGMENTS
        INITIALIZE EXTENDED SWITCHES/ LIGHTS, DIALS, WINDOW AND TRANS./ROT.
    F:
        (NULL)
    UPDATING DISPLAY
    T:
        SET PICTURE PROCESSOR TRANS. TO IDENTITY
        FIRST ARM
        T:
            CALL DATOUT TO OUTPUT EVANS AND SUTH. DISPLAY TEXT DATA
        F:
            (NULL)
        SET WINDOW BOUNDARIES AND PICTURE PROCESSOR TRANS.
        PROCESSING FIRST ARM AND ENVIRONMENT DATA EXISTS
        T:
            SET NUMBER OF COMPONENTS IN ENV. PARAMETER
            DO FOR EACH COMPONENT IN ENVIRONMENT
                SET GRAPHICS FLAGS AND CALL D3DATA
        F:
            (NULL)
        PROCESSING FIRST ARM AND TARGETS DATA EXISTS
        T:
            DO FOR EACH TARGET
                SET TRANS./ROT. AND SET NUMBER OF COMPONENTS IN TARGETS
                DO FOR EACH COMPONENT IN TARGETS
                    SET GRAPHICS FLAGS AND CALL D3DATA
        F:
            (NULL)
        PROCESSING FIRST ARM AND LOAD OBJECTS DATA EXISTS
        T:
            DO FOR EACH LOAD OBJECT
                SET TRANS./ROT. AND NUMBER OF COMPONENTS IN LOADS
                DO FOR EACH COMPONENT IN LOAD
                    SET GRAPHICS FLAGS AND CALL D3DATA
        F:
            (NULL)
        DO FOR BASE, EACH LINK, AND TOOL OF CURRENT ARM
            SET TRANS./ROT. AND NUMBER OF COMPONENTS IN LINKS
            DO FOR EACH COMPONENT IN LINK
                SET GRAPHICS FLAGS AND CALL D3DATA
    F:
        (NULL)
    CLOSE AND REPLACE SEGMENT
DO UNTIL ALL ARMS HAVE BEEN DISPLAYED
CALL HARD-COP FOR USER GENERATED HARDCOPY OF DISPLAY IF TERMINATING
CALL MPSTOP TO TERMINATE EVANS AND SUTHERLAND
RETURN
END
```

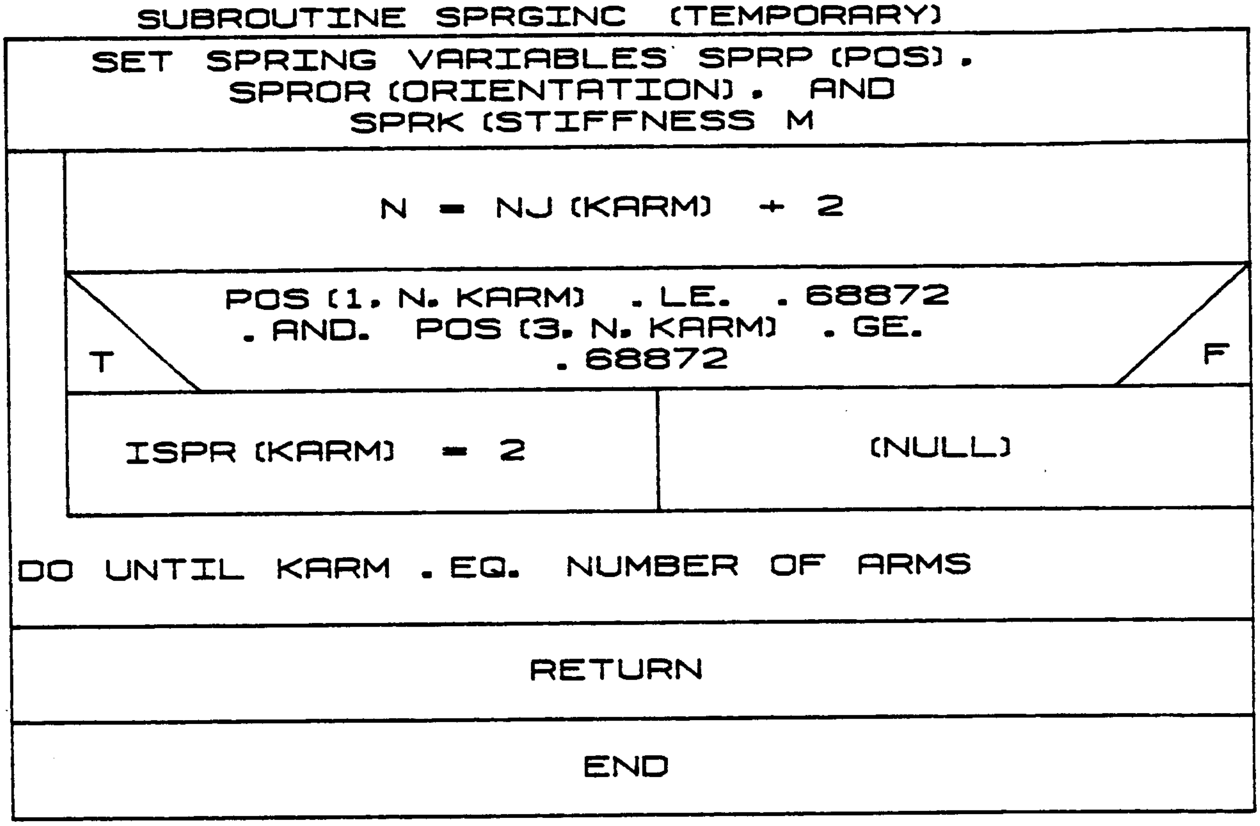
2.2.5 CNTRLR

Subroutine CNTRLR is called from REQUIR to obtain the angular position, velocity, and acceleration for each joint of each arm at each processing time step. If the variable IDATA was set to 1 earlier, the data are obtained by reading an existing file that contains just these data. If IDATA equals 2, the values are calculated from the motion profiles. Subroutine PCNTRL is called for the position control calculations and RCNTRL is called for the rate control calculations and TRACKING is called for sensor control. IDATA equal to 3 allows the system motion to be controlled by dials on the Evans and Sutherland.


SUBROUTINE CNTRLR
T
F
IDATA .EQ. 1
READ TIM
READ TH, THD, THDD
DO UNTIL J=NARM
IDATA .EQ. 2
TIME .EQ. START
READ INITIAL TH
INITIALIZE VALUES
(NULL)
TIME .EQ. STOPTIM
RETURN
(NULL)
TIME .ST. SEGSTOP
INITIALIZE NEW SEGMENT DATA
(NULL)
IRATE .NE. 3
CALCULATE NEW TH
(NULL)
DO UNTIL KARM=NARM
(NULL)
IDATA .EQ. 3
TIME .EQ. START
READ INITIAL TH
CALL SETUP2
INITIALIZE VALUES
(NULL)
TIME .GT. STOPTIM
RETURN
(NULL)
CALCULATE NEW TH
DO UNTIL KARM=NARM
CALL ESCNTRL
(NULL)
CALL SETUP
CALL SETUP
CALL POSSPJT
DOCASE
IRATE .EQ. 1
IRATE .EQ. 2
IRATE .EQ. 3
CALL RNCTRL
CALL RATEPRO
CALL PCNTRL
CALL TRACKING
(NULL)
DO UNTIL KARM=NARM
RETURN
RETURN
END

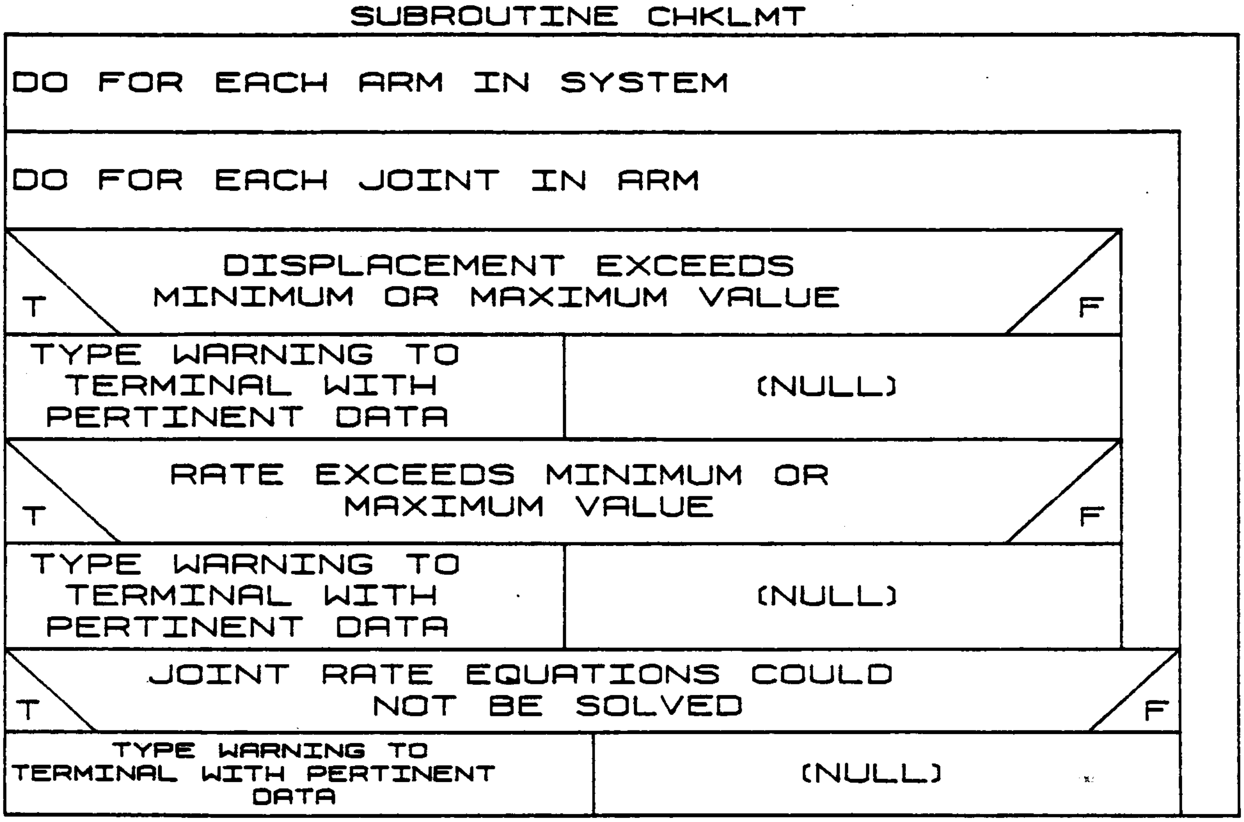
2.2.6 SPRGINC

Subroutine SPRGINC is called from REQUIR to set the variables used when the end-effector is to have compliance associated with it. The variables set includes spring reference position, orientation and the spring constant.



2.2.7 CHKLMT

CHKLMT checks joint displacement and rate limits during requirements analysis. It does not modify any values but prints a warning to the terminal if any limits are exceeded.



2.2.8 DYNAM

Subroutine DYNAM is called from REQUIR to compute the manipulator system dynamics at each processing time step by calling the SETUP, CABSM, FORCE, TORQUE, and ACTORQ subroutines.

```
SUBROUTINE DYNAM
CALL SETUP TO FIND ALL POSITIONS IN WORLD COORDINATES
CALL CABSM TO FIND ABSOLUTE VEL. AND ACCEL. OF ALL LINKS
CALL FORCE TO FIND JOINT REACTION FORCES
CALL TORQUE TO FIND JOINT REACTION TORQUES
CALL ACTORQ TO FIND JOINT ACTUATOR TORQUES
RETURN
END
```

2.2.9 VOLTAGE

(Not implemented yet.)

2.2.10 OUTREQ

Subroutine OUTREQ is called from REQUIR to write output data to files requested by the user. The files the user may elect to have data written to are:

1) Run time output data file;

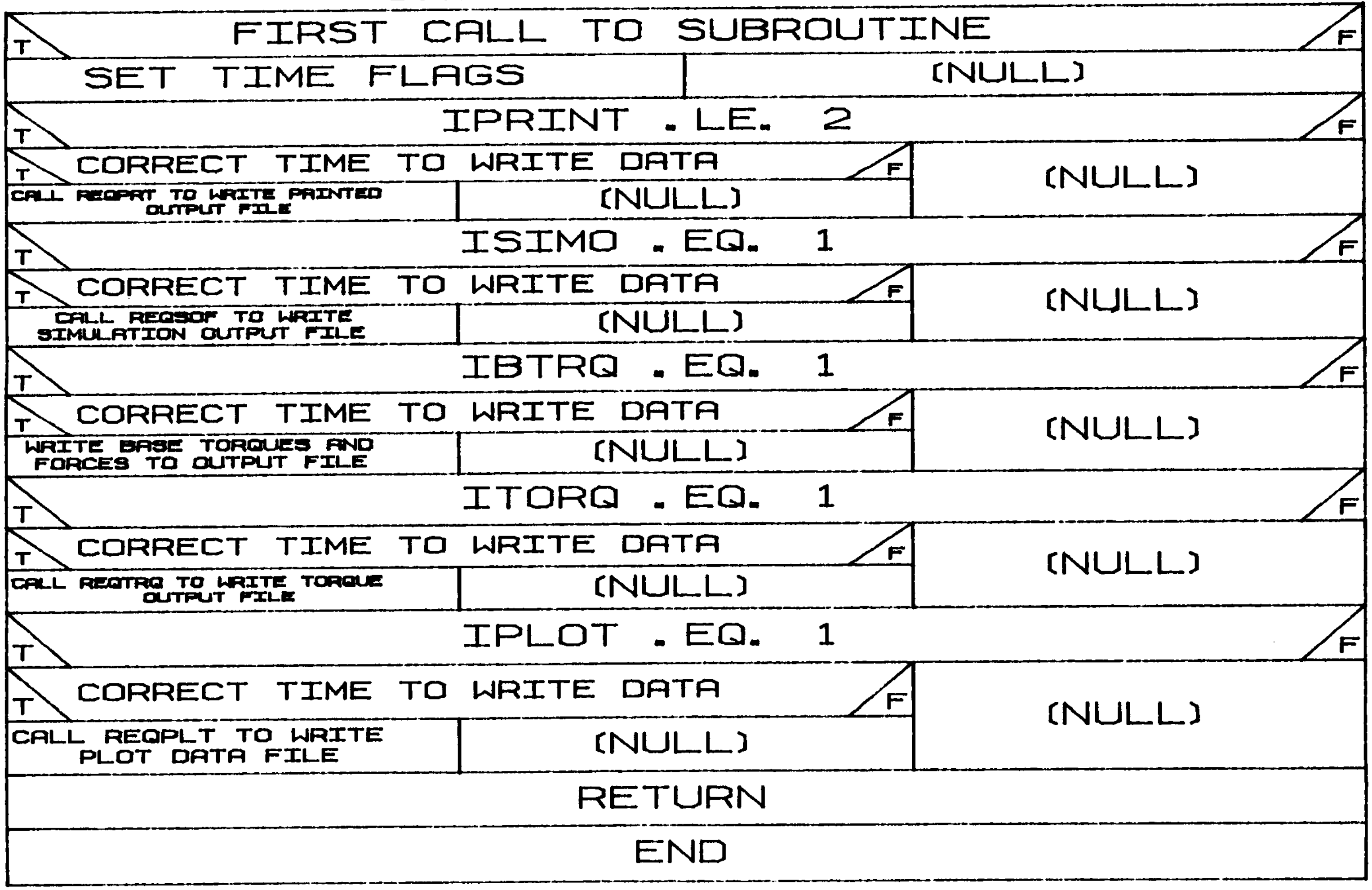
2) Data file for subsequent replay of motion on a vector graphics system;

3) Actuator torque data file;

4) Run time data file for subsequent plotting;

5) Base torques and forces data file.

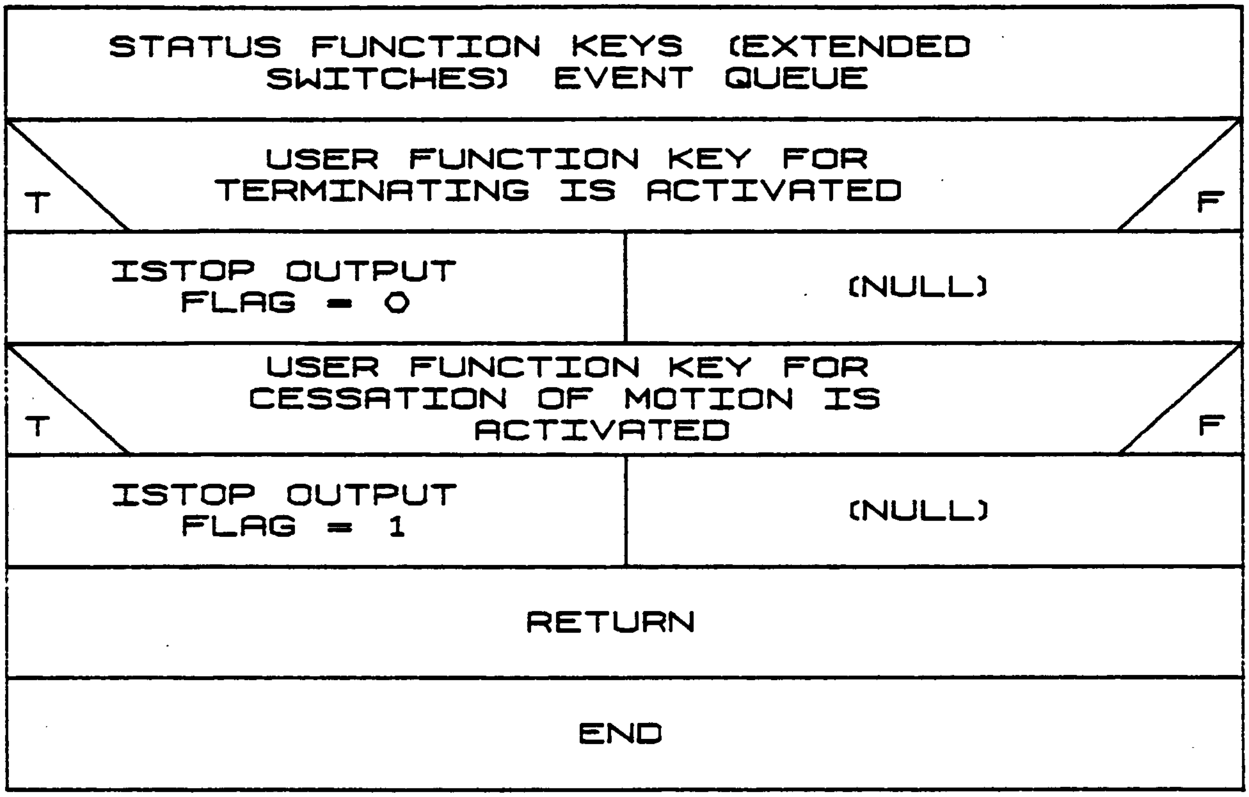
SUBROUTINE OUTREQ



2.2.11 ESPAUS

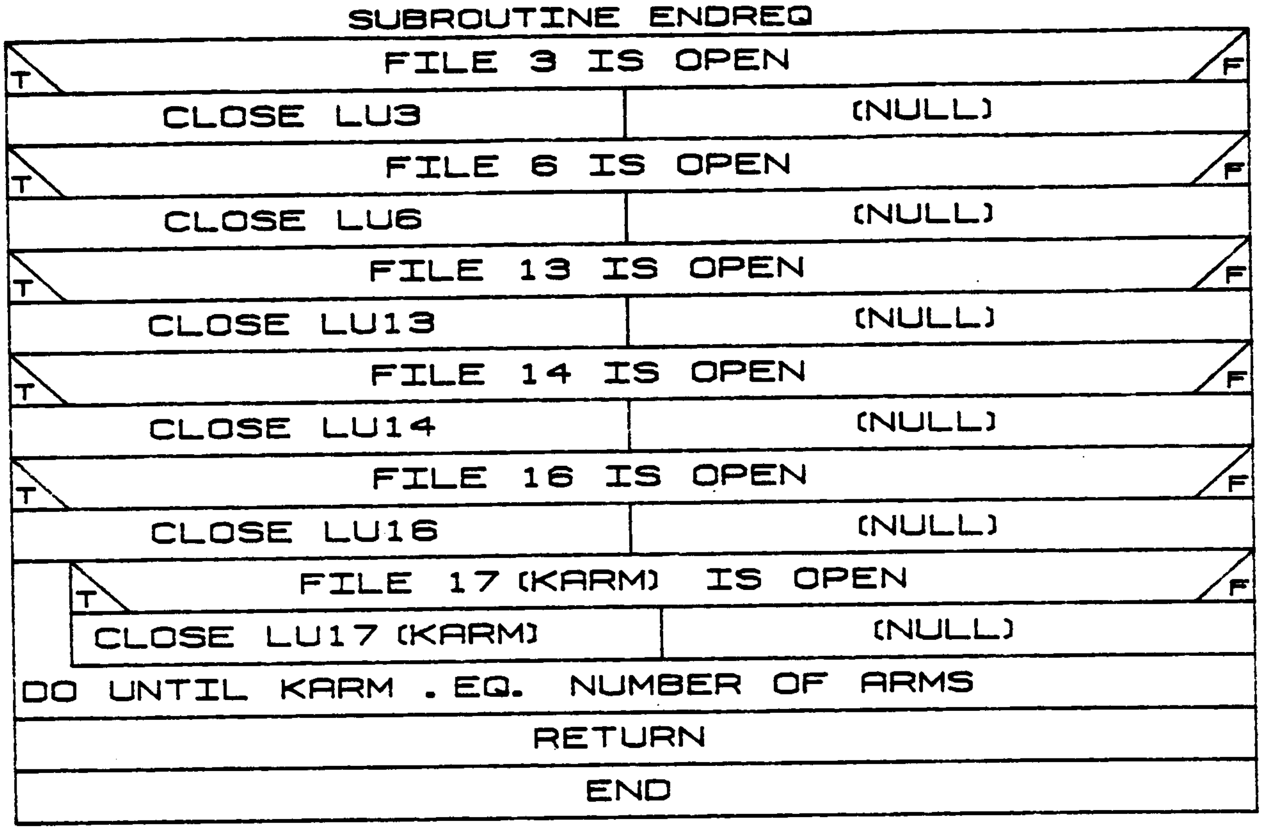
Routine ESPAUS is responsible for polling the status of the E&S function keys to determine the on/off status of the devices switch for playback motion cessation. A light indicator in the function key is used to inform the user of the key status; when lighted, the perspective viewing is in operation.

SUBROUTINE ESPAUS



2.2.12 ENDREQ

Subroutine ENDREQ closes any files opened during running of the requirements analysis portion of ROBSIM.



```
SUBROUTINE ENDREQ
FILE 3 IS OPEN
  T: CLOSE LU3
  F: (NULL)
FILE 6 IS OPEN
  T: CLOSE LU6
  F: (NULL)
FILE 13 IS OPEN
  T: CLOSE LU13
  F: (NULL)
FILE 14 IS OPEN
  T: CLOSE LU14
  F: (NULL)
FILE 16 IS OPEN
  T: CLOSE LU16
  F: (NULL)
    FILE 17 (KARM) IS OPEN
      T: CLOSE LU17 (KARM)
      F: (NULL)
DO UNTIL KARM .EQ. NUMBER OF ARMS
RETURN
END
```

2.2.13 SIMOPT

Subroutine SIMOPT interactively prompts the user for the program start time, stop time, processing time step, and several flags for control of output and the selection of some computational capabilities. Among these output options is a simulation output file that contains the data required by the postprocessing function for further study. The user also specifies the time frequency of the output of data to the file. The user is also allowed to request printed output during the analysis tools function execution.

The content and format of the data to be printed are provided for within each of the analysis tools. The flag set within SIMOPT is used only to turn the print routines on. The time frequency of the printed output is also specified. Other options are for generation of an acceleration-velocity-theta file and/or a plot output data file that may be plotted with the ROBSIM postprocessing plot utility with their associated output time steps. The user may also request use of a torque input file or a control option to read a hardware input voltage file for computational capabilities.

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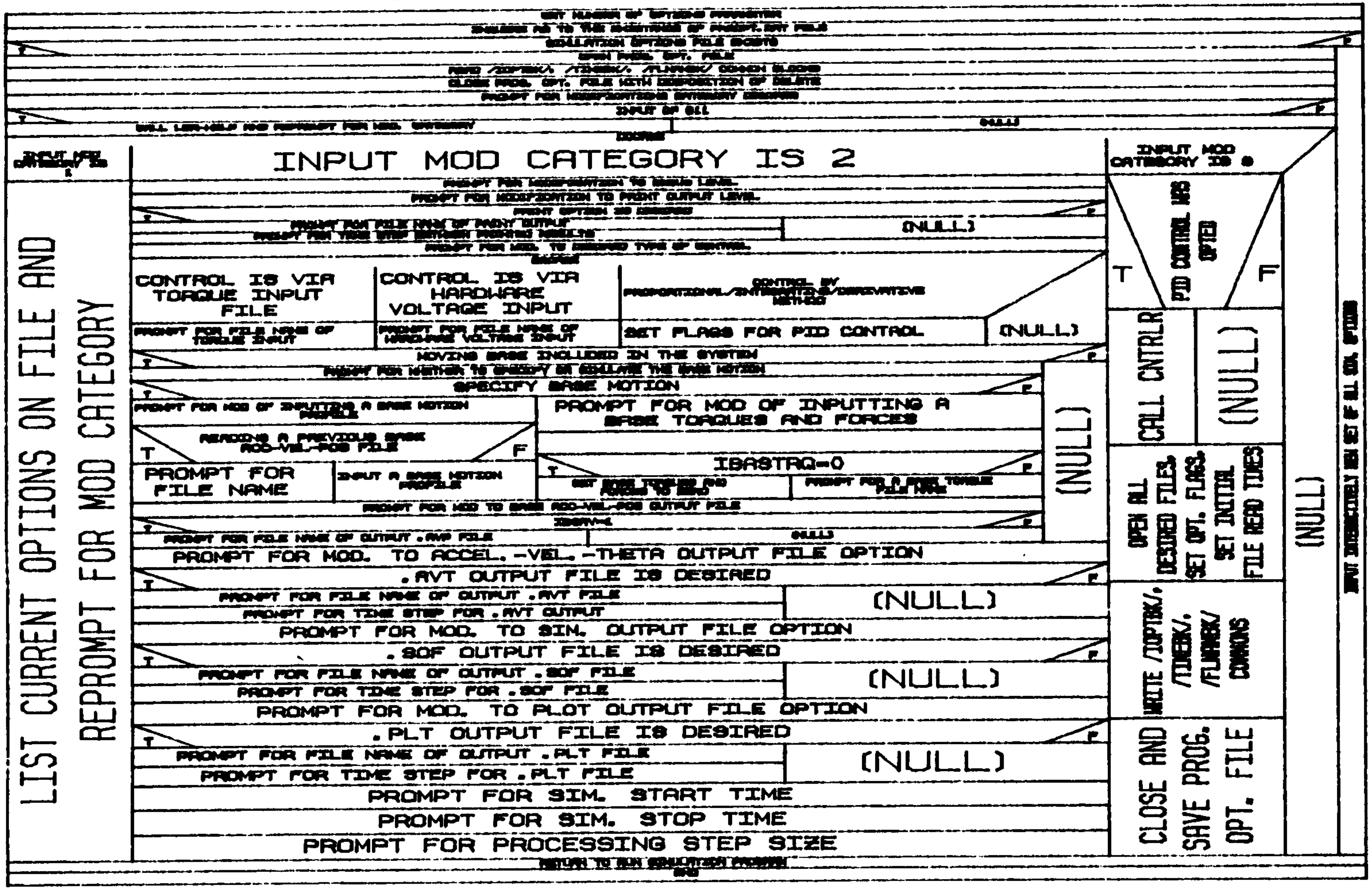
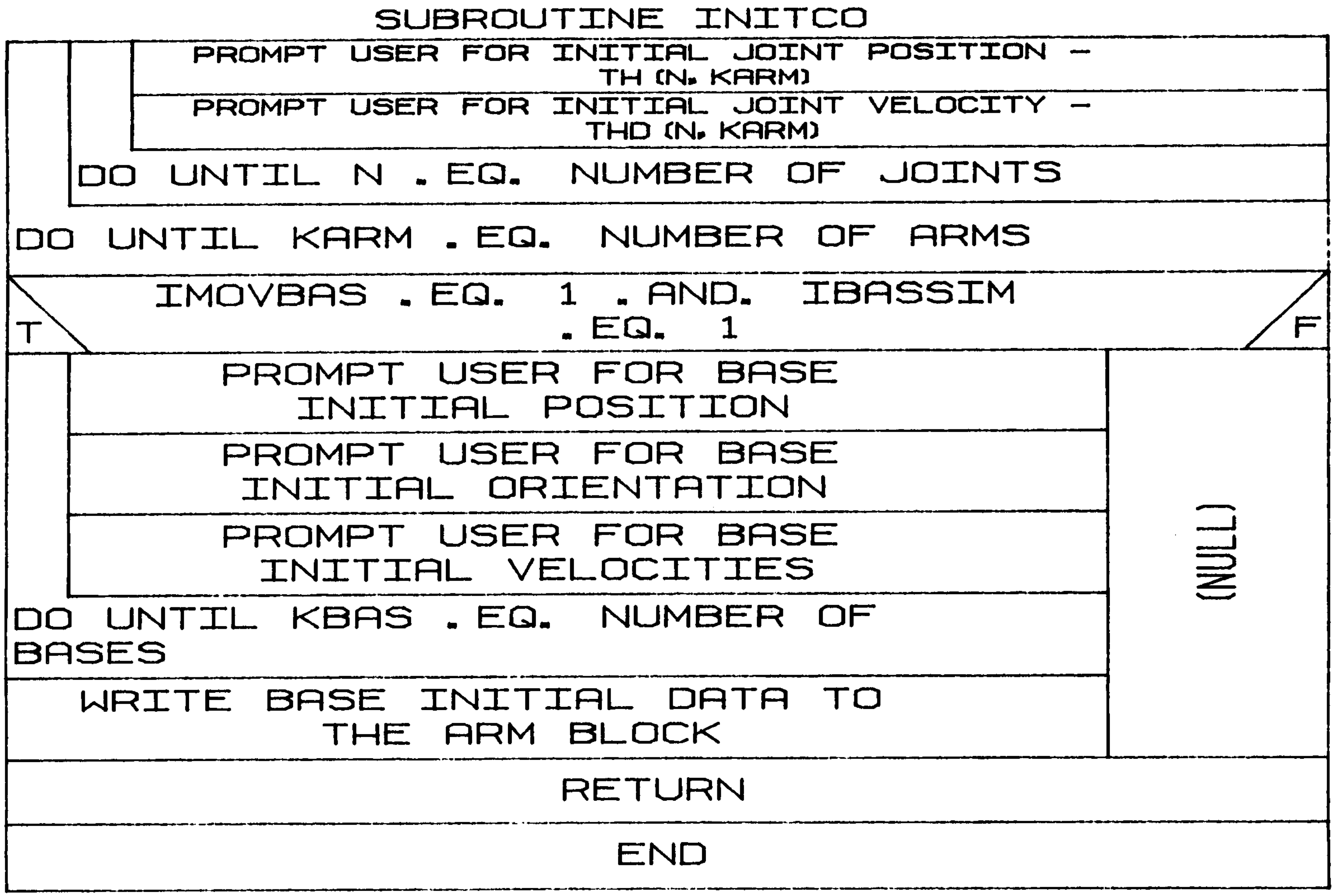
SUBROUTINE SIMOPT



2.2.14 INITCO

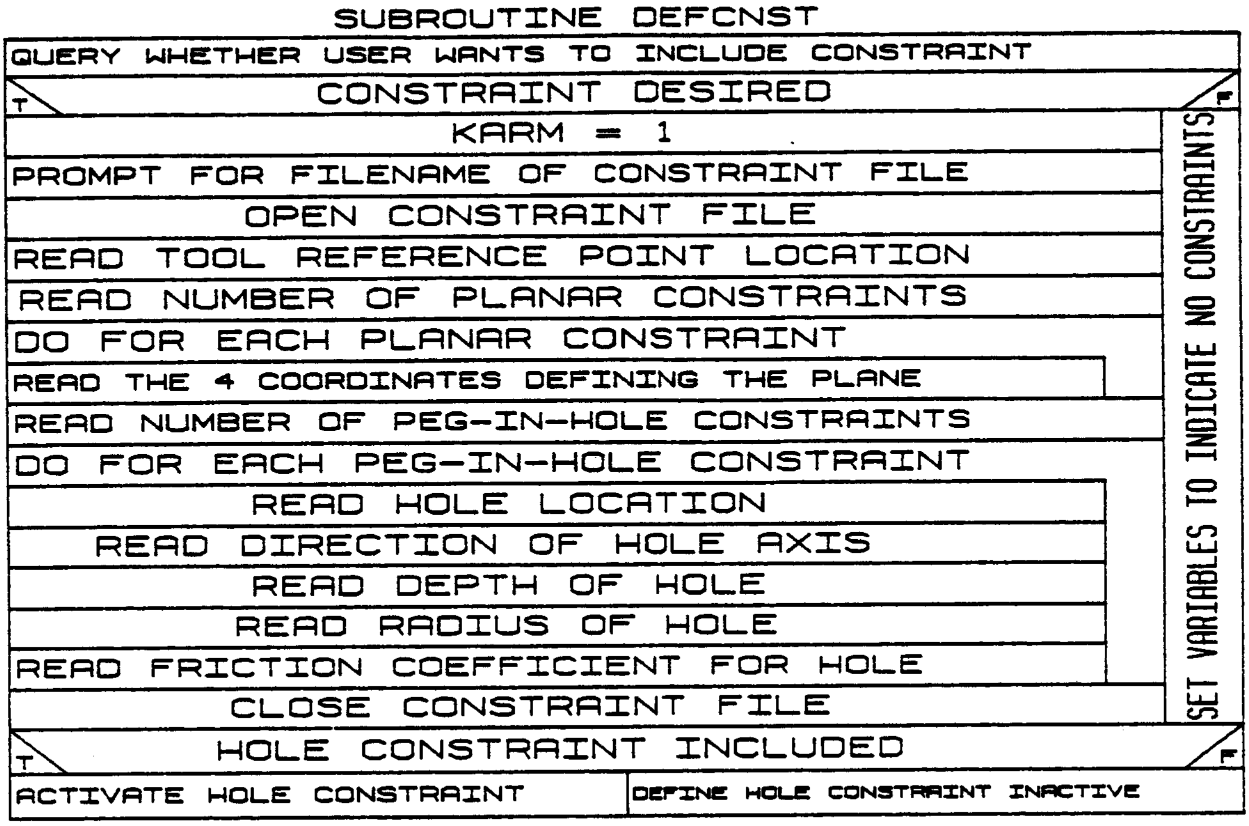
Subroutine INITCO prompts the user for the initial joint position (TH) and velocity (THD) of each joint of each arm. If moving base is simulated, the routine prompts the user for the initial base positions, orientations and velocities.



```
SUBROUTINE INITCO
    DO UNTIL KARM .EQ. NUMBER OF ARMS
        DO UNTIL N .EQ. NUMBER OF JOINTS
            PROMPT USER FOR INITIAL JOINT POSITION - TH (N, KARM)
            PROMPT USER FOR INITIAL JOINT VELOCITY - THD (N, KARM)
    IMOVBAS .EQ. 1 .AND. IBASSIM .EQ. 1
    T:
        DO UNTIL KBAS .EQ. NUMBER OF BASES
            PROMPT USER FOR BASE INITIAL POSITION
            PROMPT USER FOR BASE INITIAL ORIENTATION
            PROMPT USER FOR BASE INITIAL VELOCITIES
        WRITE BASE INITIAL DATA TO THE ARM BLOCK
    F:
        (NULL)
    RETURN
END
```

2.2.15 DEFCNST

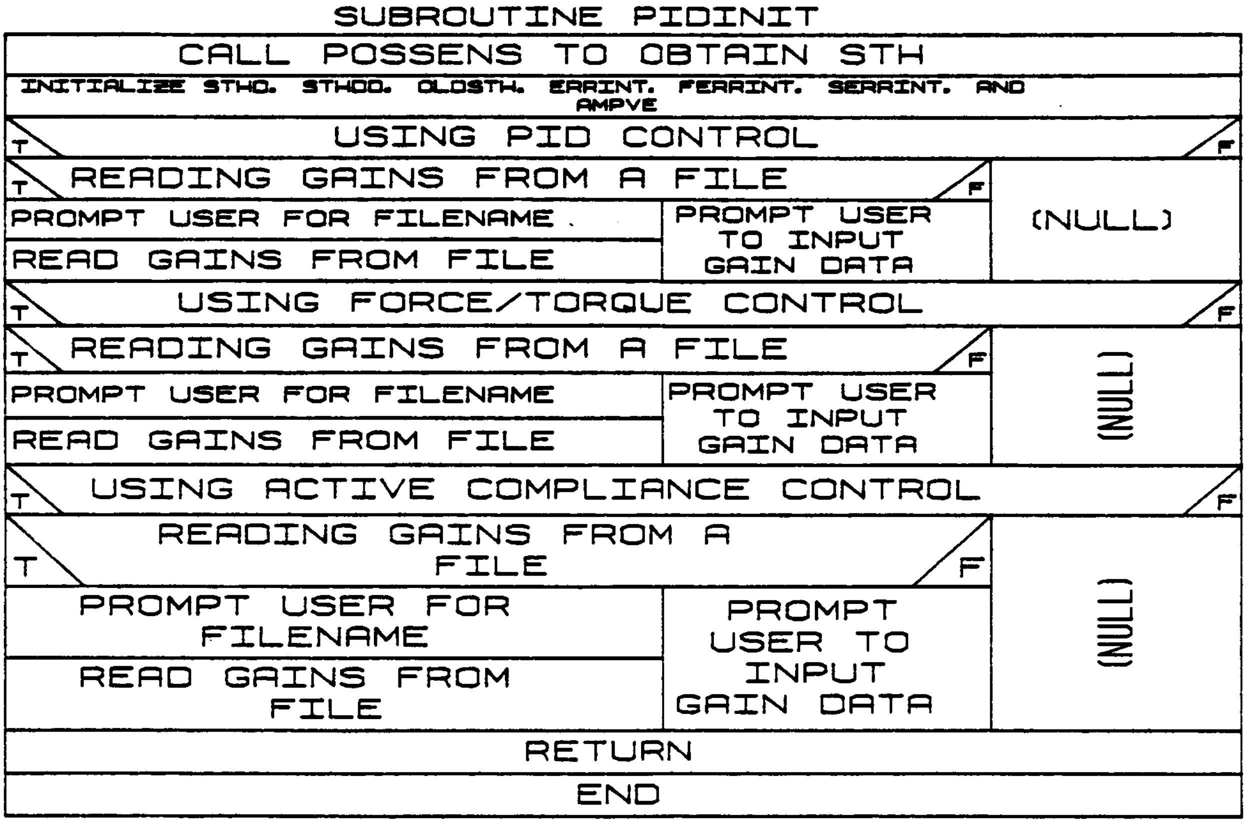
DEFCNST reads a file containing the information needed to define a constraint (either planar or peg-in-hole type) on the end-effector motion during dynamic simulation of the arm response. The user specifies the name of the constraint file in response to interactive prompts.



```
SUBROUTINE DEFCNST
QUERY WHETHER USER WANTS TO INCLUDE CONSTRAINT
CONSTRAINT DESIRED
  T:
    KARM = 1
    PROMPT FOR FILENAME OF CONSTRAINT FILE
    OPEN CONSTRAINT FILE
    READ TOOL REFERENCE POINT LOCATION
    READ NUMBER OF PLANAR CONSTRAINTS
    DO FOR EACH PLANAR CONSTRAINT
      READ THE 4 COORDINATES DEFINING THE PLANE
    READ NUMBER OF PEG-IN-HOLE CONSTRAINTS
    DO FOR EACH PEG-IN-HOLE CONSTRAINT
      READ HOLE LOCATION
      READ DIRECTION OF HOLE AXIS
      READ DEPTH OF HOLE
      READ RADIUS OF HOLE
      READ FRICTION COEFFICIENT FOR HOLE
    CLOSE CONSTRAINT FILE
  F:
    SET VARIABLES TO INDICATE NO CONSTRAINTS
HOLE CONSTRAINT INCLUDED
  T:
    ACTIVATE HOLE CONSTRAINT
  F:
    DEFINE HOLE CONSTRAINT INACTIVE
```

2.2.16 PIDINIT

Subroutine PIDINT is called from RESPON to initialize variables used in the program's control algorithms. POSSENS is called first to determine the actual joint positions. Initial values for some control variables are set. The user is then asked to supply system gains for the methods of control that will be used during program execution. These gains may be supplied by either reading in a file of existing gains or by the user interactively inputting the gains.



2.2.17 OUTSIM

Subroutine OUTSIM is called from RESPON to write the appropriate output data to the different types of files requested by the user. Types of output files available are:

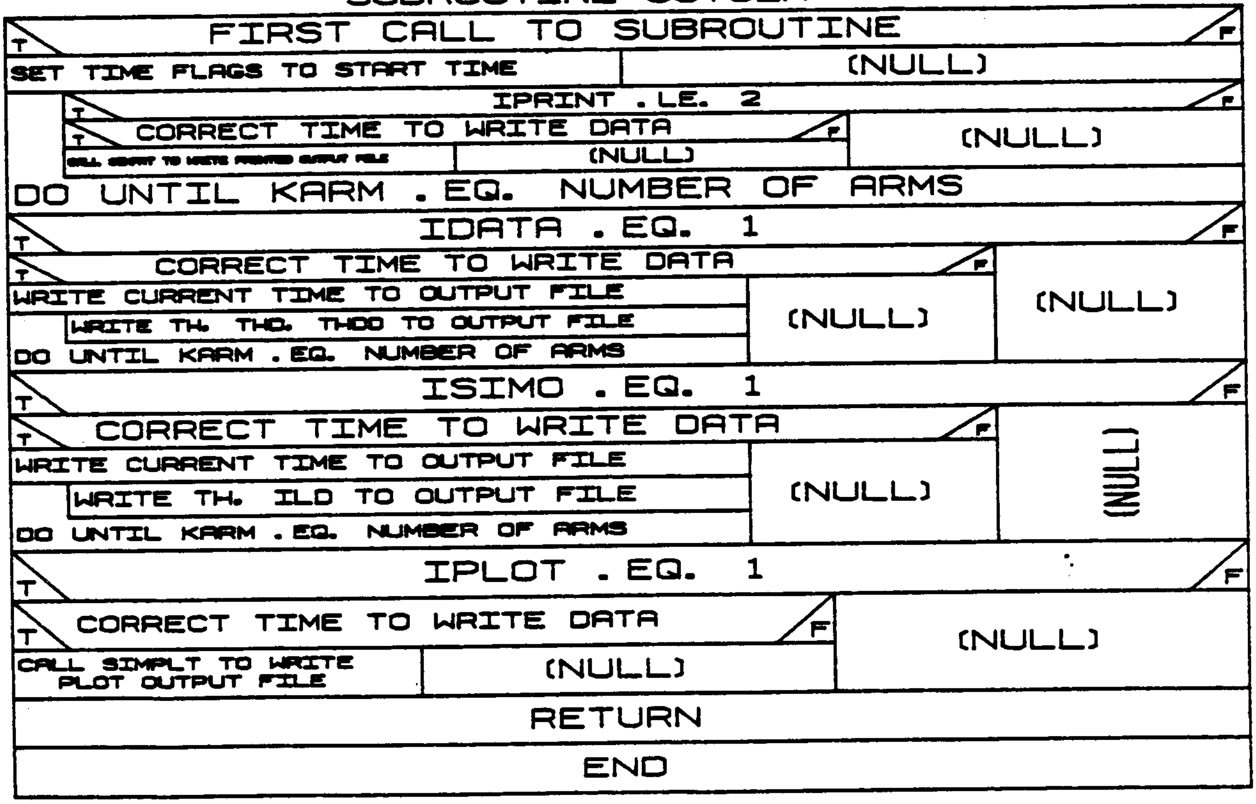
1) File of run time data for subsequent tabular printout;

2) File of joint positions, velocities and accelerations as functions of time;

3) Data file for later motion replay on vector graphics machine;

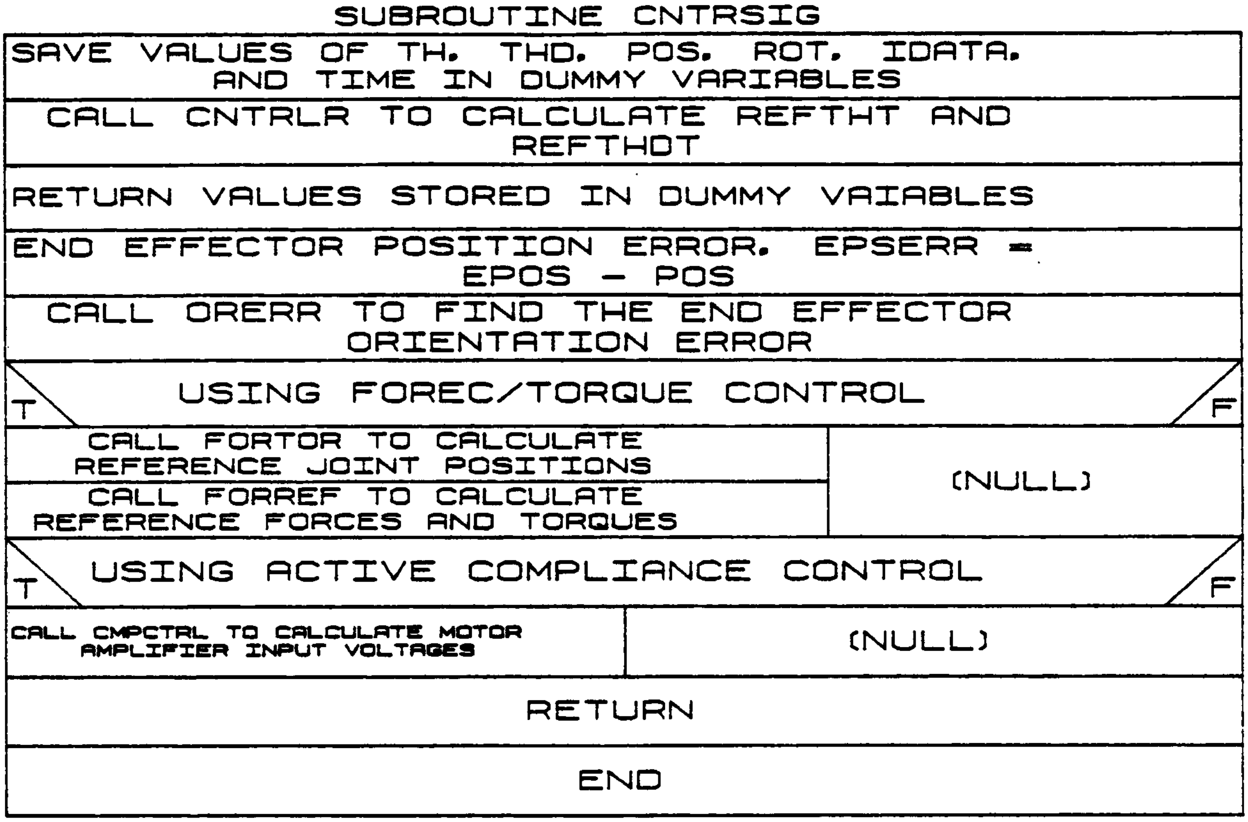
4) File of data for subsequent x-y plotting.

SUBROUTINE OUTSIM



2.2.18 CNTRSIG

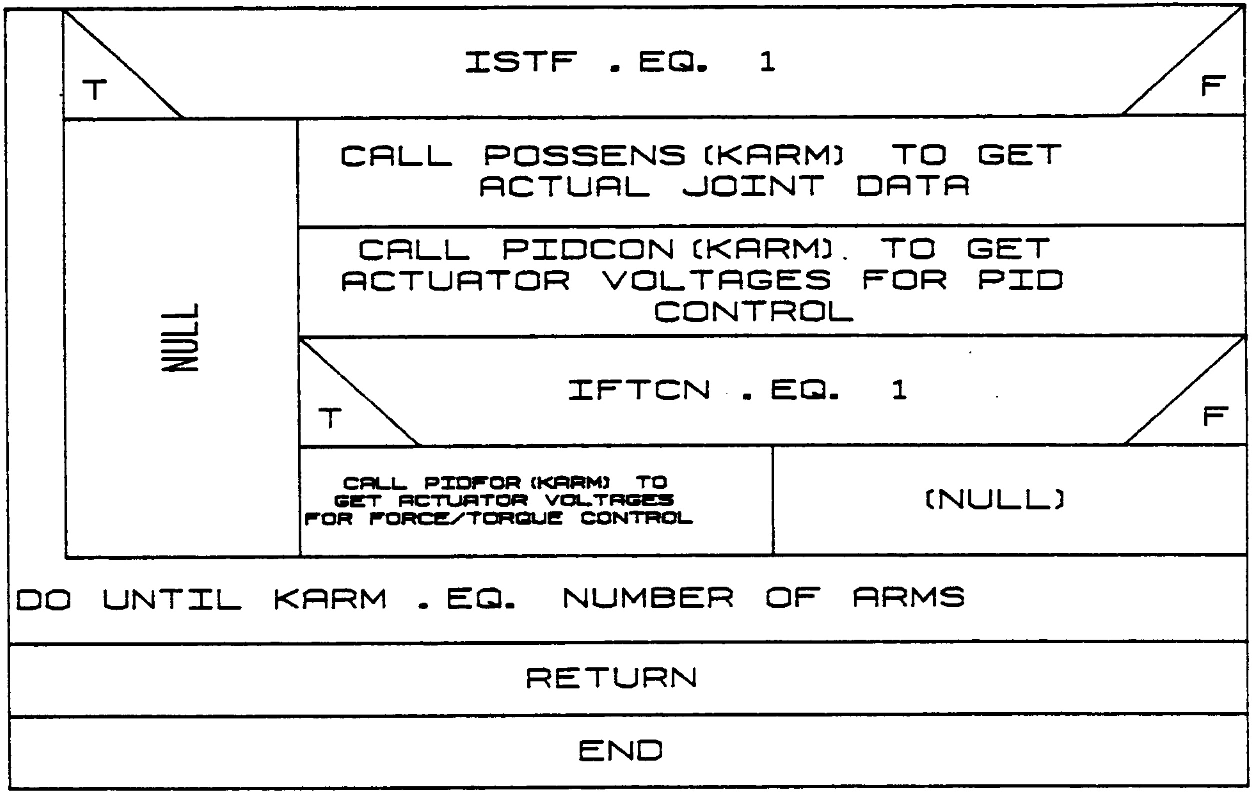
Subroutine CNTRSIG is called from the routine REQUIR. Joint variables are stored in dummy variables and CNTRLR is called to calculate joint angular reference positions and velocities. The end-effector position error is calculated and ORERR is called to determine the orientation error. If force/torque control is being used, subroutines FORTOR and FORREF are called to calculate joint reference positions and reference forces and torques. If active compliance control is being used, subroutine CMPCTRL is called to calculate amplifier input voltages.



2.2.19 CONTROL

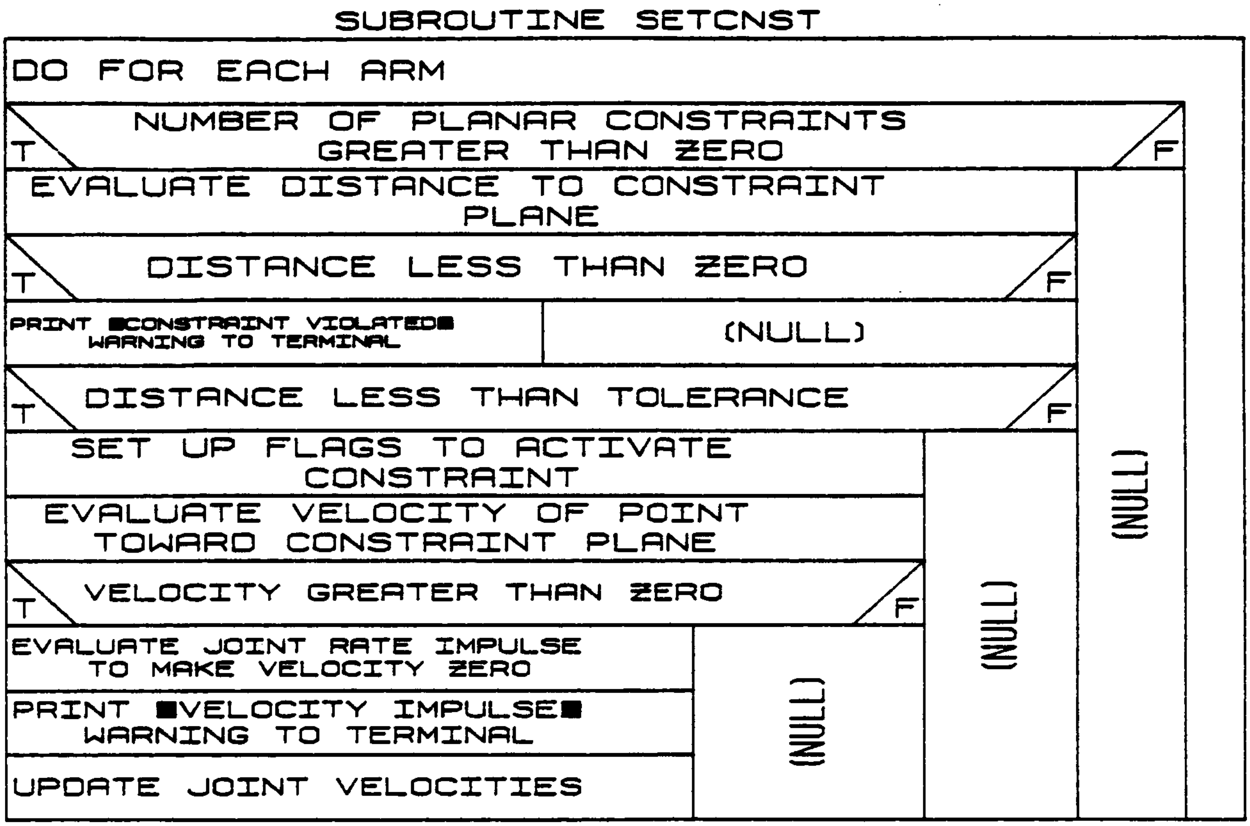
Subroutine CONTROL is called from RESPON at every processing time step. If a feedback control law is to be used, POSSENS is called to get the actual joint data and PIDCON is called to get actuator voltages for PID control. If force/torque control is being used, PIDFOR is also called to get actuator voltages caused by the force-controlled components.

SUBROUTINE CONTROL



2.2.20 SETCNST

SETCNST checks planar constraints to see if they are violated or need to be activated. If the current velocity violates the constraint, the velocity impulse to satisfy the constraint is evaluated.



2.2.21 DERIV

DERIV is used during response simulation to interface between INTGRT and the dynamics module NLINK. This routine puts the state vector Z into the appropriate common variables, calls NLINK and puts the results from the common variable THDD into ZD.

C.3

SUBROUTINE DERIV

```
SET TEMP. TIME TO TIME
IMOVBAS .EQ. 1 .AND. IBASSIM .EQ. 1
  T:
    (DO UNTIL KBAS=NBAS)
      LOAD BASE STATE INTO MOVING BASE VARIABLES
      LOAD BASE VELOCITIES INTO DERIV. STATE VECTOR
    DO UNTIL KBAS=NBAS
  F:
    (NULL)
DO FOR EACH ARM
  DO FOR EACH JT. IN ARM
    SET ANG. POS., VEL. AND ACC. FROM STATE VECTOR
    SET DERIV. STATE VECTOR FROM ANG. ACC.
  SET DIMENSION OF STATE VECTOR
CALL NLINK TO SOLVE FOR JT. ACC.
CALL SIMLMT TO CHECK JT. DISPLACEMENTS AND RATE LIMITS
SET TIME TO TEMP. TIME
IMOVBAS. EQ. 1. AND. IBASSIM. EQ. 1
  T:
    SET DERIV. STATE VECTOR FROM BASE ACCELERATIONS
    DO UNTIL KBAS=NBAS
  F:
    (NULL)
DO FOR EACH ARM
  DO FOR EACH JT. OF ARM
    SET STATE DERIV. VECTOR FROM ANG. ACC.
    JT. POS./RATES WERE MODIFIED TO KEEP WITHIN LIMITS THEN
      T:
        SET STATE DERIV. VECTOR FROM ANG. VEL.
        SET STATE VECTOR FROM ANG. VEL.
        SET STATE VECTOR FROM ANG. POS.
      F:
        (NULL)
    SET DIMENSION OF STATE VECTOR
RETURN
END
```

2.2.22 INTGRT

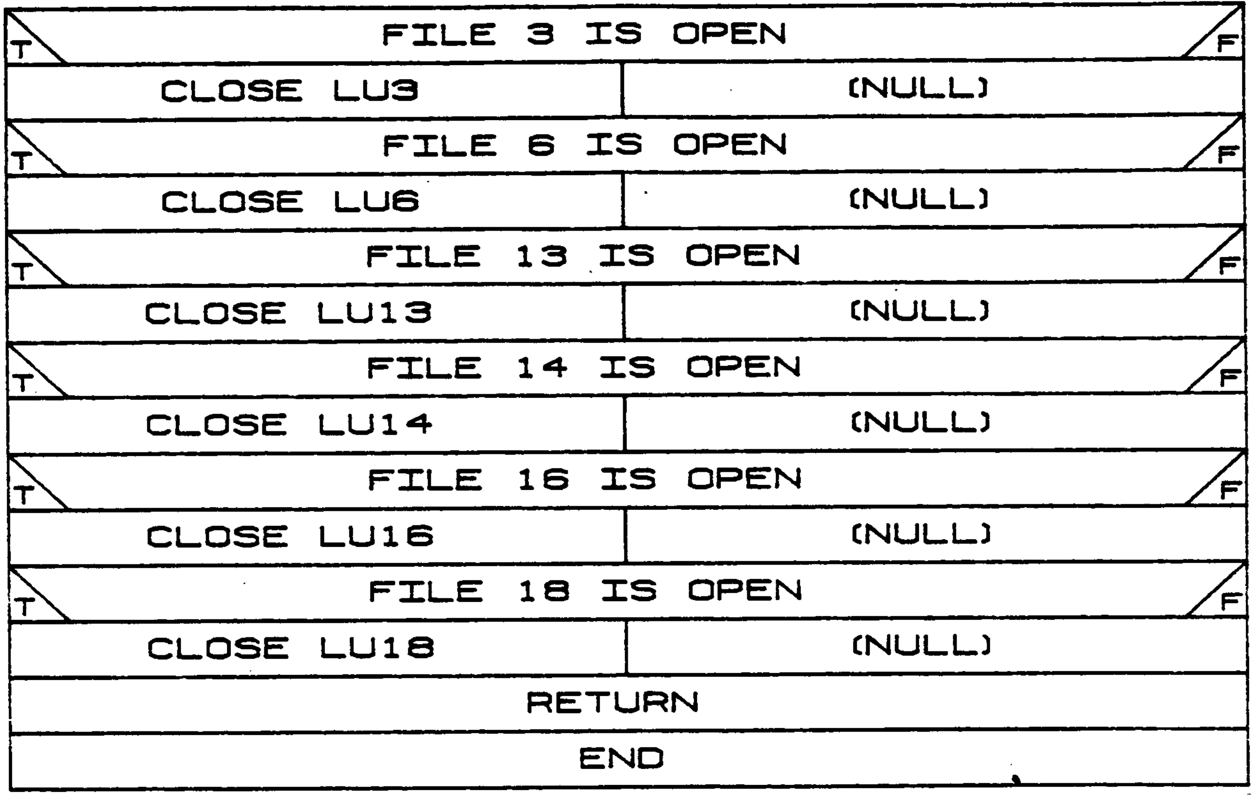
Subroutine INTGRT is called from RESPON and uses a fourth-order Runge-Kutta algorithm to integrate a state vector Z. State derivatives are computed by the subroutine DERIV.

```
SUBROUTINE INTGRT
SET T TO INITIAL TIME FOR INTEGRATION
SET HDT TO TIME STEP/2.
DO FOR EACH COMPONENT IN STATE
    SAVE STATE VECTOR COMPONENT
    SET DELZ TO STATE DERIVATIVE*HDT COMPONENT
    SET STATE VECTOR TO STATE VECT.+DELZ
CALL STOPFR TO STOP MOTION DUE TO DRY FRICTION
SET T TO INITIAL TIME+HDT
CALL DERIV TO CALCULATE STATE DERIVATIVES
DO FOR EACH COMPONENT IN STATE
    SET ZDT TO STATE DERIVATIVE VECTOR COMPONENT*TIME STEP
    SET DELZ TO LAST DELZ+ZDT
    SET STATE VECTOR TO STATE VECT.+ZDT/2.
CALL STOPFR
CALL DERIV
DO FOR EACH COMPONENT IN STATE
    SET ZDT TO STATE DERIVATIVE VECTOR COMPONENT*TIME STEP
    SET DELZ TO LAST DELZ+ZDT
    SET STATE VECTOR TO STATE VECT.+ZDT
CALL STOPFR
SET T TO INITIAL TIME + TIME STEP
CALL DERIV
DO FOR EACH COMPONENT IN STATE
    SET DELZ TO LAST DELZ+STATE DERIV.*HDT
    SET STATE VECTOR TO SAVE STATE VECTOR+DELZ/3.
CALL STOPFR
CALL DERIV
RETURN
END
```

2.2.23 ENDSIM

Subroutine ENDSIM closes any files opened during execution of the response simulation portion of ROBSIM.

SUBROUTINE ENDSIM



2.2.24 SEGTASK

Subroutine SEGTASK is called from TASK and allows the user to create a file that specifies manipulator motion using the following task commands:

1) Pick up object;
2) Place object at specified location;
3) Move arm;
4) Hold current position;
5) Change end effector reference point;
6) Operator control (not implemented yet);
7) Set control mode for response simulation;
8) Sensor of end effector position.

The user is prompted for initial joint angles and other necessary data after which a sequence of task commands may be implemented.

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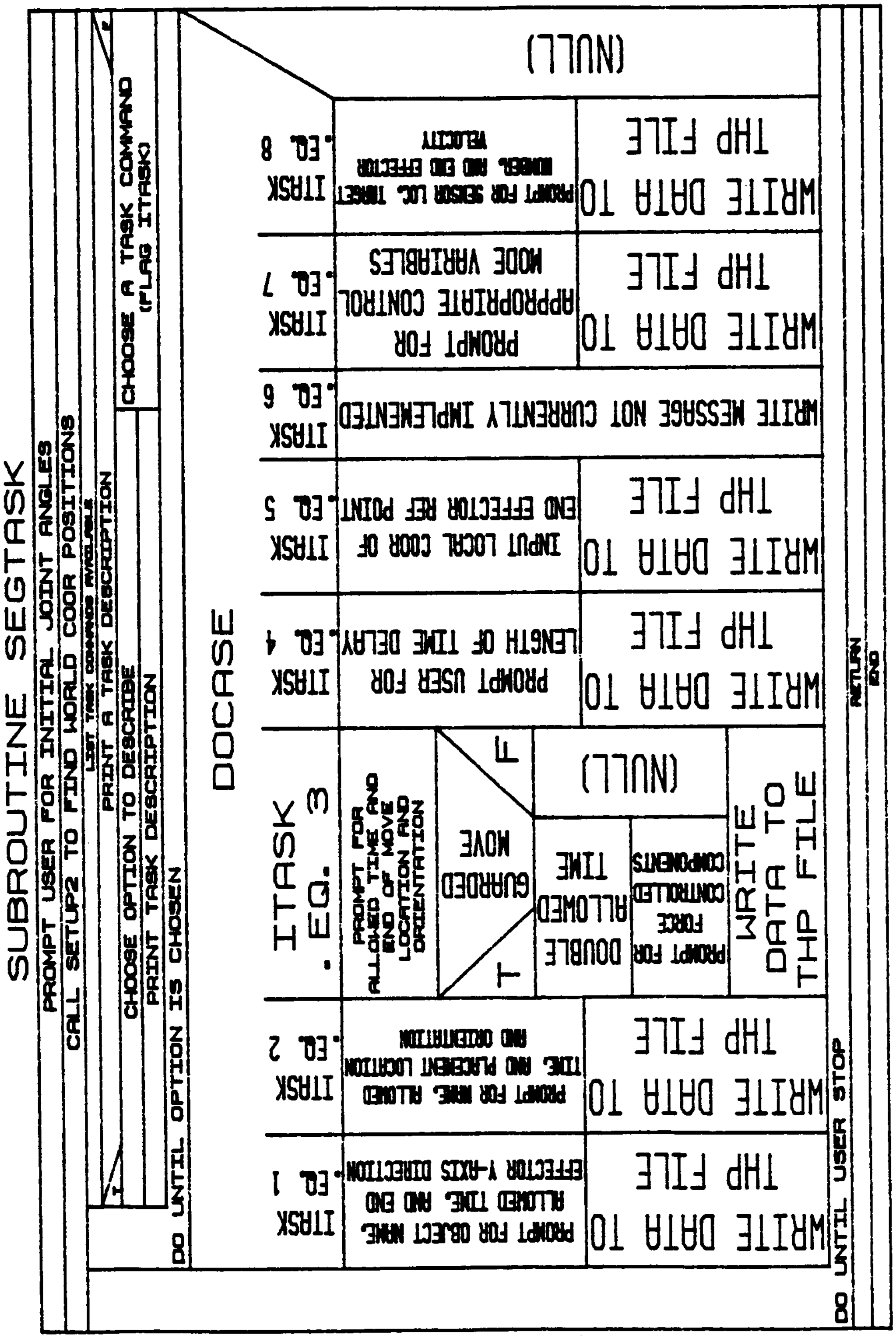
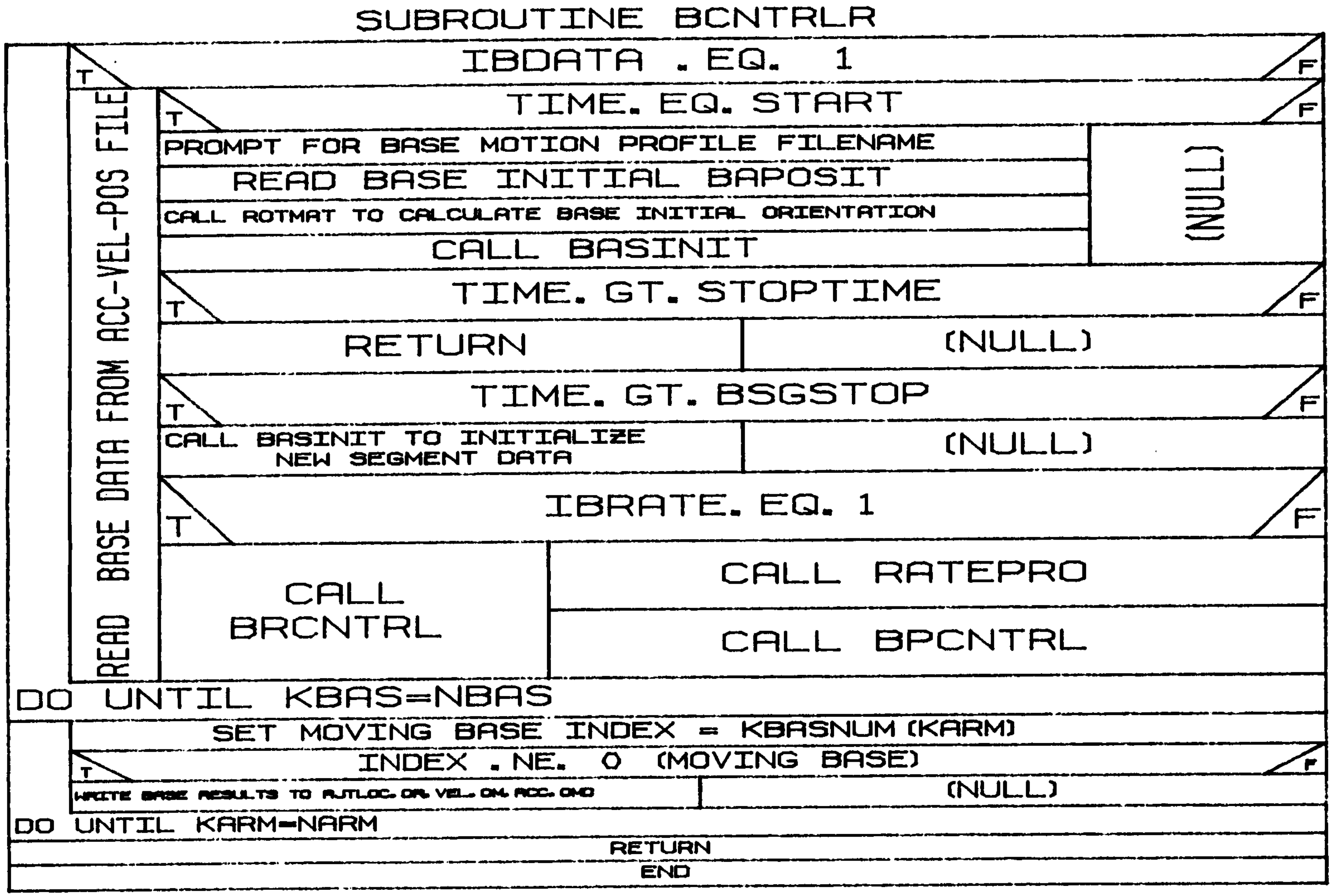


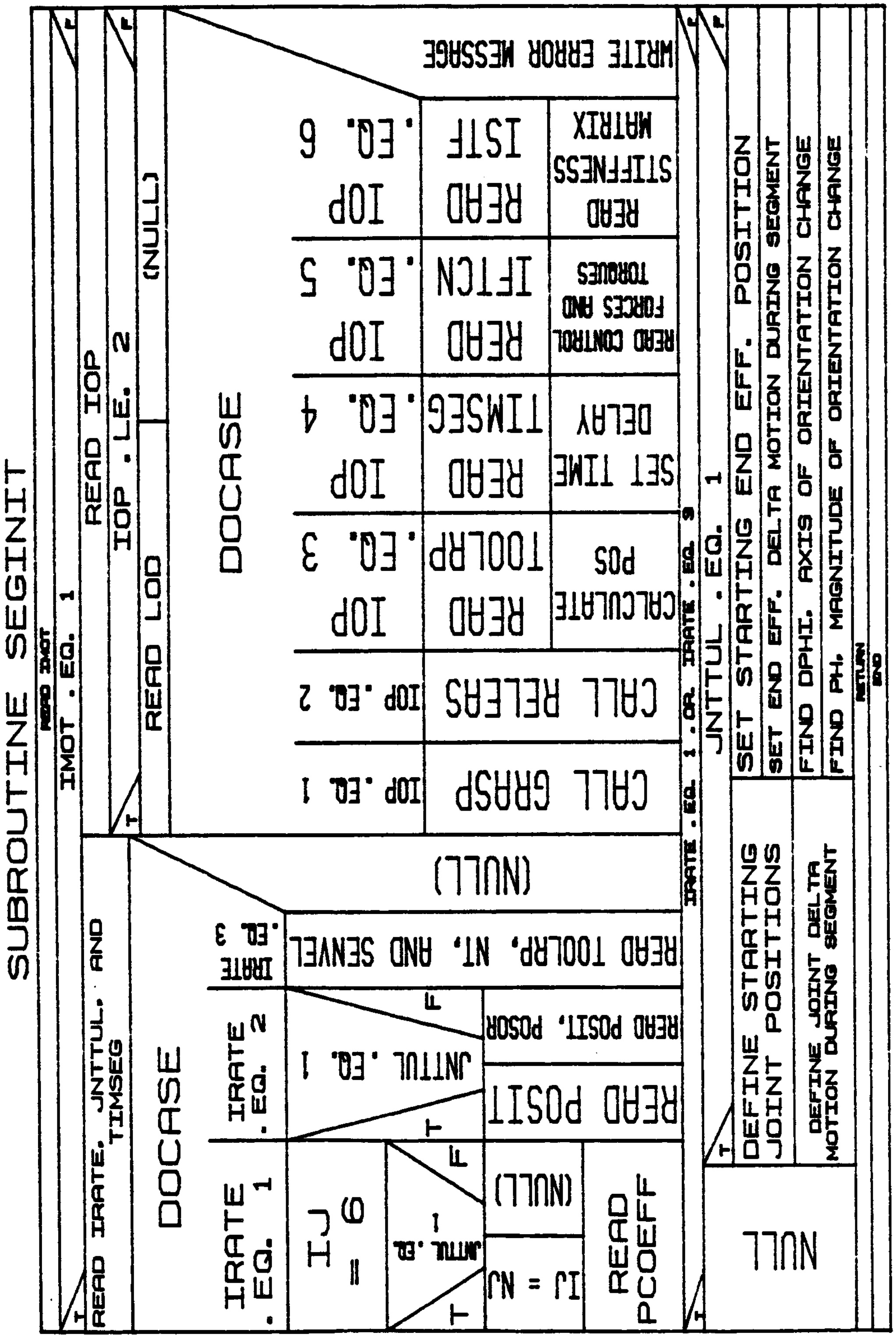
2.2.25 BCNTRLR

Subroutine BCNTRLR is called from REQUIR to obtain the position, velocity and acceleration for each moving base at each processing time step. If the variable IBDATA was set to 1 earlier, the base data are obtained by reading an existing file that contains just these data. If IBDATA equals 2, the base values are calculated from the base motion profiles. Subroutines RATEPRO and BPCNTRL are called for the base position control calculations and BRCNTRL is called for the base rate control calculation.


SUBROUTINE BCNTRLR
IBDATA .EQ. 1
T
F
READ BASE DATA FROM ACC-VEL-POS FILE
TIME. EQ. START
T
F
PROMPT FOR BASE MOTION PROFILE FILENAME
READ BASE INITIAL BAPOSIT
CALL ROTMAT TO CALCULATE BASE INITIAL ORIENTATION
CALL BASINIT
(NULL)
TIME. GT. STOPTIME
T
F
RETURN
(NULL)
TIME. GT. BSGSTOP
T
F
CALL BASINIT TO INITIALIZE NEW SEGMENT DATA
(NULL)
IBRATE. EQ. 1
T
F
CALL BRCNTRL
CALL RATEPRO
CALL BPCNTRL
DO UNTIL KBAS=NBAS
SET MOVING BASE INDEX = KBASNUM (KARM)
INDEX .NE. 0 (MOVING BASE)
T
F
WRITE BASE RESULTS TO AJTLOC. OR. VEL. OM. ACC. OMD
(NULL)
DO UNTIL KARM=NARM
RETURN
END

2.3.1 SEGINIT

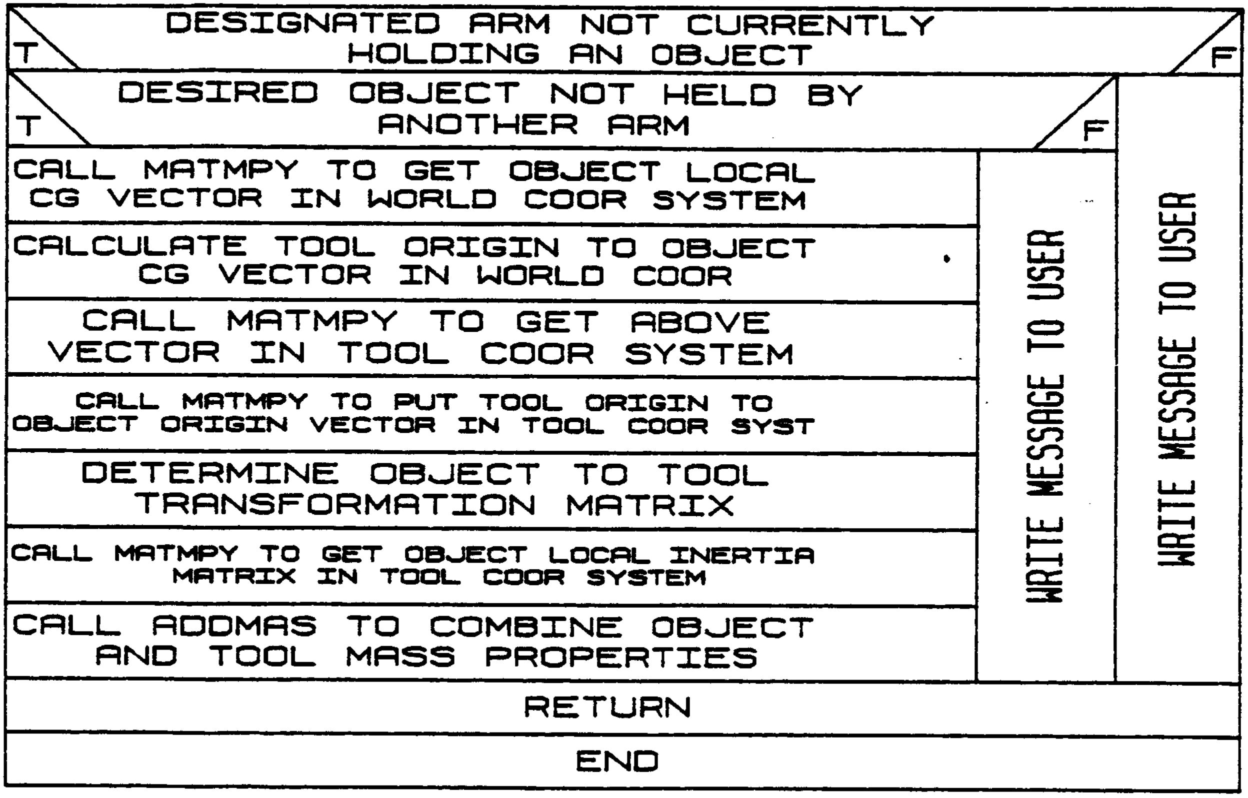
Subroutine SEGINIT is called from CNTRLR at the beginning of each new motion profile segment. If the segment is to define motion of the manipulator, the sensor and target data or the coefficients of the polynomials defining the motion rates, the desired positions and orientations are read from the motion history file. If it is a nonmotion segment, the appropriate subroutines are called or variables are defined to ensure these actions are carried out. If position control is specified, the motion deltas for the current time segment are calculated.


SUBROUTINE SEGINIT
READ IMOT
IMOT .EQ. 1
T
F
READ IRATE, JNTTUL, AND TIMSEG
DOCASE
IRATE .EQ. 1
IJ = 6
JNTTUL .EQ. 1
T
F
IJ = NJ
(NULL)
READ PCOEFF
IRATE .EQ. 2
JNTTUL .EQ. 1
T
F
READ POSIT
READ POSIT, POSOR
IRATE .EQ. 3
READ TOOLRP, NT, AND SENVEL
(NULL)
READ IOP
IOP .LE. 2
T
F
READ LOD
(NULL)
DOCASE
IOP .EQ. 1
CALL GRASP
IOP .EQ. 2
CALL RELERS
IOP .EQ. 3
READ TOOLRP
CALCULATE POS
IOP .EQ. 4
READ TIMSEG
SET TIME DELAY
IOP .EQ. 5
READ IFTCN
READ CONTROL FORCES AND TORQUES
IOP .EQ. 6
READ ISTF
READ STIFFNESS MATRIX
WRITE ERROR MESSAGE
IRATE .EQ. 1 .OR. IRATE .EQ. 3
T
F
JNTTUL .EQ. 1
T
F
DEFINE STARTING JOINT POSITIONS
DEFINE JOINT DELTA MOTION DURING SEGMENT
SET STARTING END EFF. POSITION
SET END EFF. DELTA MOTION DURING SEGMENT
FIND DPHI. AXIS OF ORIENTATION CHANGE
FIND PH. MAGNITUDE OF ORIENTATION CHANGE
NULL
RETURN
END

2.3.2 GRASP

Subroutine GRASP is called from SEGINIT when the option flag IOP equals 1 (this denotes that the arm is to grasp a load object). The subroutine first checks to make sure the arm is not already holding an object and that the desired object is not being held by another arm. The location and orientation of the load object are then defined with respect to the end-effector coordinate system. This ensures that the object's location and orientation with respect to the world coordinate system will be updated correctly during a move and that the display shows the object moving with the arm. The end-effector mass properties are modified to include the load object to ensure the correct system response.

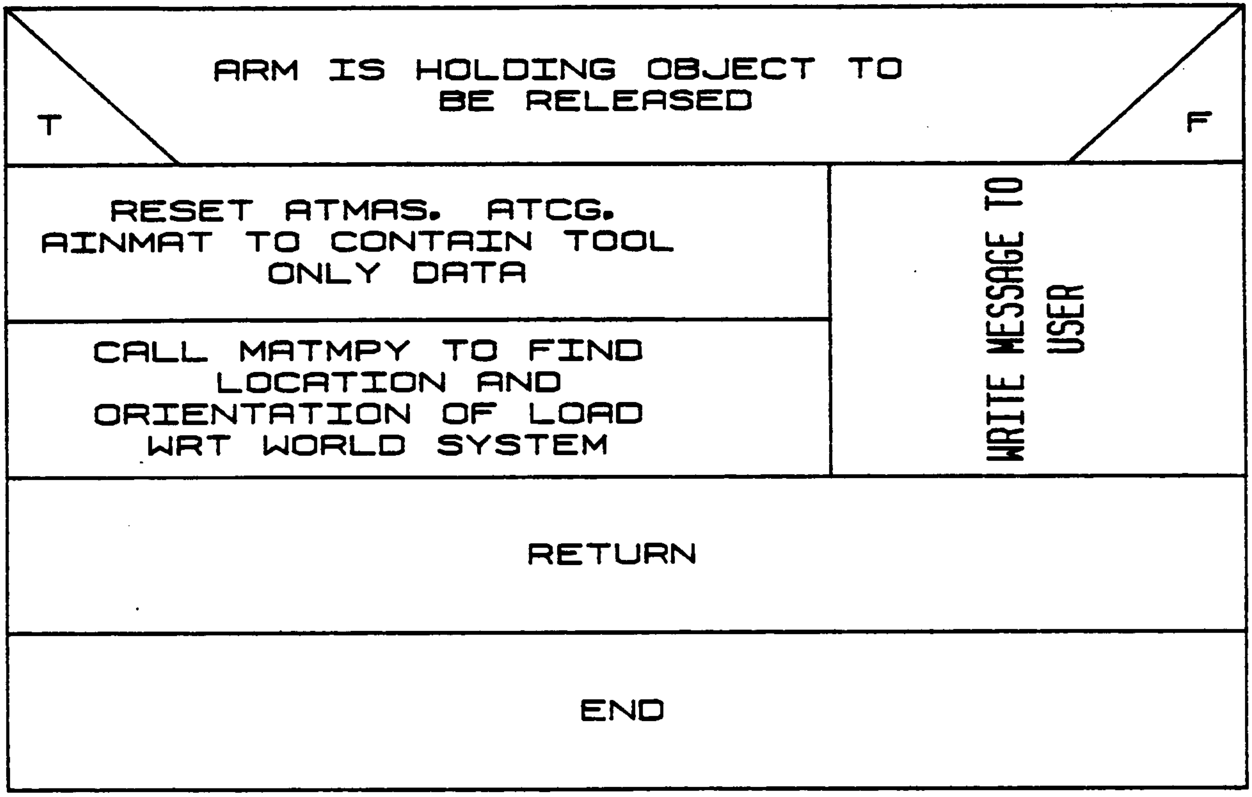
SUBROUTINE GRASP



2.3.3 RELEAS

Subroutine RELEAS is called from SEGINIT when the arm is to let go of a load object. The routine first makes sure the load object to be released is being held by the current arm. If it is being held, the end-effector mass properties are reset to the values held before the object was picked up and MATMPY is called to obtain the location and orientation of the load object with respect to the world. If the object is not being held, a message is displayed to the user.

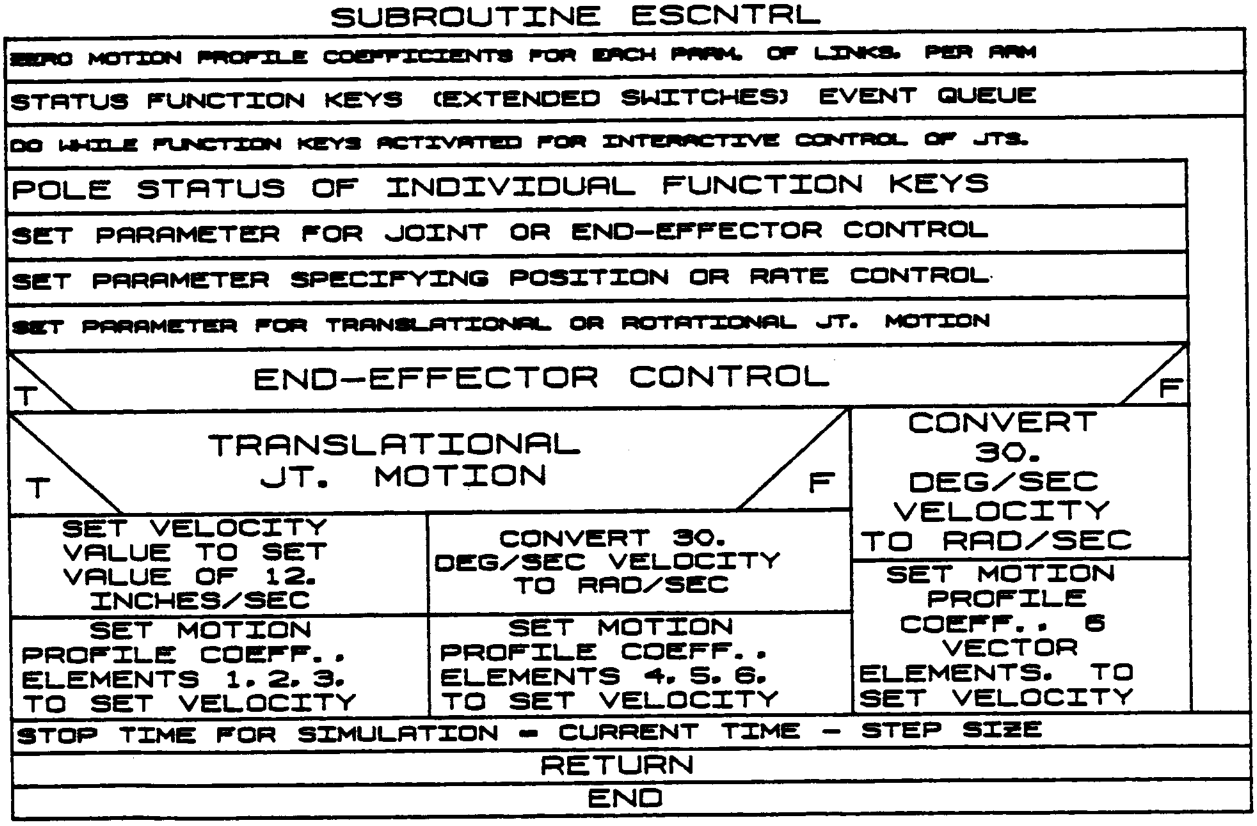
SUBROUTINE RELEAS



2.3.4 ESCNTRL

ESCNTRL allows control of system motion through use of the Evans and Sutherland extended switches (function keys) and loads the coefficients of the polynomial describing the motion, PCOEF. Options include individual joint control or end-effector control. For end-effector control, either the base coordinates or tool coordinates may be used as the reference frame. Also, the controlled motion may be either translation or rotation. The manipulator motion is always rate-controlled rather than joint-controlled. The user may select which arm and joint is to move.

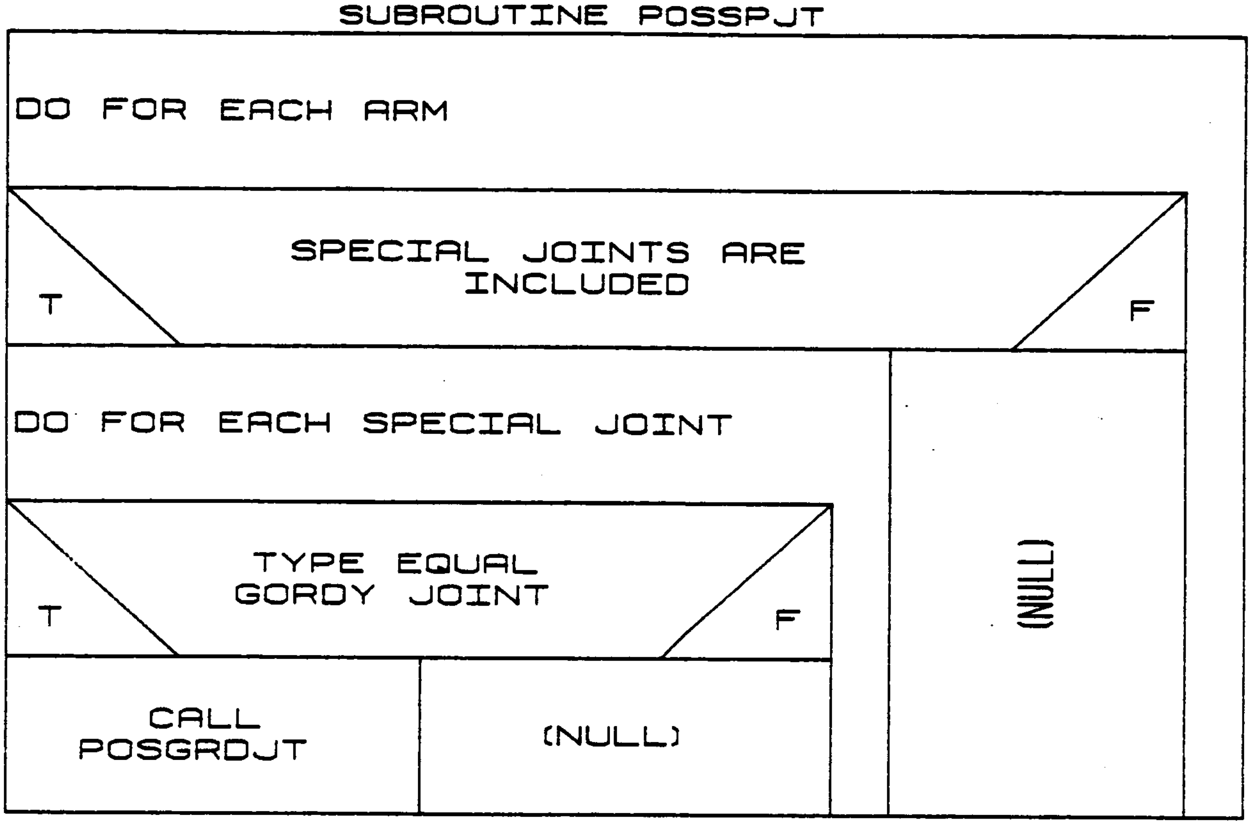
SUBROUTINE ESCNTRL



```
ZERO MOTION PROFILE COEFFICIENTS FOR EACH PARM. OF LINKS. PER ARM
STATUS FUNCTION KEYS (EXTENDED SWITCHES) EVENT QUEUE
DO WHILE FUNCTION KEYS ACTIVATED FOR INTERACTIVE CONTROL OF JTS.
    POLE STATUS OF INDIVIDUAL FUNCTION KEYS
    SET PARAMETER FOR JOINT OR END-EFFECTOR CONTROL
    SET PARAMETER SPECIFYING POSITION OR RATE CONTROL
    SET PARAMETER FOR TRANSLATIONAL OR ROTATIONAL JT. MOTION
    END-EFFECTOR CONTROL
    T:
        TRANSLATIONAL JT. MOTION
        T:
            SET VELOCITY VALUE TO SET VALUE OF 12. INCHES/SEC
            SET MOTION PROFILE COEFF., ELEMENTS 1, 2, 3, TO SET VELOCITY
        F:
            CONVERT 30. DEG/SEC VELOCITY TO RAD/SEC
            SET MOTION PROFILE COEFF., ELEMENTS 4, 5, 6, TO SET VELOCITY
    F:
        CONVERT 30. DEG/SEC VELOCITY TO RAD/SEC
        SET MOTION PROFILE COEFF., 6 VECTOR ELEMENTS, TO SET VELOCITY
STOP TIME FOR SIMULATION = CURRENT TIME - STEP SIZE
RETURN
END
```

2.3.5 POSSPJT

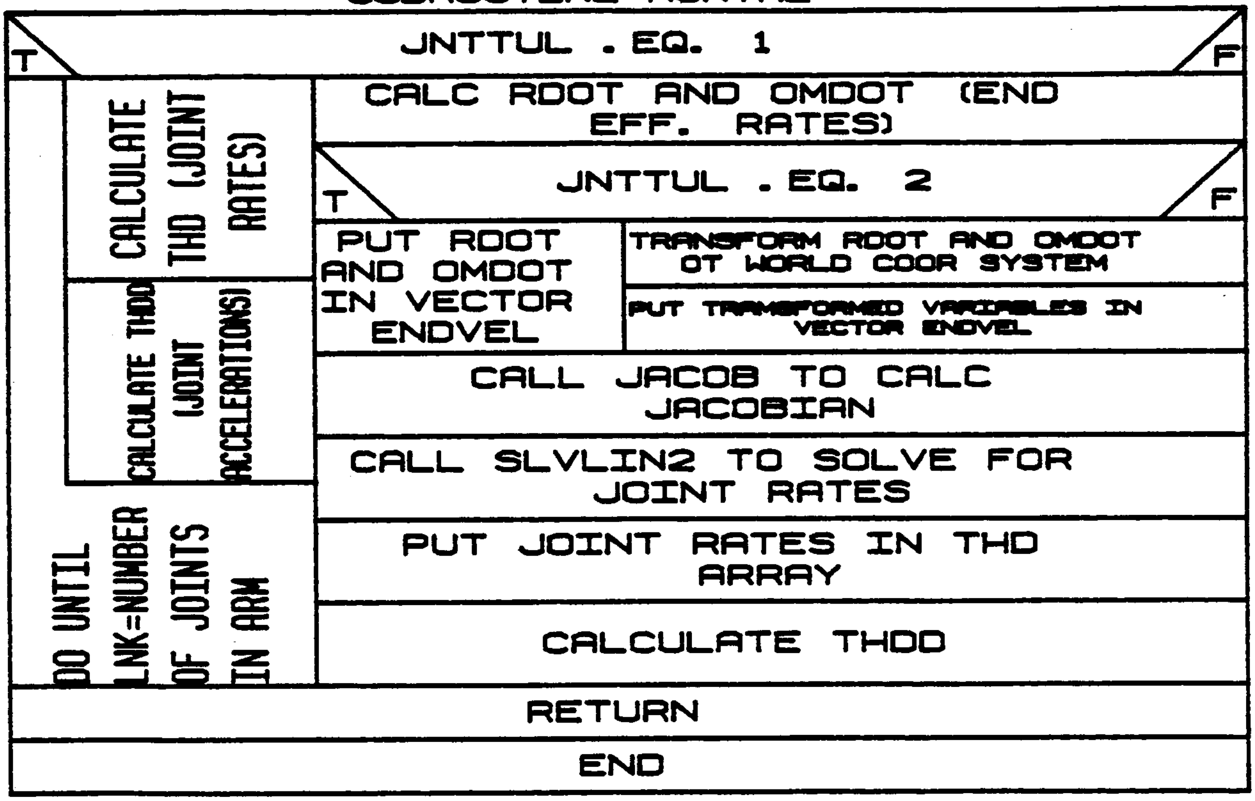
POSSPJT is the executive routine that calls handling routines for finding the position of special joints within the manipulator. Currently only one type of special joint can be included.



2.3.6 RCNTRL

Subroutine RCNTRL is called from CNTRLR when rate control of the joints or end-effector is specified. If joint rate control was chosen, the joint rates THD are calculated from their polynomial definitions and the accelerations THDD by finite difference methods. For end-effector rate control, the defining polynomials are evaluated for the current time. JACOB and SLVLIN2 are then called to transform these end-effector rates to individual joint rates. Accelerations (of each joint) are again calculated using finite difference methods.

SUBROUTINE RCNTRL



2.3.7 RATEPRO

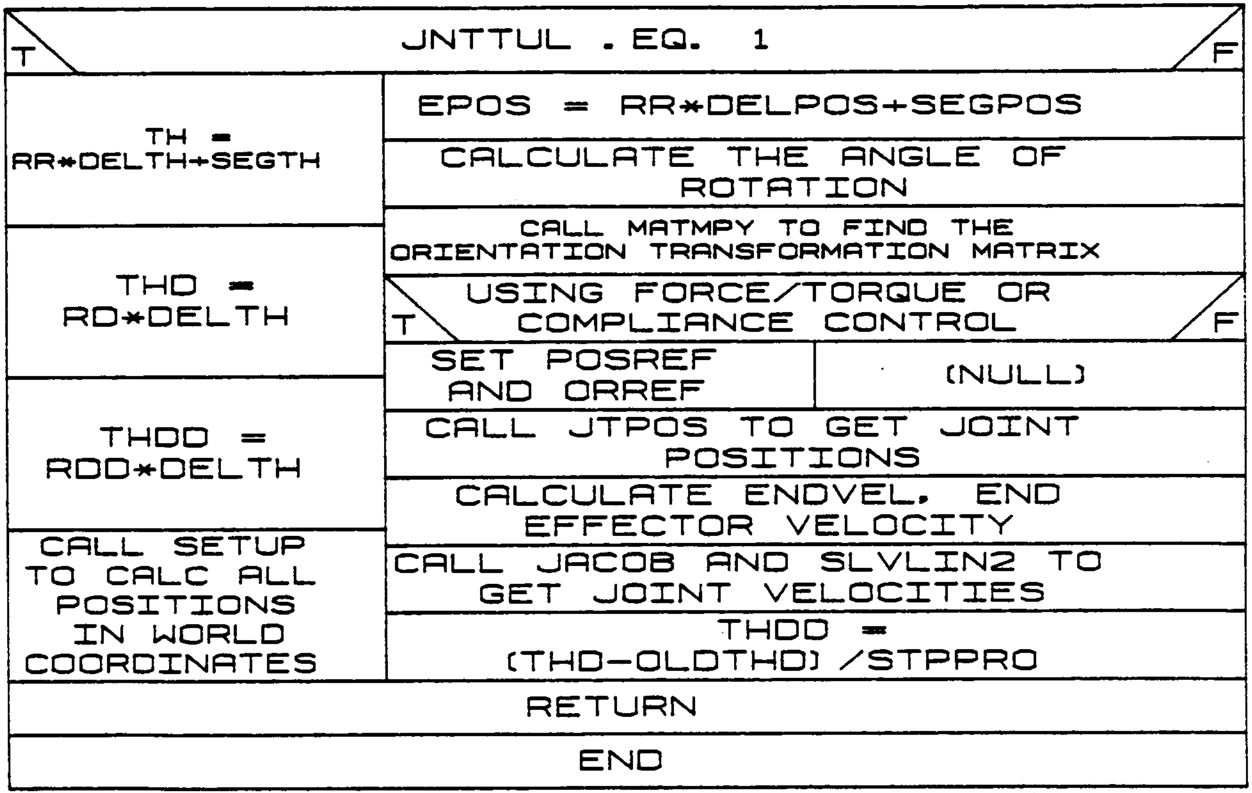
RATEPRO is called from subroutine CNTRLR when position control of the manipulator is desired. The time allowed for the move is divided into six equal portions. The first portion is defined to be constant acceleration. The next four are constant velocity. The last is constant deceleration equal in magnitude to the first portion. The distance traveled in the whole time is set to 1 and the appropriate distance traveled, velocity and acceleration for each portion are calculated.

```
SUBROUTINE RATEPRO
DELTIM = TIMSEG/6.0
ACCEL = 1.0/(5.0*DELTIM**2)
VELOC = ACCEL*DELTIM
DOCASE
    T .LT. DELTIM
        R = .5*ACCEL**2
        RD = ACCEL*T
        RDD = ACCEL
    T .GE. DELTIM .AND. T .LT. (5.0*DELTIM)
        R = .5*ACCEL*DELTIM**2
        R = R+VELOC*(T-DELTIM)
        RD = VELOC
        RDD = 0.0
    T .GE. (5.0*DELTIM)
        R = 4.5*ACCEL*DELTIM**2
        R = R+VELOC*(T-5.0*DELTIM)
        R = R-.5*ACCEL*(T-5.0*DELTIM)**2
        RD = VELOC-(ACCEL*(T-5.0*DELTIM))
        RDD = -ACCEL
    (NULL)
RETURN
END
```

2.3.8 PCNTRL

PCNTRL is called from CNTRLR when position control of the manipulator is to be used. Joint position control uses the segment rate profile defined by subroutine RATEPRO to calculate the joint positions, velocities, and accelerations. End-effector position control uses the same rate profile to get the end-effector rates. JTPOS is then called to get joint positions, and JACOB and SLVLIN2 are called to get the joint velocities. Joint accelerations are calculated by finite difference methods.

SUBROUTINE PCNTRL



2.3.9 CABSM

CABSM uses a recursive technique to compute the absolute angular and translational velocity and acceleration of each joint/link combination in the system.

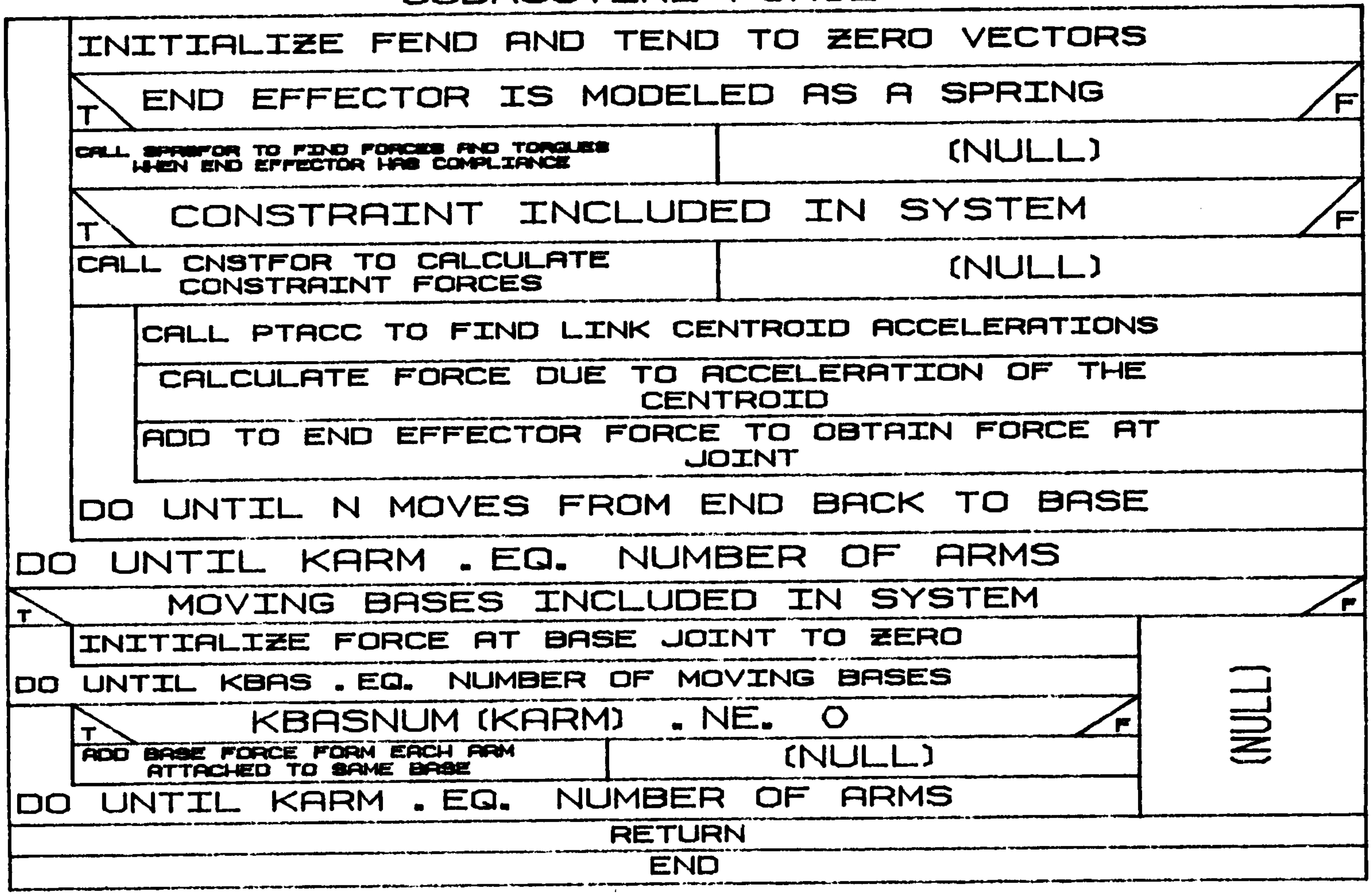
SUBROUTINE CABSM

```
DO FOR EACH ARM IN SYSTEM
    MOVING BASES INCLUDED IN SYSTEM
    T:
        INDEX = BASE NUMBER KBASNUM (KARM)
        INDEX .NE. 0
        T:
            INITIALIZE BASE VELOCITIES AND ACCELERATIONS APPROPRIATELY
        F:
            SET BASE VELOCITIES AND ACCELERATIONS TO ZERO
    F:
        (NULL)
    INITIALIZE W, V, AL, AND A WITH ANG. AND TRANS. VEL. AND ACC. OF BASE
    DO FOR EACH LINK
        V = V + W CROSS HIJ (VECTOR FROM PREVIOUS JOINT TO CURRENT JOINT)
        A = A + (W CROSS (W CROSS HIJ)) + (AL CROSS HIJ)
        VJ = THETA-DOT TIMES DIRECTION VECTOR FOR JOINT AXIS
        AJ = THETA-DOUBLE-DOT TIMES DIRECTION VECTOR FOR JOINT AXIS
        WCVJ = W CROSS VJ
        JOINT IS REVOLUTE
        T:
            W = W + VJ
            AL = AL + AJ + WCVJ
        F:
            V = V + VJ
            A = A + AJ + 2*WCVJ
```

2.3.10 FORCE

Subroutine FORCE is called from DYNAM to calculate the force exerted on each joint. The force at the end-effector is determined first. PTACC is called to find link centroid accelerations, and the forces caused by these accelerations are added to the end-effector forces to find the force at each joint. If the system includes multiple arms on a moving base, the reaction force at the base is a sum of the individual base reaction forces from each arm that is attached to the base.

SUBROUTINE FORCE



```
INITIALIZE FEND AND TEND TO ZERO VECTORS
    END EFFECTOR IS MODELED AS A SPRING
    T: CALL SPRSFOR TO FIND FORCES AND TORQUES
       WHEN END EFFECTOR HAS COMPLIANCE
    F: (NULL)
    CONSTRAINT INCLUDED IN SYSTEM
    T: CALL CNSTFOR TO CALCULATE
       CONSTRAINT FORCES
    F: (NULL)
        CALL PTACC TO FIND LINK CENTROID ACCELERATIONS
        CALCULATE FORCE DUE TO ACCELERATION OF THE
        CENTROID
        ADD TO END EFFECTOR FORCE TO OBTAIN FORCE AT
        JOINT
    DO UNTIL N MOVES FROM END BACK TO BASE
DO UNTIL KARM .EQ. NUMBER OF ARMS
MOVING BASES INCLUDED IN SYSTEM
T:
        INITIALIZE FORCE AT BASE JOINT TO ZERO
    DO UNTIL KBAS .EQ. NUMBER OF MOVING BASES
        KBASNUM (KARM) .NE. 0
        T: ADD BASE FORCE FORM EACH ARM
           ATTACHED TO SAME BASE
        F: (NULL)
    DO UNTIL KARM .EQ. NUMBER OF ARMS
F: (NULL)
RETURN
END
```

2.3.11 TORQUE

Subroutine TORQUE is called from DYNAM to calculate individual joint torques. The torques at the end-effector are determined first. Torques at the preceding joint are then calculated by adding the torques attributable to link inertias and centroid forces to the end-effector torques. The routine works back toward the base of the manipulator, adding the torques caused by inertias and centroid forces to the cumulative torques thus far to obtain the current joint torques. If the system includes multiple arms on a moving base, the total reaction torque at the base is the sum of all the individual reaction torques at the base from each arm that is attached to the base.

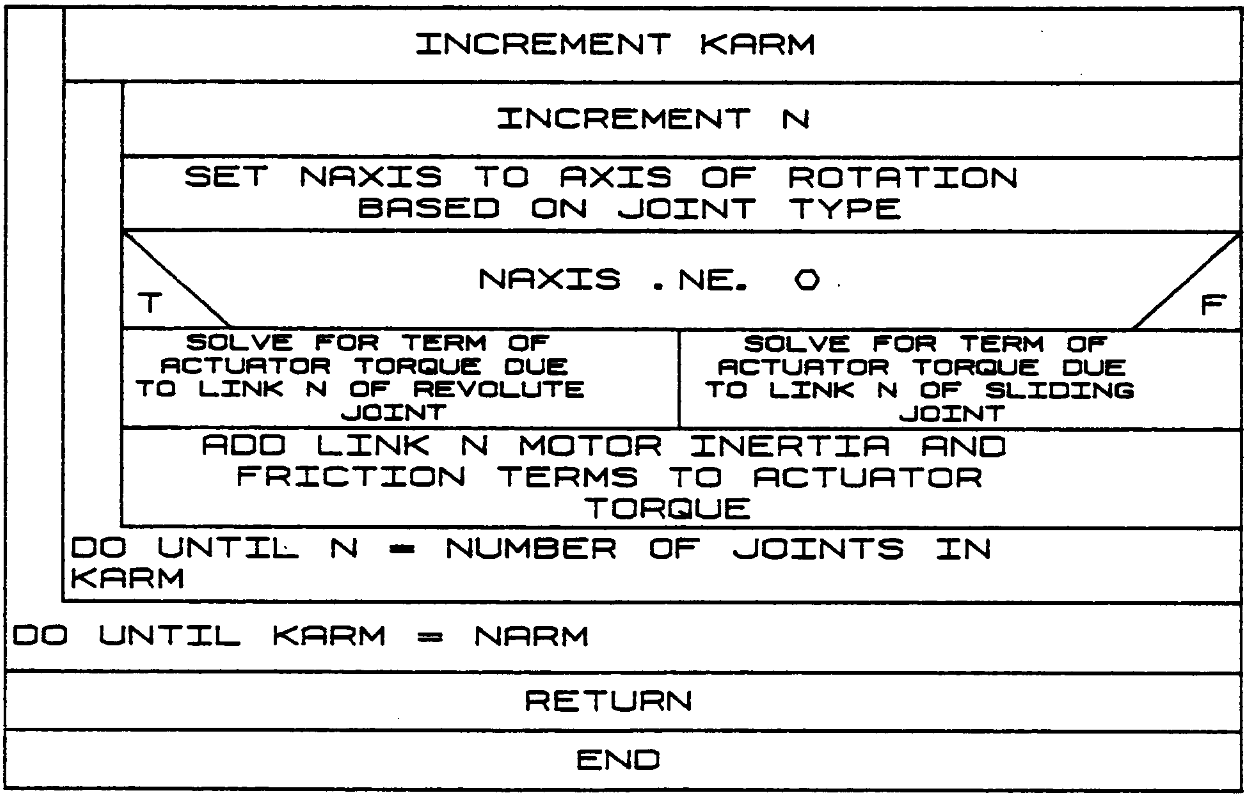
SUBROUTINE TORQUE

```
INITIALIZE T TO TEND
DO UNTIL KARM .EQ. NUMBER OF ARMS
    DO UNTIL N MOVES FROM END BACK TO BASE
        IF N DENOTES END EFFECTOR
            T: DEFINE THE TORQUE TERM FOR THE END EFFECTOR
            F: (NULL)
        CALL MATMPY AND CRPD TO COMPUTE INERTIA TORQUES
        CALL CRPD TO COMPUTE TORQUES DUE TO CENTROID FORCES
IF MOVING BASES INCLUDED IN SYSTEM
    T:
        INITIALIZE BASE TORQUES TO ZERO
        DO UNTIL KBAS .EQ. NUMBER OF BASES
        DO UNTIL KARM .EQ. NUMBER OF ARMS
            IF KBASNUM (KARM) .NE. 0
                T: ADD BASE TORQUE FROM EACH ARM ATTACHED TO SAME BASE
                F: (NULL)
    F: (NULL)
RETURN
END
```

2.3.12 ACTORQ

Subroutine ACTORQ calculates actuator drive torques for each joint. It is called from REQUIR when running requirements analysis and from NLINK when running response simulation. This routine first solves for the free axis of each joint and the component of joint reaction torque about this axis. The torque needed to overcome inertia and viscous and dry friction are added to the joint reaction torques to obtain a total actuator drive torque for each joint.

SUBROUTINE ACTORQ



2.3.13 REQPRT

Subroutine REQPRT is called from OUTREQ to write run data to an output file if this option was requested by the user. Data written to this file includes time, angular position, velocity and acceleration, translational position, velocity and acceleration, and joint force and torque vectors.

```
SUBROUTINE REQPRT
DO FOR EACH ROBOTIC ARM
    WRITE TIME, ARM NUMBER TO PRINT FILE
    CONVERT THETA VALUES TO OUTPUT UNITS
    WRITE ANG. POSITION, VEL., ACC., ACT. TOR. FOR EACH JT. TO FILE
    DO FOR EACH JT. AND END-EFF.
        WRITE TRANS. POS., VEL., ACC. TO FILE
        NOT END-EFF.
        T
            WRITE ABSOLUTE ANG. VEL., ANG. ACC.
            WRITE ROT. MAT. FROM JT. TO INERTIAL, INERTIA MAT. FOR LINK IN WORLD
            WRITE JT. FORCE VECT., FORCE VECT. AT JT./LINK CENTROID
            WRITE JT. TORQUE VECTOR
        F
            (NULL)
RETURN
END
```

2.3.14 REQSOF

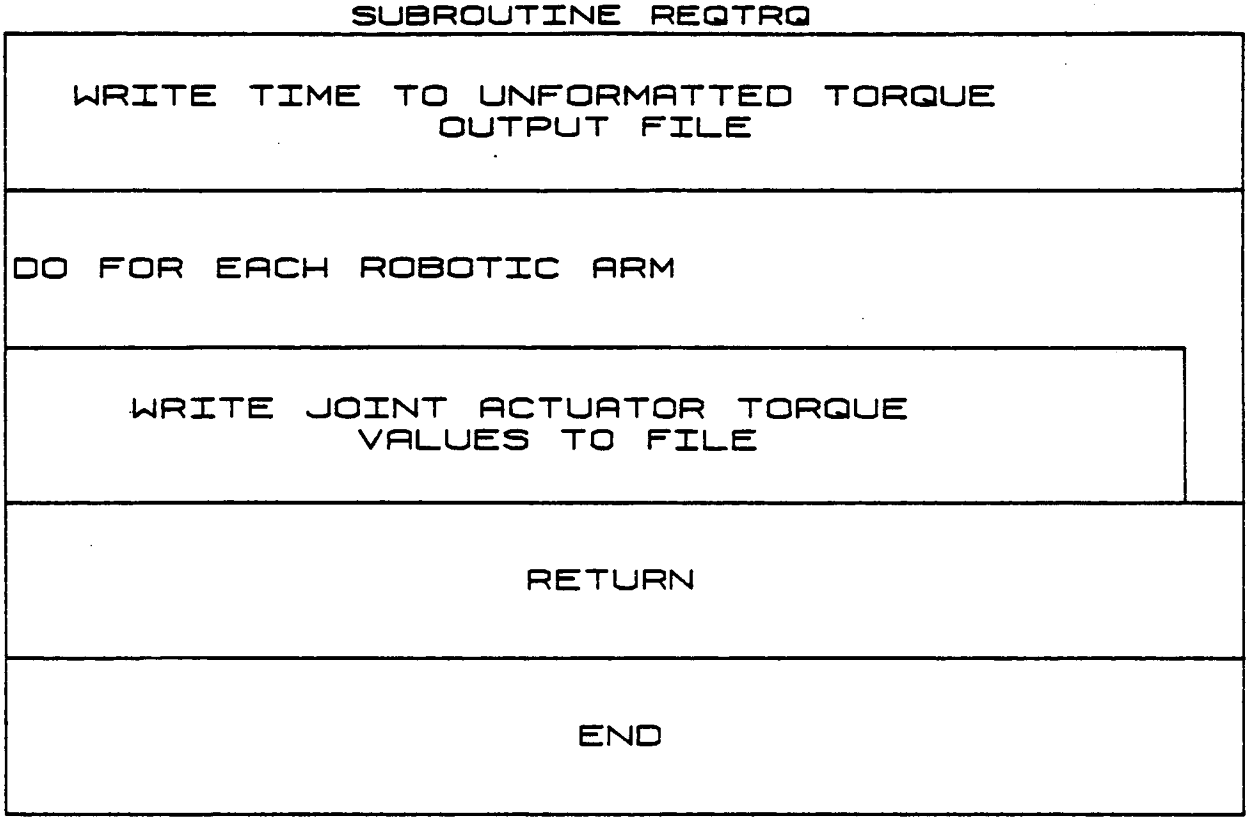
REQSOF is called from OUTREQ to write a simulation playback file if this option was requested by the user. The simulation playback file contains joint angular positions, task commands and load objects flags as a function of time and is used to replay the motion that occurred during a requirements analysis run without doing the calculations normally associated with that run.

SUBROUTINE REQSOF

```
WRITE TIME TO UNFORMATTED SIM.
      OUTPUT FILE
DO FOR EACH ROBOTIC ARM
    WRITE OPERATION TASK TO SOF
    WRITE JOINT THETA VALUES TO SOF
    WRITE FLAG FOR NUMBER OF LOAD
          AT END-EFF. TO SOF
RETURN
END
```

2.3.15 REQTRQ

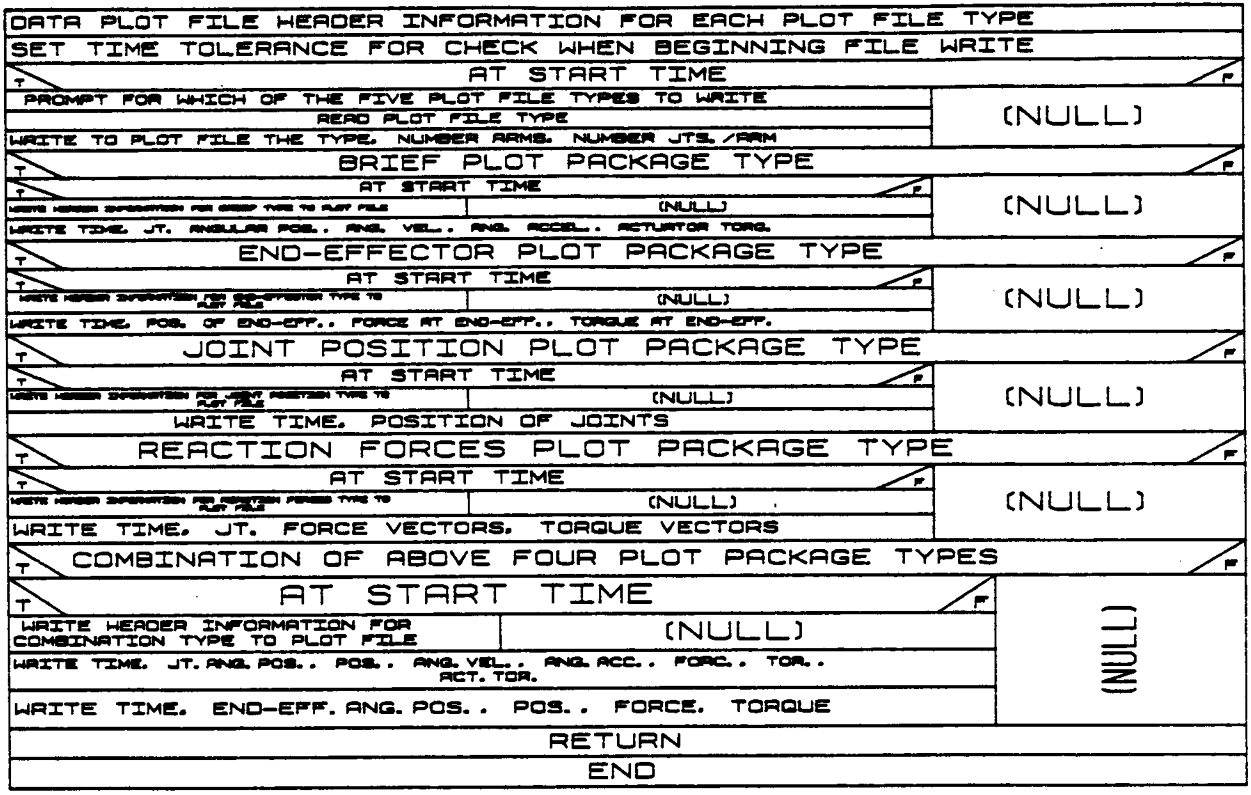
REQTRQ is called from OUTREQ to write a file of actuator torques as a function of time if this option was chosen by the user. These data may then be used to run a response simulation run.



2.3.16 REQPLT

Subroutine REQPLT is called from OUTREQ to write a file of various manipulator parameters as a function of time during a requirements analysis run. This file may then be used to create x-y plots of these parameters as a function of time.

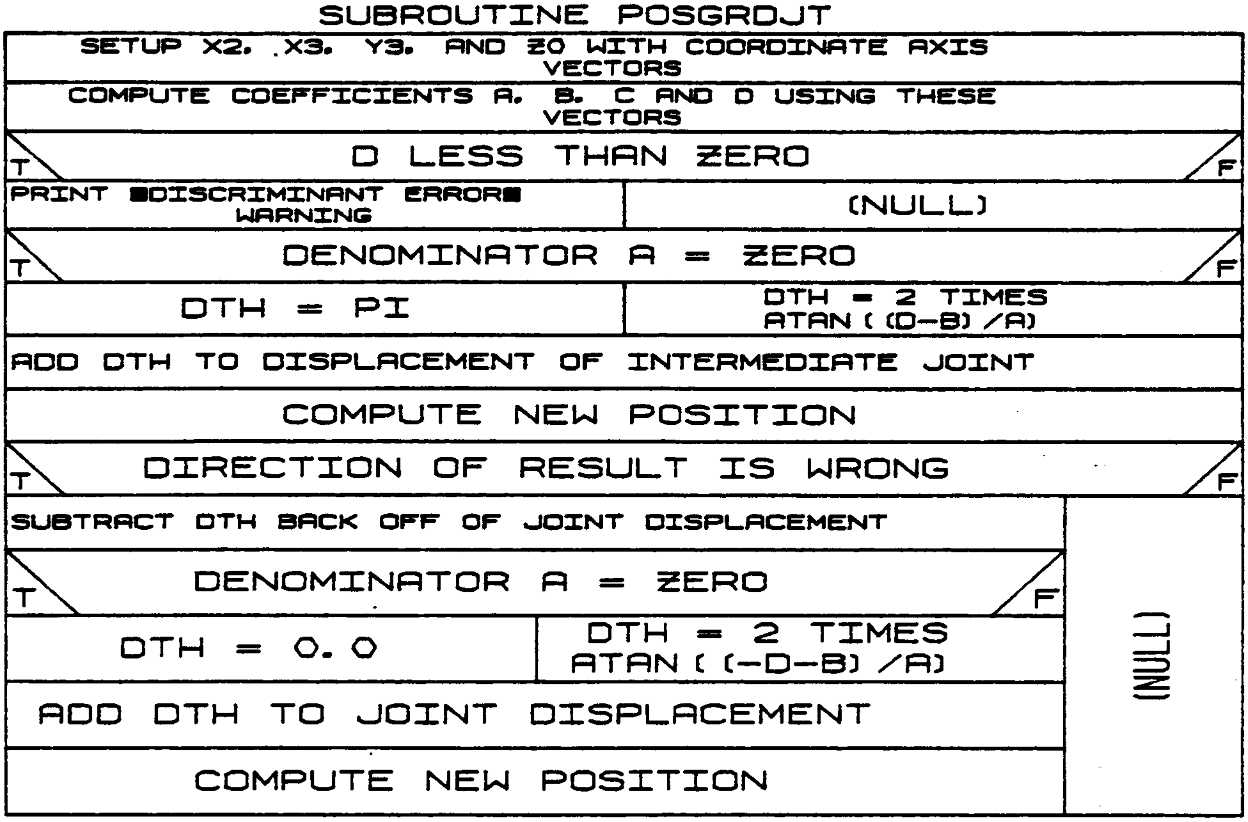
SUBROUTINE REQPLT



```
DATA PLOT FILE HEADER INFORMATION FOR EACH PLOT FILE TYPE
SET TIME TOLERANCE FOR CHECK WHEN BEGINNING FILE WRITE
T  AT START TIME  F
   T:
      PROMPT FOR WHICH OF THE FIVE PLOT FILE TYPES TO WRITE
      READ PLOT FILE TYPE
      WRITE TO PLOT FILE THE TYPE, NUMBER ARMS, NUMBER JTS./ARM
   F:
      (NULL)
T  BRIEF PLOT PACKAGE TYPE  F
   T:
      T  AT START TIME  F
         T: WRITE HEADER INFORMATION FOR BRIEF TYPE TO PLOT FILE
         F: (NULL)
      WRITE TIME, JT. ANGULAR POS., ANG. VEL., ANG. ACCEL., ACTUATOR TORQ.
   F:
      (NULL)
T  END-EFFECTOR PLOT PACKAGE TYPE  F
   T:
      T  AT START TIME  F
         T: WRITE HEADER INFORMATION FOR END-EFFECTOR TYPE TO PLOT FILE
         F: (NULL)
      WRITE TIME, POS. OF END-EFF., FORCE AT END-EFF., TORQUE AT END-EFF.
   F:
      (NULL)
T  JOINT POSITION PLOT PACKAGE TYPE  F
   T:
      T  AT START TIME  F
         T: WRITE HEADER INFORMATION FOR JOINT POSITION TYPE TO PLOT FILE
         F: (NULL)
      WRITE TIME, POSITION OF JOINTS
   F:
      (NULL)
T  REACTION FORCES PLOT PACKAGE TYPE  F
   T:
      T  AT START TIME  F
         T: WRITE HEADER INFORMATION FOR REACTION FORCES TYPE TO PLOT FILE
         F: (NULL)
      WRITE TIME, JT. FORCE VECTORS, TORQUE VECTORS
   F:
      (NULL)
T  COMBINATION OF ABOVE FOUR PLOT PACKAGE TYPES  F
   T:
      T  AT START TIME  F
         T: WRITE HEADER INFORMATION FOR COMBINATION TYPE TO PLOT FILE
         F: (NULL)
      WRITE TIME, JT. ANG. POS., POS., ANG. VEL., ANG. ACC., FORC., TOR., ACT. TOR.
      WRITE TIME, END-EFF. ANG. POS., POS., FORCE, TORQUE
   F:
      (NULL)
RETURN
END
```

2.3.17 POSGRDJT

POSGRDJT computes the position of the intermediate joint in a special joint combination called a "Gordy Joint." This position is selected to satisfy a constraint on the three joints in this combination.

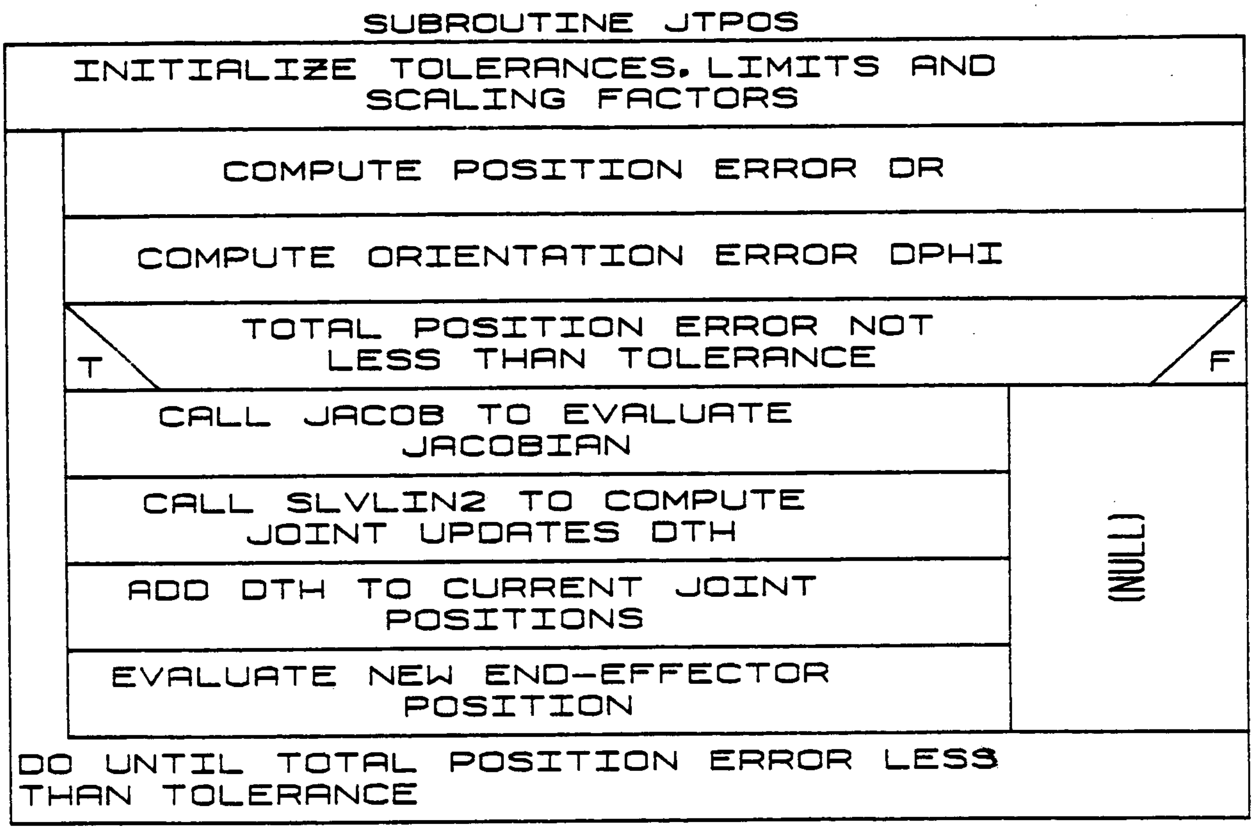


SUBROUTINE POSGRDJT

```
SETUP X2. X3. Y3. AND Z0 WITH COORDINATE AXIS VECTORS
COMPUTE COEFFICIENTS A. B. C AND D USING THESE VECTORS
D LESS THAN ZERO
  T: PRINT "DISCRIMINANT ERROR" WARNING
  F: (NULL)
DENOMINATOR A = ZERO
  T: DTH = PI
  F: DTH = 2 TIMES ATAN ( (D-B) /A)
ADD DTH TO DISPLACEMENT OF INTERMEDIATE JOINT
COMPUTE NEW POSITION
DIRECTION OF RESULT IS WRONG
  T: SUBTRACT DTH BACK OFF OF JOINT DISPLACEMENT
     DENOMINATOR A = ZERO
       T: DTH = 0. 0
       F: DTH = 2 TIMES ATAN ( (-D-B) /A)
     ADD DTH TO JOINT DISPLACEMENT
     COMPUTE NEW POSITION
  F: (NULL)
```

2.3.18 JTPOS

JTPOS is an iterative routine for finding a set of joint angles corresponding to a desired hand position and orientation. The error DPOS in position is calculated and then ORERR is called to find the orientation error and transform it into a rotation vector. This rotation vector is combined with DPOS, giving DP. The Jacobian relating hand motion to joint motion is computed and the set of six linear equations [J](DTG) - (DP) is solved for the joint updates DTH. This procedure is repeated until the desired position is obtained.



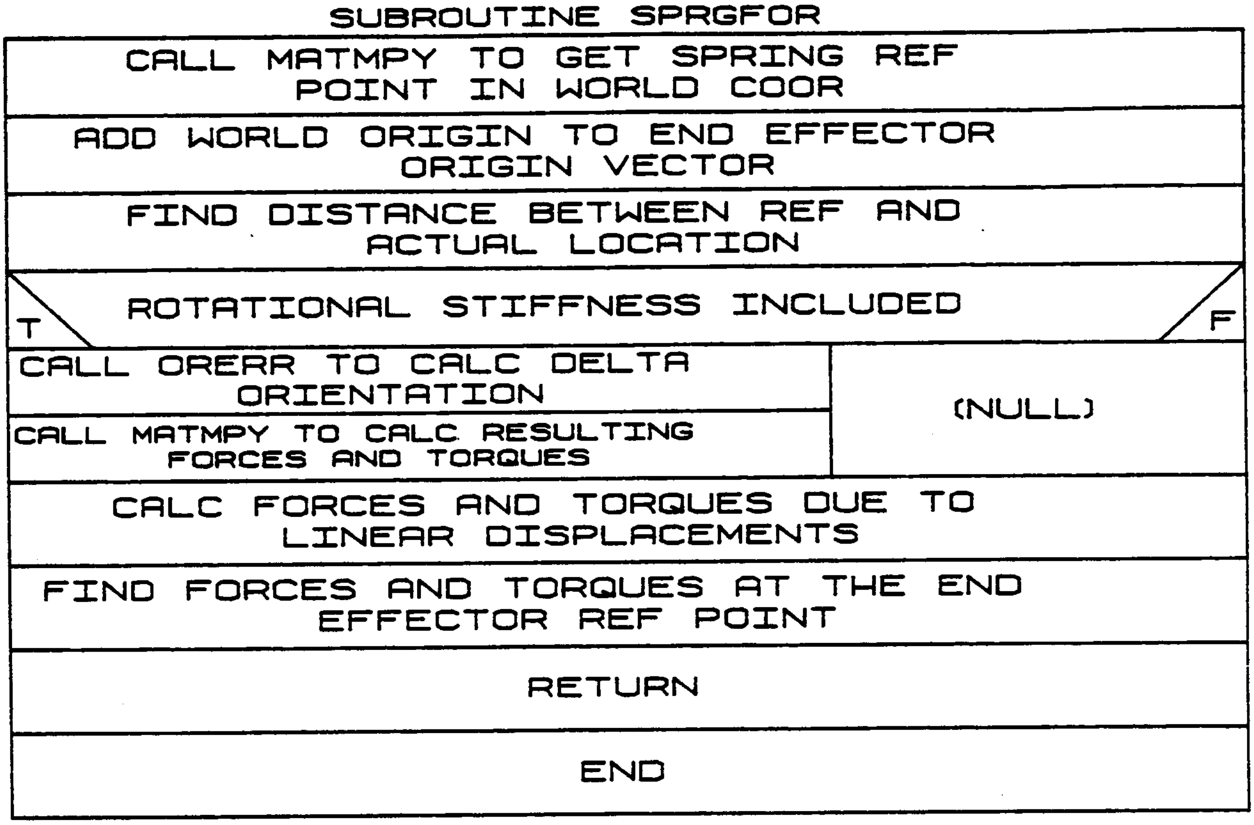
2.3.19 CVTIN

CVTIN transforms link inertia matrices from local coordinates into their equivalent representation in world coordinates for use in dynamic analysis.

```
SUBROUTINE CVTIN
DO FOR EACH ARM
    DO FOR EACH JOINT
        PT = TRANSPOSE OF ROTATION
             MATRIX (ROT) FOR JOINT
        AINW = ROT TIMES AINMAT TIMES PT
```

2.3.20 SPRGFOR

Subroutine SPRGFOR is called from FORCE when the manipulator end-effector is modeled as a compliant entity. This routine calculates the forces and torques at the end-effector reference point caused by its having compliance.



2.3.21 CNSTFOR

CNSTFOR is called from subroutine FORCE to compute the force on the end-effector and the torque about the end-effector reference point attributable to external constraints. These values are then added to the variables FEND and TEND.

```
SUBROUTINE CNSTFOR
    COMPUTE F. FORCE ON END EFFECTOR DUE TO CONSTRAINT
    COMPUTE T. TORQUE ABOUT END EFFECTOR REF POINT DUE TO CONSTRAINT
    ADD F AND T TO FEND AND TEND
    RETURN
    END
```

2.3.22 PTACC

PTACC computes the acceleration of any point in any link of either arm. It uses the angular velocity and acceleration of the link to find the acceleration of the point relative to the acceleration of the link's origin and adds this to the acceleration of this link origin.

```
SUBROUTINE PTACC
OMEGA = LINK ANGULAR VELOCITY
VEC = VECTOR FROM LINK ORIGIN TO POINT
ALPHA = LINK ANGULAR ACCELERATION
WCV = OMEGA CROSS VEC
WCWCV = OMEGA CROSS WCV
ALCV = ALPHA CROSS VEC
RESULT = ALCV + WCWCV + ACCELERATION OF LINK ORIGIN
```

2.3.23 POSSENS

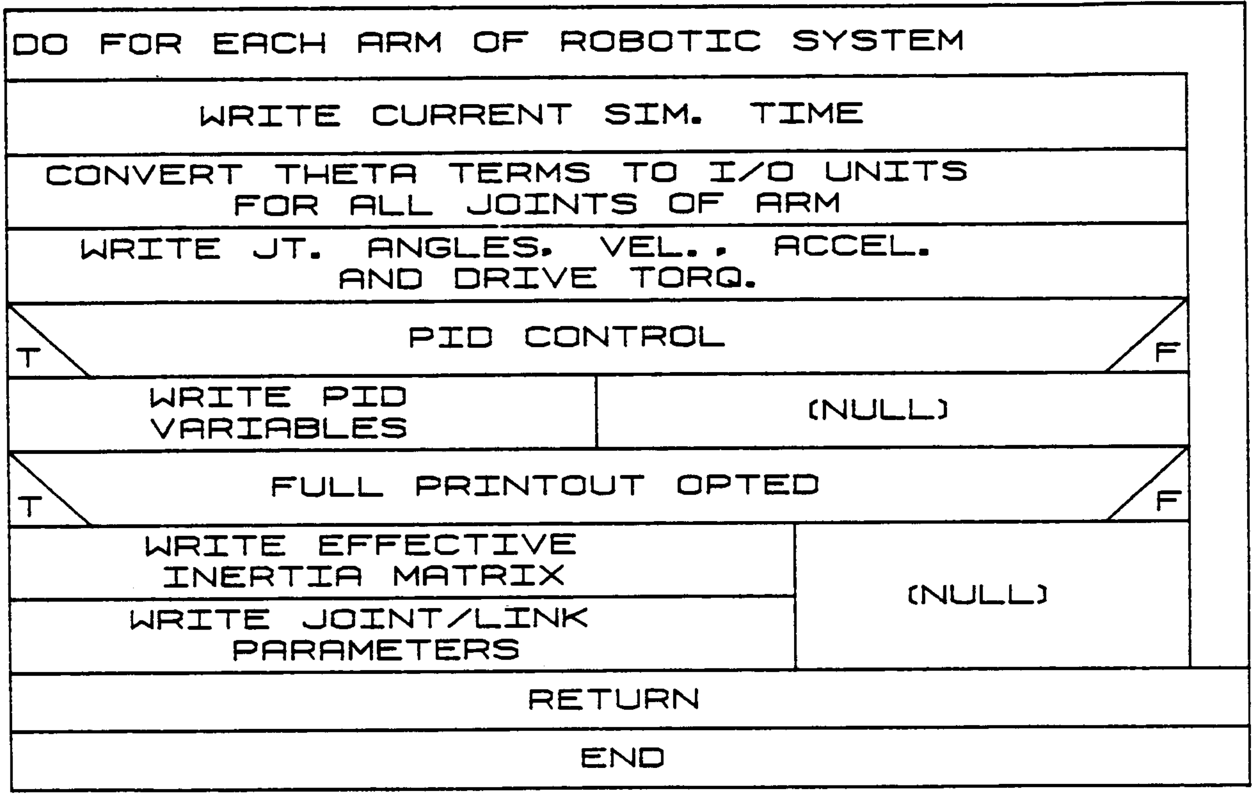
POSSENS is called from subroutine CONTROL when one of the feedback control laws is being used to drive a response simulation run. This routine obtains the discrete representation of the actual joint positions and also determines the actual joint velocities and accelerations.

```
SUBROUTINE POSSENS
    DISCRETIZE JOINT POSITION DATA.
    STH
    JOINT VELOCITIES. STHD =
    (STH-OLDSTH1) / (TIME-SIGLAST)
    JOINT ACCEL.. STHDD =
    (STH-2.0*OLDSTH1+OLDSTH2) /
    (TIME-SIGLAST)**2
    OLDSTH2 = OLDSTH1
    OLDSTH1 = STH
DO UNTIL NJ .EQ. NUMBER OF JOINTS
IN CURRENT ARM
RETURN
END
```

2.3.24 SIMPRT

SIMPRT outputs the condensed or full data printout to file. It prints the position, velocity, and acceleration data for the arm at the time when called. If input flag IPRINT equals 2, a limited amount of information is printed (only TH, THD, THDD, and TDR).

SUBROUTINE SIMPRT



2.3.25 SIMPLT

SIMPLT allows the user to write a plot file for output. The user is asked to choose from among several different plot package options. The chosen package determines which response simulation parameters are written to the plot file.

Option 1, the BRIEF PLOT PACKAGE, writes joint angular displacements, joint angular velocities, joint angular accelerations and drive torques.

Option 2, the END-EFFECTOR PLOT PACKAGE, writes end-effector translational position, force vector at the end-effector and torque vector at the end-effector.

Option 3, the JOINT POSITIONS PLOT PACKAGE, writes translational joint positions.

Option 4, the REACTION FORCES PLOT PACKAGE, writes force joint vectors and torque joint vectors.

Option 5, the COMBINATION PLOT PACKAGE, writes all of the above--joint angular displacements, translational joint positions, joint angular velocities, joint angular accelerations, force joint vectors, torque joint vectors, drive torques, end-effector translational position, force vector at the end-effector and torque vector at the end-effector.

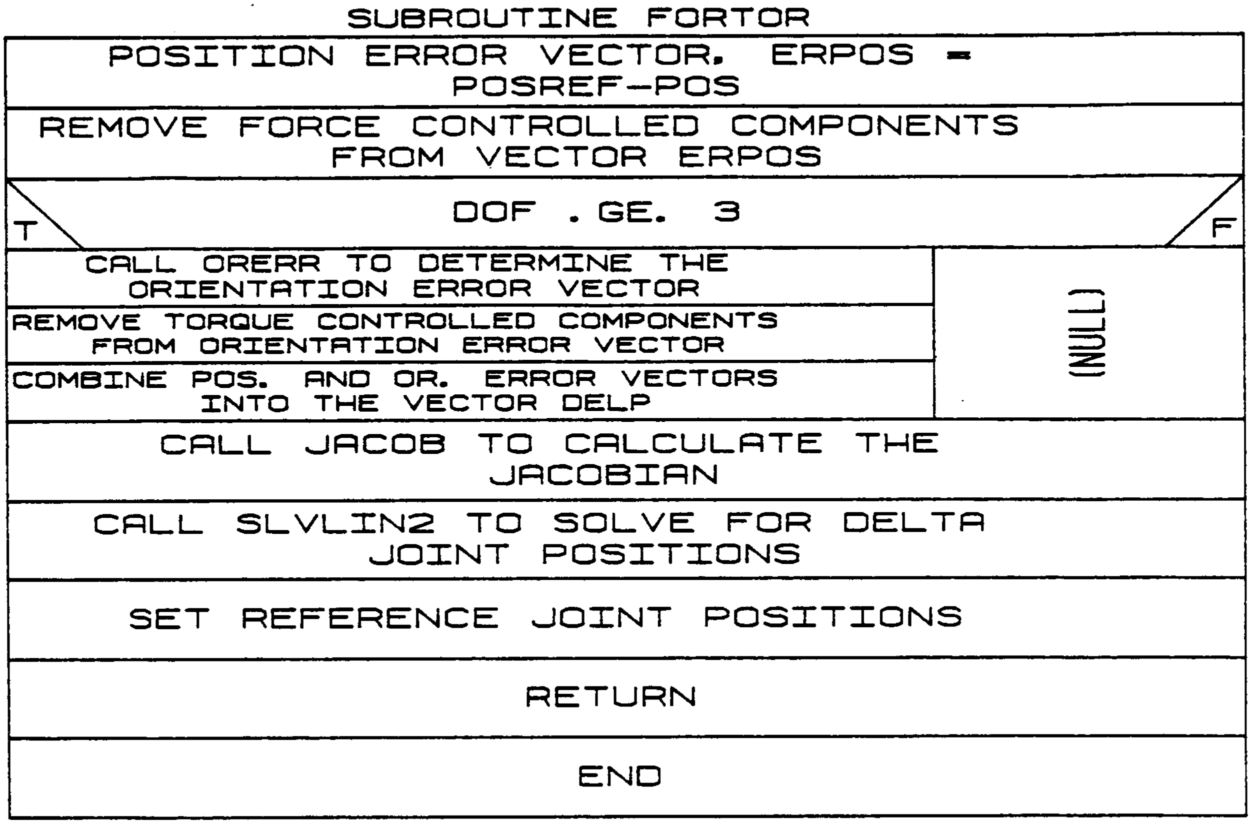
Option 6, the PID CONTROL PLOT PACKAGE, writes amplifier voltages, joint reference positions, joint position errors, end-effector reference position and end-effector position error.

Option 7, the FORCE/TORQUE PLOT PACKAGE, writes amplifier voltages, reference position, reference force, end-effector translational position, force vector at the end-effector, torque vector at the end-effector, error in position and error in force/torque.

```
SUBROUTINE SIMPLT
SET PLOT HEADER DATA RECORDS FOR EACH PLOT TYPE
SIM. AT START TIME
  T: WRITE PLOT FILE TYPE DESCRIPTIONS TO TERMINAL
     PROMPT FOR PLOT FILE TYPE TO WRITE
  F: (NULL)
BRIEF PACKAGE CHOSEN
  T: WRITE HEADER RECORD IF START TIME
     WRITE TIME, ANGLE, VEL., ACC., AND DRIVE TORQ.
  F: (NULL)
END-EFFECTOR PACKAGE CHOSEN
  T: WRITE HEADER RECORD IF START TIME
     WRITE TIME, POS., FORC., AND TORQ. AT END-EFFECTOR
  F: (NULL)
JOINT POSITION PACKAGE CHOSEN
  T: WRITE HEADER RECORD IF START TIME
     WRITE TIME, AND JOINT POS. VECTORS
  F: (NULL)
REACTION FORCES PACKAGE CHOSEN
  T: WRITE HEADER RECORD IF START TIME
     WRITE TIME, FORC. AND TORQUES AT JOINTS
  F: (NULL)
COMBINATION PACKAGE CHOSEN
  T: WRITE HEADER RECORD IF START TIME
     WRITE TIME, AND ALL OF THE ABOVE PARAMETERS
  F: (NULL)
PID CONTROL PACKAGE CHOSEN
  T: WRITE HEADER RECORD IF START TIME
     WRITE TIME, JOINT VOLTS., REF. ANGLE AND JT. POS. ERRORS
     WRITE TIME, END-EFFECTOR REF. POS., POS. AND ROT. ERR.
  F: (NULL)
FORCE/TORQUE CONTROL PACKAGE CHOSEN
  T: WRITE HEADER RECORD IF START TIME
     WRITE TIME, AND JOINT VOLTS.
     WRITE TIME, REF.POS., REF.FOR./ROT.VECT., END-EFF. POS./FOR., AND ERRS.
  F: (NULL)
RETURN
END
```

2.3.26 FORTOR

FORTOR is called from subroutine CNTRSIG if manual force/torque control is used to drive a response simulation. This routine calculates the joint position error vectors caused by the error in the position-controlled components of end-effector motion.



2.3.27 FORREF

FORREF is called from subroutine CNTRSIG when manual force/torque control is used to drive a response simulation. Individual joint torque error vectors are calculated from the end-effector force error and torque error vectors.

```
SUBROUTINE FORREF
CALCULATE END EFFECTOR FORCE ERROR COMPONENTS
CALCULATE END EFFECTOR TORQUE ERROR COMPONENTS
STORE ERROR COMPONENTS IN VECTOR DELFT
CALCULATE REFERENCE FORCE/TORQUE VECTOR
CALL JACOB TO DETERMINE THE JACOBIAN. RJACOB
CALCULATE JOINT TORQUES. TORJNT = TORJNT-DELFT*RJACOB
RETURN
END
```

2.3.28 CMPCTRL

CMPCTRL is called from CNTRSIG when active compliance control is used in a response simulation run. This subroutine first calculates end position deltas (ref-actual), joint control torques, and joint torque deltas (control-sensed). The thetas are put through a derivative control block to get joint torques. The joint torque deltas are put through a lead-lag filter in parallel with an integrating control block. The joint control torques are summed with the other processed signals to get a total joint torque. This is then converted to motor amplifier input voltages.

```
SUBROUTINE CMPCTRL
SET TVCVT. JOINT TORQUE TO VOLTS CONVERSION FACTOR
CALL JACOB TO CALCULATE THE JACOBIAN. RJACOB
DETERMINE RJTRANS. THE TRANSPOSE OF THE JACOBIAN
CALL MATMPY TO FIND TOR. THE INPUT TORQUES
CALL MATMPY TO FIND TBIAS. THE BIAS TORQUES
JOINT CONTROL TORQUES. TCTRL = TOR + TBIAS
DETERMINE TSENS. SENSED FORCES AND TORQUES
TORQUE DELTAS. DELTOR = TCTRL + TSENS
CALCULATE RJTORQ. JOINT ACTUATOR DRIVE TORQUES
CONVERT JOINT TORQUES TO INPUT VOLTAGES
RETURN
END
```

2.3.29 PIDCON

Subroutine PIDCON is called from CONTROL when a control law is used to drive a response simulation run. The routine takes the vector of joint position errors and, simulating a PID control loop, calculates joint actuator voltages.

```
SUBROUTINE PIDCON
SET JOINT ACTUATOR TORQUE TO VOLTS CONVERSION FACTOR
CALCULATE JOINT POSITION ERROR. DELTH = THREF - STH
CALCULATE ERRINT. THE ERROR INTEGRAL
CALCULATE RJTORQ. JOINT ACTUATOR TORQUES
CONVERT ACTUATOR TORQUES TO VOLTAGES
RETURN
END
```

2.3.30 PIDFOR

Subroutine PIDFOR is called from CONTROL when force/torque control is being used to drive a response simulation run. This routine calculates the joint actuator voltages caused by the force-controlled components of manipulator motion.

```
SUBROUTINE PIDFOR
COMPUTE TVCVT. JOINT ACTUATOR TORQUE TO VOLTS CONVERSION FACTOR
COMPUTE FERRINT. FORCE ERROR INTEGRAL
CALCULATE RJTORQ. JOINT ACTUATOR TORQUES
CONVERT JOINT ACTUATOR TORQUES TO VOLTAGES
RETURN
END
```

2.3.31 EFINRT2

EFINRT2 computes the effective inertia matrix (in joint coordinates) for a manipulator. The effective inertia matrix is an NxN matrix that gives the joint torques attributable to joint accelerations. The (m,n) term corresponds to joints m and n and depends on the mass of the arm from link n to the end-effector so the program evaluates composite masses, centroids and inertia distributions for these "composite masses." Each term of the effective inertia matrix is then evaluated as a combination of dot products and cross-products among the joint axis directions and locations and the mass parameters of the composite links (see Study Results volume).

SUBROUTINE EFINRT2

```
INITIALIZE TOTM. TOTIN AND TMCG (TOTAL MASS. INERTIA AND MASS TIMES CG L
DO FOR N = LAST LINK TO FIRST
    TOTM = TOTM + MASS OF LINK N
    FIND NEW COMPOSITE CENTROID BY ADDING PROPERTIES OF LINK N
    FIND NEW COMPOSITE INERTIA MATRIX
    N NOT EQUAL BASE
    T:
        N IS A REVOLUTE JOINT
        T:
            DO FOR ALL JOINTS M FROM N TO BASE
                M IS A REVOLUTE JOINT
                T:
                    FIND ROTATIONAL TERM OF EFFECTIVE INERTIA COMPONENT (M. N)
                F:
                    EFFECTIVE INERTIA COMPONENT (M. N) = ZERO
        F:
            DO FOR ALL JOINTS M FROM N TO BASE
                EFFECTIVE INERTIA COMPONENT (M. N) = ZERO
        DO FOR ALL JOINTS M FROM N TO BASE
            FIND TRANSLATIONAL CONTRIBUTION TO EFFECTIVE INERTIA COMPONENT (M. N) AND
            EFFECTIVE INERTIA TERM (N. M) = TERM (M. N)
    F:
        (NULL)
```

2.3.32 NLINK

Subroutine NLINK is called from DERIV during response simulation to compute the base accelerations BASACC, BASOMD and joint accelerations THDD. It sets the joint accelerations to zero, the base accelerations to zero if moving base is simulated. The requirement analysis is used to compute effective joint torques. If moving base is simulated, BDRTORQ is called to input base driving torques and the base acceleration torques are calculated and DRTORQ is called to find the joint driving torques. EFINRT is called to compute the effective inertias. If moving base is simulated, SLVMBAS is called to solve for base and joint accelerations. If dual arm control, SLV2ARM is called to compute joint accelerations. Otherwise SLVTHDD is called to solve for joint accelerations.

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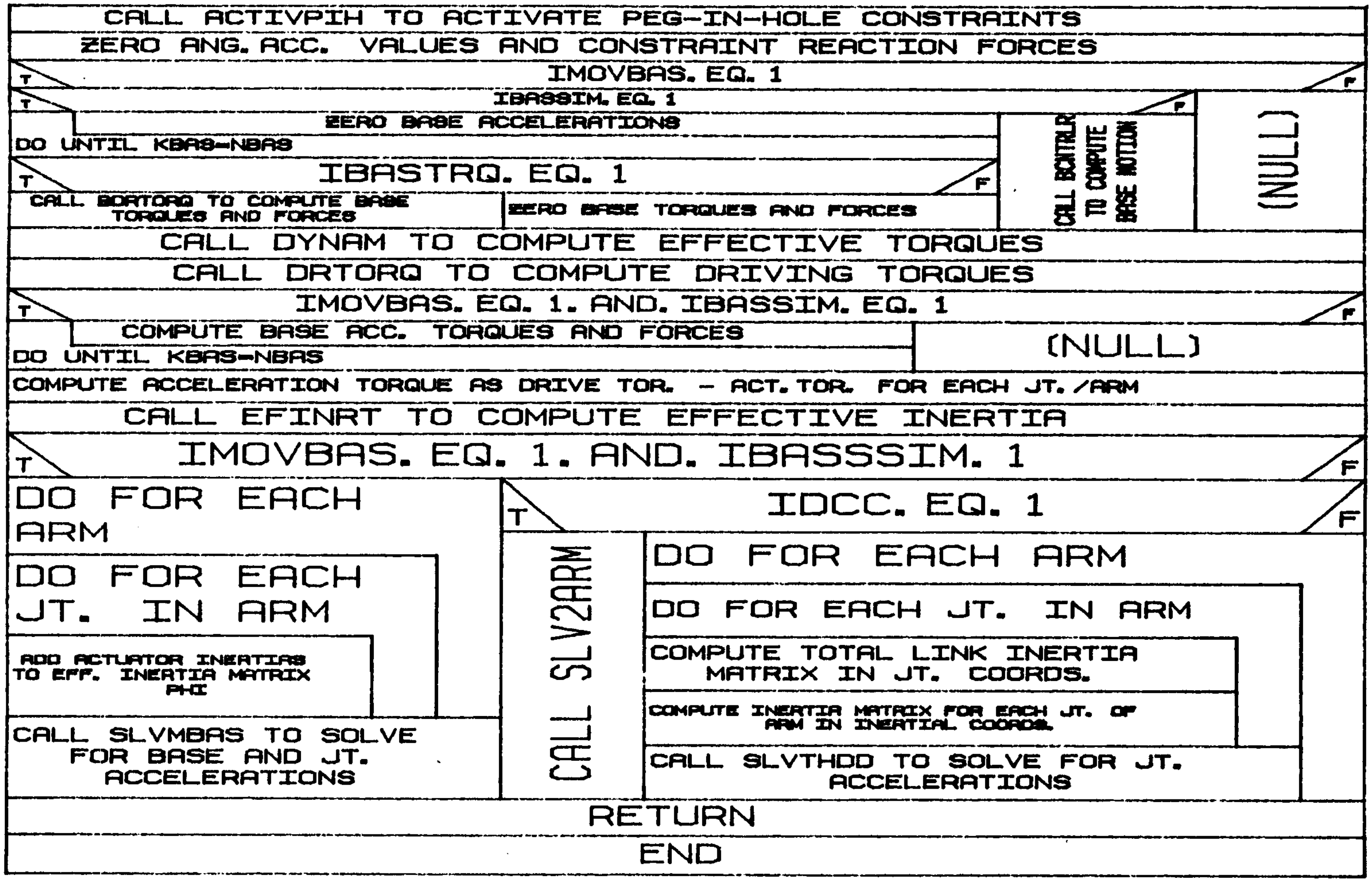
SUBROUTINE NLINK



```
CALL ACTIVPIH TO ACTIVATE PEG-IN-HOLE CONSTRAINTS
ZERO ANG. ACC. VALUES AND CONSTRAINT REACTION FORCES
IMOVBAS. EQ. 1
  T:
    IBASSIM. EQ. 1
      T:
        DO UNTIL KBAS-NBAS
          ZERO BASE ACCELERATIONS
        IBASTRQ. EQ. 1
          T:
            CALL BORTORQ TO COMPUTE BASE TORQUES AND FORCES
          F:
            ZERO BASE TORQUES AND FORCES
      F:
        CALL BCNTRLR TO COMPUTE BASE MOTION
  F:
    (NULL)
CALL DYNAM TO COMPUTE EFFECTIVE TORQUES
CALL DRTORQ TO COMPUTE DRIVING TORQUES
IMOVBAS. EQ. 1. AND. IBASSIM. EQ. 1
  T:
    DO UNTIL KBAS-NBAS
      COMPUTE BASE ACC. TORQUES AND FORCES
  F:
    (NULL)
COMPUTE ACCELERATION TORQUE AS DRIVE TOR. - ACT. TOR. FOR EACH JT. /ARM
CALL EFINRT TO COMPUTE EFFECTIVE INERTIA
IMOVBAS. EQ. 1. AND. IBASSSIM. 1
  T:
    DO FOR EACH ARM
      DO FOR EACH JT. IN ARM
        ADD ACTUATOR INERTIAS TO EFF. INERTIA MATRIX PHI
    CALL SLVMBAS TO SOLVE FOR BASE AND JT. ACCELERATIONS
  F:
    IDCC. EQ. 1
      T:
        CALL SLV2ARM
      F:
        DO FOR EACH ARM
          DO FOR EACH JT. IN ARM
            COMPUTE TOTAL LINK INERTIA MATRIX IN JT. COORDS.
            COMPUTE INERTIA MATRIX FOR EACH JT. OF ARM IN INERTIAL COORDS.
          CALL SLVTHDD TO SOLVE FOR JT. ACCELERATIONS
RETURN
END
```

2.3.33 SIMLMT

SIMLMT is called by DERIV and first checks the joint displacements against their limits. If any limits are exceeded, the joint position is set to that limit and the joint rate and acceleration are limited to zero. Similarly, the rate limits are checked and if any are exceeded, the corresponding rate is set to that limit and the acceleration is bounded by zero. IMOD is set if any positions or rates are modified.

SUBROUTINE SIMLMT

```
IMOD = 0
DO FOR EACH ARM
    DO FOR EACH JOINT N
        T \ JOINT DISPLACEMENT EXCEEDS UPPER BOUND / F
            SET DISPLACEMENT TO UPPER BOUND                                  (NULL)
            LIMIT VELOCITY AND ACCELERATION TO LESS THAN OR EQUAL TO ZERO
            IMOD = 1
        T \ JOINT DISPLACEMENT EXCEEDS LOWER BOUND / F
            SET DISPLACEMENT TO LOWER BOUND                                  (NULL)
            LIMIT VELOCITY AND ACCELERATION TO GREATER THAN OR EQUAL TO ZERO
            IMOD = 1
        T \ JOINT RATE EXCEEDS UPPER BOUND / F
            SET RATE TO UPPER BOUND                                          (NULL)
            LIMIT ACCELERATION TO LESS THAN OR EQUAL TO ZERO
            IMOD = 1
        T \ JOINT RATE EXCEEDS LOWER BOUND / F
            SET RATE TO LOWER BOUND                                          (NULL)
            LIMIT ACCELERATION TO GREATER THAN OR EQUAL TO ZERO
            IMOD = 1
```

2.3.34 STOPFR

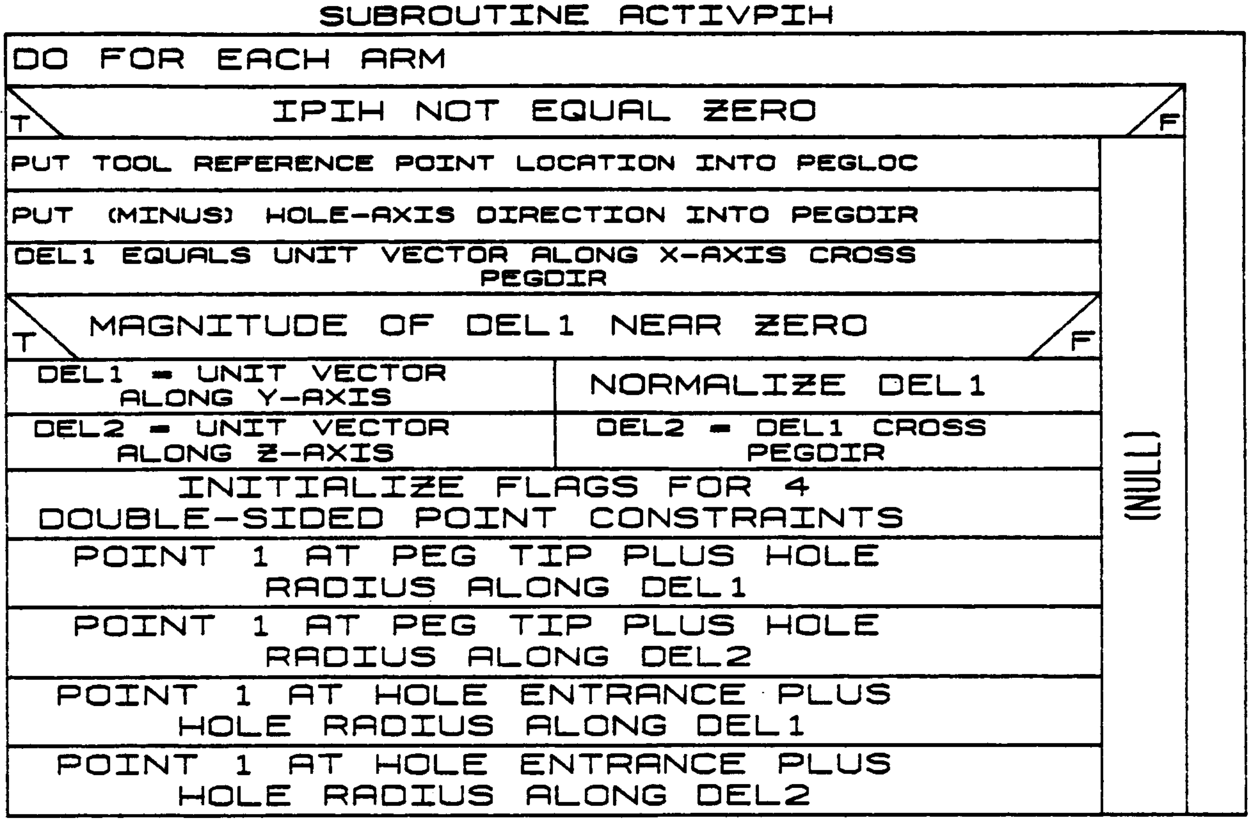
Subroutine STOPFR is called from INTGRT to simulate static friction in the joints during a response simulation run. If the joint velocity at the previous time step is not equal to zero and the sign is the opposite of the sign of the current time step, the current velocity and position delta are set to zero. If moving base is simulated, assume no friction at the base joints.

SUBROUTINE STOPFR

```
IMOVBAS. EQ. 1. AND. IBASSIM. EQ. 1
    T: INDEX=12*NBAS
    F: INDEX=0
DO UNTIL KARM . EQ. NUMBER OF ARMS
    DO UNTIL N . EQ. NUMBER OF JOINTS
        OLD JOINT VELOCITY . NE. ZERO
            T: DETERMINE SIGN OF OLD JOINT VELOCITY, SO
               DETERMINE SIGN OF CURRENT JOINT VELOCITY, SC
            F: (NULL)
        SO . NE. SC
            T: SET CURRENT VELOCITY TO ZERO
               SET POSITION DELTA TO ZERO
            F: (NULL)
RETURN
END
```

2.3.35 ACTIVPIH

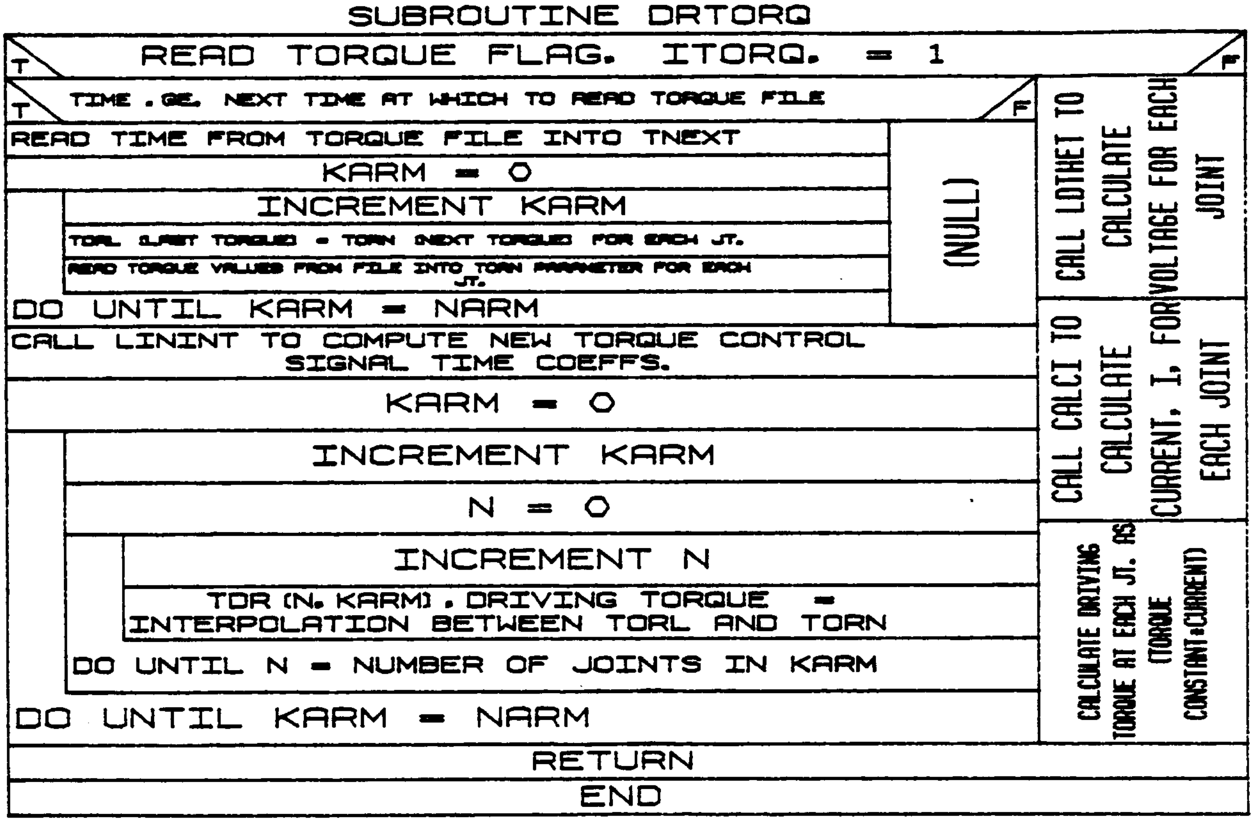
ACTIVPIH sets up the flags and variables activating a peg-in-hole constraint if such a constraint is included. It sets up four point constraints--two each (in orthogonal directions) at the top of the hole and at the tip of the peg.



```
SUBROUTINE ACTIVPIH
DO FOR EACH ARM
    IPIH NOT EQUAL ZERO
    T:
        PUT TOOL REFERENCE POINT LOCATION INTO PEGLOC
        PUT (MINUS) HOLE-AXIS DIRECTION INTO PEGDIR
        DEL1 EQUALS UNIT VECTOR ALONG X-AXIS CROSS PEGDIR
        MAGNITUDE OF DEL1 NEAR ZERO
        T:
            DEL1 = UNIT VECTOR ALONG Y-AXIS
            DEL2 = UNIT VECTOR ALONG Z-AXIS
        F:
            NORMALIZE DEL1
            DEL2 = DEL1 CROSS PEGDIR
        INITIALIZE FLAGS FOR 4 DOUBLE-SIDED POINT CONSTRAINTS
        POINT 1 AT PEG TIP PLUS HOLE RADIUS ALONG DEL1
        POINT 1 AT PEG TIP PLUS HOLE RADIUS ALONG DEL2
        POINT 1 AT HOLE ENTRANCE PLUS HOLE RADIUS ALONG DEL1
        POINT 1 AT HOLE ENTRANCE PLUS HOLE RADIUS ALONG DEL2
    F:
        (NULL)
```

2.3.36 DRTORQ

The DRTORQ routine calculates the torque output from each joint motor by using a control algorithm strategy or reading them from a file. The calculations are based on the torque constant for each joint and the armature current.



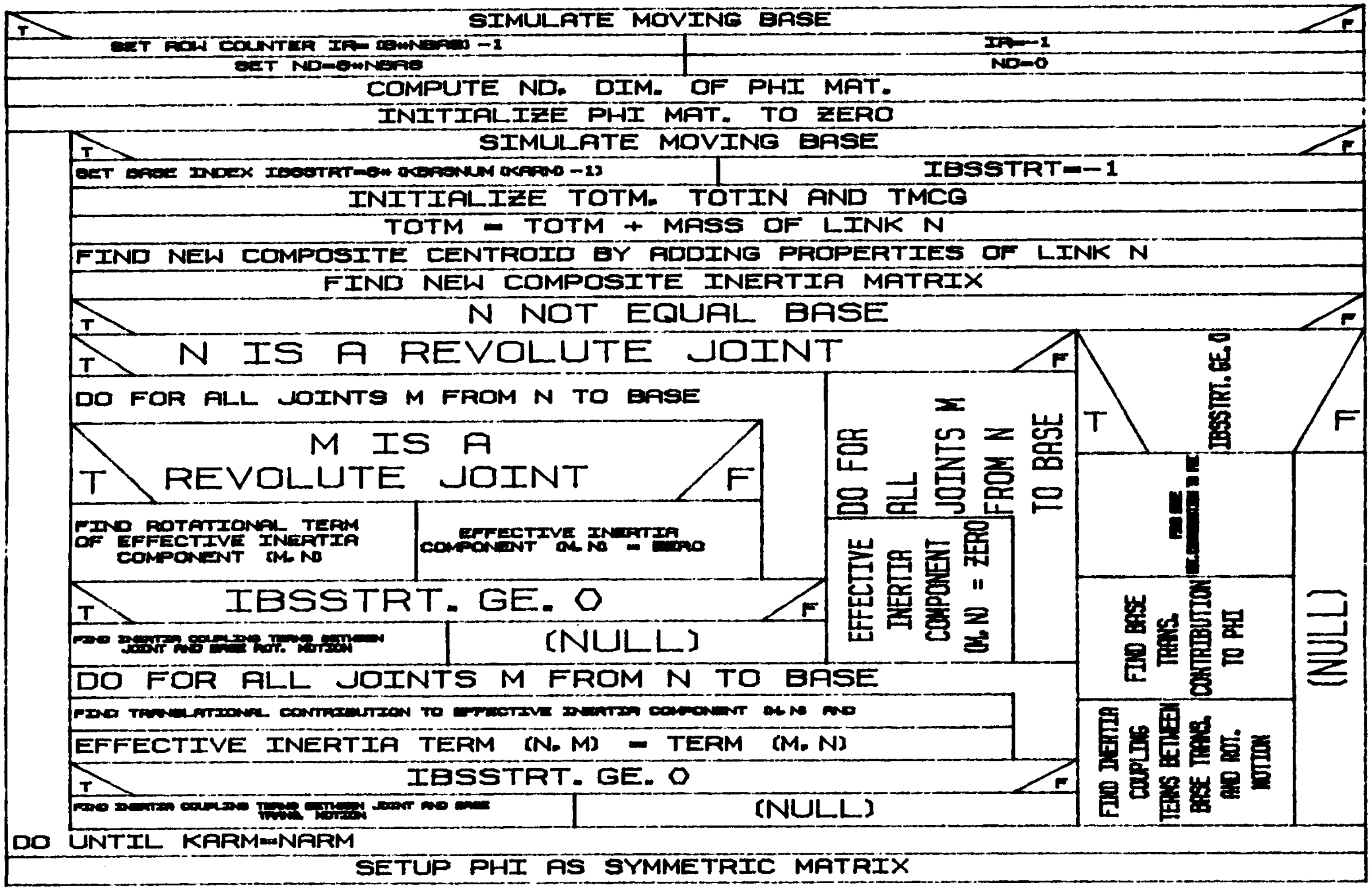
```
SUBROUTINE DRTORQ
IF READ TORQUE FLAG. ITORQ. = 1
T:
    IF TIME .GE. NEXT TIME AT WHICH TO READ TORQUE FILE
    T:
        READ TIME FROM TORQUE FILE INTO TNEXT
        KARM = 0
        DO
            INCREMENT KARM
            TORL (LAST TORQUE) = TORN (NEXT TORQUE) FOR EACH JT.
            READ TORQUE VALUES FROM FILE INTO TORN PARAMETER FOR EACH JT.
        DO UNTIL KARM = NARM
    F:
        (NULL)
    CALL LININT TO COMPUTE NEW TORQUE CONTROL SIGNAL TIME COEFFS.
    KARM = 0
    DO
        INCREMENT KARM
        N = 0
        DO
            INCREMENT N
            TOR (N. KARM) . DRIVING TORQUE = INTERPOLATION BETWEEN TORL AND TORN
        DO UNTIL N = NUMBER OF JOINTS IN KARM
    DO UNTIL KARM = NARM
F:
    CALL LDTHET TO CALCULATE VOLTAGE FOR EACH JOINT
    CALL CALCI TO CALCULATE CURRENT, I, FOR EACH JOINT
    CALCULATE DRIVING TORQUE AT EACH JT. AS (TORQUE CONSTANT*CURRENT)
RETURN
END
```

2.3.37 EFINRT

EFINRT computes the effective inertia matrix for a system containing one or more arms on fixed or moving bases. The effective inertia matrix PHI gives the base torques, forces and joint torques attributable to base and joints accelerations. The dimension of PHI is (ND, ND)

where $ND = (6 * NBAS) + \sum_{I=1}^{NARM} NJ(I)$

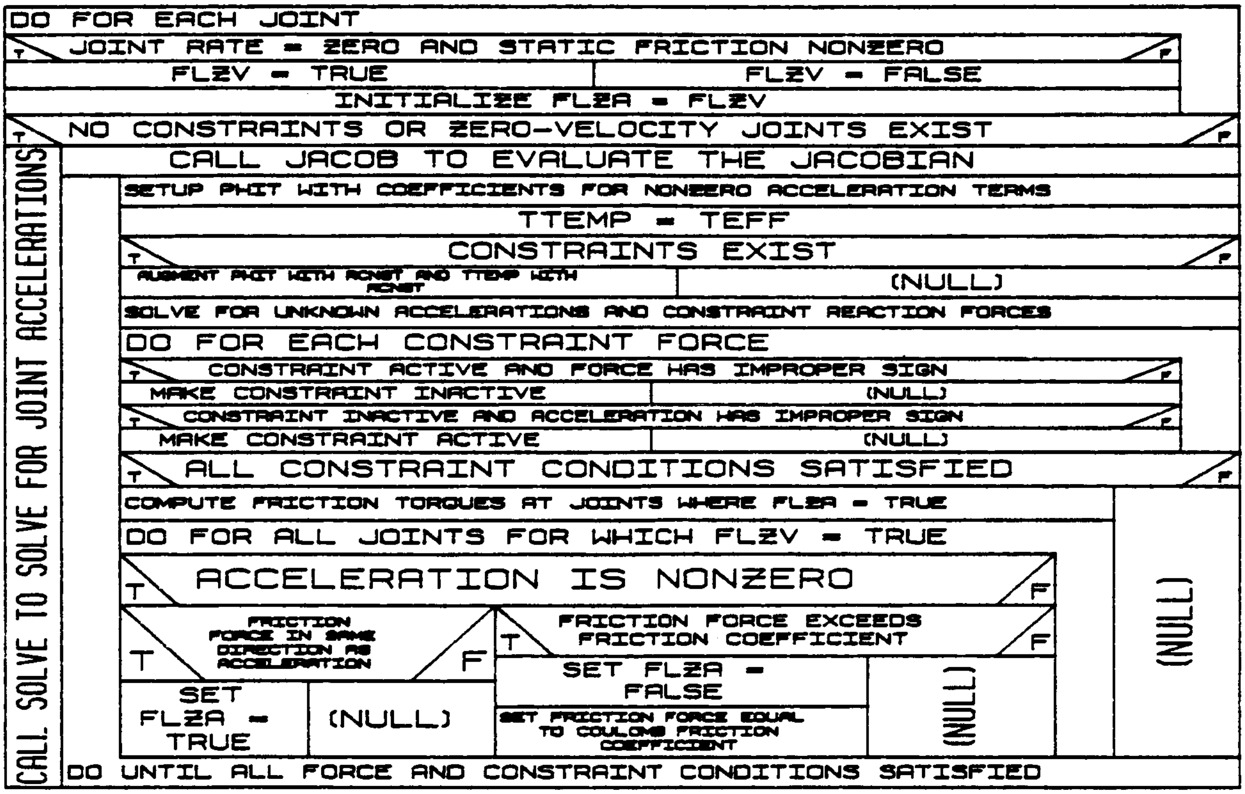
SUBROUTINE EFINRT



2.3.38 SLVTHDD

SLVTHDD solves for unknown joint accelerations and constraint reaction forces for a given arm state and joint driving forces. All zero-velocity joints are assumed to have zero acceleration. If the friction forces needed to produce zero acceleration are greater than the static friction force, the acceleration is assumed finite and the equations are re-solved. Similarly, the constraints are assumed active and if the resulting constraint force is in the wrong direction the constraint becomes inactive and the equations are re-solved. This process is repeated until all conditions on the friction forces and constraints are satisfied.

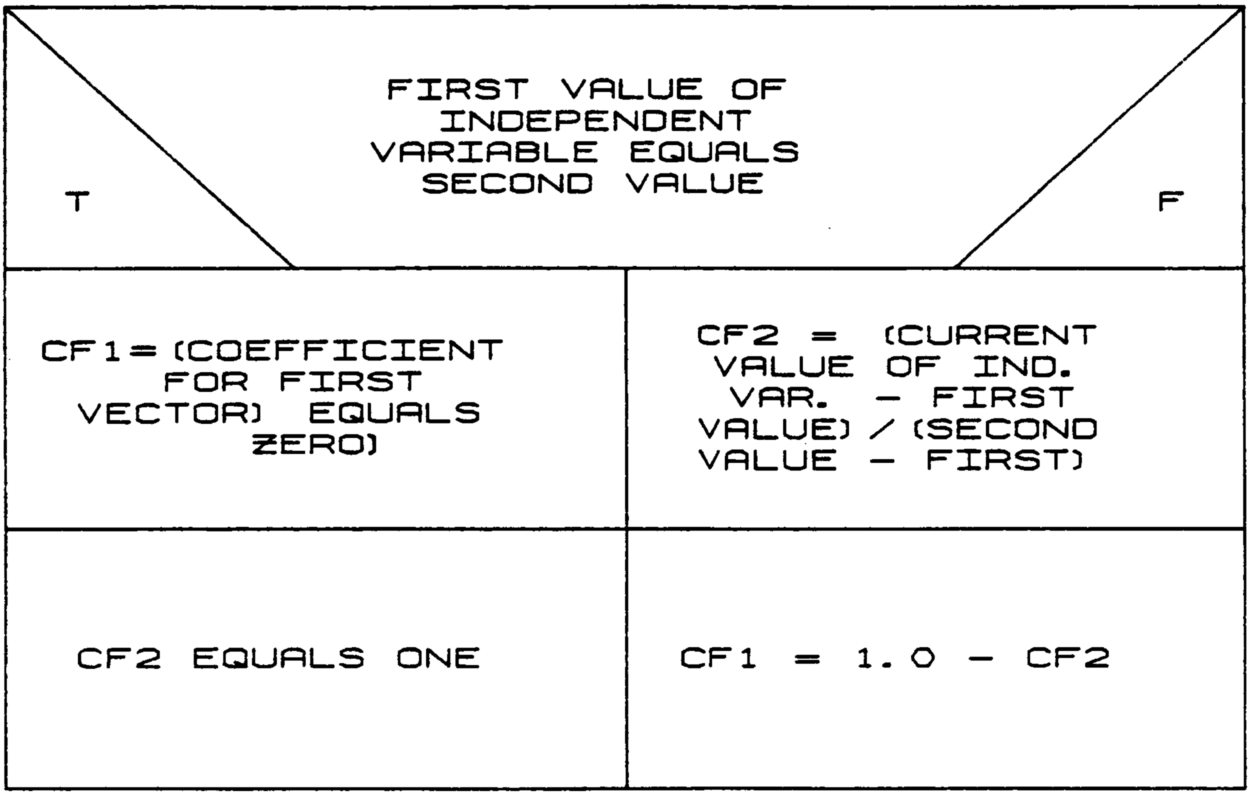
SUBROUTINE SLVTHDD



2.3.39 LININT

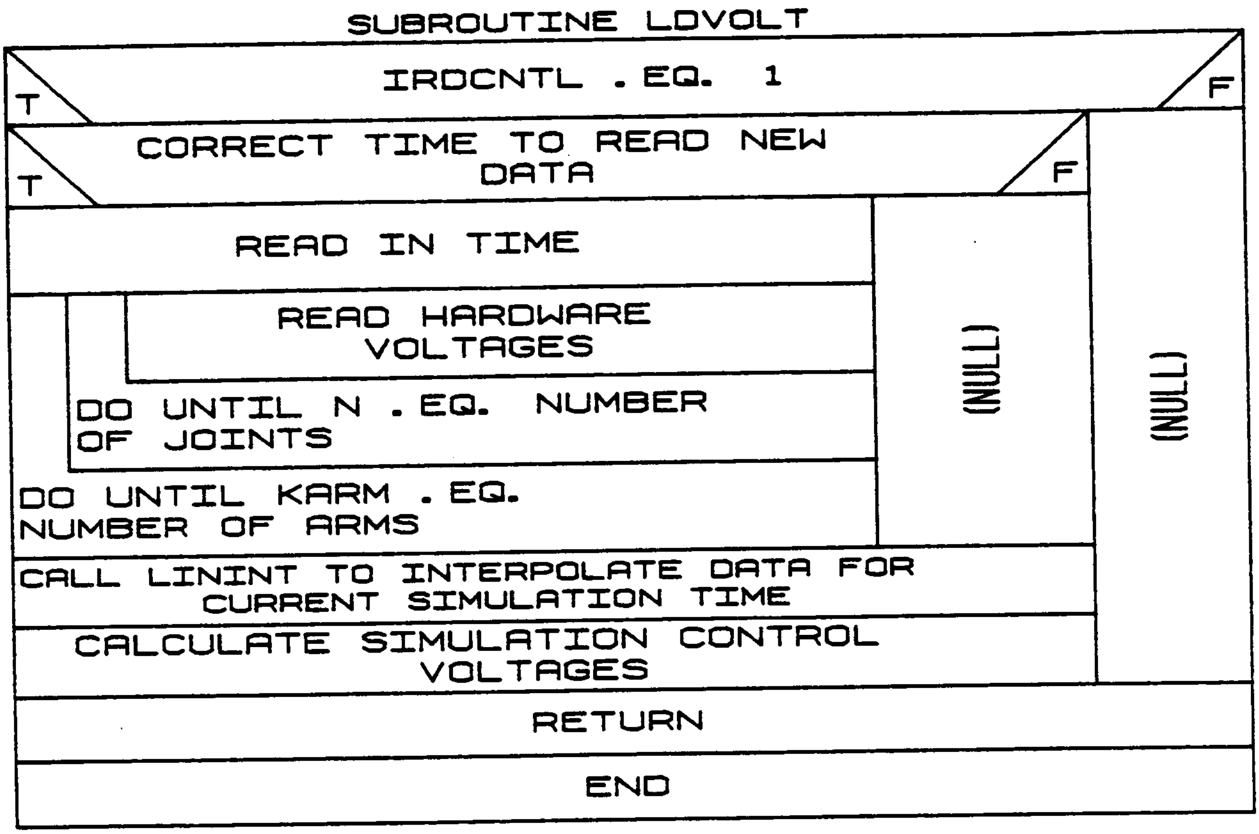
Subroutine LININT is called to set up the coefficient for performing linear interpolation between two vectors.

SUBROUTINE LININT



2.3.40 LDVOLT

Subroutine LDVOLT is called from DRTORQ when a file of actuator voltages is to be read in and used to drive a response simulation run. At the correct time the routine reads time and voltage from an existing file. LININT is called to interpolate the best voltage for the current simulation time. The control voltage is then calculated from this.



2.3.41 CALCI

The CALCI subroutine calculates the amplifier current values for each of the joints in the system given the motor parameter values and the state velocity.

```
SUBROUTINE CALCI
KARM. ARM COUNTER = 0
    INCREMENT KARM
    N. JOINT COUNTER = 0
        ARMATURE I (N. KARM) = (AMP GAIN*VOLTAGE - BACK EMF*JT. VEL. ) /ARM RES.
    DO UNTIL N = NUMBER OF JOINTS FOR KARM
DO UNTIL KARM = NARM. TOTAL NUMBER OF ARMS
RETURN
END
```

2.3.42 SOLVE

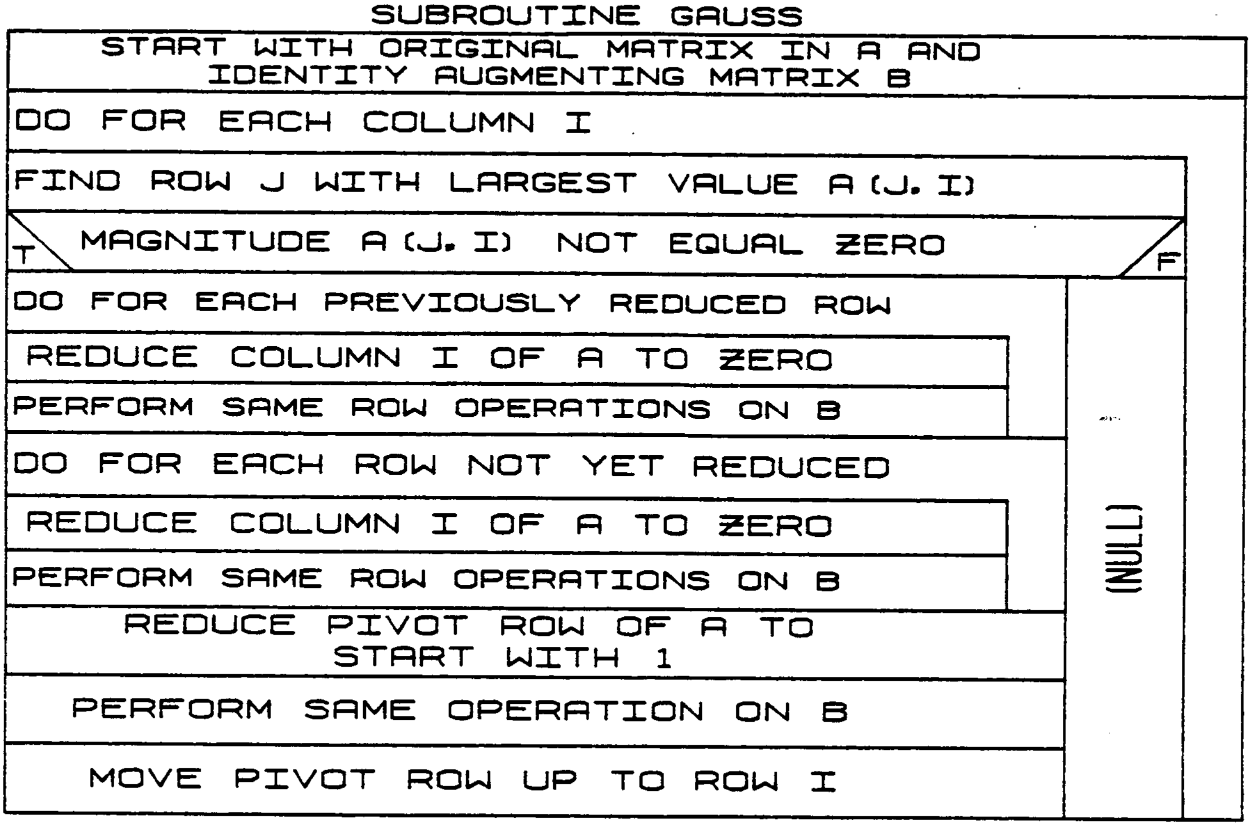
SOLVE is used to solve a set of N linear equations in N unknowns. It sets up an identity-augmenting matrix, calls GAUSS to invert the original matrix and then multiplies this inverse times the right-hand side of the equations to obtain the resulting solution.

SUBROUTINE SOLVE

```
PUT ORIGINAL MATRIX INTO C
FORM IDENTITY AUGMENTING MATRIX IN AUG
CALL GAUSS TO PERFORM ELIMINATION. PUTTING INVERSE OF C INTO AUG
MULTIPLY AUG BY RIGHT-HAND-SIDE OF ORIGINAL EQUATIONS TO GET X
```

2.3.43 GAUSS

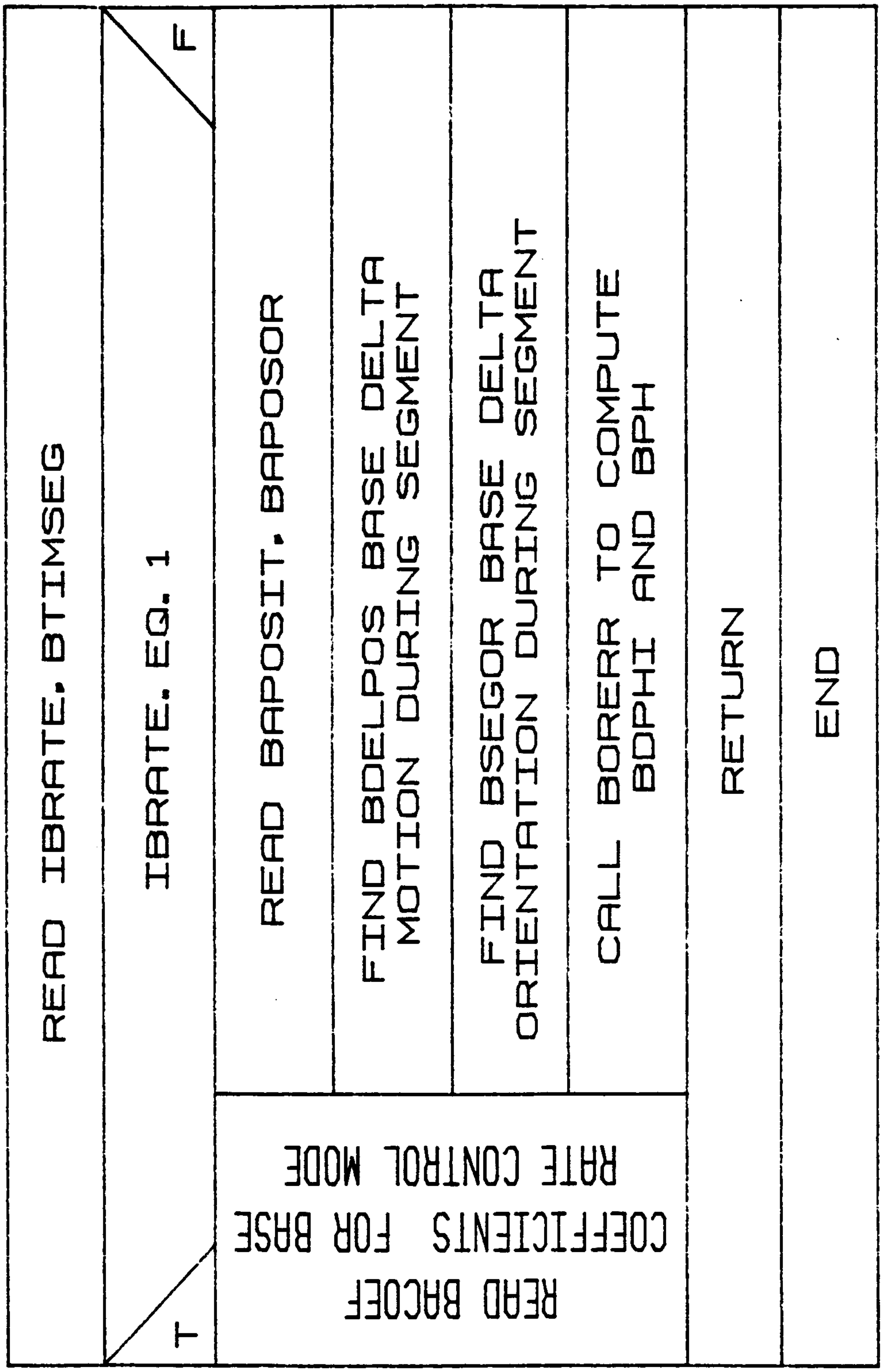
GAUSS performs Gauss-Jordan elimination with partial pivoting on an augmented matrix system to reduce the system to row-echelon form during the matrix inversion process. The largest value remaining in a column is used as the pivot value for that column during reduction.



```
SUBROUTINE GAUSS
START WITH ORIGINAL MATRIX IN A AND
    IDENTITY AUGMENTING MATRIX B
DO FOR EACH COLUMN I
    FIND ROW J WITH LARGEST VALUE A (J. I)
    MAGNITUDE A (J. I) NOT EQUAL ZERO
    T
        DO FOR EACH PREVIOUSLY REDUCED ROW
            REDUCE COLUMN I OF A TO ZERO
            PERFORM SAME ROW OPERATIONS ON B
        DO FOR EACH ROW NOT YET REDUCED
            REDUCE COLUMN I OF A TO ZERO
            PERFORM SAME ROW OPERATIONS ON B
        REDUCE PIVOT ROW OF A TO
            START WITH 1
        PERFORM SAME OPERATION ON B
        MOVE PIVOT ROW UP TO ROW I
    F
        (NULL)
```

2.3.44 BASINIT

Subroutine BASINIT is called from BCNTRLR at the beginning of each new base motion people segment. The coefficients of the polynomials defining the base rates or the desired positions and orientations are read from the base motion profile.



```
SUBROUTINE BASINIT
READ IBRATE, BTIMSEG
IBRATE. EQ. 1
  T: READ BACOEF
     COEFFICIENTS FOR BASE
     RATE CONTROL MODE
  F: READ BAPOSIT, BAPOSOR
     FIND BDELPOS BASE DELTA
       MOTION DURING SEGMENT
     FIND BSEGOR BASE DELTA
       ORIENTATION DURING SEGMENT
     CALL BORERR TO COMPUTE
       BDPHI AND BPH
RETURN
END
```

2.3.45 BRCNTRL

Subroutine BRCNTRL is called from BCNTRLR when rate control of the base is specified. The rate polynomials are used to calculate the base translational and angular velocities. The base positions, orientations and accelerations are calculated from the velocities.

SUBROUTINE BRCNTRL

```
OLDVEL = BASVEL
BAPOSIT = BAPOSIT + BASVEL*STPPRO
BASVEL = 0.
IF T .EQ. 0.
  T:
    BASVEL = BACOEF
  F:
    DO
      BASVEL=BACOEF*T** (MAXORD+1-MO) +BASVEL
    UNTIL MO=MAXORD+1
OLDOM = BASOM
DBPHI = BASOM*STPPRO
BASOM = 0.
IF T .EQ. 0.
  T:
    BASOM = BACOEF
  F:
    DO
      BASOM=BACOEF*T** (MAXORD+1-MO) +BASOM
    UNTIL MO=MAXORD+1
IF NO ROTATION
  T:
    SET ROTATION MAGNITUDE DP TO ZERO
    SET ROATATION AXIS TO X-AXIS
  F:
    CONVERT ROTATION AXIS TO BASE COORD.
    SCALE ROTATION AXIS
FORM LOCAL ROTATION MATRIX
UPDATE BASE ORIENTATION BAPOSOR
BASACC= (BASVEL-OLDVEL) /STPPRO
BASOMD= (BASOM-OLDOM) /STPPRO
RETURN
END
```

2.3.46 BPCNTRL

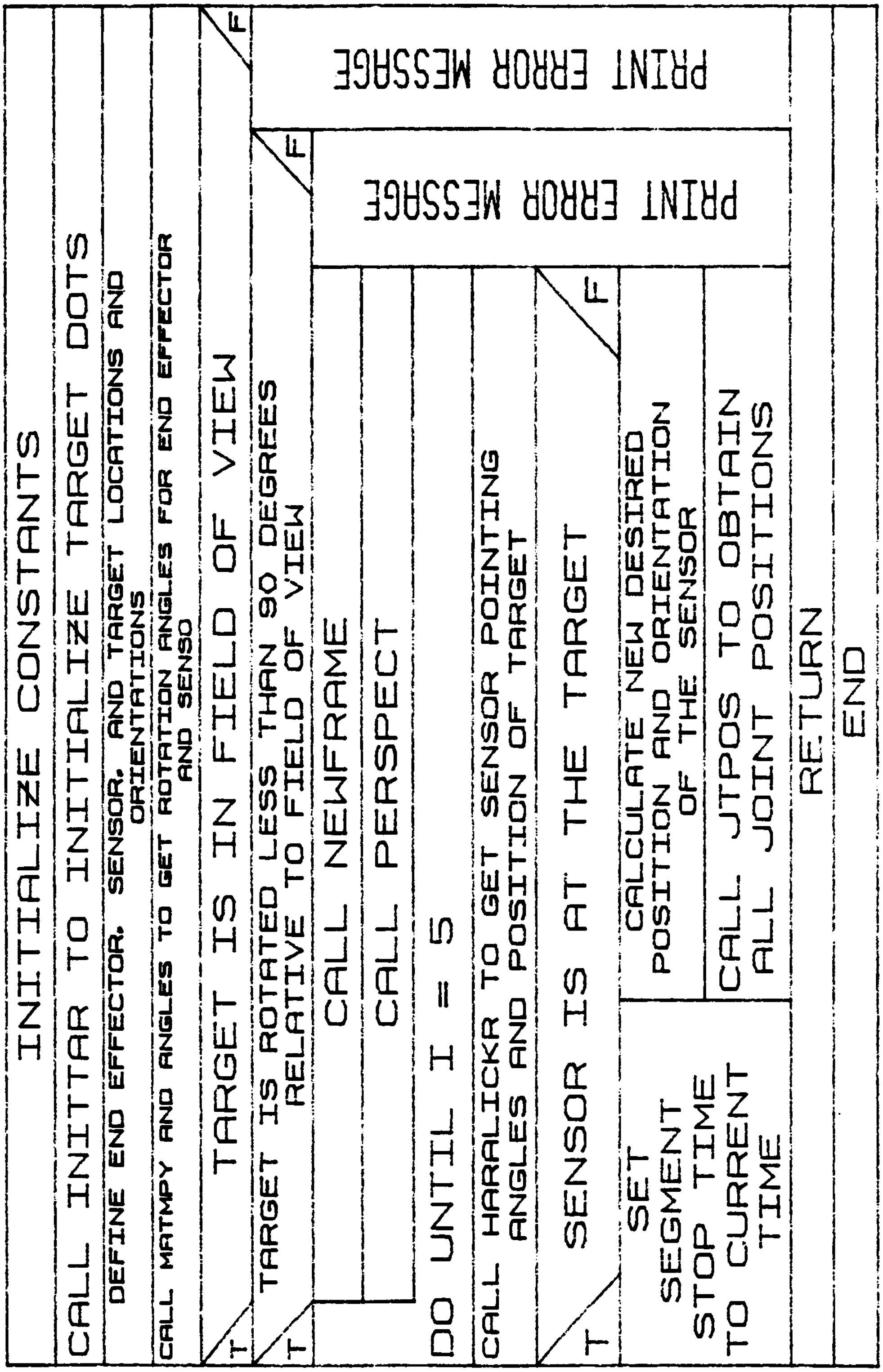
Subroutine BPCNTRL is called from BCNTRLR when position control of the base is to be used. The rate profile is used to calculate the base positions, velocities and accelerations.

SUBROUTINE BPCNTRL

```
CALCULATE NEW BASE POSTION BAPOSIT
CALCULATE CHANGE IN BASE ORIENTATION DURING A TIME STEP
CALCULATE NEW BASE ORIENTATION BAPOSOR
CALC BASE BASVEL. BASOM
CALC BASE BASACC. BASOMD
RETURN
END
```

2.3.47 TRACKING

Subroutine TRACKING is called from CNTRLR when sensor control of end-effector motion is chosen by the user. This simulates tracking of a target by a video device mounted on a manipulator end-effector.



```
SUBROUTINE TRACKING
    INITIALIZE CONSTANTS
    CALL INITTAR TO INITIALIZE TARGET DOTS
    DEFINE END EFFECTOR, SENSOR, AND TARGET LOCATIONS AND ORIENTATIONS
    CALL MATMPY AND ANGLES TO GET ROTATION ANGLES FOR END EFFECTOR AND SENSO
    TARGET IS IN FIELD OF VIEW
    T
        TARGET IS ROTATED LESS THAN 90 DEGREES RELATIVE TO FIELD OF VIEW
        T
                CALL NEWFRAME
                CALL PERSPECT
            DO UNTIL I = 5
            CALL HARALICKR TO GET SENSOR POINTING ANGLES AND POSITION OF TARGET
            SENSOR IS AT THE TARGET
            T
                SET SEGMENT STOP TIME TO CURRENT TIME
            F
                CALCULATE NEW DESIRED POSITION AND ORIENTATION OF THE SENSOR
                CALL JTPOS TO OBTAIN ALL JOINT POSITIONS
        F
            PRINT ERROR MESSAGE
    F
        PRINT ERROR MESSAGE
    RETURN
END
```

2.3.48 INITTAR

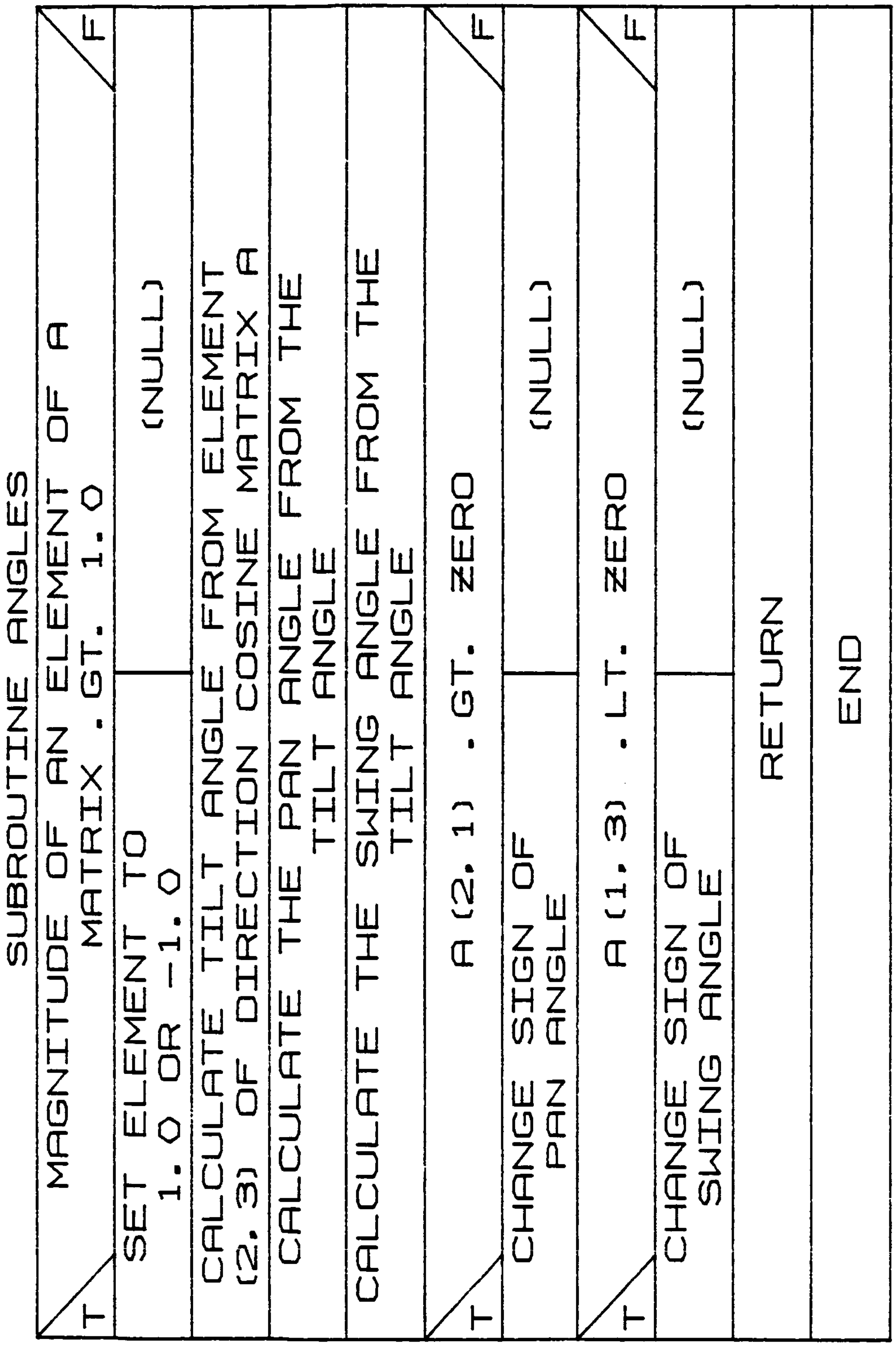
Subroutine INITTAR is called from TRACKING to obtain the coordinates of the target corner points.

SUBROUTINE INITTAR

```
COORDINATES OF FIRST CORNER OF
TARGET ARE PTAR(I, 1) = (-L/2, 0,
-W/2)
COORDINATES OF SECOND CORNER OF
TARGET ARE PTAR(I, 2) = (L/2, 0, -W/2)
COORDINATES OF THIRD CORNER OF
TARGET ARE PTAR(I, 3) = (-L/2, 0, W/2)
COORDINATES OF FOURTH CORNER OF
TARGET ARE PTAR(I, 4) = (L/2, 0, W/2)
PTAR(I, 5) = (0, 0, 0)
RETURN
END
```

2.3.49 ANGLES

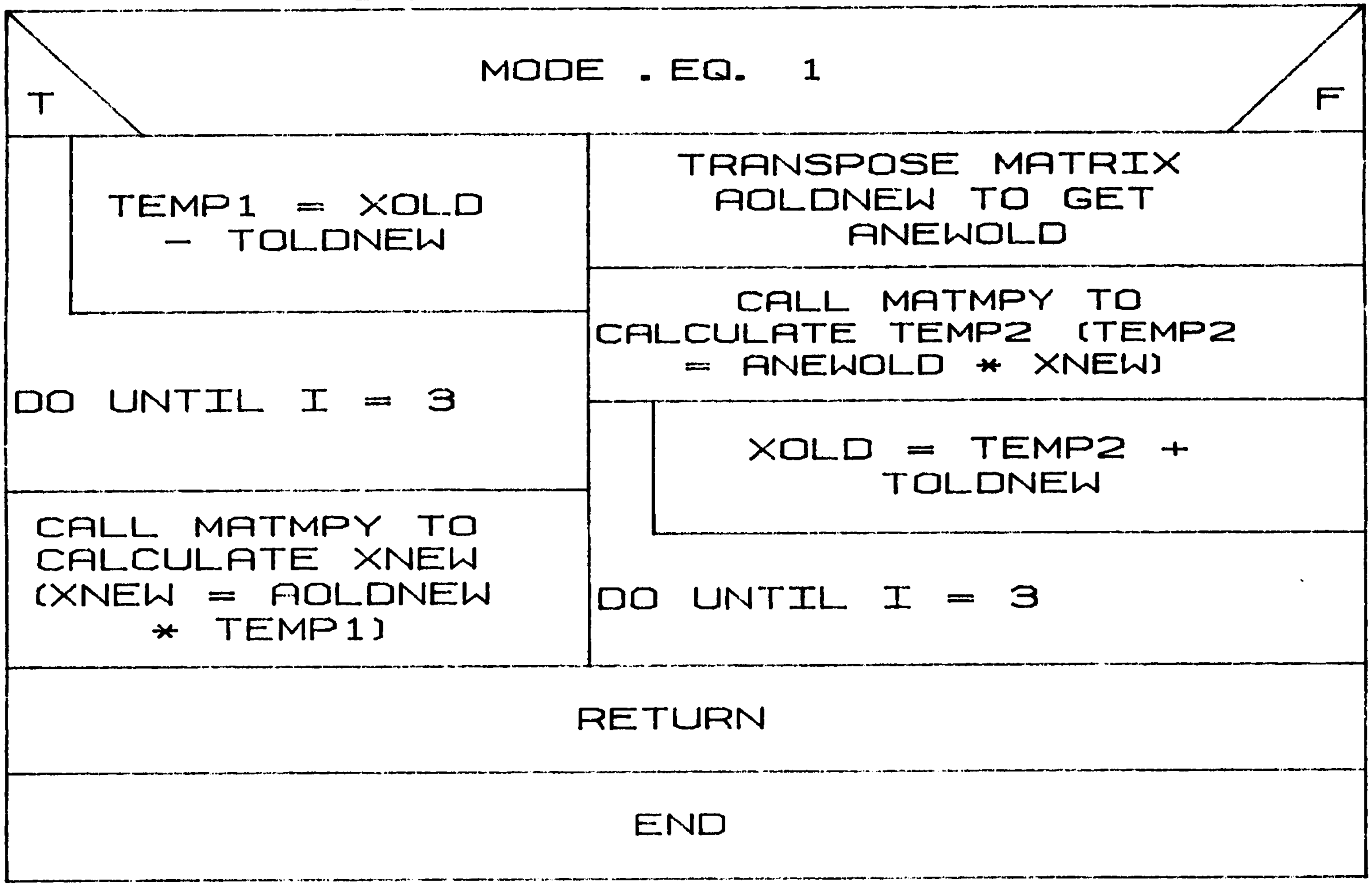
Subroutine ANGLES is called from TRACKING to calculate the Euler angles given a direction cosine matrix.


SUBROUTINE ANGLES
MAGNITUDE OF AN ELEMENT OF A MATRIX .GT. 1.0
T
F
SET ELEMENT TO 1.0 OR -1.0
(NULL)
CALCULATE TILT ANGLE FROM ELEMENT (2,3) OF DIRECTION COSINE MATRIX A
CALCULATE THE PAN ANGLE FROM THE TILT ANGLE
CALCULATE THE SWING ANGLE FROM THE TILT ANGLE
A(2,1) .GT. ZERO
T
F
CHANGE SIGN OF PAN ANGLE
(NULL)
A(1,3) .LT. ZERO
T
F
CHANGE SIGN OF SWING ANGLE
(NULL)
RETURN
END

2.3.50 NEWFRAME

Subroutine NEWFRAME is called from TRACKING to obtain the coordinates of a three-dimensional vector in a new coordinate system.

SUBROUTINE NEWFRAME



2.3.51 PERSPECT

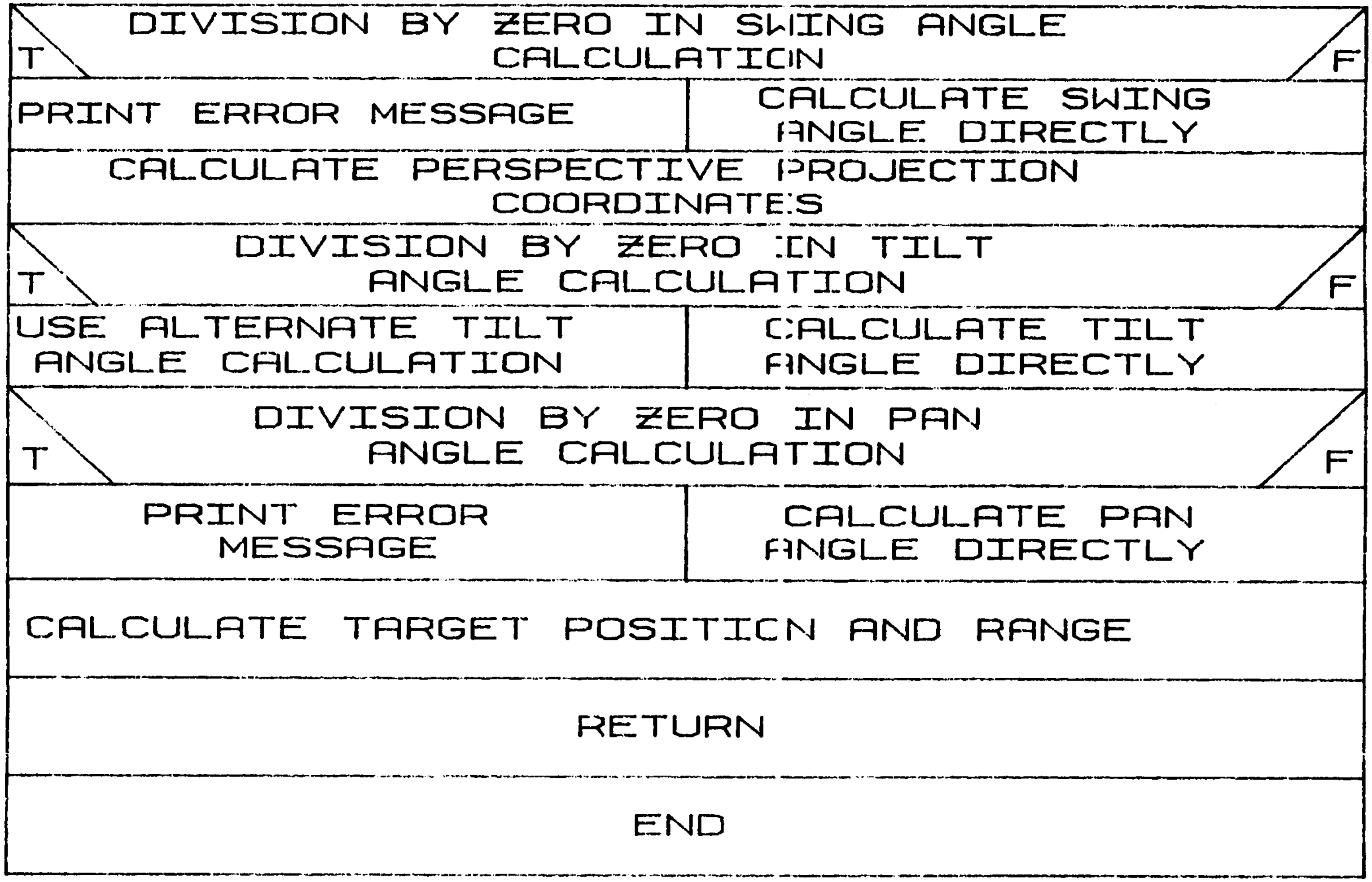
Subroutine PERSPECT is called from TRACKING to calculate the perspective projection of a three-dimensional vector. The result is a two-dimensional vector.

```
SUBROUTINE PERSPECT
XSTAR (1)  = F (X (1) /X (2) )
XSTAR (2)  = F (X (3) /X (2) )
RETURN
END
```

2.3.52 HARALICKR

Subroutine HARALICKER is called from TRACKING and calculates the pointing angles of a camera relative to a rectangular target, based on the perspective projection of the four corners of the rectangle.

SUBROUTINE HARALICKR



2.3.53 BDRTORQ

Subroutine BDRTORQ reads base torques and forces from a file and computes new torques and forces by linear interpolation.

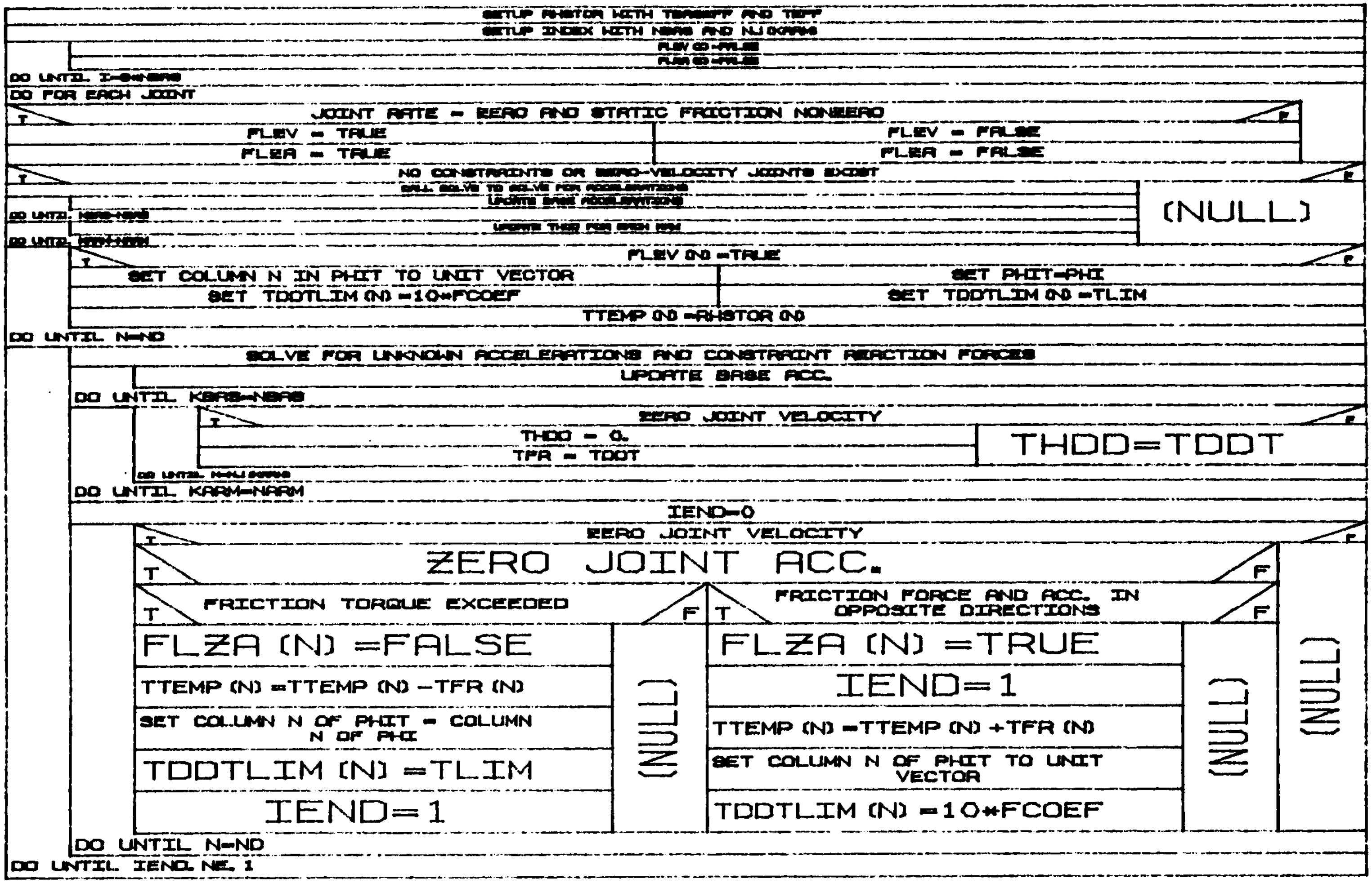
SUBROUTINE BDRTORQ

```
TIME .GE. BTNEXT AT WHICH TO READ BASE TORQUE FILE
T:
    READ TIME FROM BASE TORQUE FILE INTO BTNEXT
        BTORL (LAST TORQUE) = BTORN (NEXT TORQUE) FOR EACH BASE
        READ TORQUE VALUES FROM FILE INTO BTORN PARAMETER FOR EACH JT.
    DO UNTIL KBAS=NBAS
F:
    (NULL)
CALL LININT TO COMPUTE NEW TORQUE CONTROL SIGNAL TIME COEFFS.
        TBDR (N, KBAS) = INTERPOLATION BETWEEN BTORL AND BTORN
    DO UNTIL N = 6
DO UNTIL KBAS=NBAS
RETURN
END
```

2.3.54 SLVMBAS

Subroutine SLVMBAS solves for base and joint accelerations for a given arm state and driving forces.

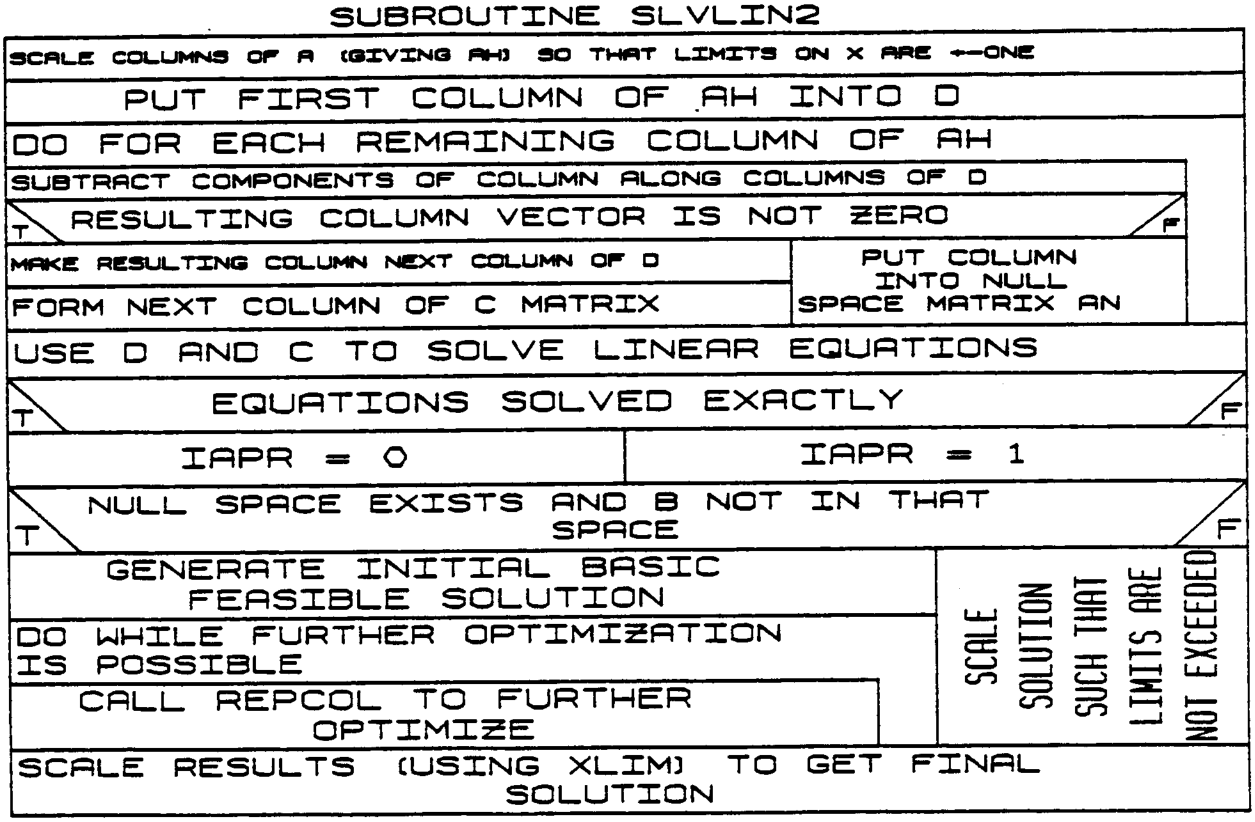
SUBROUTINE SLVMBAS



```
SETUP RHSTOR WITH TBRKOFF AND TEFF
SETUP INDEX WITH NBAS AND NJ(KARM)
    FLEV(I)=FALSE
    FLZA(I)=FALSE
DO UNTIL I=6*NBAS
DO FOR EACH JOINT
IF JOINT RATE = ZERO AND STATIC FRICTION NONZERO
  T:  FLEV = TRUE
      FLZA = TRUE
  F:  FLEV = FALSE
      FLZA = FALSE
IF NO CONSTRAINTS OR ZERO-VELOCITY JOINTS EXIST
  T:  CALL SOLVE TO SOLVE FOR ACCELERATIONS
          UPDATE BASE ACCELERATIONS
      DO UNTIL KBAS=NBAS
          UPDATE THDD FOR EACH ARM
      DO UNTIL KARM=NARM
  F:  (NULL)
    IF FLEV(N)=TRUE
      T:  SET COLUMN N IN PHIT TO UNIT VECTOR
          SET TDDTLIM(N)=10*FCOEF
      F:  SET PHIT=PHI
          SET TDDTLIM(N)=TLIM
    TTEMP(N)=RHSTOR(N)
DO UNTIL N=ND
    SOLVE FOR UNKNOWN ACCELERATIONS AND CONSTRAINT REACTION FORCES
        UPDATE BASE ACC.
    DO UNTIL KBAS=NBAS
            IF ZERO JOINT VELOCITY
              T:  THDD = 0.
                  TFR = TDDT
              F:  THDD=TDDT
        DO UNTIL N=NJ(KARM)
    DO UNTIL KARM=NARM
    IEND=0
        IF ZERO JOINT VELOCITY
          T:  IF ZERO JOINT ACC.
                T:  IF FRICTION TORQUE EXCEEDED
                      T:  FLZA(N)=FALSE
                          TTEMP(N)=TTEMP(N)-TFR(N)
                          SET COLUMN N OF PHIT = COLUMN N OF PHI
                          TDDTLIM(N)=TLIM
                          IEND=1
                      F:  (NULL)
                F:  IF FRICTION FORCE AND ACC. IN OPPOSITE DIRECTIONS
                      T:  FLZA(N)=TRUE
                          IEND=1
                          TTEMP(N)=TTEMP(N)+TFR(N)
                          SET COLUMN N OF PHIT TO UNIT VECTOR
                          TDDTLIM(N)=10*FCOEF
                      F:  (NULL)
          F:  (NULL)
    DO UNTIL N=ND
DO UNTIL IEND NE. 1
```

2.4.1 SLVLIN2

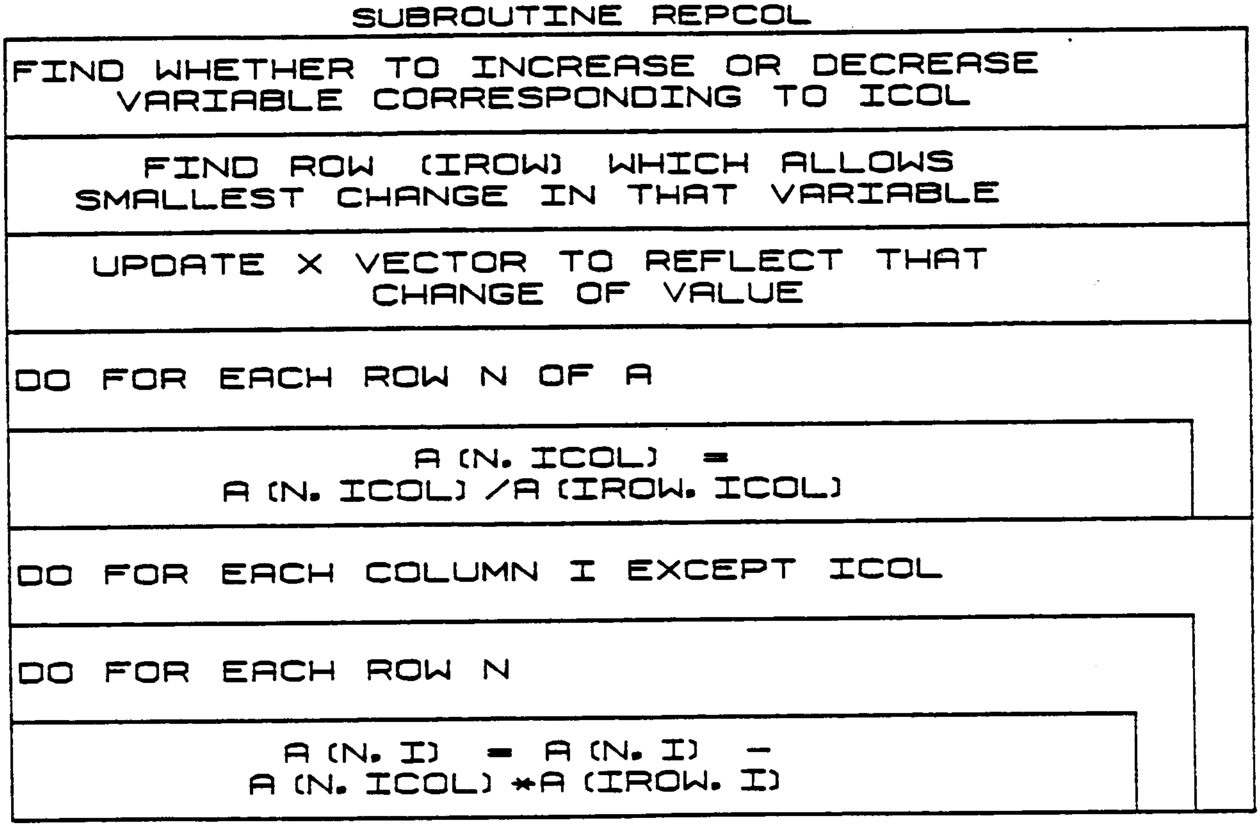
SLVLIN2 finds an optimal solution X to a linear set of equations AX = B where the magnitude of each component of X is bounded -XLIM(N)< = X(N) <= XLIM(N). The program first sets up matrices D, which forms an orthogonal basis for the reachable space of A, and C, which provides the conversion from D space to AH space. The matrix AN is also set up; it contains vectors in the null space of H along with the initial solution VH and is used as the tableau for linear programming. Once an initial solution is found, linear programming by a modification of the Simplex method is performed; the magnitude of the result is maximized subject to the constraints on X. This solution is then scaled to give the final solution.



```
SUBROUTINE SLVLIN2
SCALE COLUMNS OF A (GIVING AH) SO THAT LIMITS ON X ARE +-ONE
PUT FIRST COLUMN OF AH INTO D
DO FOR EACH REMAINING COLUMN OF AH
    SUBTRACT COMPONENTS OF COLUMN ALONG COLUMNS OF D
    RESULTING COLUMN VECTOR IS NOT ZERO
    T:
        MAKE RESULTING COLUMN NEXT COLUMN OF D
        FORM NEXT COLUMN OF C MATRIX
    F:
        PUT COLUMN INTO NULL SPACE MATRIX AN
USE D AND C TO SOLVE LINEAR EQUATIONS
EQUATIONS SOLVED EXACTLY
T:
    IAPR = 0
F:
    IAPR = 1
NULL SPACE EXISTS AND B NOT IN THAT SPACE
T:
    GENERATE INITIAL BASIC FEASIBLE SOLUTION
    DO WHILE FURTHER OPTIMIZATION IS POSSIBLE
        CALL REPCOL TO FURTHER OPTIMIZE
F:
    SCALE SOLUTION SUCH THAT LIMITS ARE NOT EXCEEDED
SCALE RESULTS (USING XLIM) TO GET FINAL SOLUTION
```

2.4.2 REPCOL

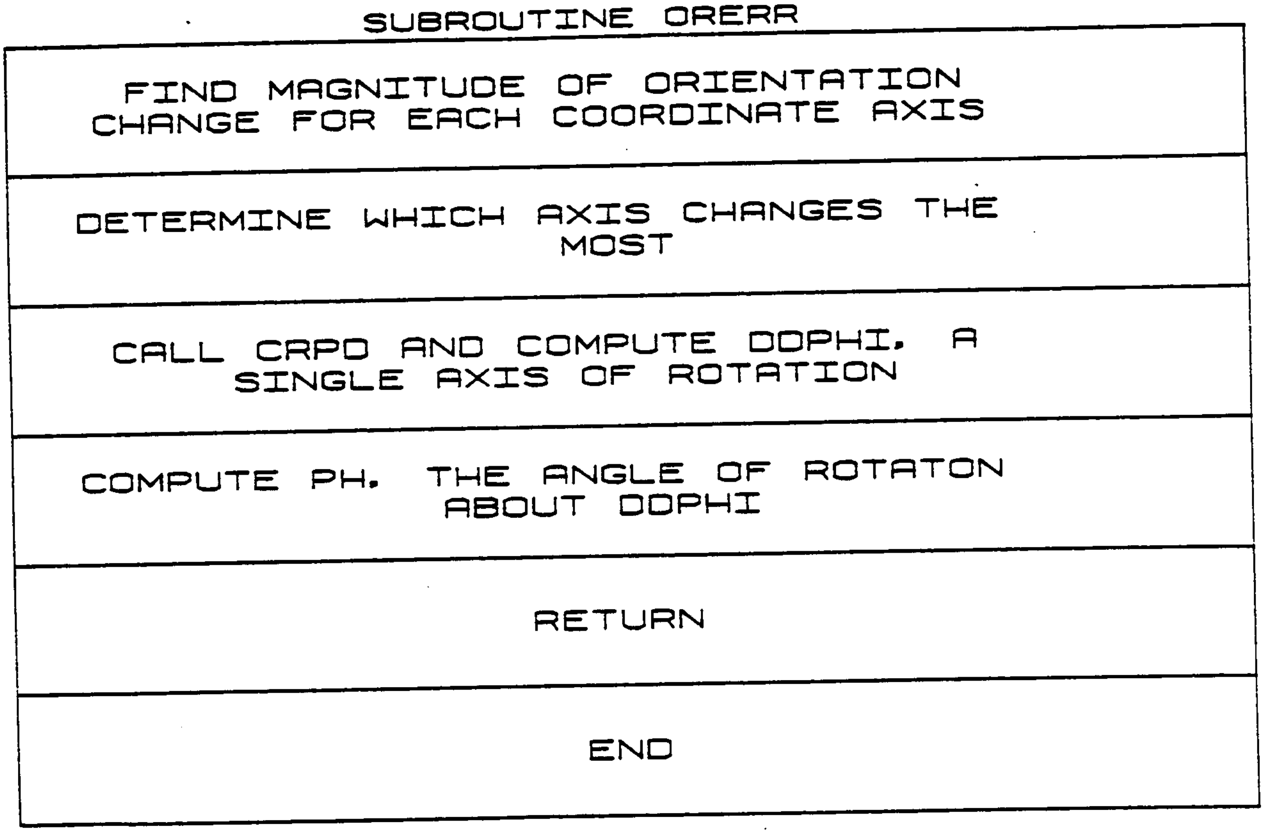
REPCOL replaces column ICOL of matrix A where A represents the tableau for a linear programming problem, X represents the variables, and the limits on each variable are plus or minus one. REPCOL first finds the largest allowable change in the free variable (the variable that corresponds to the column being replaced), and the new constraint variable that limits this change. The solution is updated and tableau A is modified to reflect this change of constraint variables.



```
SUBROUTINE REPCOL
FIND WHETHER TO INCREASE OR DECREASE
    VARIABLE CORRESPONDING TO ICOL
FIND ROW [IROW] WHICH ALLOWS
    SMALLEST CHANGE IN THAT VARIABLE
UPDATE X VECTOR TO REFLECT THAT
    CHANGE OF VALUE
DO FOR EACH ROW N OF A
    A [N. ICOL] =
        A [N. ICOL] /A [IROW. ICOL]
DO FOR EACH COLUMN I EXCEPT ICOL
    DO FOR EACH ROW N
        A [N. I] = A [N. I] -
            A [N. ICOL] *A [IROW. I]
```

2.4.3 ORERR

Subroutine ORERR is used to find the change in orientation between two coordinate systems. The error in orientation is computed and then transformed into a rotation (magnitude less than pi) about a unique rotation axis. This axis is computed as the cross-product of two of the columns of DOR, and the rotation angle PH is computed by (COS(PH)= 1+.5*(X.DX+Y.DY+Z.DZ), where X.DX is the dot product of the X column of ROR with the X column of DOR, etc.



```
SUBROUTINE ORERR
  FIND MAGNITUDE OF ORIENTATION CHANGE FOR EACH COORDINATE AXIS
  DETERMINE WHICH AXIS CHANGES THE MOST
  CALL CRPD AND COMPUTE DDPHI, A SINGLE AXIS OF ROTATION
  COMPUTE PH, THE ANGLE OF ROTATON ABOUT DDPHI
  RETURN
  END
```

2.4.4 OUTUN

OUTUN is a function that converts a value from internal (metric) units to the user-specified input/output units by dividing by a conversion factor.

FUNCTION OUTUN

```
CONVERT A VALUE FROM INTERNAL TO
I/O UNITS USING OUTUN =VAL/CONUNIT
RETURN
END
```

2.4.5 ICVTATD

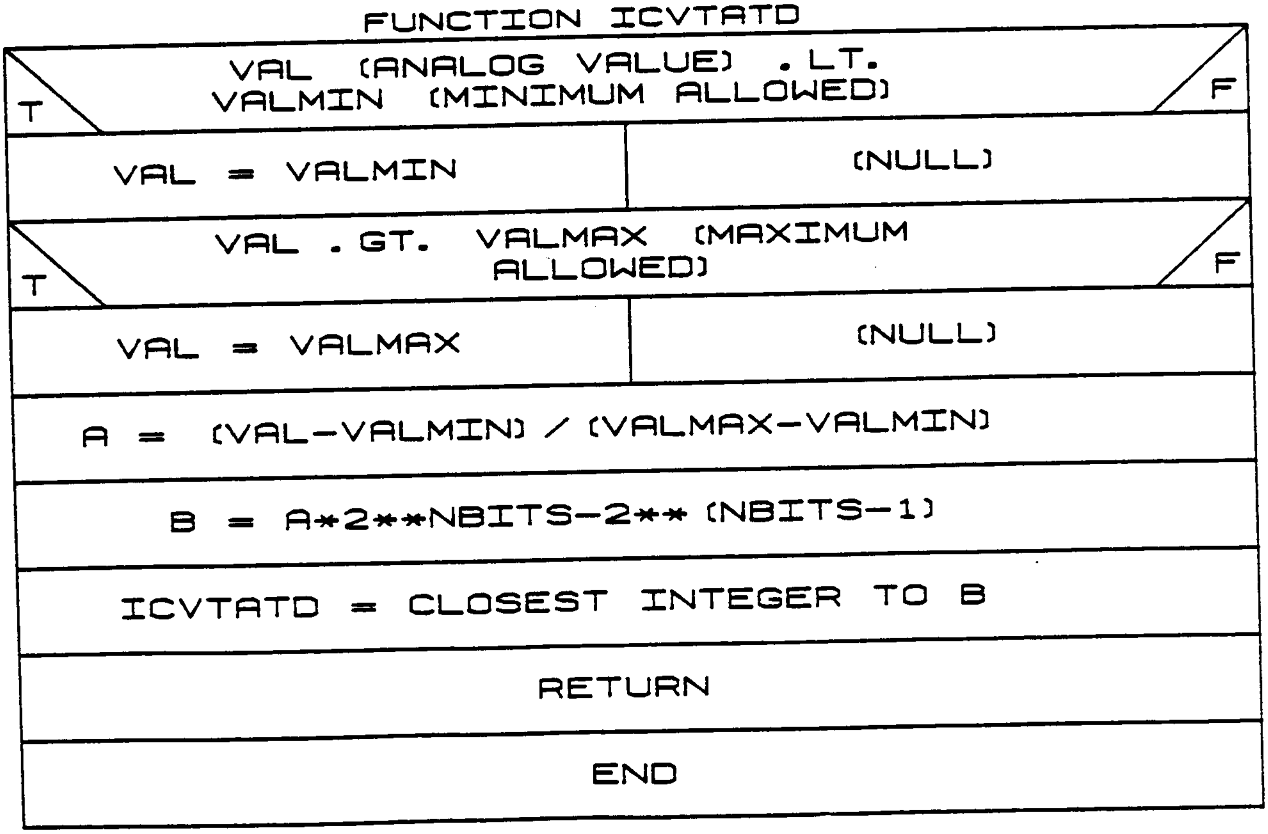
ICVTATD is a function that returns a digitized number when given a real value. If the value is outside an allowable minimum or maximum, it is set equal to the appropriate limit. The digitized number is then computed using the following relation:

$$B = \frac{(VAL - VALMIN)}{(VALMAX - VALMIN)} * \left(2^{MBITS} - 2^{(NBITS-1)}\right)$$

where

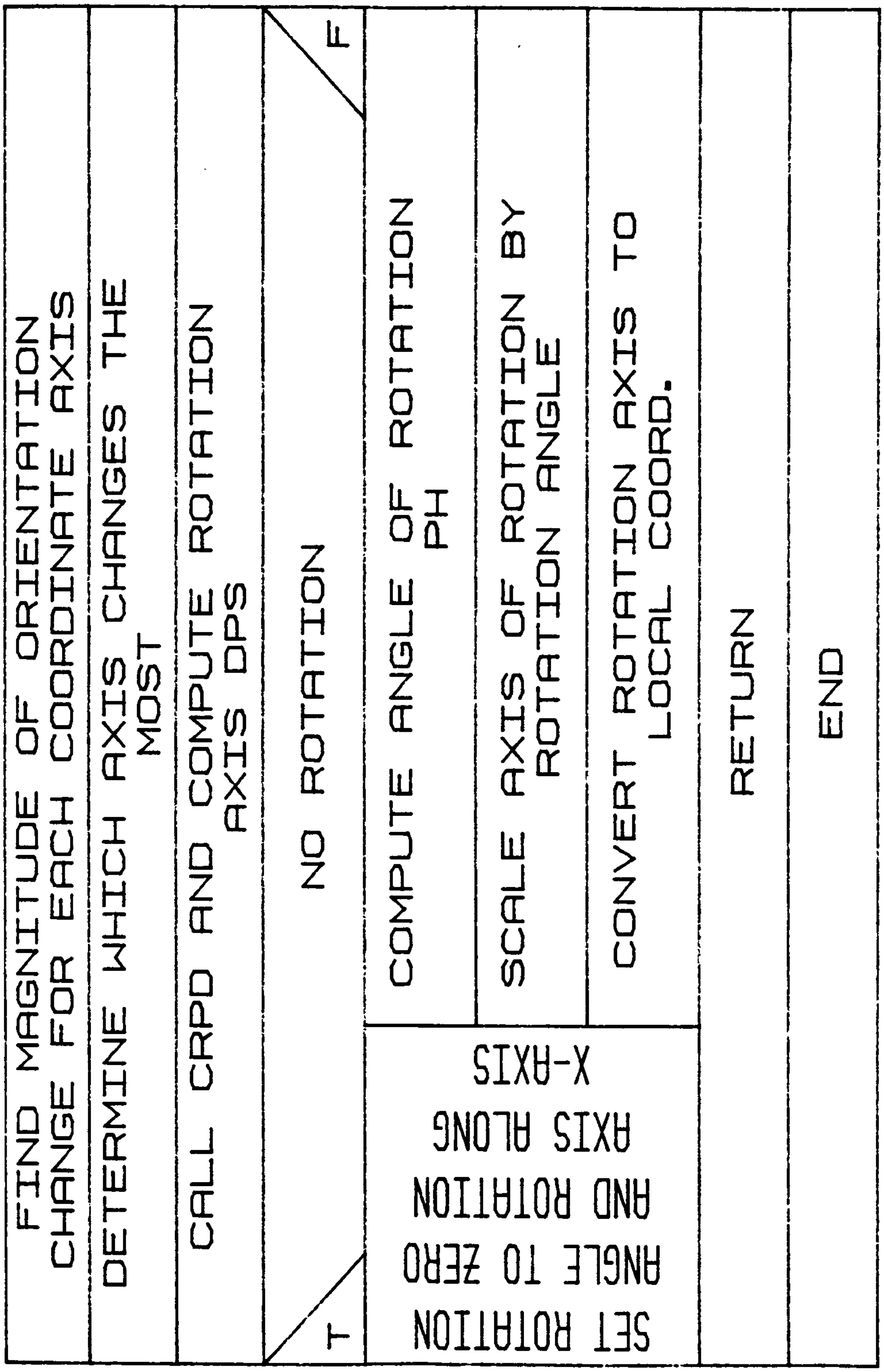
NBITS = number of bits available for digitized value,
VALMIN = minimum allowable value for VAL,
VALMAX = maximum allowable value for VAL,
VAL = output value.

ICVTATD, the digitized number, is set equal to the closest integer to B.



2.4.6 BORERR

Subroutine BORERR is used to find the change in orientation between two coordinate systems. The error in orientation is computed and then transformed into a rotation (magnitude less than pi) about a rotation axis referenced to the base coordinate system.


SUBROUTINE BORERR
FIND MAGNITUDE OF ORIENTATION CHANGE FOR EACH COORDINATE AXIS
DETERMINE WHICH AXIS CHANGES THE MOST
CALL CRPD AND COMPUTE ROTATION AXIS DPS
NO ROTATION
T
F
SET ROTATION ANGLE TO ZERO AND ROTATION AXIS ALONG X-AXIS
COMPUTE ANGLE OF ROTATION PH
SCALE AXIS OF ROTATION BY ROTATION ANGLE
CONVERT ROTATION AXIS TO LOCAL COORD.
RETURN
END

The Postprocessing Function

The program POSTDRVR is the postprocessing function driver. The following set of routine functional descriptions and VCLRs (visual control logic representations) are the modules found in the postprocessor function of ROBSIM.

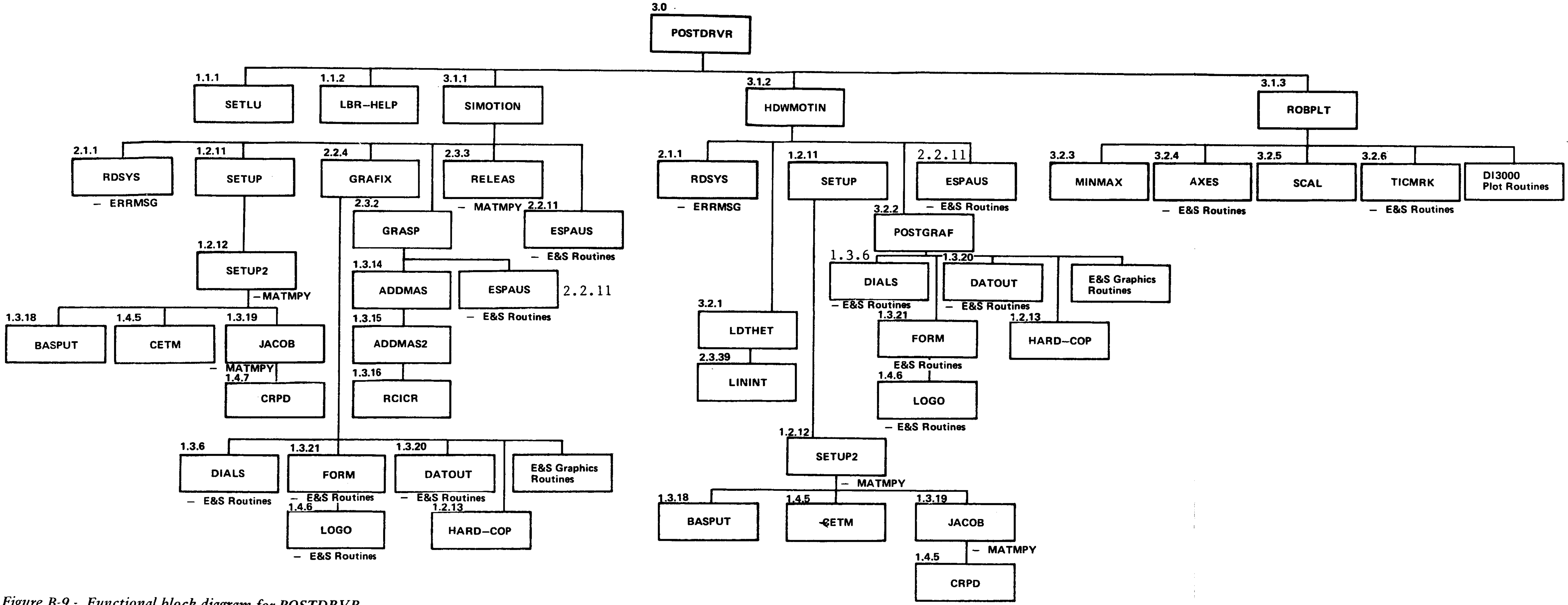


Figure B-9.- Functional block diagram for POSTDRVR.

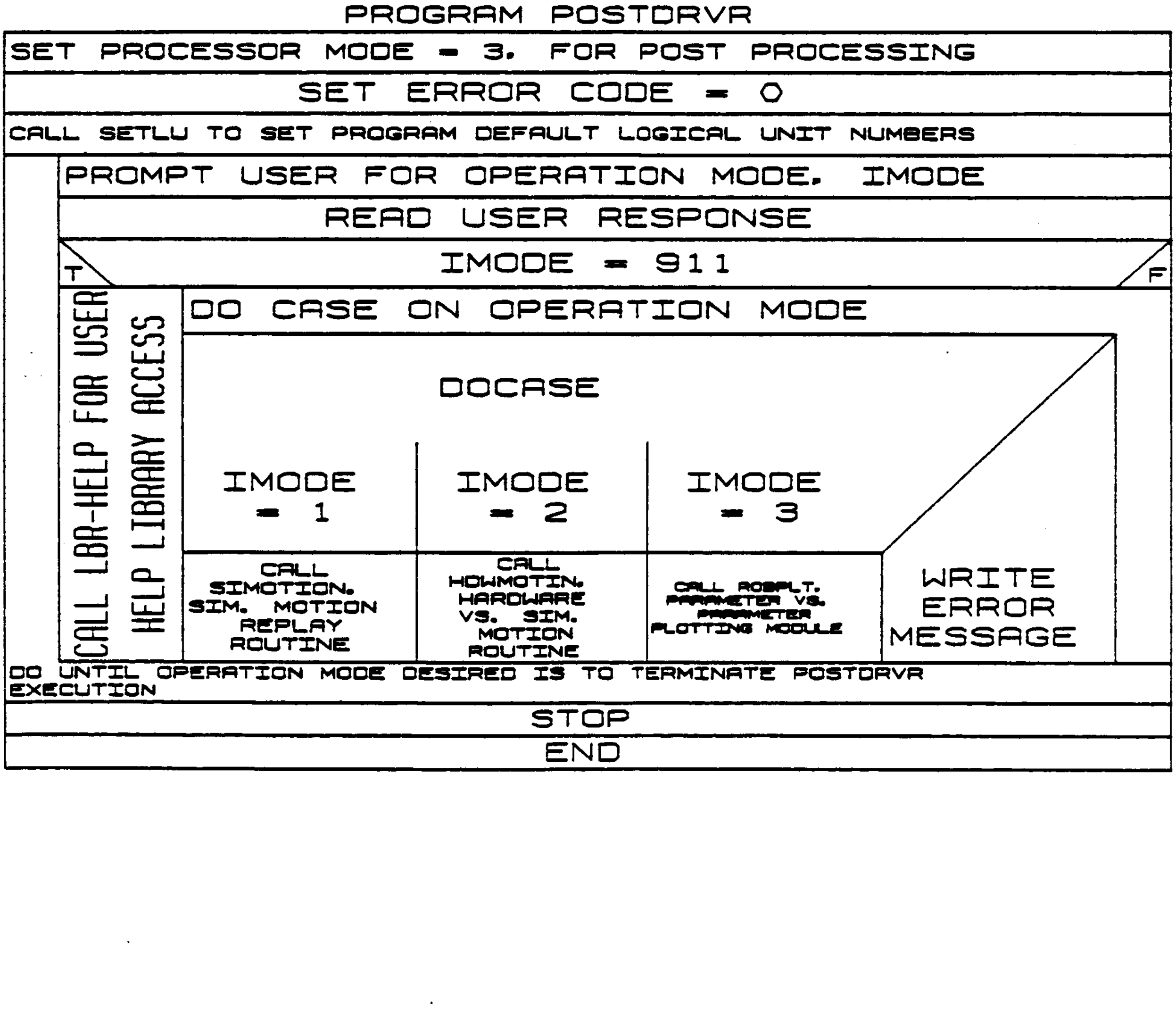
2

TAble B-VII. - PROGRAMS EMPLOYED IN POSTDRVR

3.0	POSTDRVR
3.1.1	SIMOTION
3.1.2	HDWMOTIN
3.1.3	ROBPLT
3.2.1	LDTHET
3.2.2	POSTGRAF
3.2.3	MINMAX
3.2.4	AXES
3.2.5	SCAL
3.2.6	TICMRK

3.0 POSTDRVR

The program POSTDRVR is the postprocessing function driver. It operates in an interactive mode, prompting the user for the postprocessing option desired: replay robotic system simulation motion, replay simulation versus hardware motion, parameter versus parameter plots, or terminate POSTDRVR execution. For simulation replay, option 1, subroutine SIMOTION, is called. Option 2 provides a comparison of hardware and the corresponding simulation motion through subroutine HDWMOTIN. If option 3 is selected, ROBPLT plots any of the data computed and written to one of the seven types of plot file packages during the requirements or simulation analysis tools functions.



3.1.1 SIMOTION

SIMOTION is called during the postprocessing function to provide a replay of the robotic system motion produced during a previous run of the requirements or simulation phase of the analysis tools function. It opens the chosen robotic system geometry file and simulation output file for each graphics replay, and calls GRAFIX with the displacements at each time step to update the system motion display.

SUBROUTINE SIMOTION

```
SET PROCESSOR MODE TO 3 FOR POST PROCESSING
CALL ROSYS TO READ THE ROBOTIC SYSTEM FILE
PROMPT FOR FILENAME OF SIMULATION MOTION OUTPUT
READ SOF FILENAME
OPEN SOF FILE
READ INITIAL TIME FROM FILE
DO WHILE KARM .LT. NARM
    INCREMENT KARM
    READ OP. TASK. INITIAL THETA. LOAD NUM. FOR EACH JT. OF KARM
REWIND SOF FILE
CALL SETUP TO LOAD THE POS AND ROT MATRICES
SET GRAPHICS FLAG = 1
CALL GRAFIX TO INITIALIZE GRAPHICS
    READ TIME FROM FILE
    DO WHILE KARM .LT. NARM
        INCREMENT KARM
        READ OP TASK. INITIAL THET. LOAD NUM FOR EACH JT OF KARM
        CURRENT LOAD .NE. PLANNED LOAD
        T:
            CURRENTLY NO LOAD AT TOOL
            T:
                CALL GRASP FOR PLANNED LOAD
            F:
                (NULL)
            NO LOAD PLANNED
            T:
                CALL RELEAS TO RELEASE CURRENT LOAD
            F:
                (NULL)
            CURRENTLY HOLDING LOAD AND A LOAD IS PLANNED
            T:
                CALL RELEAS TO RELEASE CURRENT LOAD
                CALL GRASP TO GRASP PLANNED LOAD
            F:
                (NULL)
            SET CURRENT LOAD NUMBER TO PLANNED LOAD NUMBER
        F:
            (NULL)
    CALL SETUP TO LOAD POS AND ROT MATRICES
    SET GRAPHICS FLAG = 2
    CALL ESPAUS TO CHECK OPTION FOR HALTING SIM MOTION
    CALL GRAFIX TO DISPLAY CURRENT TIME GRAPHICS
DO UNTIL END OF FILE
SET GRAPHICS FLAG = 3
CALL GRAFIX TO TERMINATE GRAPHICS
CLOSE SOF FILE
RETURN
END
```

3.1.2 HDWMOTIN

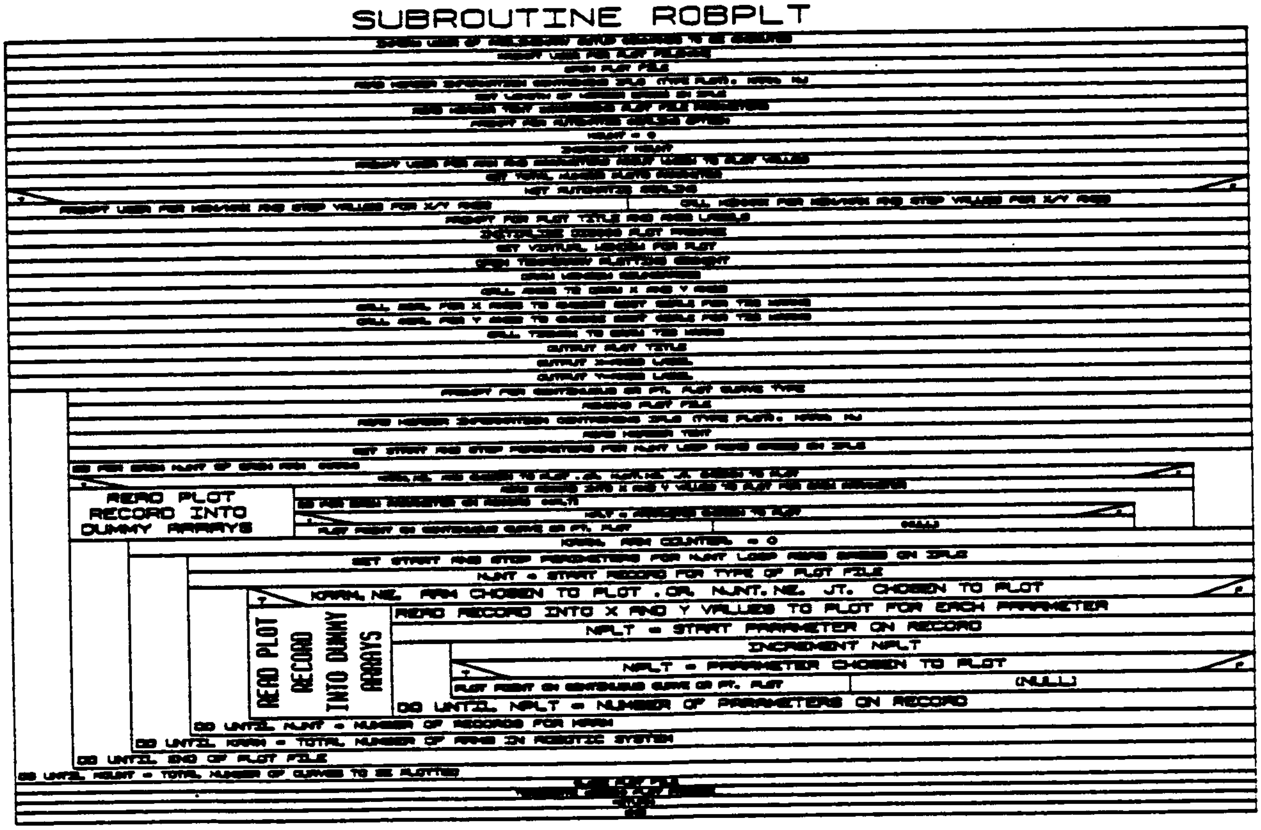
HDWMOTIN is called during the postprocessing function to provide a replay of the robotic system motion produced during the requirements/simulation analysis tools functions versus the actual motion that occurred during the corresponding hardware run. It opens the chosen system geometry file, simulation output file for graphics replay and hardware file containing recorded joint theta values. It calls POSTGRAF with the hardware and simulation displacements at each time step to update the system motion display.

SUBROUTINE HDWMOTIN

```
SET PROCESSOR MODE TO 3 FOR POST PROCESSING
CALL ROSYS TO READ THE ROBOTIC SYSTEM FILE
PROMPT, READ FILENAME OF SIMULATION MOTION OUTPUT FILE, SOF
SET HARDWARE THETA READ FLAG, IRDTHET, = 1
OPEN SOF FILE
PROMPT, READ FILENAME AND OPEN HARDWARE THETA FILE
READ INITIAL TIME FROM SOF
SET THE TIME CHECK INCREMENT PARAMETERS
CALL LDTHET TO LOAD THE HARDWARE THETA VALUES
LOAD HWANG ARRAY WITH HARDWARE THETAS FOR EACH JT. OF EACH ARM
CALL SETUP TO LOAD THE HARDWARE POSITION AND ROTATION MATRICES
LOAD HWPOS AND HWROT WITH VALUES FOR EACH JT. OF EACH ARM
DO WHILE KARM .LT. NARM
    INCREMENT KARM
    READ FROM SOF, OP TASK AND INITIAL THET FOR EACH JT OF KARM
CALL SETUP TO LOAD THE SIM POS AND ROT MATRICES
CALL POSTGRAF TO INITIALIZE GRAPHICS W/ FLAG = 1
    READ TIME FROM SOF
    CALL LDTHET TO LOAD THE HARDWARE THETAS
    LOAD HWANG ARRAY WITH THETA VALUES FOR EACH JT. OF EACH ARM
    CALL SETUP TO LOAD THE HARDWARE POS AND ROT MATRICES
    LOAD HWPOS AND HWROT WITH VALUES FOR EACH JT. OF EACH ARM
    DO WHILE KARM .LT. NARM
        INCREMENT KARM
        READ FROM SOF, OP TASK AND INITIAL THET FOR EACH JT OF KARM
    CALL SETUP TO LOAD THE SIM POS AND ROT MATRICES
    CALL ESPAUS TO CHECK OPTION FOR HALTING SIM MOTION
    CALL POSTGRAF TO DISPLAY CURRENT TIME POST GRAPHICS W/ FLAG = 2
DO UNTIL END OF FILE
CALL POSTGRAF TO TERMINATE GRAPHICS W/ FLAG = 3
CLOSE SOF FILE AND HARDWARE THETA FILE
RETURN
END
```

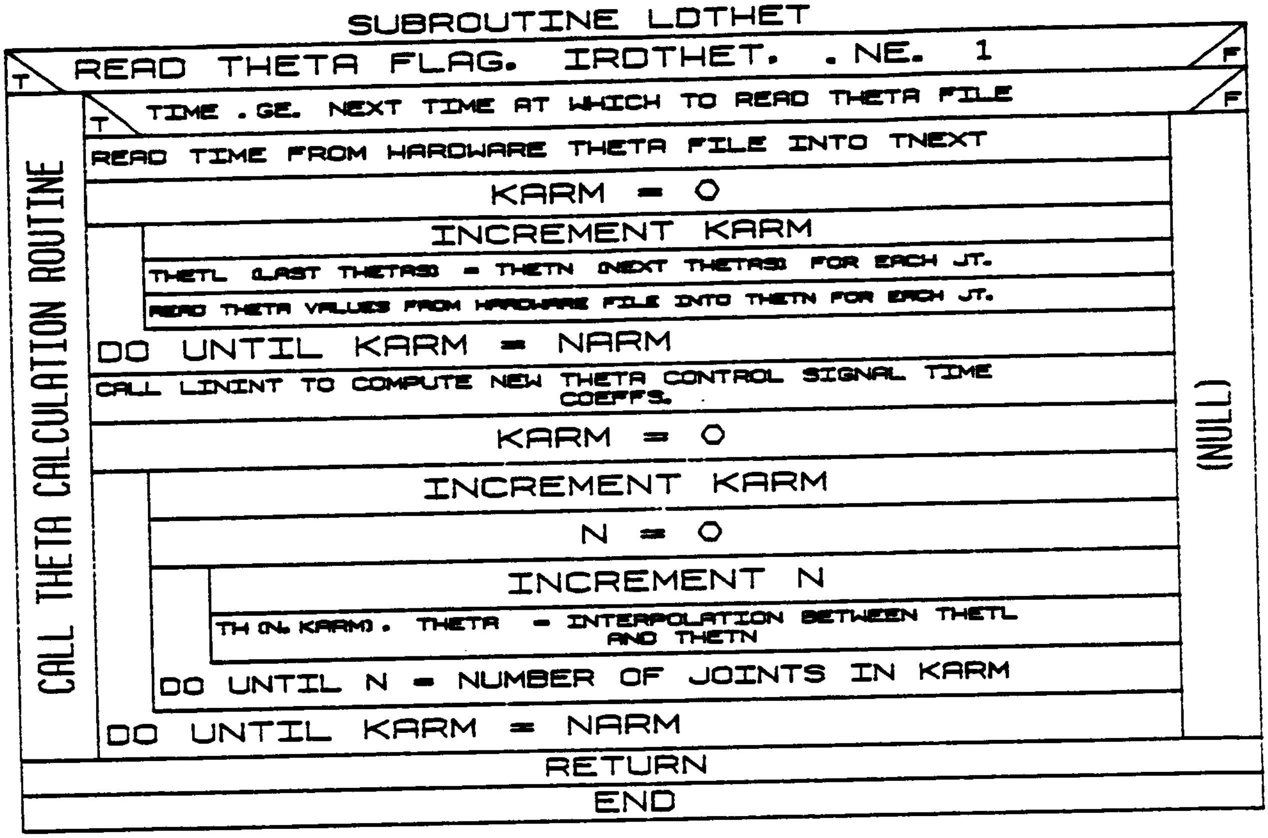
3.1.3 ROBPLT

The ROBPLT subroutine plots the contents of one of several choices for plot package formats on a Hewlett-Packard X-Y plotter or a VAX VT125 graphics terminal. It uses exclusively the DI3000 plot package. ROBPLT requests the user to select the appropriate one of seven plot file types that was written at the user's discretion during the requirements or simulation analysis tools functions: the brief package, the end-effector package, the joint positions package, the reaction forces package, a combination of the above four packages, the PID control package or the force/torque control package.



3.2.1 LDTHET

The LDTHET routine loads the theta values for each joint from direct read of the hardware control theta values file. It is called from HDWMOTIN during the postprocessing function for each simulation time step. There is a limit of one theta signal value for each joint that can be read.

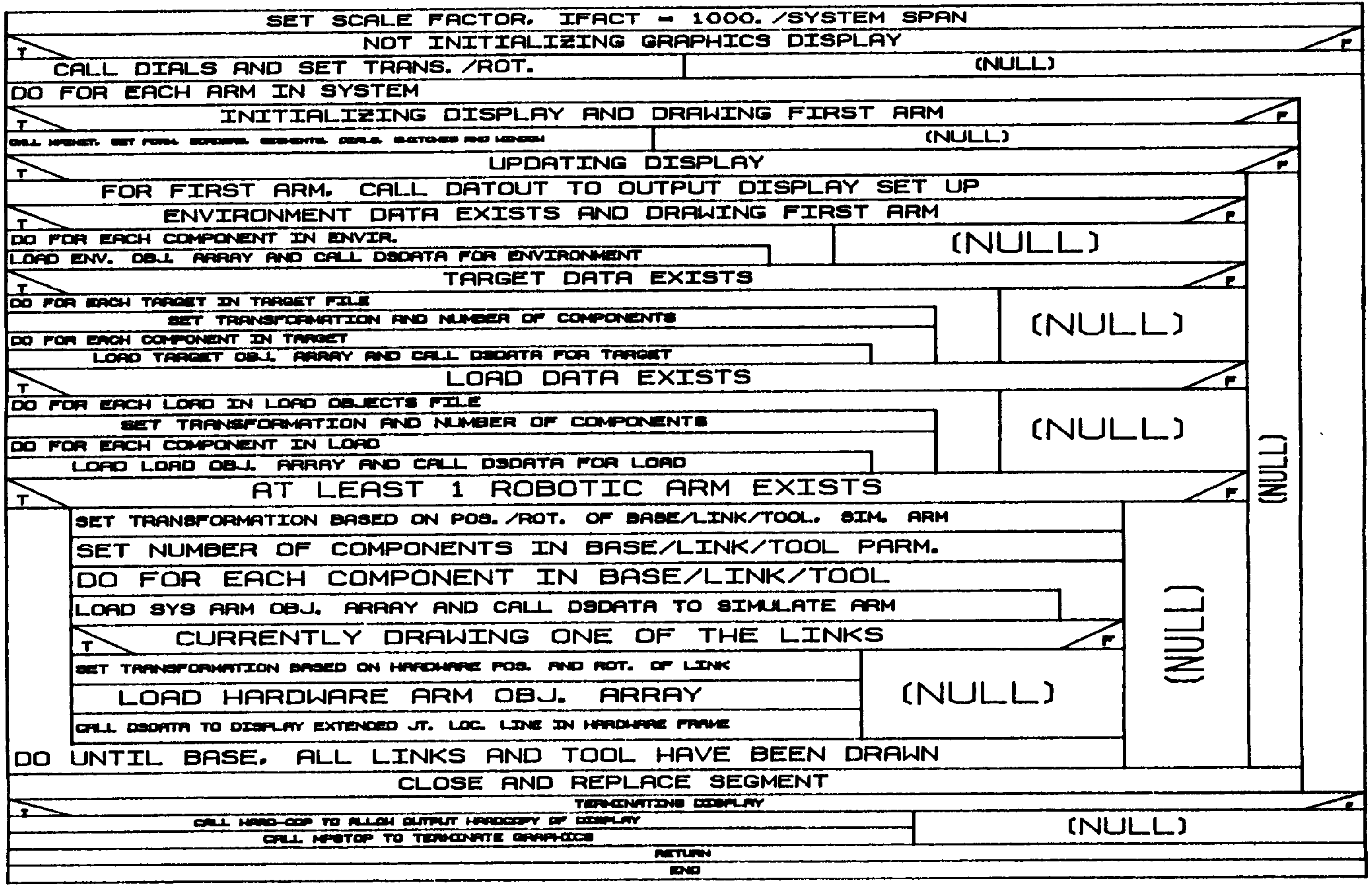


```
SUBROUTINE LDTHET
READ THETA FLAG. IRDTHET. .NE. 1
T
    TIME .GE. NEXT TIME AT WHICH TO READ THETA FILE
    T
        READ TIME FROM HARDWARE THETA FILE INTO TNEXT
        KARM = 0
            INCREMENT KARM
            THETL (LAST THETAS) = THETN (NEXT THETAS) FOR EACH JT.
            READ THETA VALUES FROM HARDWARE FILE INTO THETN FOR EACH JT.
        DO UNTIL KARM = NARM
        CALL LININT TO COMPUTE NEW THETA CONTROL SIGNAL TIME COEFFS.
        KARM = 0
            INCREMENT KARM
            N = 0
                INCREMENT N
                TH (N, KARM) . THETA = INTERPOLATION BETWEEN THETL AND THETN
            DO UNTIL N = NUMBER OF JOINTS IN KARM
        DO UNTIL KARM = NARM
    F
        (NULL)
F
    CALL THETA CALCULATION ROUTINE
RETURN
END
```

3.2.2 POSTGRAF

Subroutine POSTGRAF provides the motion graphics capability in the post-processing function for HDWMOTIN, a replay of the simulation motion versus actual hardware motion. The value of the difference in the simulation and hardware thetas is displayed, along with the environment, robotic arms, targets and load objects.

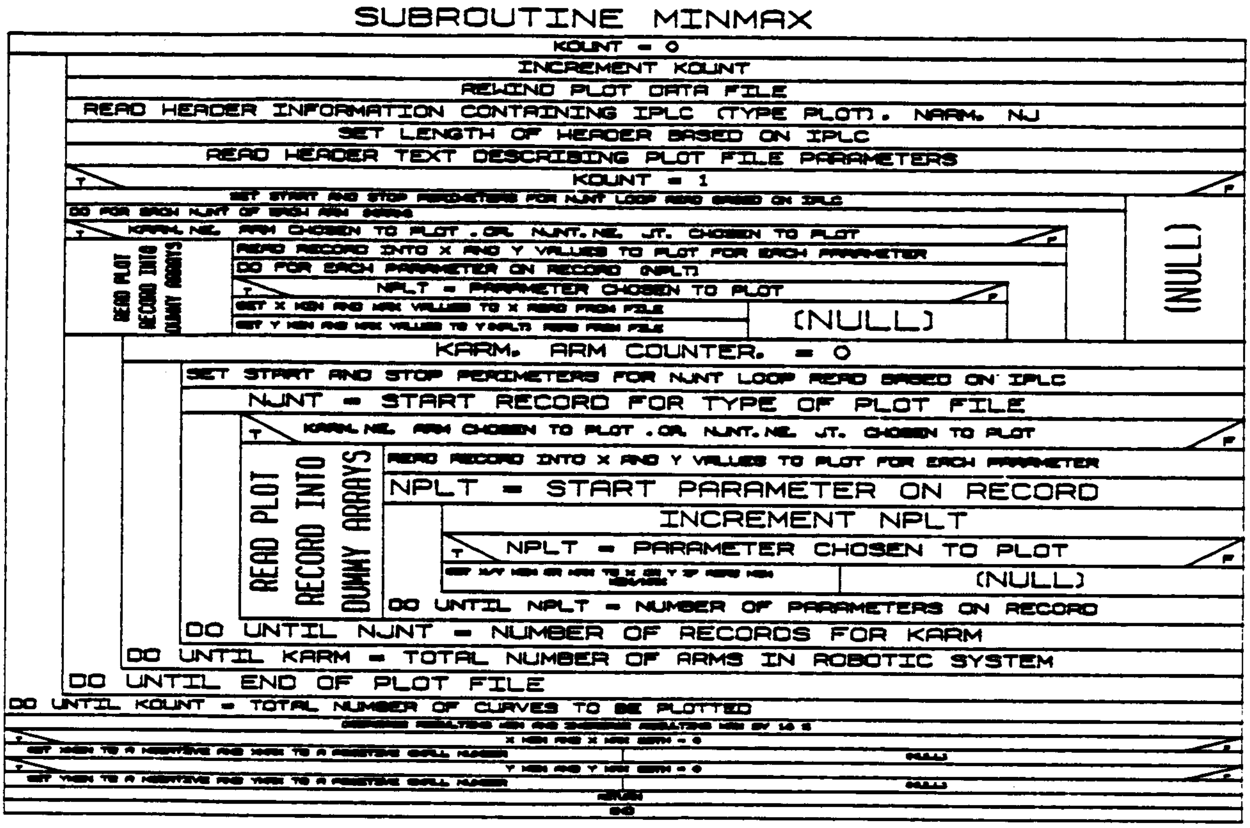
SUBROUTINE POSTGRAF



```
SET SCALE FACTOR. IFACT = 1000./SYSTEM SPAN
IF NOT INITIALIZING GRAPHICS DISPLAY
  T: CALL DIALS AND SET TRANS./ROT.
  F: (NULL)
DO FOR EACH ARM IN SYSTEM
  IF INITIALIZING DISPLAY AND DRAWING FIRST ARM
    T: CALL HPINIT. SET FORM. BORDERS. SEGMENTS. DIALS. SKETCHES AND WINDOW
    F: (NULL)
  IF UPDATING DISPLAY
    T: FOR FIRST ARM, CALL DATOUT TO OUTPUT DISPLAY SET UP
       IF ENVIRONMENT DATA EXISTS AND DRAWING FIRST ARM
         T: DO FOR EACH COMPONENT IN ENVIR.
              LOAD ENV. OBJ. ARRAY AND CALL DSDATA FOR ENVIRONMENT
         F: (NULL)
       IF TARGET DATA EXISTS
         T: DO FOR EACH TARGET IN TARGET FILE
              SET TRANSFORMATION AND NUMBER OF COMPONENTS
              DO FOR EACH COMPONENT IN TARGET
                LOAD TARGET OBJ. ARRAY AND CALL DSDATA FOR TARGET
         F: (NULL)
       IF LOAD DATA EXISTS
         T: DO FOR EACH LOAD IN LOAD OBJECTS FILE
              SET TRANSFORMATION AND NUMBER OF COMPONENTS
              DO FOR EACH COMPONENT IN LOAD
                LOAD LOAD OBJ. ARRAY AND CALL DSDATA FOR LOAD
         F: (NULL)
    F: (NULL)
  IF AT LEAST 1 ROBOTIC ARM EXISTS
    T: DO
         SET TRANSFORMATION BASED ON POS./ROT. OF BASE/LINK/TOOL, SIM. ARM
         SET NUMBER OF COMPONENTS IN BASE/LINK/TOOL PARM.
         DO FOR EACH COMPONENT IN BASE/LINK/TOOL
           LOAD SYS ARM OBJ. ARRAY AND CALL DSDATA TO SIMULATE ARM
         IF CURRENTLY DRAWING ONE OF THE LINKS
           T: SET TRANSFORMATION BASED ON HARDWARE POS. AND ROT. OF LINK
              LOAD HARDWARE ARM OBJ. ARRAY
              CALL DSDATA TO DISPLAY EXTENDED JT. LOC. LINE IN HARDWARE FRAME
           F: (NULL)
       UNTIL BASE, ALL LINKS AND TOOL HAVE BEEN DRAWN
    F: (NULL)
  CLOSE AND REPLACE SEGMENT
IF TERMINATING DISPLAY
  T: CALL HARD-COP TO ALLOW OUTPUT HARDCOPY OF DISPLAY
     CALL HPSTOP TO TERMINATE GRAPHICS
  F: (NULL)
RETURN
END
```

3.2.3 MINMAX

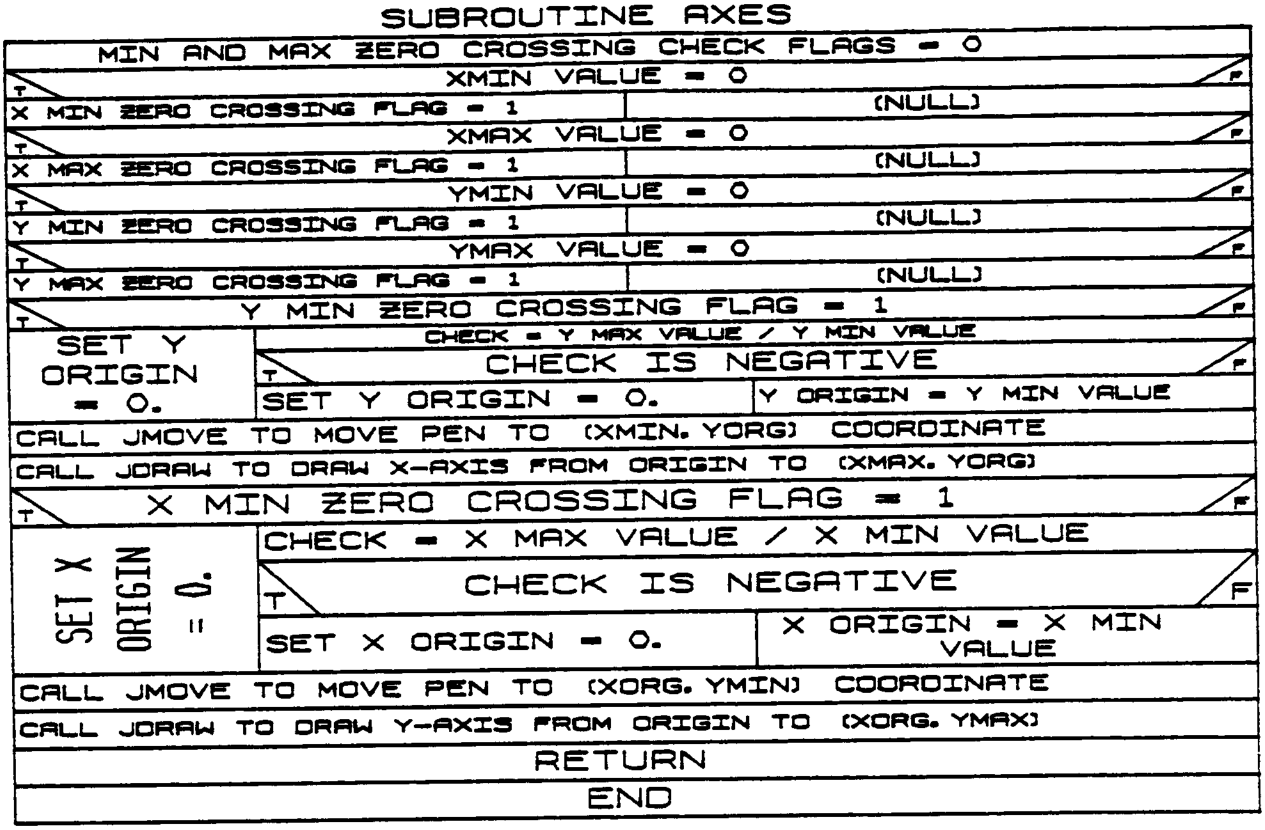
MINMAX searches the postprocessor plot file for the maximum and minimum values to be used in scaling the axes of the plot. The x and y minimums and maximums are found for all parameters the user chooses for plotting.



```
SUBROUTINE MINMAX
KOUNT = 0
    INCREMENT KOUNT
    REWIND PLOT DATA FILE
    READ HEADER INFORMATION CONTAINING IPLC (TYPE PLOT). NARM. NJ
    SET LENGTH OF HEADER BASED ON IPLC
    READ HEADER TEXT DESCRIBING PLOT FILE PARAMETERS
    KOUNT = 1
    T:
        SET START AND STOP PERIMETERS FOR NJNT LOOP READ BASED ON IPLC
        DO FOR EACH NJNT OF EACH ARM [illegible]
            KARM.NE. ARM CHOSEN TO PLOT .OR. NJNT.NE. JT. CHOSEN TO PLOT
            T:
                READ PLOT RECORD INTO DUMMY ARRAYS
                READ RECORD INTO X AND Y VALUES TO PLOT FOR EACH PARAMETER
                DO FOR EACH PARAMETER ON RECORD (NPLT)
                    NPLT = PARAMETER CHOSEN TO PLOT
                    T:
                        SET X MIN AND MAX VALUES TO X READ FROM FILE
                        SET Y MIN AND MAX VALUES TO Y(NPLT) READ FROM FILE
                    F:
                        (NULL)
    F:
        (NULL)
    KARM. ARM COUNTER. = 0
        SET START AND STOP PERIMETERS FOR NJNT LOOP READ BASED ON IPLC
        NJNT = START RECORD FOR TYPE OF PLOT FILE
            KARM.NE. ARM CHOSEN TO PLOT .OR. NJNT.NE. JT. CHOSEN TO PLOT
            T:
                READ PLOT RECORD INTO DUMMY ARRAYS
                READ RECORD INTO X AND Y VALUES TO PLOT FOR EACH PARAMETER
                NPLT = START PARAMETER ON RECORD
                    INCREMENT NPLT
                    NPLT = PARAMETER CHOSEN TO PLOT
                    T:
                        SET X/Y MIN OR MAX TO X OR Y IF NEW MIN [illegible]
                    F:
                        (NULL)
                DO UNTIL NPLT = NUMBER OF PARAMETERS ON RECORD
        DO UNTIL NJNT = NUMBER OF RECORDS FOR KARM
    DO UNTIL KARM = TOTAL NUMBER OF ARMS IN ROBOTIC SYSTEM
    DO UNTIL END OF PLOT FILE
DO UNTIL KOUNT = TOTAL NUMBER OF CURVES TO BE PLOTTED
DECREASE RESULTING MIN AND INCREASE RESULTING MAX BY 10 %
X MIN AND X MAX BOTH = 0
T:
    SET XMIN TO A NEGATIVE AND XMAX TO A POSITIVE SMALL NUMBER
F:
    (NULL)
Y MIN AND Y MAX BOTH = 0
T:
    SET YMIN TO A NEGATIVE AND YMAX TO A POSITIVE SMALL NUMBER
F:
    (NULL)
RETURN
END
```

3.2.4 AXES

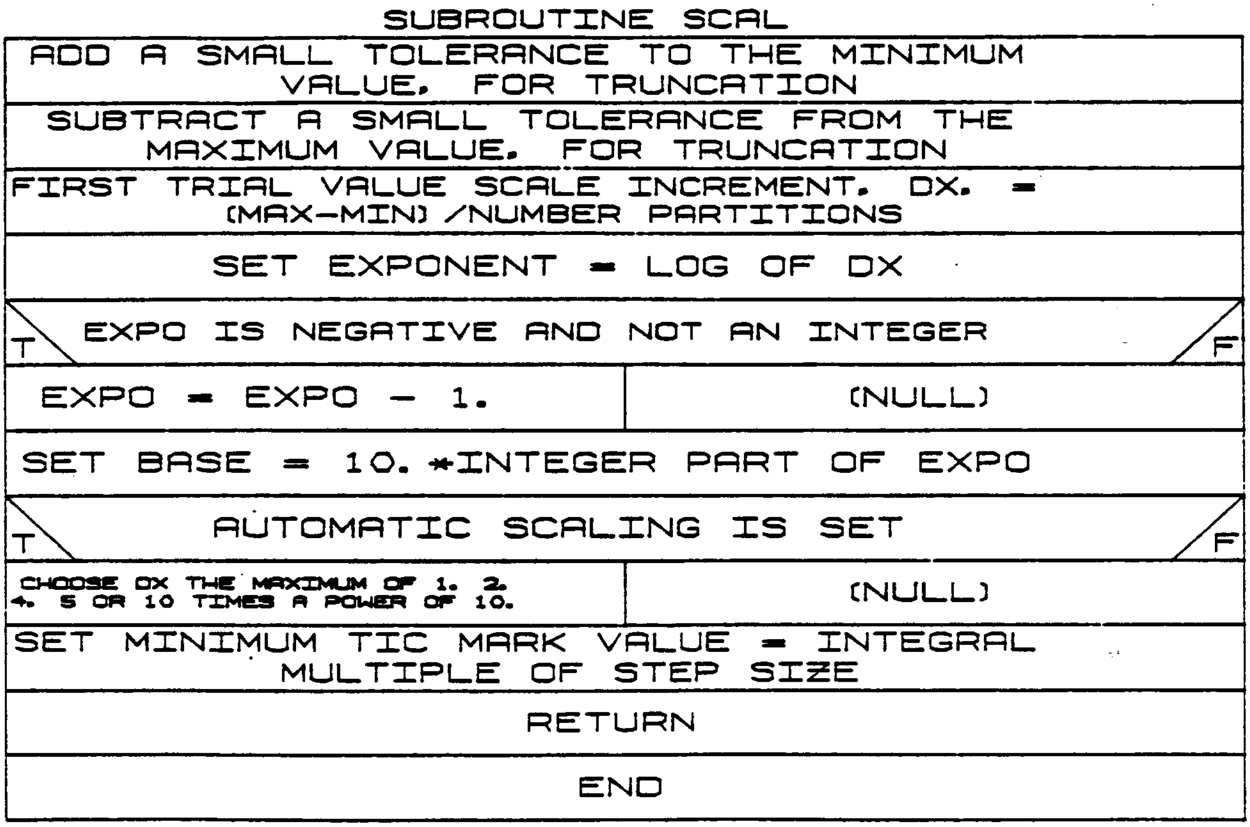
Subroutine AXES draws the x and y axes for a plot during the x-y plotting option of the postprocessor.



```
SUBROUTINE AXES
MIN AND MAX ZERO CROSSING CHECK FLAGS = 0
XMIN VALUE = 0
  T: X MIN ZERO CROSSING FLAG = 1
  F: (NULL)
XMAX VALUE = 0
  T: X MAX ZERO CROSSING FLAG = 1
  F: (NULL)
YMIN VALUE = 0
  T: Y MIN ZERO CROSSING FLAG = 1
  F: (NULL)
YMAX VALUE = 0
  T: Y MAX ZERO CROSSING FLAG = 1
  F: (NULL)
Y MIN ZERO CROSSING FLAG = 1
  T: SET Y ORIGIN = 0.
  F: CHECK = Y MAX VALUE / Y MIN VALUE
     CHECK IS NEGATIVE
       T: SET Y ORIGIN = 0.
       F: Y ORIGIN = Y MIN VALUE
CALL JMOVE TO MOVE PEN TO (XMIN, YORG) COORDINATE
CALL JDRAW TO DRAW X-AXIS FROM ORIGIN TO (XMAX, YORG)
X MIN ZERO CROSSING FLAG = 1
  T: SET X ORIGIN = 0.
  F: CHECK = X MAX VALUE / X MIN VALUE
     CHECK IS NEGATIVE
       T: SET X ORIGIN = 0.
       F: X ORIGIN = X MIN VALUE
CALL JMOVE TO MOVE PEN TO (XORG, YMIN) COORDINATE
CALL JDRAW TO DRAW Y-AXIS FROM ORIGIN TO (XORG, YMAX)
RETURN
END
```

3.2.5 SCAL

For both user-selected automatic or specified scaling of the postprocessor plot file, routine SCAL is called from the ROBPLT option. It chooses the most appropriate scale for the x- and y-axis tic marks. It finds the exponent of the scale base, the tic mark spacing and the minimum tic mark value. The minimum value, XI, to be used for the scale, and DX, the scale increment between tic marks, are chosen to satisfy specific constraints.



```
SUBROUTINE SCAL
ADD A SMALL TOLERANCE TO THE MINIMUM VALUE. FOR TRUNCATION
SUBTRACT A SMALL TOLERANCE FROM THE MAXIMUM VALUE. FOR TRUNCATION
FIRST TRIAL VALUE SCALE INCREMENT. DX. = (MAX-MIN) /NUMBER PARTITIONS
SET EXPONENT = LOG OF DX
EXPO IS NEGATIVE AND NOT AN INTEGER
    T: EXPO = EXPO - 1.
    F: (NULL)
SET BASE = 10. *INTEGER PART OF EXPO
AUTOMATIC SCALING IS SET
    T: CHOOSE DX THE MAXIMUM OF 1. 2. 4. 5 OR 10 TIMES A POWER OF 10.
    F: (NULL)
SET MINIMUM TIC MARK VALUE = INTEGRAL MULTIPLE OF STEP SIZE
RETURN
END
```

3.2.6 TICMRK

Routine TICMRK actually draws and labels the tic marks for a plot during the postprocessor function.

```
SUBROUTINE TICMRK
COMPUTE X AND Y AXIS LENGTHS
DRAW TIC MARKS OVER RANGE OF X-AXIS ORIGIN TO XMAX VALUE
DO AT X-AXIS TIC MARK FREQUENCY
    DETERMINE LENGTH OF THE CURRENT TIC MARK LABEL
    LABEL THE X-AXIS TIC MARKS WITH VALUES
DETERMINE LENGTH OF THE EXPONENT FOR THE X-AXIS SCALE
OUTPUT EXPONENT FOR THE X-AXIS SCALE
DRAW TIC MARKS OVER RANGE OF Y-AXIS ORIGIN TO YMAX VALUE
DO AT Y-AXIS TIC MARK FREQUENCY
    DETERMINE LENGTH OF THE CURRENT TIC MARK LABEL
    LABEL THE Y-AXIS TIC MARKS WITH VALUES
DETERMINE LENGTH OF THE EXPONENT FOR THE Y-AXIS SCALE
OUTPUT EXPONENT FOR THE Y-AXIS SCALE
RETURN
END
```

THE PREPROCESSING FUNCTION

The program PREPDRVR is the preprocessor function driver. It operates in an interactive mode, prompting the user to for the preprocessor option desired. Valid options are, create or modify a CAD/CAM object file or terminate PREPDRVR program execution. Figure B-10 shows the functional diagram for PREPDRVR and Table B-VIII lists the subroutine employed.

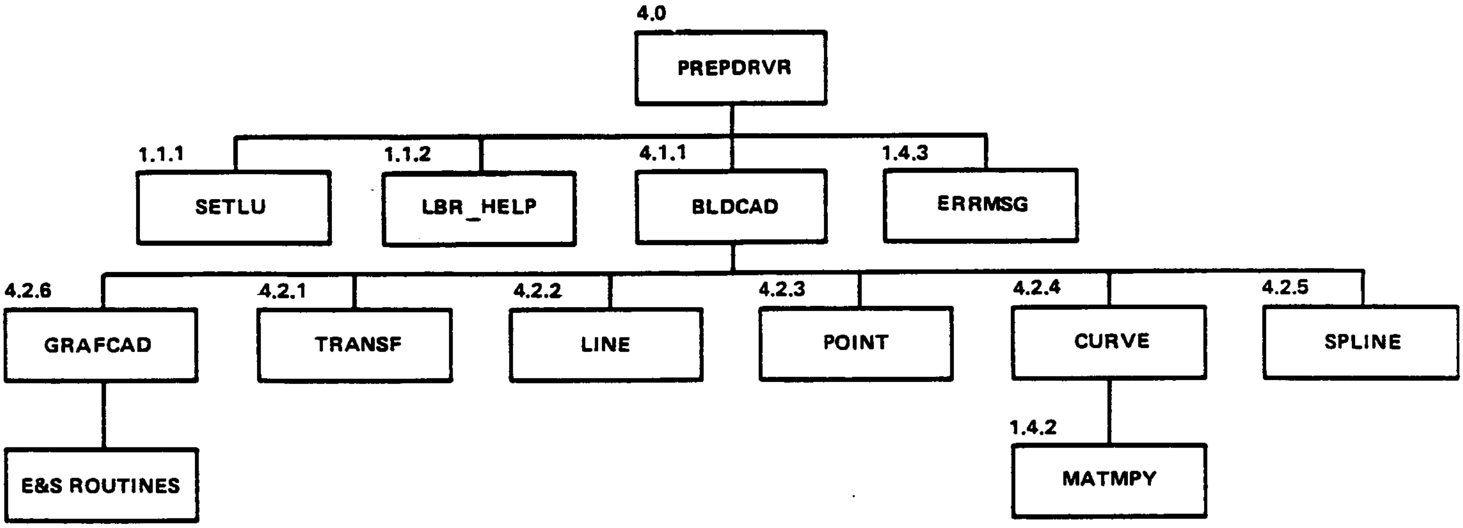


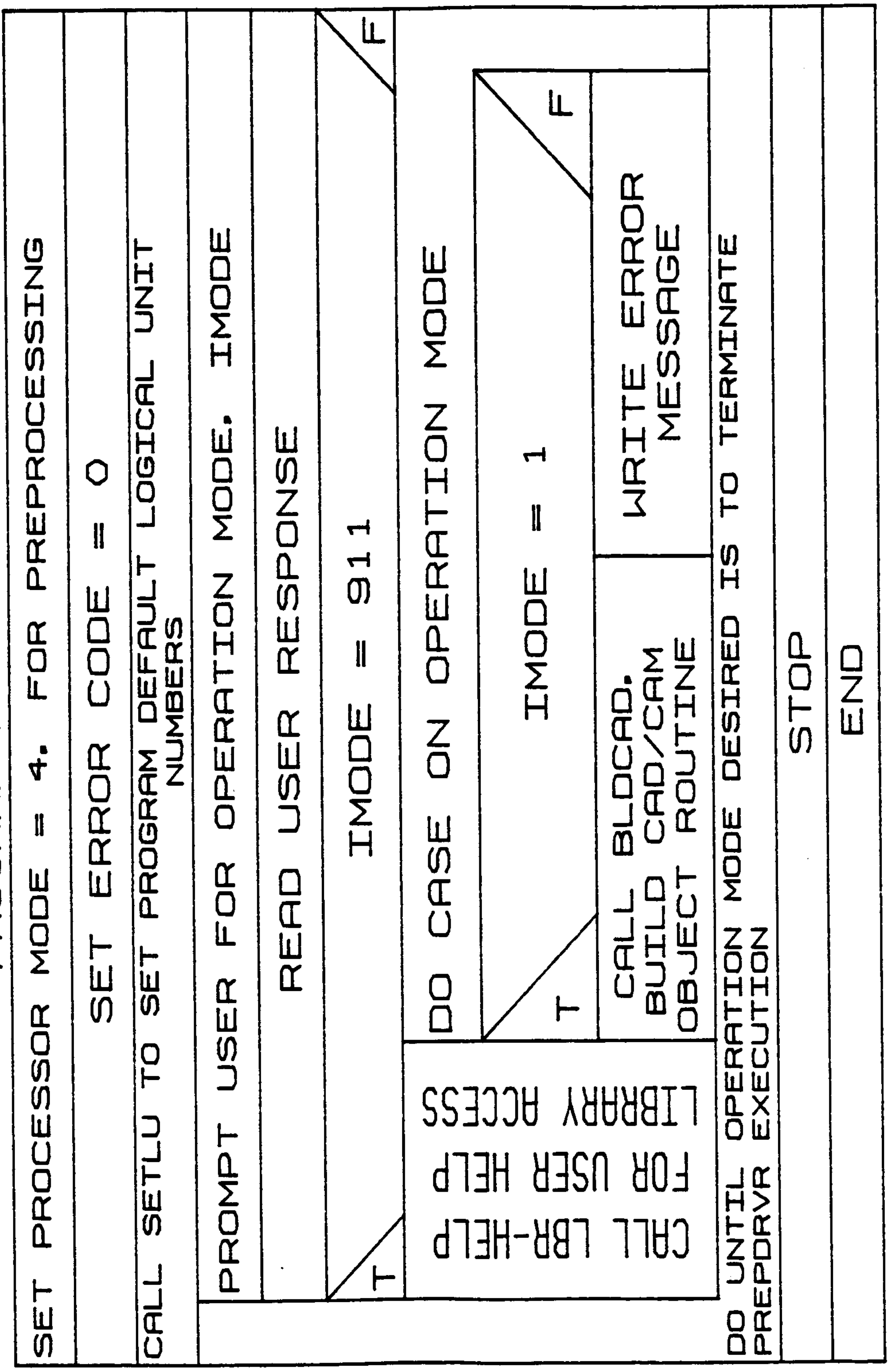
Figure B-10. Functional Block Diagram for PREPDRVR

TABLE B-VIII.-PROGRAMS EMPLOYED IN PREPDRVR

4.0	PREPDRVR
4.1.1	BLDCAD
4.2.1	TRANSF
4.2.2	LINE
4.2.3	POINT
4.2.4	CURVE
4.2.5	SPLINE
4.2.6	GRAFCAD

4.0 PREPDRVR

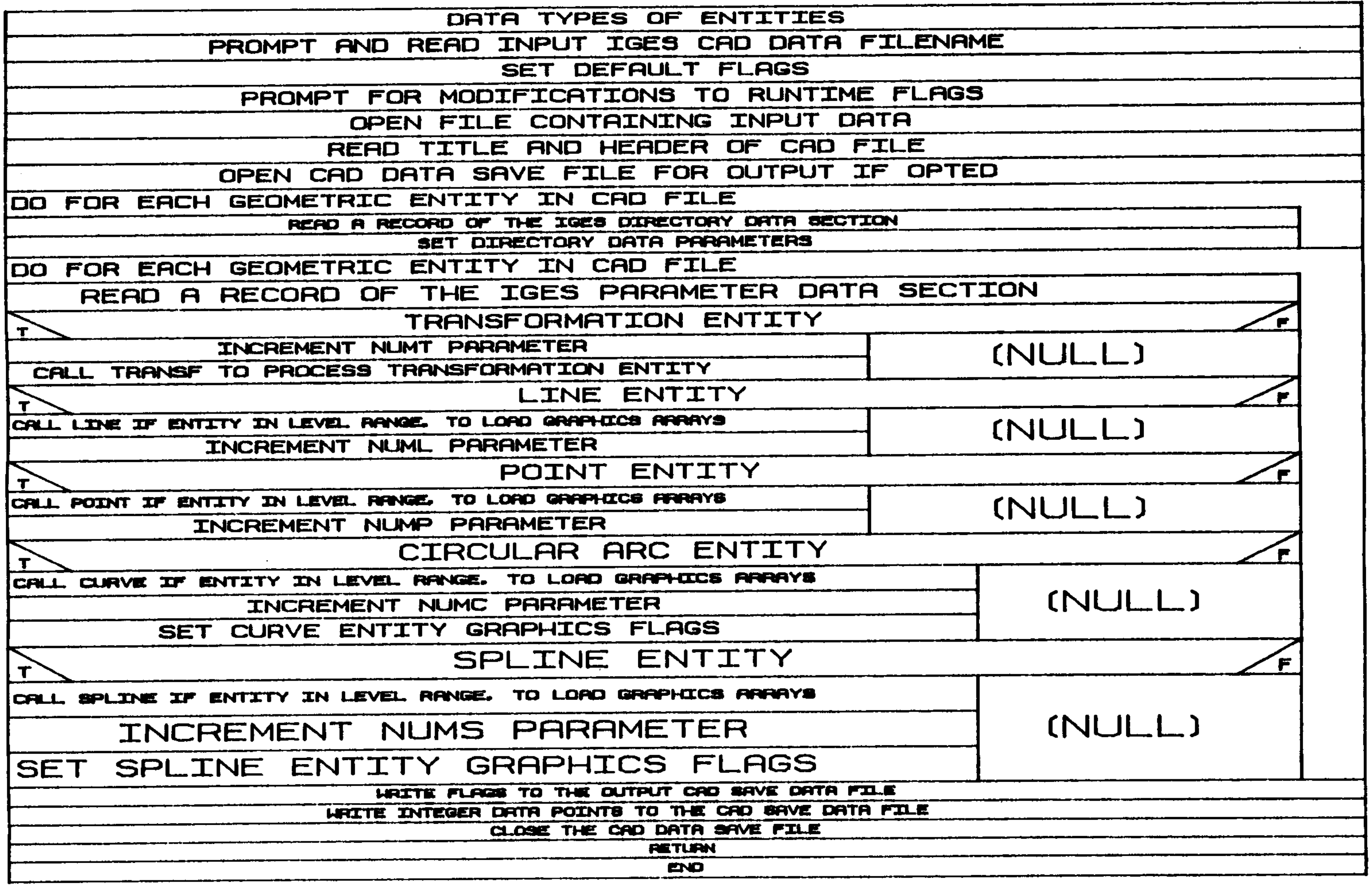
The program PREPDRVR is the Preprocessor function driver. It operates in an interactive mode, prompting the user for the preprocessor option desired. Valid options are, currently: create or modify a CAD/CAM object file or terminate PREPDRVR program execution.


PROGRAM PREPDRVR
SET PROCESSOR MODE = 4. FOR PREPROCESSING
SET ERROR CODE = 0
CALL SETLU TO SET PROGRAM DEFAULT LOGICAL UNIT NUMBERS
PROMPT USER FOR OPERATION MODE. IMODE
READ USER RESPONSE
IMODE = 911
T
F
CALL LBR-HELP FOR USER HELP LIBRARY ACCESS
DO CASE ON OPERATION MODE
IMODE = 1
T
F
CALL BLDCAD. BUILD CAD/CAM OBJECT ROUTINE
WRITE ERROR MESSAGE
DO UNTIL OPERATION MODE DESIRED IS TO TERMINATE PREPDRVR EXECUTION
STOP
END

4.1.1 BLDCAD

BLDCAD is called in the preprocessor driver. It reads a CAD/CAM initial graphics exchange specification (IGES) - formatted file, calls the appropriate entity routine to fill the real number and integer data arrays (for graphics routine interaction), and if graphics display is opted by the user, calls a graphics routine to display the entities or an Evans and Sutherland device. The file of IGES data may be saved for input during the system definition function detailed graphics generation for arms, loads, environment or targets. The format read from the IGES database follows the documentation for version 2.0 published by the National Bureau of Standards.

SUBROUTINE BLDCAD



```
DATA TYPES OF ENTITIES
PROMPT AND READ INPUT IGES CAD DATA FILENAME
SET DEFAULT FLAGS
PROMPT FOR MODIFICATIONS TO RUNTIME FLAGS
OPEN FILE CONTAINING INPUT DATA
READ TITLE AND HEADER OF CAD FILE
OPEN CAD DATA SAVE FILE FOR OUTPUT IF OPTED
DO FOR EACH GEOMETRIC ENTITY IN CAD FILE
    READ A RECORD OF THE IGES DIRECTORY DATA SECTION
    SET DIRECTORY DATA PARAMETERS
DO FOR EACH GEOMETRIC ENTITY IN CAD FILE
    READ A RECORD OF THE IGES PARAMETER DATA SECTION
    TRANSFORMATION ENTITY
    T:
        INCREMENT NUMT PARAMETER
        CALL TRANSF TO PROCESS TRANSFORMATION ENTITY
    F:
        (NULL)
    LINE ENTITY
    T:
        CALL LINE IF ENTITY IN LEVEL RANGE. TO LOAD GRAPHICS ARRAYS
        INCREMENT NUML PARAMETER
    F:
        (NULL)
    POINT ENTITY
    T:
        CALL POINT IF ENTITY IN LEVEL RANGE. TO LOAD GRAPHICS ARRAYS
        INCREMENT NUMP PARAMETER
    F:
        (NULL)
    CIRCULAR ARC ENTITY
    T:
        CALL CURVE IF ENTITY IN LEVEL RANGE. TO LOAD GRAPHICS ARRAYS
        INCREMENT NUMC PARAMETER
        SET CURVE ENTITY GRAPHICS FLAGS
    F:
        (NULL)
    SPLINE ENTITY
    T:
        CALL SPLINE IF ENTITY IN LEVEL RANGE. TO LOAD GRAPHICS ARRAYS
        INCREMENT NUMS PARAMETER
        SET SPLINE ENTITY GRAPHICS FLAGS
    F:
        (NULL)
WRITE FLAGS TO THE OUTPUT CAD SAVE DATA FILE
WRITE INTEGER DATA POINTS TO THE CAD SAVE DATA FILE
CLOSE THE CAD DATA SAVE FILE
RETURN
END
```

4.2.1 TRANSF

TRANSF CAD/CAM IGES read entity-associated transformation data and loads the transformation array for the rotations and translations to be applied to the entity before graphics display.

```
SUBROUTINE TRANSF

READ CAD FILE REAL NUMBER VALUES
FOR TRANSFORMATION/TRANSLATION

LOAD TRANSFORMATION ARRAY FOR
APPLYING ROTATIONS TO ENTITIES

RETURN

END
```

4.2.2 LINE

LINE reads CAD/CAM IGES line endpoint entity data and loads the line array for the graphics display.

SUBROUTINE LINE

READ CAD FILE REAL NUMBER VALUES FOR X, Y, Z OF LINE ENDPOINTS

LOAD LINE INTEGER ARRAY FOR GRAPHICS

RETURN

END

4.2.3 POINT

POINT reads CAD/CAM IGES point entity data and loads the points array for the graphics display.

SUBROUTINE POINT

```
READ CAD FILE REAL NUMBER VALUES
FOR X. Y. Z OF POINT
LOAD POINT INTEGER ARRAY FOR
GRAPHICS
RETURN
END
```

4.2.4 CURVE

CURVE reads CAD/CAM IGES circular arc data and loads the arc points array for the graphics display.

SUBROUTINE CURVE

```
READ CAD FILE REAL NUMBER VALUES DEFINING CURVE
CALCULATE ARC RADIUS
CALCULATE THETA REFERENCE ANGLE FOR ARC DIVISION INTO LINES
CALCULATE DISTANCE BETWEEN ENDPOINTS OF ARC
SET FLAG IF ARC IS A CIRCLE
CALCULATE TOTAL ANGLE THAT ARC SWEEPS
CALCULATE DELTA ANGLES FOR ARC DIVISIONS
DO FOR EACH DIVISION OF THE ARC
    SET ARC INTERMEDIATE POINTS ARRAY
    FIND APPROPRIATE TRANSFORMATION MATRIX FOR ARC
    CALL MATMPY TO APPLY TRANSFORMATION TO ARC POINTS
DO FOR EACH DIVISION OF THE ARC
    LOAD CURVE INTEGER ARRAY FOR GRAPHICS
RETURN
END
```

4.2.5 SPLINE

(not implemented yet)

4.2.6 GRAFCAD

GRAFCAD displays the CAD/CAM IGES entity data on an Evans and Sutherland graphics device.