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A FORTRAN PROGRAM FOR THE ANALYSIS OF LINEAR CONTINUOUS AND SAMPLED-DATA SYSTEMS

John W. Edwards

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NASA Dryden Flight Research Center
Edwards, California 93523

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16. Abstract

A FORTRAN digital computer program which performs the general analysis of linearized control systems is described. State variable techniques are used to analyze continuous, discrete, and sampled-data systems. Analysis options include the calculation of system eigenvalues, transfer functions, root loci, root contours, frequency responses, power spectra, and transient responses for open- and closed-loop systems. A flexible data input format allows the user to define systems in a variety of representations. Data may be entered by inputting explicit data matrices or matrices constructed in user-written subroutines, by specifying transfer function block diagrams, or by using a combination of these methods.

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A FORTRAN PROGRAM FOR THE ANALYSIS OF LINEAR CONTINUOUS AND SAMPLED-DATA SYSTEMS

John W. Edwards
Dryden Flight Research Center

INTRODUCTION

A FORTRAN digital computer program is described which analyzes linear continuous or sampled-data systems using state variable techniques. Open- and closed-loop systems may be analyzed using frequency response or transient response techniques. Root locus and root contour options are also available. Systems may be defined by inputting explicit data matrices, by constructing matrices in user written subroutines, or by specifying transfer function block diagrams. The program also allows the user to define a system using a combination of the above methods. For instance, the plant may be described as a set of coupled differential equations and its control system described by a block diagram. The program allows the user to analyze such a system without converting the subsystems into a common representation.

SYMBOLS

A, B, C, H, G, F, K1, K2, K3, K4, D	matrices used to define system models
$G(\cdot)$	transfer function
I	identity matrix
m	fractional computational time delay for sampled-data systems

NX, NY, NU	dimensions of state, output, and input vectors
R, S	matrices used to define system interconnections for MIXED option
s, z, w	Laplace, z-, and w- transform variables
z, v	output and input vectors for block diagram portions of MIXED systems
x, y, u	state, output, and input vectors
t	time-sec.
T	sampled-data system sample period-sec.
ϵ	incremental time period-sec.
$\phi(t)$	state transition matrix
$\theta(t)$	integral of $\phi(t)$
Subscripts:	
com	command signal
ext	external signal
n	time index for sampled-data systems
Superscripts:	
c	designates continuous subsystem of sampled-data system
d	designates discrete subsystem of sampled-data system
T	transpose of a matrix

PROGRAM DESCRIPTION

CONTROL is a FORTRAN digital program capable of performing general analysis of linearized control systems problems. It utilizes state variable matrix operations to find system eigenvalues, transfer functions, root contours, root loci, frequency responses, power spectra, and transient responses. Continuous, discrete, and sampled-data system analyses may be accomplished. The data input format is quite flexible, allowing data to be entered in matrix form, block diagram form, general parameter input form, or a combination of these forms. The analysis options available are listed in Table I.

The basic systems which CONTROL analyses are

$$\dot{x} = Ax + Bu \qquad \text{(plant equation)} \qquad (1a)$$

$$y = Hx + Fu \qquad \text{(output equation)} \qquad (1b)$$

$$u = K1\,x + Du_{com} \qquad \text{(control law)} \qquad (1c)$$

for continuous systems and

$$x_{n+1} = Ax_n + Bu_n \qquad \text{(plant equation)} \qquad (2a)$$

$$y_n = Hx_n + Fu_n \qquad \text{(output equation)} \qquad (2b)$$

$$u_n = K1\,x_n + Du_{com_n} \qquad \text{(control law)} \qquad (2c)$$

for discrete systems. The state vector, x, is NX dimensional; the output vector, y, is NY dimensional; and the input vector, u, is NU dimensional.

To allow user flexibility, additional matrix equations are used in the program for definition of feedback control laws, etc., and will be discussed later. In all cases, the system equations are reduced to the form of systems (1) or (2) before being analyzed.

CONTROL program analysis is performed in the CNTRLR subroutine which is diagrammed in figure 1. The use of each subroutine is briefly described below.

CARD - reads data cards which specify program options chosen

LOAD, MATRIX, CHANGE, CLASS - data input subroutines

LOAD - reads data input matrices

MATRIX - a user written subprogram which constructs system matrices from basic data

CHANGE - a user written subprogram which changes data already in the program. Used for parameter variation studies

CLASS - constructs system matrices from data describing a block diagram of transfer functions

SETUP - reduces input data matrices to the system equations (1) or (2)

EIGEN - determines system eigenvalues from the A matrix using QR-algorithm

ROOT - performs root loci analysis as a function of two independently incremented feedback gains

NMRATR - determines numerator zeroes of transfer functions defined by the NU inputs, u, and NY outputs, y.

FRQRSP - computes a frequency response at discrete frequencies for each transfer function determined by NMRATR

PSD - computes a power spectrum of the transfer functions determined by NMRATR assuming unity variance white noise excitation

THIST - computes a transient response of the system at discrete time points

INPUT - a user written subroutine which constructs the input vector to the transient response

The CONTROL program is on disc in the CDC CYBER 70 system and is called by the user with appropriate control cards. To utilize the full flexibility of CONTROL, the user may write several of the subroutines to perform data preparation for his specific problem. These subroutines are:

MAIN

MATRIX

CHANGE

INPUT

These subroutines may be compiled in SOURCE language. Note that they are not required. These subroutines are defined in the program on disc and are overridden by the user's source subroutines. If a specific output format is desired, any of the CONTROL subroutines may be modified by the user and compiled to override the disc versions. A brief description of the use of these routines is given below:

MAIN - Provides variable dimensioning capability. The size of all arrays used in CONTROL is declared here and passed through COMMON to all other subroutines. Thus the size of the system matrixes may be quickly and easily changed. The disc program is provided with:

MX = 15 = n + 1; n = dimension of maximum state

MY = 15 = dimension of maximum output vector

MY = 10 = dimension of maximum input vector

MATRIX - A user written subroutine which constructs the system matrices. For instance, MATRIX may read the nondimensional aircraft stability derivatives, perform axes transformations, dimensionalize the derivatives, and insert the proper numbers into the system matrixes. General MATRIX routines are available for the standard lateral-directional and longitudinal linearized equations of motion which are generally used at FRC.

CHANGE - A user written subroutine which changes specified elements in the system matrices (which are already constructed through MATRIX, LOAD, or CLASS). This routine allows the capability of doing parameter variation studies on a basic system configuration without having to reload the problem data for each variation.

INPUT - This user written routine constructs the input vector for a time history calculation. Thus the user may generate step, impulse, ramp, sinusoidal, random inputs as desired. A basic routine which simply reads 1 card for the input vector $\underline{u}$ is provided.

All of these routines have specified calling sequences which are given in Appendix 1. Each routine has specific COMMON and DIMENSION statements which are required and which the user will not change. The structure of the CONTROL deck is shown in figure 2. The job control language for CONTROL is given in Table II. All figures, tables and information required to set up data for the CONTROL program are gathered at the end of this document for easy reference by the user.

CONTINUOUS SYSTEM MODELS

The basic continuous system model which CONTROL analyzes is given by (1) and is repeated here:

$$\dot{x} = Ax + Bu$$
$$y = Hx + Fu$$
$$u = K1x + Du_{com}$$

CONTROL analyzes three configurations of continuous system models: open loop, closed loop, and root loci. These three configurations are under the control of SYSTEM. For ease in problem setup, the additional matrices D, K1, K2, K3, K4, C, and G are defined.

Open Loop (SYSTEM = 1)

$$C\dot{x} = Ax + Bu \tag{3a}$$
$$y = Hx + G\dot{x} + Fu \tag{3b}$$

Closed Loop (SYSTEM = 2)

$$C\dot{x} = Ax + Bu \tag{4a}$$
$$u = K1x + K2\dot{x} + Du_{com} \tag{4b}$$
$$y = Hx + G\dot{x} + Fu \tag{4c}$$

Subscript COM indicates a "command" signal. Note that the inclusion of the C matrix allows inertial cross-coupling between states. K2 and G allow for state derivative feedback and output. D allows for controller interconnections and feedforward gains.

CONTROL reduces the systems (3) and (4) with the substitutions

$$A \leftarrow C^{-1}A + C^{-1}B\left(I - K2\,C^{-1}B\right)^{-1}\left(K1 + K2\,C^{-1}A\right)$$
$$B \leftarrow C^{-1}B\left(I - K2\,C^{-1}B\right)^{-1}D$$
$$H \leftarrow H + GC^{-1}A + \left(F + GC^{-1}B\right)\left(I - K2\,C^{-1}B\right)^{-1}D$$
$$F \leftarrow \left(F + GC^{-1}B\right)\left(I - K2\,C^{-1}B\right)^{-1}D$$

to the system,

$$\dot{x} = Ax + Bu_{com} \tag{5a}$$
$$y = Hx + Fu_{com} \tag{5b}$$

Note that (5) is identical to the basic system (1) with u replaced by u_{COM}. Obviously, for the open-loop system D = I, K1 = K2 = 0, and $u = u_{COM}$.

<u>Root Loci</u> (SYSTEM = 3)

$$C\dot{x} = Ax + Bu \tag{6a}$$
$$u = k_1(K1\,x + K2\,\dot{x}) + k_3(K3\,x + K4\,\dot{x}) \tag{6b}$$

This root loci model allows root loci as a function of two independent feedback variables. The first feedback variable is defined by the matrices K1 and K2 (e.g., normal acceleration = $\frac{V}{g}(\dot{\alpha} - q)$). K3 and K4 define the second feedback variable (commonly K3 = K4 = 0). The condition codes N1, N2, GAIN1, and GAIN2 determine the locus gain and number of locus points as follows:

$$k_1 = r * GAIN1 \qquad r = \begin{cases} 0, 1, 2, 3, \ldots, N1\,; & N1 > 0 \\ 0, 1, 2, 4, \ldots, 2^{(|N1|-2)}\,; & N1 < 0 \end{cases}$$

$$k_3 = t * GAIN2 \qquad t = \begin{cases} 0, 1, 2, 3, \ldots, N2\,; & N1 > 0 \\ 0, 1, 2, 4, \ldots, 2^{(|N2|-2)}\,; & N1 < 0 \end{cases}$$

CONTROL computes the closed-loop system matrix as:

$$\dot{x} = A x$$

where

$$A \longleftarrow A' + B'\left(I - k_1 K' - k_3 K^2\right)^{-1}\left(k_1 K^3 + k_3 K^4\right)$$

$$A' \longleftarrow C^{-1} A$$
$$B' \longleftarrow C^{-1} B$$
$$K' \longleftarrow K2\,B'$$
$$K^2 \longleftarrow K4\,B'$$
$$K^3 \longleftarrow K1 + K2\,A'$$
$$K^4 \longleftarrow K3 + K4\,A'$$

The eigenvalues of A are then determined to find the system root locus. The zeroes corresponding to the first feedback variable are determined by forming the observation equation:

$$y = Hx + Fu$$

where

$$H = \begin{bmatrix} K1 + K2\,A' \\ \hdashline K3 + K4\,A' \end{bmatrix}$$

$$F = \begin{bmatrix} K2\,B' \\ \hdashline K4\,B' \end{bmatrix}$$

A subsequent call to NMRATR then determines the zeroes. NMRATR determines the zeroes of the transfer function specified by the first nonzero row of these derived H and F matrices. If PLOT $\neq 0$, an additional data card is required for each root locus specifying the maximum and minimum axis coordinates desired for the plot (see Table II).

The continuous system models given above are summarized in Table III(a).

MIXED Systems

This problem formulation can be used to model a system which is described by a combination of differential equations and Laplace transform blocks. An example of such a system is an aircraft-control system. The aircraft equations of motion are usually known as differential equations while the control system is often given in block diagram form. The MIXED option gives the user the capability of easily modeling such a system. This option, which is a great convenience in analyzing continuous systems, becomes indispensable in the analysis of sampled-data systems. There it is used to correctly connect the continuous and discrete subsystems and to discretize to the continuous subsystem at the proper times.

The MIXED option involves a two-step data input stream. In the first step, the plant equations of motion are loaded as an open-loop system. The second step loads the block diagram control system data (CLASS subroutine) and augments the open-loop plant matrices with the control system dynamics.

Finally, the two subsystems are coupled together. The open-loop, closed-loop, and root locus options are available with the MIXED option.

The CLASS subroutine may be used by itself to construct state space formulations of systems described entirely by block diagrams. The input format for the MIXED option will be given after the CLASS loading option has been discussed.

DATA DECK FORMAT

CONTROL problem definition is accomplished in CARD. Condition codes defining the analysis options chosen, data input mode, and data handling procedures are read in a namelist format (CODE). Each pass through CNTRLR (figure 1) defines a case.

The CONTROL program data deck structure is shown in figure 3. The title card, namelist CODE, output label card, input label card, system data, and transient response input data formats are given in Table IV.

The format for entering data using namelist is illustrated in figure 4. Column 1 of each card must be blank. Column 2 of card 1 begins the name of the namelist (CODE) which is followed by a blank. Variable names in the namelist must be right justified with respect to the "=" sign, variable values must be right justified with respect to the "," sign and be of the proper type (real, integer). The namelist data entry is closed by the code ",&END."

The analysis options chosen, data input format, and system structure are defined in the namelist, CODE. The variables which are defined by the namelist are:

Integer variables

READ, SYSTEM, OUTPUT, MIXED, DIGITL, FRPS, NUMERS, TRESP, NX, NY, NU, NXC, NUC, ZOH, N1, N2, CONTUR, MULTRT, MODEL, NSCALE, CMAT, NK2, FORM, IPT, IGO, SAV, IFLAG, READ3

Real variables

DELT, FINALT, IFREQ, FFREQ, DELFRQ, GAIN1, GAIN2, M

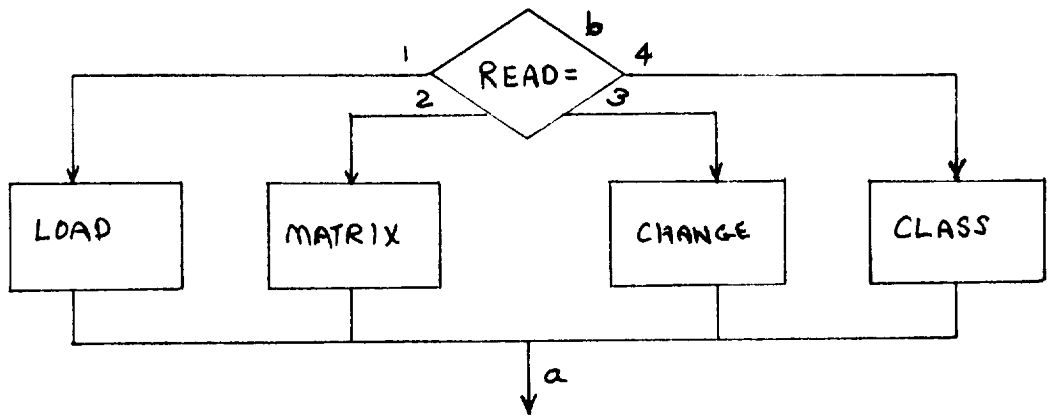
These variables are described in Appendix 2. All variables are initialized to zero at the start of each case (unless SAV = 1) and only nonzero variables need be defined in the namelist.

For root locus cases in which plots are requested, one card is required for each root locus by the plotter program to define the $j\omega$ scale on the plot. This card(s) follows the PLOT CARDS card.

Figure 1 indicates that CONTROL will return to the top of the program and look for more data at the end of each case. Thus data decks may be stacked together to analyze many cases on a single computer run.

DATA INPUT OPTIONS

The system data may be input in four different methods. The control loading option is determined by the condition code READ:



CHANGE (READ = 3) The CHANGE option is meant to be used on cases following an initial case. For instance, on case 1, the system matrices are loaded or constructed in LOAD, MATRIX, or CLASS. These "original" system matrices (as defined at point (a) on case 1) may be saved and made available at point (b) in case 2. If CHANGE is utilized in case 2, the "original" system matrices may be altered as desired. Thus a parameter variation study may be accomplished using a simple CHANGE subroutine.

The remaining three options--LOAD, MATRIX, and CLASS--will now be described.

LOAD (READ = 1) The subroutine LOAD reads explicit data matrices under the control of the condition codes. Each data matrix (e.g., A) is read row by row with an (8F10.4) format. Each data matrix must be preceded by a dimension card (2I10) giving the number of rows and columns in the matrix. For example, a 5 x 5 matrix would require 6 data cards (1 dimension card, 1 card per row) while an 8 x 9 matrix would require 19 data cards (1 dimension card, 2 cards per row). The matrices required are listed in STEP 1 of Table V.

MATRIX (READ = 2) MATRIX is a user written subroutine which constructs the system matrices required by the condition codes. These matrices are the same as those given in STEP 1 of Table V. Data defined in MATRIX are not destroyed by CONTROL. Thus the user may input data to the MATRIX subroutine for case 1 and reuse the data on subsequent cases.

CLASS (READ = 4) If READ = 4 the system matrices are constructed in CLASS from block diagram input data. If MIXED = 1, the control system dynamics, in block diagram form, are added on to the plant dynamics by the CLASS subroutine. Thus the CLASS subroutine has a dual function in CONTROL. In both cases, the data format describing the block diagram is the same. The data format is given as STEP 2 of Table V. Two options of inputting the block diagram information are provided. The first option describes the block diagram by inputting the transfer function polynomial coefficients explicitly for general fourth-order transfer functions. The second option allows the user to pick standard form constant, first-order, or second-order blocks to describe the system. These blocks are defined by a small number of parameters and are given in Table VI. The first option is used only if a particular transfer function form cannot be found in Table VI. The first option will not be described. A description of the second option begins on page 21.

The data required to describe a system given entirely by block diagrams are summarized below. The additional data required if MIXED = 1 will be described later.

NBLOCK = No. of blocks in block diagram

GRAPH = Integer matrix describing interconnection of blocks

BLOCK = Integer matrix describing dimension of numerator and denominator polynomials of each block

NUMER = Matrix of polynomial coefficients of numerators of each block (ordered from $s^\circ \longrightarrow s^m$)

DENOM = Matrix of polynomial coefficients of denominators of each block (ordered from $s^\circ \longrightarrow s^n$)

GAIN = Vector of gains of each block

ITHINY = Integer vector describing which block outputs are to be saved in final H matrix

Allowable forms of blocks:

Form

1 $\longrightarrow \boxed{\dfrac{K\left(b_m s^m + b_{m-1} s^{m-1} + \cdots + b_1 s + b_0\right)}{a_n s^n + a_{n-1} s^{n-1} + \cdots + a_1 s + a_0}} \longrightarrow \quad (m < n)$

2 $\longrightarrow \boxed{\dfrac{K\left(b_n s^n + b_{n-1} s^{n-1} + \cdots + b_1 s + b_0\right)}{a_n s^n + a_{n-1} s^{n-1} + \cdots + a_1 s + a_0}} \longrightarrow$

3 $\longrightarrow \boxed{Ks} \longrightarrow$

4 $\longrightarrow \boxed{K} \longrightarrow$

Restrictions:

a.) Inputs into a type 3.) block must be outputs of a type 1.) block.

b.) $n \leq 4$

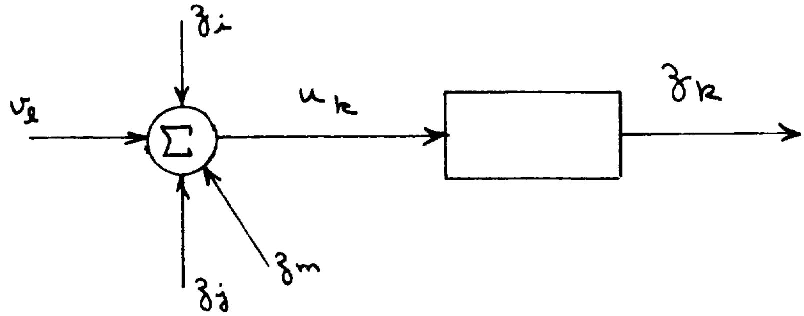
c.) Number of blocks $\leq$ 20

Interconnection of blocks:

The interconnection of blocks may be described with the concept of internal and external inputs to a block:

Internal input - an input which is an output of a block in the system.

External input - any input other than internal inputs, designated by v . The input to any block may be the sum of three or less internal inputs and one external input.



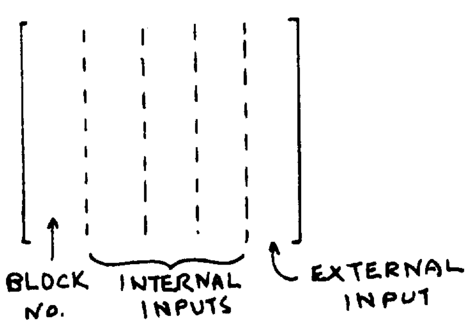
$$u_k = \pm v_l \pm z_i \pm z_j \pm z_m$$

The ± indicates that either sign may be used on any of the inputs. Whenever an external input is defined, a summing junction is implied at the input to the block.

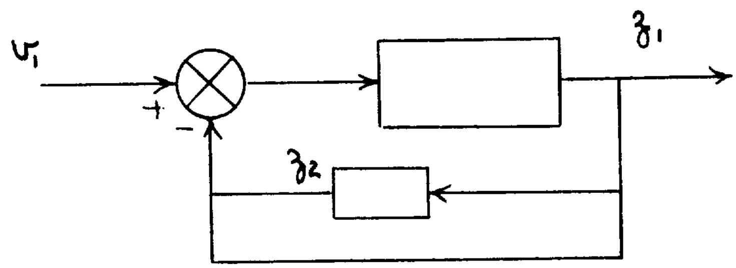
Problem formulation

1. Label the outputs of the blocks consecutively z_i, i = 1,2,3,....
2. Label the external inputs consecutively v_j , j = 1,2,3,...
3. Construct the GRAPH Matrix (dimension NBLOCK x 5) where NBLOCK = number of blocks in the diagram:

GRAPH =



A simple example will illustrate the method:



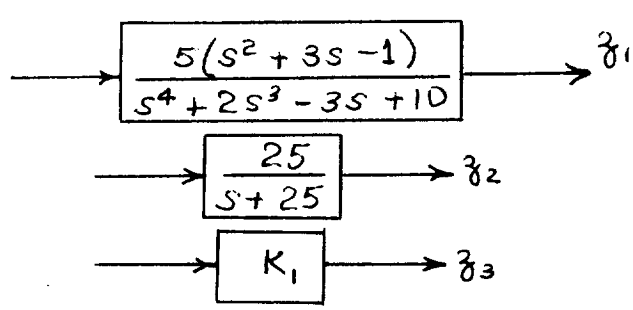
$$\text{GRAPH} = \begin{bmatrix} 1 & -2 & -1 & 0 & 1 \\ 2 & 1 & 0 & 0 & 0 \end{bmatrix}$$

Note that negative inputs to summing junctions are indicated by the negative sign attached to the input label.

The following input data describe the internal composition of each block:

BLOCK - Describes the number of coefficients of the numerator and denominator polynomials which will be loaded (dimension NBLOCK x 3). The first column contains the block number (the sequence must correspond to the sequence of the first column of GRAPH). The second column contains the number of numerator coefficients to be loaded. The third column contains the number of denominator coefficients to be loaded.

example:



$$\longrightarrow \boxed{K_2 s} \longrightarrow z_4$$

$$\longrightarrow \boxed{\frac{3(s+10)}{s+20}} \longrightarrow z_5$$

$$\longrightarrow \boxed{\frac{s}{s+4}} \longrightarrow z_6$$

$$\text{BLOCK} = \begin{bmatrix} 1 & 3 & 5 \\ 2 & 1 & 2 \\ 3 & 1 & 1 \\ 4 & 2 & 1 \\ 5 & 2 & 2 \\ 6 & 2 & 2 \end{bmatrix}$$

Note that a constant block K is treated as $K\frac{1}{1}$.

Also

$$\boxed{Ks} = \boxed{\frac{K(s+0)}{1}}$$

NUMER (NBLOCK x 5)

NUMER contains the numerator coefficients.

For the above example:

$$\text{NUMER} = \begin{bmatrix} -1. & 3. & 1. & 0 & 0 \\ 25. & 0 & 0 & 0 & 0 \\ 1. & 0 & 0 & 0 & 0 \\ 0 & 1. & 0 & 0 & 0 \\ 10. & 1. & 0 & 0 & 0 \\ 0 & 1. & 0 & 0 & 0 \end{bmatrix}$$

DENOM (NBLOCK x 5)

Denom contains the denominator coefficients.

For the above example:

$$\text{DENOM} = \begin{bmatrix} 10. & -3. & 0 & 2. & 1. \\ 25. & 1. & 0 & 0 & 0 \\ 1. & 0 & 0 & 0 & 0 \\ 1. & 0 & 0 & 0 & 0 \\ 20. & 1. & 0 & 0 & 0 \\ 4. & 1. & 0 & 0 & 0 \end{bmatrix}$$

GAIN (NBLOCK)

Gain is a vector containing the gain constants of the blocks.

For the above example:

$$\text{GAIN} = \begin{bmatrix} 5 & 1 & K_1 & K_2 & 3 & 1 \end{bmatrix}$$

ITHINY ($\leqslant$ NBLOCK)

In constructing the system matrices, CLASS constructs the output equation

$$y = Hx + Fu$$

where y is an NBLOCK vector. That is, the output of each block is defined as a component of the y vector. Ordinarily, the user will want to study only a few of these outputs. The ITHINY vector "thins" out the y vector. For the above example if;

$$\text{ITHINY} = \begin{bmatrix} 1 & 3 & 4 \end{bmatrix}$$

then $y^t = (z_1, z_3, z_4)^t$

The second option of defining a block diagram will now be described. This option allows the user to pick standard form transfer functions given in Table VI to describe the block diagram. Only one data card per block is required to describe the system. The option is chosen by setting NIT = 1 on the first card of STEP 2. The data required to specify each block are NUM, TYPE, CONNEC, MOD, PARAM where

NUM is the block number.

TYPE is the type of transfer function from Table VI.

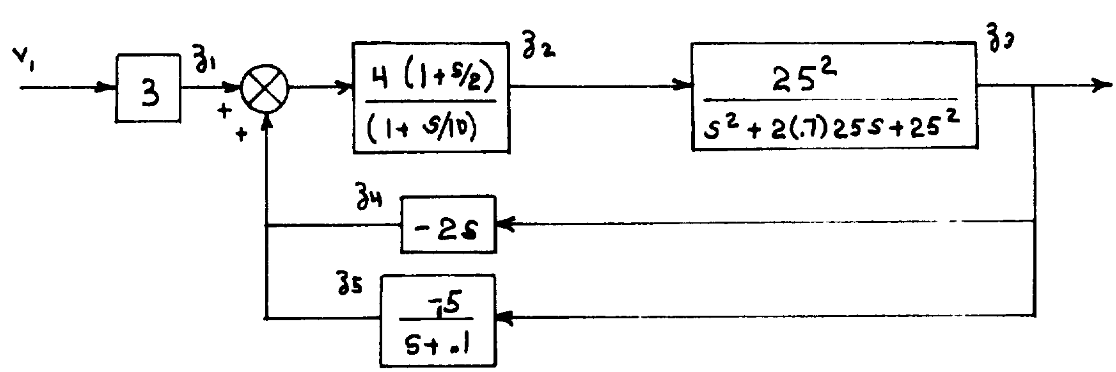
CONNEC specifies the connections between blocks and the external inputs. (This is the last four columns of GRAPH.)

MOD specifies whether the transfer function is an s, z, or w -transform.

PARAM gives the parameters defining the block as indicated in Table VI.

Following the cards giving the above data for each block, one card for ITHINY is read.

example: set up the input data required to describe the system



The data required are

5	1								
1	1	0	0	0	1	0	3.		
2	5	1	4	5	0	0	4.	10.	2.
3	8	2	0	0	0	0	1.	25.	.7
4	2	3	0	0	0	0	-2.		
5	4	3	0	0	0	0	-5.	.1	
1	2	3	4	5					

CLASS constructs a state space representation of each individual block using the phase variable canonical form. For example, the first block of the previous example:

$$G(s) = \frac{5(s^2 + 3s - 1)}{s^4 + 2s^3 - 3s + 10}$$

is modeled as

$$\dot{x} = Ax + Bu$$
$$y = Hx + Fu$$

where

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -10 & 3 & 0 & -2 \end{bmatrix} \qquad B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

$$H = \begin{bmatrix} -5 & 15 & 5 & 0 \end{bmatrix} \qquad F = \begin{bmatrix} 0 \end{bmatrix}$$

CLASS constructs the state space representation of the entire block diagram in the following manner:

1. Write the output vector of the collection of blocks as

$$Cz = Hx + Fv$$
$$z = C^{-1}Hx + C^{-1}Fv$$

2. Write the state equation describing the internal structure of each block (in phase variables) ignoring all connections between blocks and defining the "internal" input

vector, u

$$\dot{x} = Ax + Bu$$

3. Define the connection matrix, G, as

$$u = Gz$$

where

$$G(i, \text{GRAPH}(i,j)) = 1 \quad \text{if} \quad \text{GRAPH}(i,j) \neq 0 \quad j = 2,3,4$$
$$= 0 \quad \text{otherwise}$$

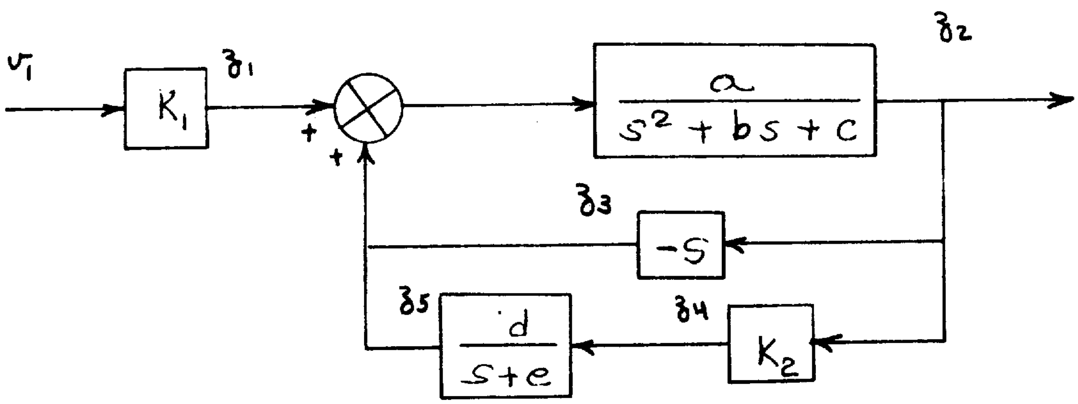
4. Couple the blocks together as

$$\dot{x} = (A + BGC^{-1}H)x + (BGC^{-1}F)v$$

$$y = (C^{-1}H)x + (C^{-1}F)v$$

The process of constructing the state variable representation is illustrated in the following example.

example: The operations described above will be performed for the system in the diagram.



$$\text{GRAPH} = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 2 & 1 & -3 & 5 & 0 \\ 3 & 2 & 0 & 0 & 0 \\ 4 & 2 & 0 & 0 & 0 \\ 5 & 4 & 0 & 0 & 0 \end{bmatrix}$$

1. Write the output equation.

$$C z \quad = \quad H x \quad + \quad F v$$

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & -K_2 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \\ z_5 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ a & 0 & 0 \\ 0 & -a & 0 \\ 0 & 0 & 0 \\ 0 & 0 & d \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} K_1 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} v_1 \end{bmatrix}$$

$$z = C^{-1} H x + C^{-1} F v$$

$$z = \begin{bmatrix} 0 & 0 & 0 \\ a & 0 & 0 \\ 0 & -a & 0 \\ aK_2 & 0 & 0 \\ 0 & 0 & d \end{bmatrix} x + \begin{bmatrix} K_1 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} v$$

2. Write the state equation of the uncoupled blocks.

$$\dot{x} = Ax + Bu$$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ -c & -b & 0 \\ 0 & 0 & -e \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \end{bmatrix}$$

3. Write the connection matrix.

$$u = Gz$$

$$\begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \\ z_5 \end{bmatrix}$$

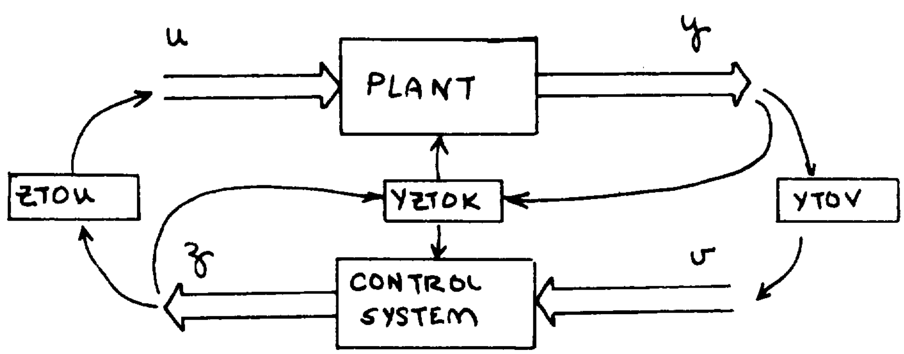
4. Couple the blocks together.

$$\dot{x} = (A + BGC^{-1}H)\,x + (BGC^{-1}F)\,v$$

$$\dot{x} = \begin{bmatrix} 0 & 1 & 0 \\ -c & -(a+b) & d \\ aK_2 & 0 & -e \end{bmatrix} x + \begin{bmatrix} 0 \\ K_1 \\ 0 \end{bmatrix} v$$

MIXED INPUT OPTION (CONTINUOUS SYSTEMS)

Mixed systems are characterized by having a portion of the system described by a set of differential equations and the remainder of the system described in block diagram form. The MIXED input option allows these systems to be analyzed without requiring the user to convert the system into a common representation. Typically the plant equations of motion are given and the control system is represented in block diagram form. The MIXED option constructs the state space representation of the system in a two-step process, the first step defining the plant and the second step augmenting the system with the control system block diagram data.



The input-output pairs for the plant and control system are designated ($\underline{u}$, $\underline{y}$) and ($\underline{v}$, $\underline{z}$), respectively. The state of the plant is $\underline{x}_1$, and the state of the control system is $\underline{x}_2$. The blocks YTOV, ZTOU, and YZTOK in the above diagram are additional connection data required by CLASS. They are used to connect the plant and controller. YZTOK defines a feedback gain matrix to allow a conventional root locus to be performed while connections specified by YTOV and ZTOU are incorporated directly into the total system A matrix. Table V indicates the input data required for the MIXED option.

STEP 1 The plant is modeled as an open-loop system regardless of the value of SYSTEM. (In this case, SYSTEM refers to the total, augmented system).

$$C_1 \dot{x}_1 = A_1 x_1 + B_1 u_1$$

$$y = H_1 x_1 + G_1 \dot{x}_1 + F u$$

The quantities NX, NY, NU in the namelist must refer to this step. Additional dimensions required in step 2 are added by the program.

STEP 2 The control system is modeled by CLASS in the same manner described in the previous section. The required data are:

NBLOCK, GRAPH, BLOCK, NUMER, DENOM, GAIN,
ITHINY, ITHINU, NYTOV, NZTOU, NYZTOK, YTOV,
ZTOU, YZTOK.

The first seven quantities were defined in the last section while the remaining quantities specify how the system is connected.

ITHINY - Integer vector numbering, in sequence, those components of the augmented output vector $(y^T, z^T)^T$ to be saved for analysis.

ITHINU - Integer vector numbering, in sequence those components of the augmented input vector $(u^T, v^T)^T$ to be saved for analysis.

NYTOV - Number of connections from y to v.

NZTOU - " " " z to u.

NYZTOK - Number of feedback paths defined (with root locus option, the first connection specifies K1 and the second connection specifies K3.).

YTOV - Integer matrix of dimension (NYTOV) x 2. Each row of the matrix describes a connection from y to v. The first element of a row specifies the component of y to be connected to the element of v specified by the second element.

ZTOU - Integer matrix of dimension (NZTOU) x 2 specifying connections between z and u in the same fashion as YTOV.

YZTOK - Integer matrix of dimension (NYZTOK) x 2 specifying a feedback gain matrix. The first number of a row specifies which element of the augmented output $(y^T, z^T)^T$ is to be fed back to the element of the augmented input $(u^T, v^T)^T$ specified by the second number of the row.

Note that numbers in YTOV and ZTOU refer to indexing in the individual vectors u, v, y, z while numbers in YZTOK refer to indexing in the augmented vectors $(u^T, v^T)^T$ and $(y^T, z^T)^T$. In all cases, the indexing is specified before any thinning of the output or input has occurred.

The CLASS subroutine constructs the state space representation of the control system with the above data. The system is:

$$\dot{x}_2 = A_2 x_2 + B_2 v$$
$$z = H_2 x_2 + F_2 v$$

The total system, at this point, is in the form of uncoupled diagonal blocks:

$$\begin{bmatrix} \dot{x}_1 \\ \hdashline \dot{x}_2 \end{bmatrix} = \left[\begin{array}{c:c} A_1 & 0 \\ \hdashline 0 & A_2 \end{array}\right] \begin{bmatrix} x_1 \\ \hdashline x_2 \end{bmatrix} + \left[\begin{array}{c:c} B_1 & 0 \\ \hdashline 0 & B_2 \end{array}\right] \begin{bmatrix} u \\ \hdashline v \end{bmatrix} \quad (7a)$$

$$\begin{bmatrix} y \\ \hdashline z \end{bmatrix} = \left[\begin{array}{c:c} H_1 & 0 \\ \hdashline 0 & H_2 \end{array}\right] \begin{bmatrix} x_1 \\ \hdashline x_2 \end{bmatrix} + \left[\begin{array}{c:c} F_1 & 0 \\ \hdashline 0 & F_2 \end{array}\right] \begin{bmatrix} u \\ \hdashline v \end{bmatrix} \quad (7b)$$

where the dimensions are

x_1 - NX
x_2 - NX1
y - NY
z - NY1
u - NU
v - NU1

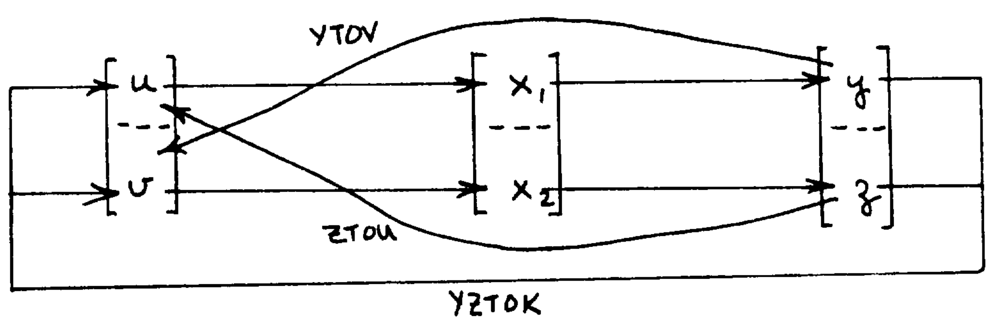
$$\begin{bmatrix} x_1 \\ \hdashline x_2 \end{bmatrix} - \quad NXT = NX + NX1$$

$$\begin{bmatrix} y \\ \hdashline z \end{bmatrix} - \quad NYT = NY + NY1$$

$$\begin{bmatrix} u \\ \hdashline v \end{bmatrix} - \quad NUT = NU + NU1$$

The last three vectors above are the augmented state, augmented output, and augmented input vectors, respectively.

The system is now coupled together using YTOV, ZTOU, and YZTOK. The connections between the augmented input, state, and output vectors may be diagramed as follows.



$$\begin{bmatrix} u \\ \hdashline v \end{bmatrix} = \begin{bmatrix} 0 & \vdots & R_1 \\ \hdashline R_2 & \vdots & 0 \end{bmatrix} \begin{bmatrix} y \\ \hdashline z \end{bmatrix} + S \begin{bmatrix} u_{com} \\ \hdashline v_{com} \end{bmatrix} \quad (8)$$

where subscript "com" designates an external "command" input. The dimensions of R_1, R_2, and S are

$$R_1 - NU \times NY1$$
$$R_2 - NU1 \times NY$$
$$S - NUT \times (\text{\# of elements in ITHINU})$$

R_1, R_2, and S are constructed according to the rules:

$$r_{1_{ij}} = \begin{cases} 1.0 & \text{if } ZTOU(k,1) = j \text{ and } ZTOU(k,2) = i \; ; \; k = 1,2,\ldots,NZTOU \\ 0 & \text{otherwise} \end{cases}$$

$$r_{2_{ij}} = \begin{cases} 1.0 & \text{if } YTOV(k,1) = j \text{ and } YTOV(k,2) = i \; ; \; k = 1,2,\ldots,NYTOV \\ 0 & \text{otherwise} \end{cases}$$

$$S_{ij} = \begin{cases} 1.0 & \text{if } \; i = ITHINU(j) \; ; \; j = 1,2,\ldots, \\ 0 & \text{otherwise} \end{cases}$$

The submatrices R_1 and R_2 will be used to couple A_1 and A_2 while S is used to thin out the augmented input vector of unnecessary inputs. Unwanted outputs are thinned out at the very end by simply deleting rows of the final H and F output matrices (ITHINY).

The six partitioned matrices in (7) and (8) are defined to be A, B, H, F, R, and S and the system of equations is reduced to the basic system (1) with the substitutions

$$A \leftarrow A + BR(I-FR)^{-1}H$$

$$B \leftarrow BR(I-FR)^{-1}FS + BS$$

$$H \leftarrow (I-FR)^{-1}H$$

$$F \leftarrow (I-FR)^{-1}FS$$

Now YZTOK is utilized to construct a feedback gain matrix if a root locus is desired. The feedback control law is

$$u = K1\,x + K2\,\dot{x}$$

The feedback gain matrices, K1 and K2, are constructed by the rule:

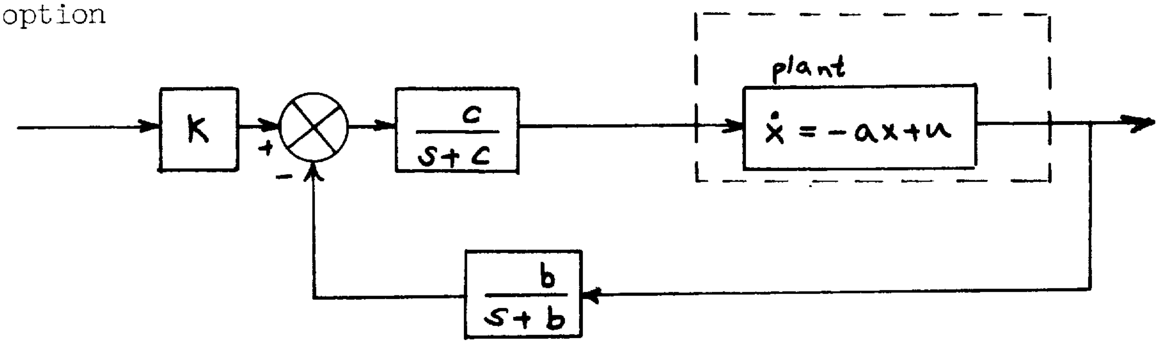
> let YZTOK (1, 1) = i
>
> YZTOK (1, 2) = j
>
> then the jth rows of K1 and K2 are copied from the ith row of the output matrices H and F. Thus feedback is defined from the ith output to the jth input.

If SYSTEM = 3 (root locus) a second row of YZTOK (if any) would be used to construct a second feedback variable into K3 and K4, which would define the second feedback of a two-dimensional root locus.

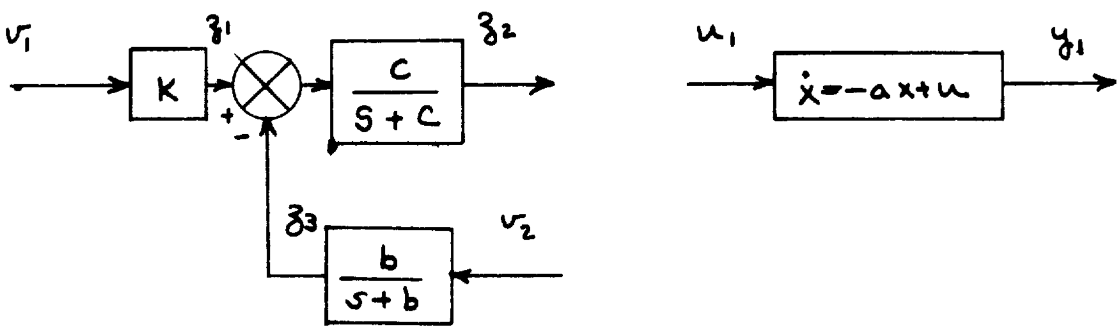
If a root locus is desired in which feedback is defined to the jth input, then the jth input cannot be thinned out of the system (i.e., j must appear in ITHINU).

If SYSTEM = 2 (closed loop) any number of feedback paths may be defined in YZTOK.

example: Set up the system indicated below using the MIXED option



The plant is described by a first order differential equation (STEP 1) and the control system is described by its block diagram representation. Redrawing the diagram:



$$\text{GRAPH} = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 2 & 1 & -3 & 0 & 0 \\ 3 & 0 & 0 & 0 & 2 \end{bmatrix}$$

a. If a closed-loop analysis is desired

$$\text{YTOV} = [1 \quad 2]$$
$$\text{ZTOU} = [2 \quad 1]$$

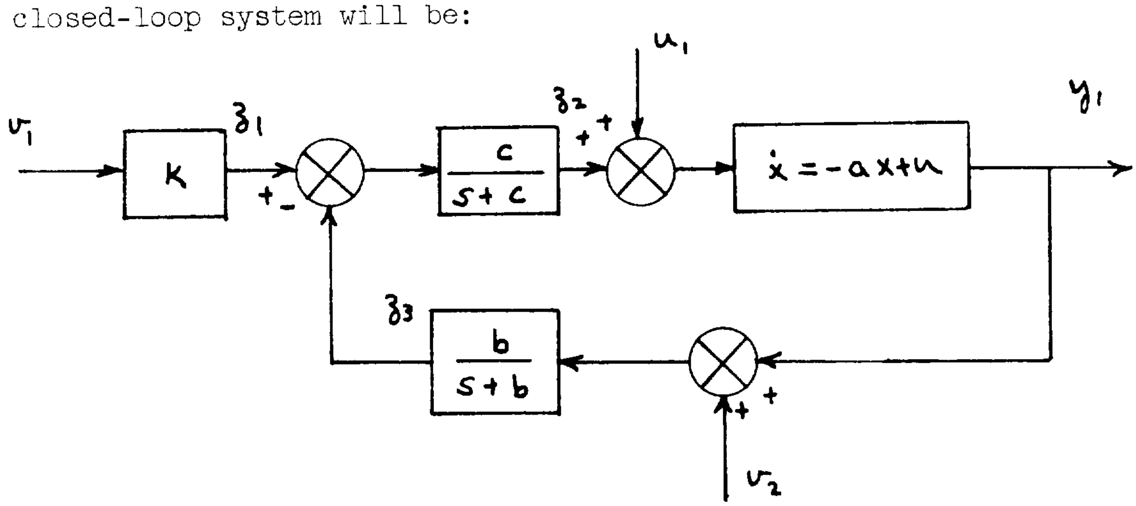
will connect the system correctly.

b. If a root locus is desired

$$\text{YTOV} = [1 \quad 2]$$
$$\text{YZTOK} = [3 \quad 1]$$

will provide the required feedback matrix (alternatively ZTOU = $[2 \ 1]$, YZTOK = $[1 \ 3]$ will also give the desired locus, defining the feedback at a different point of the system).

Returning to the closed-loop system of a., the resulting closed-loop system will be:



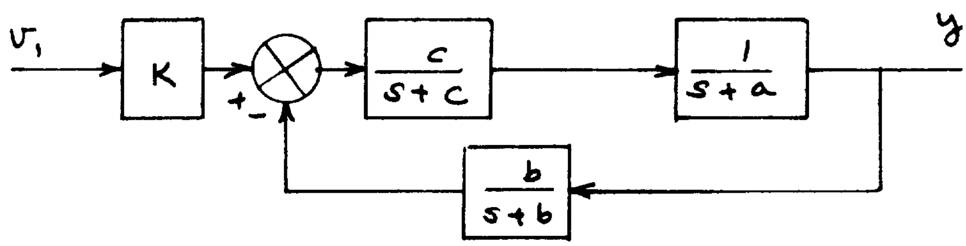
with

$$u = \begin{bmatrix} u_1 \\ \hdashline v_1 \\ v_2 \end{bmatrix} \qquad y^T = [y_1 \ z_1 \ z_2 \ z_3]$$

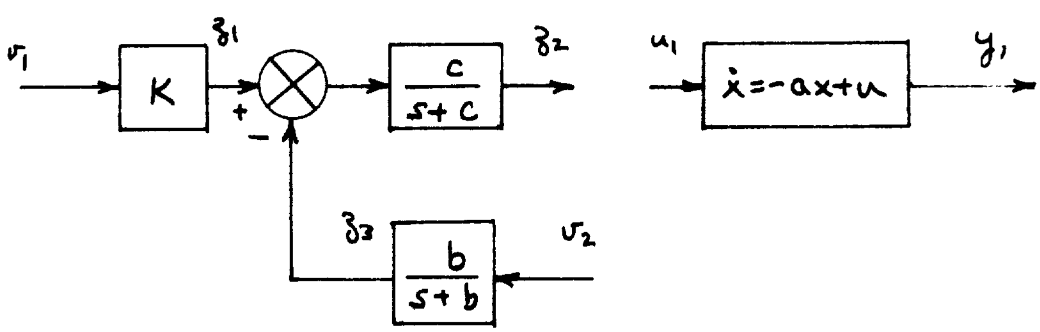
Notice that the connections defined by YTOV and ZTOU create summing junctions. Following the connection of the system the input label (e.g., v_2) refers to the "external input" to the summing junction and not to the "error signal" (output of the summing junction). In many cases these external inputs are not of interest and will be thinned out with ITHINU. Similar thinning will usually be done on the output vector. For instance

$$\text{ITHINU} = [2]$$
$$\text{ITHINY} = [1]$$

results in the system



example: set up the system of the previous example to do a root locus

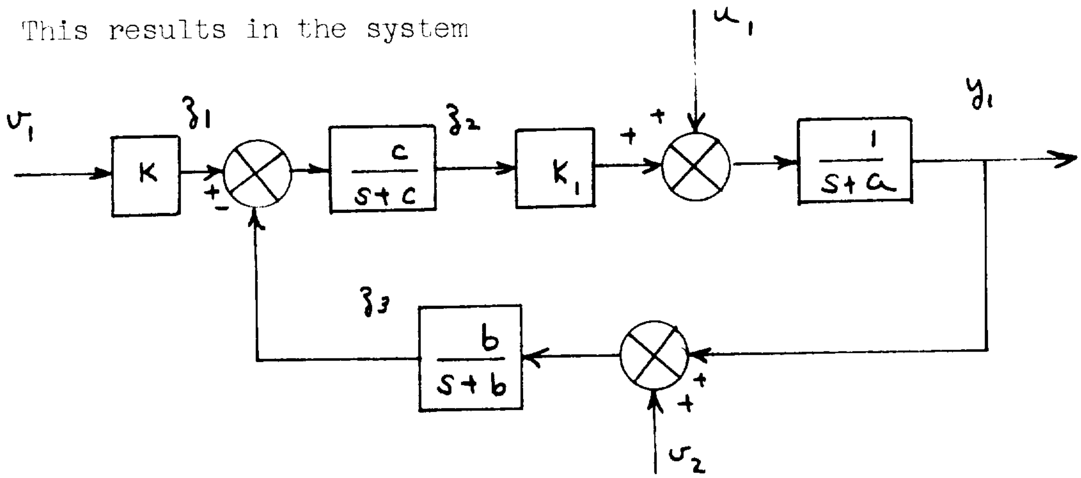


The above system can be put into the standard root locus form by defining

$$YTOV = \begin{bmatrix} 1 & 2 \end{bmatrix}$$

$$YZTOK = \begin{bmatrix} 3 & 1 \end{bmatrix}$$

This results in the system

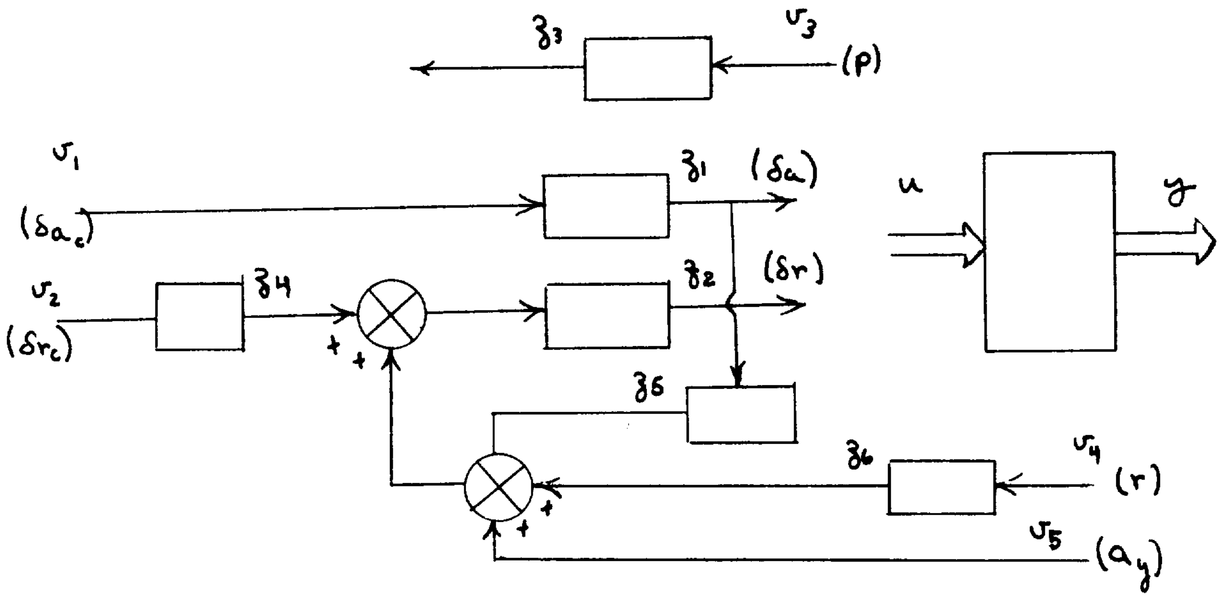


where K_1 is the root locus gain. For this system v_1 and v_2 may be thinned out but u_1 cannot be thinned out since a feedback variable has been defined to it. No output equation is defined for a root locus case, but the open-loop zeroes of z_2 due to an input at u_1 will be determined.

example: Suppose that STEP 1 of the MIXED option has defined a model of the lateral-directional dynamics of an airplane (A_1, B_1, H_1, F_1) with the plant input and output vectors:

$$u = \begin{bmatrix} \delta a \\ \delta r \end{bmatrix} \qquad y = \begin{bmatrix} p \\ r \\ \beta \\ \phi \\ a_y \end{bmatrix}$$

It is desired to add a control system with actuator dynamics, roll rate, yaw rate, and sideforce feedbacks, and an aileron-to-rudder interconnect. Finally, a root locus of the roll rate feedback is desired with the yaw rate and sideforce feedback loops closed. The block diagram is:



(The internal dynamics of the blocks are not considered in this example since we are concerned with the method of connecting the system together.) The augmented input and output vectors are

$$u = \begin{bmatrix} \delta a \\ \delta r \\ \hdashline \delta a_c \\ \delta r_c \\ p \\ r \\ a_y \end{bmatrix} \qquad y = \begin{bmatrix} p \\ r \\ \beta \\ \phi \\ a_y \\ \hdashline \delta a \\ \delta r \\ z_3 \\ z_4 \\ z_5 \\ z_6 \end{bmatrix}$$

The pertinent input data are

$$\text{GRAPH} = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 2 & 4 & 5 & 6 & 5 \\ 3 & 0 & 0 & 0 & 3 \\ 4 & 0 & 0 & 0 & 2 \\ 5 & 1 & 0 & 0 & 0 \\ 6 & 0 & 0 & 0 & 4 \end{bmatrix}$$

$$\text{YTOV} = \begin{bmatrix} 1 & 3 \\ 2 & 4 \\ 5 & 5 \end{bmatrix}$$

$$\text{ZTOU} = \begin{bmatrix} 1 & 1 \\ 2 & 2 \end{bmatrix}$$

$$\text{YZTOK} = \begin{bmatrix} 8 & 3 \end{bmatrix}$$

The loading options which have been described above are summarized in Table V.

1. If READ = 1,2,3 and MIXED = 0, use STEP 1 of Table V. The required matrices must be defined via LOAD, MATRIX, or CHANGE.
2. If READ = 4 and MIXED = 0, use only STEP 2 of Table V. The required matrices will be constructed in CLASS from the block diagram data (GRAPH, etc.).
3. If MIXED = 1, the open-loop plant is defined by STEP 1 of Table V and the control system block diagram added as STEP 2 of Table V. In STEP 1, define the open-loop

plant as if SYSTEM = 1 regardless of the actual value of SYSTEM. SYSTEM, in this case, refers to the augmented system.

DISCRETE SYSTEM MODELS

If a system is known in a completely discrete form, then the system can be described by a combination of the vector difference equations,

$$x_{n+1} = A x_n + B u_n \tag{10a}$$

$$u_n = K1 x_n + D u_{com_n} \tag{10b}$$

$$y_n = H x_n + F u_n \tag{10c}$$

The matrices G, C, K2, and K4 are not defined for discrete systems. This model is algebraically equivalent to the continuous system models (3), (4), and (6) and allows open-loop, closed-loop, and root locus models to be defined. The same computer algorithms which were used to generate eigenvalues for continuous systems can then be used for the discrete system. The resulting transfer functions are Z-transform transfer functions. The vector output sequence, y_n, corresponds to the continuous system transient response and may be generated directly from equations (10). The namelist parameters are defined in the same fashion as for continuous systems and all of the analysis options are available. To specify completely discrete system analysis, set DIGITL = 2 and DELT = T where T is the sample period. The completely discrete system models are given in Table IIIb. Frequency responses are generated in the w-plane by means of the bilinear transformation

$$z = \frac{1 + w}{1 - w}$$

SAMPLED-DATA SYSTEM MODELS

Sampled-data systems are composed of a continuous dynamical subsystem and a discrete subsystem. The continuous subsystem is called the plant and the discrete subsystem is called the digital controller. Usually, but not always, the digital controller will be a dynamical system. To analyze a sampled-data system, the continuous plant must be discretized so that the two subsystems have a common representation. Careful attention must be given to the structure of the system in this discretizing process and the interconnection of the two subsystems. The MIXED option assumes a central role in the sampled-data analysis with the YTOV, ZTOU, and YZTOU options used to define the connections between the subsystem.

The sampled-data system is block diagramed in figure 5 in which $D(z)$ is the digital controller described by the triple (u^d_n, x^d_n, y^d_n) and $G(s)$ is the continuous plant described by the triple (u^c, x^c, y^c) . The plant and digital controller dynamics are given by

$$\dot{x}^c = A_c x^c + B_c u^c \qquad (11a)$$

$$y^c = H_c x^c + F_c u^c \qquad (11b)$$

$$x^d_{n+1} = A_d x^d_n + B_d u^d_n \tag{12a}$$

$$y^d_n = H_d x^d_n + F_d u^d_n \tag{12b}$$

The dimension of x^c is NXC and the dimension of u^c is NUC. (The $G\dot{x}$ term in the output equation for y^c is allowed and has already been eliminated in equation (11)b. These two systems are combined in the partitioned matrix form,

$$\begin{bmatrix} \dot{x}^c \\ \hline x^d_{n+1} \end{bmatrix} = \left[\begin{array}{c|c} A_c & 0 \\ \hline 0 & A_d \end{array}\right] \begin{bmatrix} x^c \\ \hline x^d_n \end{bmatrix} + \left[\begin{array}{c|c} B_c & 0 \\ \hline 0 & B_d \end{array}\right] \begin{bmatrix} u^c \\ \hline u^d_n \end{bmatrix} \tag{13a}$$

$$\begin{bmatrix} y^c \\ \hline y^d_n \end{bmatrix} = \left[\begin{array}{c|c} H_c & 0 \\ \hline 0 & H_d \end{array}\right] \begin{bmatrix} x^c \\ \hline x^d_n \end{bmatrix} + \left[\begin{array}{c|c} F_c & 0 \\ \hline 0 & F_d \end{array}\right] \begin{bmatrix} u^c \\ \hline u^d_n \end{bmatrix} \tag{13b}$$

Thus the order of the augmented state and output vectors is

(a) plant states (outputs)

(b) digital controller states (outputs)

CONTROL discretizes the upper left hand (NXC) x (NXC) sub-matrix of the augmented system A matrix.

The plant is generally assumed to be an open-loop system but analog feedback loops may be defined within the plant. Any such analog feedback must be defined explicitly in the plant A matrix, in YTOV, or ZTOU. Analog actuator dynamics and sensor dynamics are included in the plant. Actuators and sensors may be modeled in block diagram form using the MIXED option. The digital controller will usually be comprised of a summing junction and digital filters. External inputs to the plant and digital controller may be defined. External inputs to the digital controller are considered to be sequences of numbers, $u^{d}_{ext_n}$, separated in time by the sample period, T. External inputs to the plant, u^{c}_{ext} , are considered as sampled continuous inputs. The inputs to the plant are comprised of the outputs of the digital controller and the sampled external inputs. These inputs may be applied to the plant as

(a) outputs of samplers (pulse trains)

(b) outputs of zero-order-hold elements,

The sampled-data block diagram of figure 5 is capable of representing a wide range of sampled-data systems. Figure 6 shows several of the possible configurations. Figure 6(a) shows an open-loop plant with a sampled (pulse train) input, figure 6(b) shows a closed-loop plant with a sampled error signal, figure 6(c) shows a closed-loop plant with digital compensation in the feedback path, and figure 6(d) shows a closed-loop plant with digital compensation in the forward path. Questions arising in the analysis of these systems involves the stability of the closed-loop system, the system transient response, and the synthesis of (digital) control systems. The CONTROL program allows these questions to be studied using the z-plane root locus, the w-plane frequency response (both standard and modified z-transforms), and the system transient response.

In order to perform this analysis, it is necessary to discretize the plant to obtain a discrete system model of the entire sampled-data system.

The form of the input function determines the proper discretization of the plant. CONTROL treats the first ZOH elements of u^c as inputs from zero-order-hold elements and the remaining (NUC - ZOH) elements of u^c as sampled inputs. Thus the ordering of the augmented input vector is

(a) zero-order-hold inputs to plant

(b) sampled inputs to plant

(c) discrete inputs to digital controller

CONTROL discretizes the upper left hand (NXC) x (NUC) submatrix of the augmented system B matrix. The first ZOH columns of the submatrix are discretized to account for the zero-order-hold effect and the remaining (NUC-ZOH) columns are discretized to account for the sampling effect.

The system which results from the discretization of the plant is block diagramed in figure 7. All of the sequences x_n^d, x_n^c, y_n^c, etc., are defined at the same instants of time

$$t = nT \; ; \quad n = 0, 1, 2, \ldots$$

However, since the system actually contains a continuous subsystem which has a continuous state trajectory it is necessary to define the exact meaning of sequences such as y_n^c. For instance, y_n^c has the two interpretations

$$y_n^{c^+} \equiv \lim_{\epsilon_2 \to 0} y^c(nT + \epsilon_2) \qquad \epsilon_2 > 0 \tag{14a}$$

$$y_n^{c^-} \equiv y^c(nT - \epsilon_1) \qquad \epsilon_1 > 0 \tag{14b}$$

Which of these two definitions is used has an important bearing on the resulting discretized system. The CONTROL program assumes

$$x_n^c \equiv \lim_{\epsilon \to 0} x^c(nT - \epsilon) \qquad \epsilon > 0$$

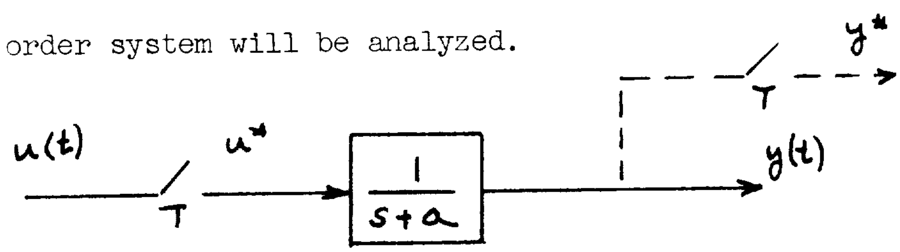
$$u_n^c \equiv u^c(nT)$$

The interpretation of these definitions is that; the state, x_n^c , is defined at time $t = nT$ prior to the application of the input, u_n^c . The updated input, u_n^c , is applied to the system at the sampling instant, $t = nT$. Thus all events are timed with respect to u_n^c as occurring before or after the application of u_n^c .

Figure 8(a) shows the time sequence of events in the complete sampled-data system. At $t = nT - \epsilon_1$, the plant is sampled to provide $y_n^{c^-}$ and $u_{ext_n}^d$ is input to the digital controller. Following the computational delay, ϵ_1 , the digital controller output, y_n^d , is updated (using $y_n^{c^-}$ and $u_{ext_n}^d$), the plant input, u_n^c , is defined (using y_n^d and $u_{ext_n}^c$) and applied to the plant. At $t = nT + \epsilon_2$ the plant output is $y_n^{c^+}$. The time delay ϵ_2 may be regarded as an infinitesimal (i.e., the limit goes to zero in eq. (14(a)) since the plant responds instantaneously to u^c_n . The time delay ϵ_1 cannot be regarded as an infinitesimal since the digital controller requires a finite time to compute the update. y^d_n. However, if $\epsilon_1 << T$ it is customary to assume $\epsilon_1 \rightarrow 0$.

Figure 8(b) shows the idealized time sequence for the sampled-data system. In this idealized model, events occur only at the sample instants and they occur instantaneously.

To illustrate the discretizing process an open-loop first order system will be analyzed.



The state equation of the plant driven by the inputer train is

$$\dot{x} = -ax + u$$

$$u = u^* = u(t)\,\delta(t - nT) \qquad n = 0, 1, 2, \ldots$$

The solution of the state equation for $0 \leq t < T$ is

$$x(t) = \phi(t)\, x_0 + \int_0^t \phi(t-\tau)\, u^*(\tau)\, d\tau$$

$$= e^{-at} x_0 + \int_0^t e^{-a(t-\tau)}\, \delta(\tau)\, u(\tau)\, d\tau$$

$$= e^{-at} x_0 + e^{-at} u_0$$

and in general

$$x_{n+1} \equiv x[(n+1)T] = e^{-aT} x_n + e^{-aT} u_n \tag{15a}$$

The output equation depends upon the choice of output; y_n^- or y_n^+.

At $t = nT - \epsilon \ (\epsilon \neq 0)$ $u^* = 0$ and

$$y_n^- = x_n \tag{15b}$$

At $t = nT + \epsilon$ the impulse at $t = nT$ will have changed the state x_n to

$$x_n^+ = x(nT+\epsilon) = \lim_{\epsilon \to 0^+} \left[\phi(\epsilon) x_n + \int_{nT}^{nT+\epsilon} \phi(nT+\epsilon-\tau) u^*(\tau) d\tau \right]$$

$$= \lim_{\epsilon \to 0^+} \left[\phi(\epsilon) x_n + \phi(\epsilon) u_n \right]$$

$$x_n^+ = x_n + u_n$$

since $\phi(0) = 1$ and $u^*(\tau) = u_n \delta(\tau - nT)$

The output y_n^+ is then

$$y_n^+ = x_n + u_n \tag{15c}$$

since $u(nT+\epsilon) = 0$.

The discretized system is given by equations (15a) and (15b) if y_n^- is chosen as the output, or by (15a) and (15c) if y_n^+ is chosen as the output. The corresponding z-transfer functions are

$$G(z) = \frac{e^{-aT}}{z - e^{-aT}} \quad \text{if} \quad y_n \equiv y_n^- \tag{16a}$$

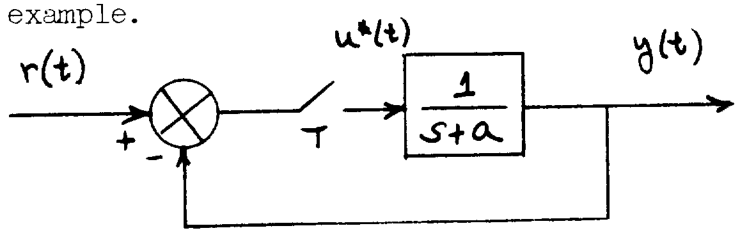
$$G(z) = \frac{z}{z - e^{-aT}} \quad \text{if} \quad y_n \equiv y_n^+ \tag{16b}$$

An interesting result of this example is that (16b) is the standard z-transfer function (pulse transfer function) of $G(s) = \frac{1}{s+a}$. Thus to generate standard z-transfer functions for the plant (11) the following convention should be used:

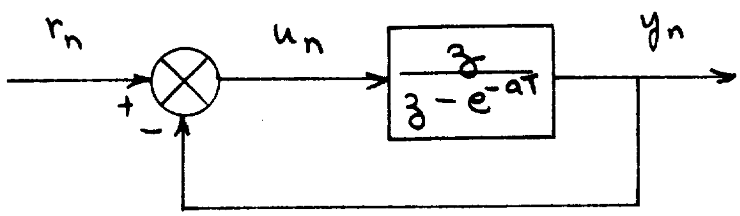
$$y_n \equiv y_n^+ = y(nT+\epsilon) \tag{17a}$$

$$x_n \equiv x_n^- = x(nT-\epsilon) \tag{17b}$$

Although this convention will generate correct pulse transfer functions, it is not the convention required for analyzing closed-loop sampled-data systems. This is evident from the following example.



This system is replaced by the equivalent discrete system:



whose state equation is (assuming $y_n = y_n^+$)

$$x_{n+1} = e^{-aT} x_n + e^{-aT} u_n$$

$$y_n = x_n + u_n$$

The control law is $\quad u_n = r_n - y_n = r_n - x_n - u_n$

This control law is nonphysical since it requires the digital controller to compute, at $t = nT - \epsilon$, a control law requiring data not available until $t = nT$ (see fig. 8). Thus for a closed-loop sampled data system the convention $y_n \equiv y_n^+$ can lead to a nonphysical realization of the system. The correct convention for closed-loop sampled-data systems is

$$y_n \equiv y_n^- = y(nT - \epsilon) \qquad \epsilon > 0$$

since this equation represents the measurements (observations) available to the digital controller at the time at which it must compute the control law.

Table VII lists the correctly discretized plant models for the various input and output definitions. Table VII(a) gives the models for the output convention $y_n \equiv y_n^-$ and Table VII(b) gives the models for the output convention $y_n \equiv y_n^+$. In Table VII(a) F = 0. This is required for the pulsed input since a continuous system with F $\neq$ 0 cannot be driven by a pulse train. The ZOH input system (Table VII(a)) cannot have F $\neq$ 0 since this would make y_n dependent on u_{n-1} and the analysis options of CONTROL are not applicable to such a system.

The only differences in Table VII(a) and (b) are in the direct feedforward term of the output equations. It is interesting to note that these terms in Table VII(b) (HBu_n for pulsed inputs and Fu_n for ZOH inputs) will be zero if

a. all input-output transfer paths have at least 2 more poles than zeroes for the pulsed input system

b. all input-output transfer paths have at least 1 more pole than zeroes for the ZOH system.

Inputs from digital controllers to continuous mechanical plants are almost always applied through zero-order-hold elements whose outputs drive actuators. If actuator dynamics are included in the plant then there will always be at least 1 more pole than zeroes for all transfer paths and there will be no difference in the two ZOH input cases of Table VII(a) and (b).

From Table VI the operations required to discretize the continuous plant are now apparent. CONTROL replaces the augmented system model of equations (13) with

$$\left[\begin{array}{c} x^c_{n+1} \\ \hline x^d_{n+1} \end{array}\right] = \left[\begin{array}{c|c} \Phi & 0 \\ \hline 0 & A_d \end{array}\right] \left[\begin{array}{c} x^c_n \\ \hline x^d_n \end{array}\right] + \left[\begin{array}{c|c} [\Theta B_c] \mid [\Phi B_c] & 0 \\ \hline \underbrace{\underbrace{0}_{\text{ZOH}} \mid 0}_{\text{NUC}} & B_d \end{array}\right] \left[\begin{array}{c} u^c_n \\ \hline u^d_n \end{array}\right] \begin{array}{l} \}\,\text{NXC} \\ \\ \end{array} \qquad (18a)$$

$$\left[\begin{array}{c} y^c_n \\ \hline y^d_n \end{array}\right] = \left[\begin{array}{c|c} H_c & 0 \\ \hline 0 & H_d \end{array}\right] \left[\begin{array}{c} x^c_n \\ \hline x^d_n \end{array}\right] + \left[\begin{array}{c|c|c} [F_c] & [H_c B_c] & 0 \\ \hline 0 & 0 & F_d \end{array}\right] \left[\begin{array}{c} u^c_n \\ \hline u^d_n \end{array}\right] \qquad (18b)$$

The partitioned submatrices $\left([\circledast B_c], [\phi B_c], [F_c], [H_c B_c]\right)$ are interpreted as follows: The first NXC rows and ZOH columns of $\circledast B_c$ are copied into the corresponding location of the B matrix, etc. At this point the sampled-data system is completely discretized and is given by

$$x_{n+1} = A x_n + B u_n \tag{19a}$$

$$y_n = H x_n + F u_n \tag{19b}$$

where the augmented vectors and matrices are:

$$x_n = \begin{bmatrix} x^c_n \\ \hdashline x^d_n \end{bmatrix} \qquad u_n = \begin{bmatrix} u^c_n \\ \hdashline u^d_n \end{bmatrix} \qquad y_n = \begin{bmatrix} y^c_n \\ \hdashline y^d_n \end{bmatrix}$$

$$A = \left[\begin{array}{c:c} \phi(T) & 0 \\ \hdashline 0 & A_d \end{array}\right] \qquad B = \left[\begin{array}{c:c:c} [\circledast B_c] & [\phi B_c] & 0 \\ \hdashline 0 & 0 & B_d \end{array}\right]$$

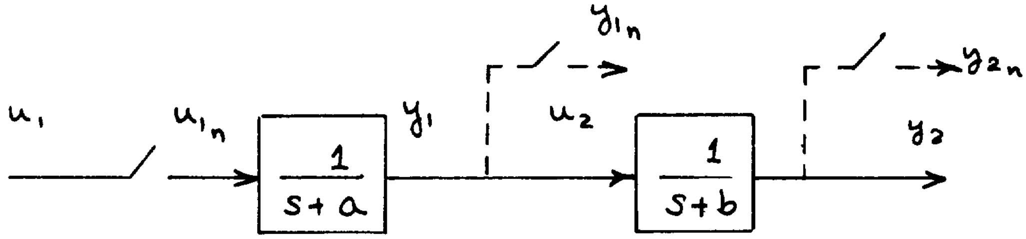
$$H = \left[\begin{array}{c:c} H_c & 0 \\ \hdashline 0 & H_d \end{array}\right] \qquad F = \left[\begin{array}{c:c:c} [F_c] & [H_c B_c] & 0 \\ \hdashline 0 & 0 & F_d \end{array}\right]$$

In light of the preceding discussion concerning the possibility of defining nonphysical feedback control laws, the submatrices $[F_c]$ and $[H_c B_c]$ must be interpreted carefully. CONTROL does not use $[F_c]$ or $[H_c B_c]$ to define connections from the plant to the discrete subsystem or to define sampled-data feedback laws. This amounts to using $y_n^{c-} = y^c(nT - \epsilon)$ instead of $y_n^{c+} = y(nT + \epsilon)$ for these connections. These submatrices are used in computing z-transfer functions, frequency responses, and transient responses. Thus pulse transfer functions such as that of the above example can be computed. This completes the discussion concerning the discretization of the plant dynamics.

The sampled-data system has been reduced to a set of uncoupled matrix difference equations (19). The remaining step in the definition of the system is the method of connecting the digital controller and the discretized plant. These connections are best illustrated by the following examples. The examples illustrate the various possible combinations of continuous and discrete subsystems. Each example contains two systems. The appropriate uncoupled state and output equations are written for each example followed by the equation giving the connection between the two systems. The state equations are discretized, the connection equation incorporated at the appropriate time, and the final coupled discretized system is given.

example: Determine the properly discretized and connected equations for the following systems.

a.)



1. Original system.

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} -a & 0 \\ 0 & -b \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

2. Connection equation.

$$u_2 = y_1 = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

3. Coupled system.

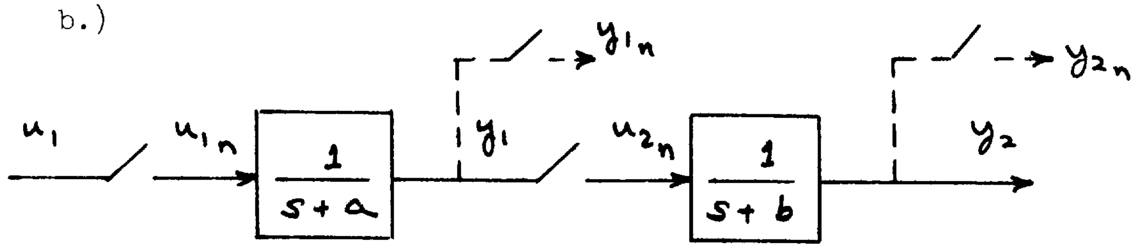
$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} -a & 0 \\ 1 & -b \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u_1$$

4. Final system.

$$\begin{bmatrix} x_{1_{n+1}} \\ x_{2_{n+1}} \end{bmatrix} = \begin{bmatrix} e^{-aT} & 0 \\ \frac{e^{-aT} - e^{-bT}}{(b-a)} & e^{-bT} \end{bmatrix} \begin{bmatrix} x_{1_n} \\ x_{2_n} \end{bmatrix} + \begin{bmatrix} e^{-aT} \\ 0 \end{bmatrix} \begin{bmatrix} u_{1_n} \end{bmatrix}$$

$$\begin{bmatrix} y_{1_n} \\ y_{2_n} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_{1_n} \\ x_{2_n} \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} \begin{bmatrix} u_{1_n} \end{bmatrix}$$

b.)



1. Original system.

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} -a & 0 \\ 0 & -b \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

2. Discretized system.

$$\begin{bmatrix} x_{1_{n+1}} \\ x_{2_{n+1}} \end{bmatrix} = \begin{bmatrix} e^{-aT} & 0 \\ 0 & e^{-bT} \end{bmatrix} \begin{bmatrix} x_{1n} \\ x_{2n} \end{bmatrix} + \begin{bmatrix} e^{-aT} & 0 \\ 0 & e^{-bT} \end{bmatrix} \begin{bmatrix} u_{1n} \\ u_{2n} \end{bmatrix}$$

$$\begin{bmatrix} y^+_{1n} \\ y^+_{2n} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_{1n} \\ x_{2n} \end{bmatrix} + \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u_{1n} \\ u_{2n} \end{bmatrix}$$

3. Connection equation.

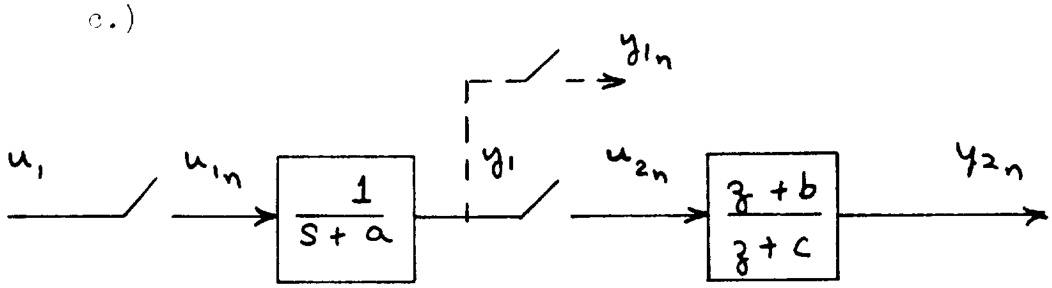
$$u_{2n} = y^-_{1n} = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x_{1n} \\ x_{2n} \end{bmatrix}$$

4. Final system.

$$\begin{bmatrix} x_{1n+1} \\ x_{2n+1} \end{bmatrix} = \begin{bmatrix} e^{-aT} & 0 \\ e^{-bT} & e^{-bT} \end{bmatrix} \begin{vmatrix} x_{1n} \\ x_{2n} \end{vmatrix} + \begin{bmatrix} e^{-aT} \\ 0 \end{bmatrix} u_{1n}$$

$$\begin{bmatrix} y^+_{1n} \\ y^+_{2n} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} x_{1n} \\ x_{2n} \end{bmatrix} + \begin{bmatrix} 1 \\ 1 \end{bmatrix} u_{1n}$$

c.)



1. Original system.

$$\begin{bmatrix}\dot{x}_1\\ x_{2n+1}\end{bmatrix} = \begin{bmatrix}-a & 0\\ 0 & -c\end{bmatrix}\begin{bmatrix}x_1\\ x_{2n}\end{bmatrix} + \begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}u_1\\ u_{2n}\end{bmatrix}$$

$$\begin{bmatrix}y_1^+\\ y_{2n}\end{bmatrix} = \begin{bmatrix}1 & 0\\ 0 & (b-c)\end{bmatrix}\begin{bmatrix}x_1\\ x_{2n}\end{bmatrix} + \begin{bmatrix}0 & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}u_1\\ u_{2n}\end{bmatrix}$$

2. Discretized system.

$$\begin{bmatrix}x_{1n+1}\\ x_{2n+1}\end{bmatrix} = \begin{bmatrix}e^{-aT} & 0\\ 0 & -c\end{bmatrix}\begin{bmatrix}x_{1n}\\ x_{2n}\end{bmatrix} + \begin{bmatrix}e^{-aT} & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}u_{1n}\\ u_{2n}\end{bmatrix}$$

3. Connection equation.

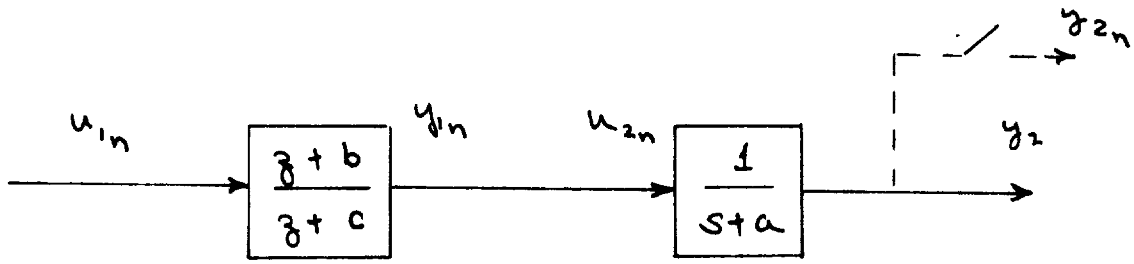
$$u_{2n} = y_{1n}^- = \begin{bmatrix}1 & 0\end{bmatrix}\begin{bmatrix}x_{1n}\\ x_{2n}\end{bmatrix}$$

4. Final system.

$$\begin{bmatrix}x_{1n+1}\\ x_{2n+1}\end{bmatrix} = \begin{bmatrix}e^{-aT} & 0\\ 1 & -c\end{bmatrix}\begin{bmatrix}x_{1n}\\ x_{2n}\end{bmatrix} + \begin{bmatrix}e^{-aT}\\ 0\end{bmatrix} u_{1n}$$

$$\begin{bmatrix}y_{1n}^+\\ y_{2n}\end{bmatrix} = \begin{bmatrix}1 & 0\\ 1 & (b-c)\end{bmatrix}\begin{bmatrix}x_{1n}\\ x_{2n}\end{bmatrix} + \begin{bmatrix}1\\ 0\end{bmatrix} u_{1n}$$

d.)



1. Original system.

$$\begin{bmatrix}\dot{x}_2\\ x_{1n+1}\end{bmatrix} = \begin{bmatrix}-a & 0\\ 0 & -c\end{bmatrix}\begin{bmatrix}x_2\\ x_{1n}\end{bmatrix} + \begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}u_2\\ u_{1n}\end{bmatrix}$$

$$\begin{bmatrix}y_2\\ y_1\end{bmatrix} = \begin{bmatrix}1 & 0\\ 0 & (b-c)\end{bmatrix}\begin{bmatrix}x_2\\ x_{1n}\end{bmatrix} + \begin{bmatrix}0 & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}u_2\\ u_{1n}\end{bmatrix}$$

2. Discretized system.

$$\begin{bmatrix}x_{2n+1}\\ x_{1n+1}\end{bmatrix} = \begin{bmatrix}e^{-aT} & 0\\ 0 & -c\end{bmatrix}\begin{bmatrix}x_{2n}\\ x_{1n}\end{bmatrix} + \begin{bmatrix}e^{-aT} & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}u_{2n}\\ u_{1n}\end{bmatrix}$$

$$\begin{bmatrix}y^{+}_{2n}\\ y_{1n}\end{bmatrix} = \begin{bmatrix}1 & 0\\ 0 & (b-c)\end{bmatrix}\begin{bmatrix}x_{2n}\\ x_{1n}\end{bmatrix} + \begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}u_{2n}\\ u_{1n}\end{bmatrix}$$

3. Connection equation.

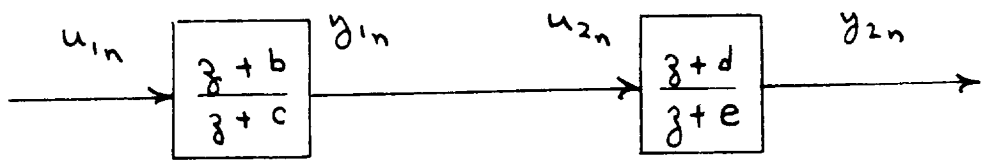
$$u_{2n} = y_{1n} = \begin{bmatrix}0 & (b-c)\end{bmatrix}\begin{bmatrix}x_{2n}\\ x_{1n}\end{bmatrix} + \begin{bmatrix}0 & 1\end{bmatrix}\begin{bmatrix}u_{2n}\\ u_{1n}\end{bmatrix}$$

4. Final system.

$$\begin{bmatrix}x_{2n+1}\\ x_{1n+1}\end{bmatrix} = \begin{bmatrix}e^{-aT} & (b-c)e^{-aT}\\ 0 & -c\end{bmatrix}\begin{bmatrix}x_{2n}\\ x_{1n}\end{bmatrix} + \begin{bmatrix}e^{-aT}\\ 1\end{bmatrix}\begin{bmatrix}u_{1n}\end{bmatrix}$$

$$\begin{bmatrix}y^{+}_{2n}\\ y_{1n}\end{bmatrix} = \begin{bmatrix}1 & (b-c)\\ 0 & (b-c)\end{bmatrix}\begin{bmatrix}x_{2n}\\ x_{1n}\end{bmatrix} + \begin{bmatrix}1\\ 1\end{bmatrix}\begin{bmatrix}u_{1n}\end{bmatrix}$$

e.)



1. Original system.

$$\begin{bmatrix} x_{1n+1} \\ x_{2n+1} \end{bmatrix} = \begin{bmatrix} -c & 0 \\ 0 & -e \end{bmatrix} \begin{bmatrix} x_{1n} \\ x_{2n} \end{bmatrix} + \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u_{1n} \\ u_{2n} \end{bmatrix}$$

$$\begin{bmatrix} y_{1n} \\ y_{2n} \end{bmatrix} = \begin{bmatrix} (b-c) & 0 \\ 0 & (d-e) \end{bmatrix} \begin{bmatrix} x_{1n} \\ x_{2n} \end{bmatrix} + \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u_{1n} \\ u_{2n} \end{bmatrix}$$

2. Connection equation.

$$u_{2n} = y_{1n} = \begin{bmatrix} (b-c) & 0 \end{bmatrix} \begin{bmatrix} x_{1n} \\ x_{2n} \end{bmatrix} + \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} u_{1n} \\ u_{2n} \end{bmatrix}$$

3. Final system.

$$\begin{bmatrix} x_{1n+1} \\ x_{2n+1} \end{bmatrix} = \begin{bmatrix} -c & 0 \\ b-c & -e \end{bmatrix} \begin{bmatrix} x_{1n} \\ x_{2n} \end{bmatrix} + \begin{bmatrix} 1 \\ 1 \end{bmatrix} \begin{bmatrix} u_{1n} \end{bmatrix}$$

$$\begin{bmatrix} y_{1n} \\ y_{2n} \end{bmatrix} = \begin{bmatrix} b-c & 0 \\ b-c & d-e \end{bmatrix} \begin{bmatrix} x_{1n} \\ x_{2n} \end{bmatrix} + \begin{bmatrix} 1 \\ 1 \end{bmatrix} \begin{bmatrix} u_{1n} \end{bmatrix}$$

A close study of these examples reveals that:

i.) Connections between two continuous systems must be made before they are discretized (a).

ii.) Connections to a continuous system from a sampler, zero-order-hold, or digital system must be made after the continuous system is discretized (b and d). Such a continuous system must have an input defined and the connection to the input is specified in a "feedback" gain matrix.

iii.) Connections to a digital system from a continuous system may be made either before or after the system is discretized (c). The discretization has no effect on the connection equation.

iv.) Connections between discrete systems may be made at any time since the discretization does not affect these systems (e).

SAMPLED-DATA SYSTEM ANALYSIS USING THE MIXED OPTION

The use of the MIXED option of the CONTROL program to model sampled-data systems may be described now. The MIXED option involves a two-step process in which a set of linear differential equations are augmented with a block diagram control system.

Sampled-data systems involve a continuous subsystem, the plant, and a discrete subsystem, the digital controller. The CONTROL program constructs the sampled-data system model by defining the plant in STEP 1 and the digital controller in STEP 2 of the MIXED option. It is not required that the plant correspond completely with STEP 1 of the MIXED option. For example, the block diagram control system (STEP 2) may contain a mixture of Laplace transformed blocks (actuator and sensor dynamics) and z-transformed blocks (the digital filters of the digital controller). The Laplace transform blocks are thus part of the plant. Conversely, difference equations defining digital filters may be written explicitly in the A matrix in STEP 1. The required ordering of inputs, outputs, and states is given in Table VIII(a). This ordering produces a preliminary sampled-data system which is a composite of the system of equations (7) and (13). (Due to the possibility of defining part of the plant in STEP 2, the correspondence between vectors (e.g., x_1 in eq. (7) and x^c in eq. (13)) is not exact.)

This preliminary system is connected together by connections specified in YTOV, ZTOU, and YZTOK. In light of the results of the examples given above, provision must be made for making some connections before the plant is discretized and the remainder after the discretization. To achieve this, the following sequence of operations is performed:

i.) YTOV and ZTOU connections completed

ii.) plant discretized

iii.) YZTOK defines feedback gain matrix, K1

iv.) feedback gain matrix, K1, incorporated into total system A matrix (closed-loop analysis) or used to perform a root locus

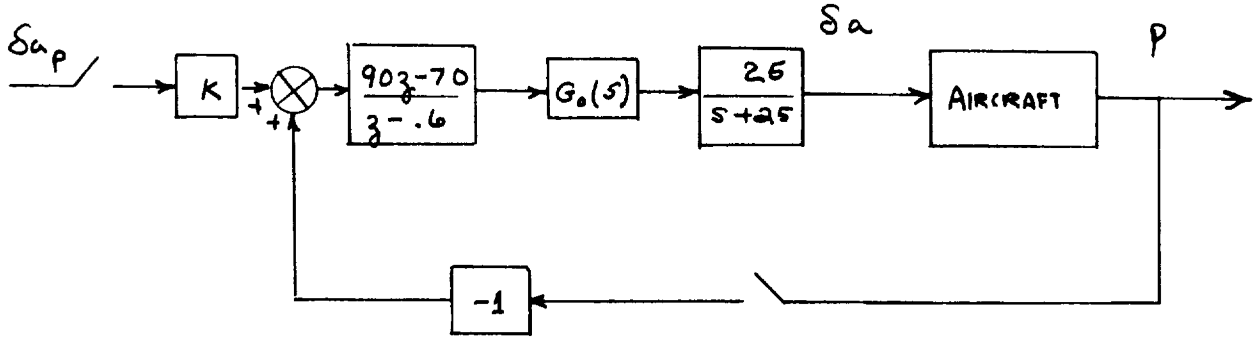
Thus connections which must be completed before the system is discretized are defined in YTOV, ZTOU, GRAPH, or the A_1 matrix of STEP 1. Connections from discrete systems to the plant (which must be made after the plant is discretized) must be defined in YZTOK. Table VIII(b) summarized the types of connections allowed and how they must be defined. $G(s)$ and $D(z)$ represent continuous and discrete subsystems, respectively. The sampled-data system model and its construction are given in Table III(c). The step indicated in Table III(c)(4) is the critical step in constructing the sampled-data system model. This step connects the digital controller to the plant in the correct manner. If a root locus is desired, this step defines the appropriate feedback gain matrix. If a root locus is called for, then the first connection specified by YZTOK will generate the feedback gain matrix, K1, and the second element of YZTOK (if any) will generate a second feedback gain matrix, K3. The control law is then

$$u_n = K1\,x_n + K3\,x_n$$

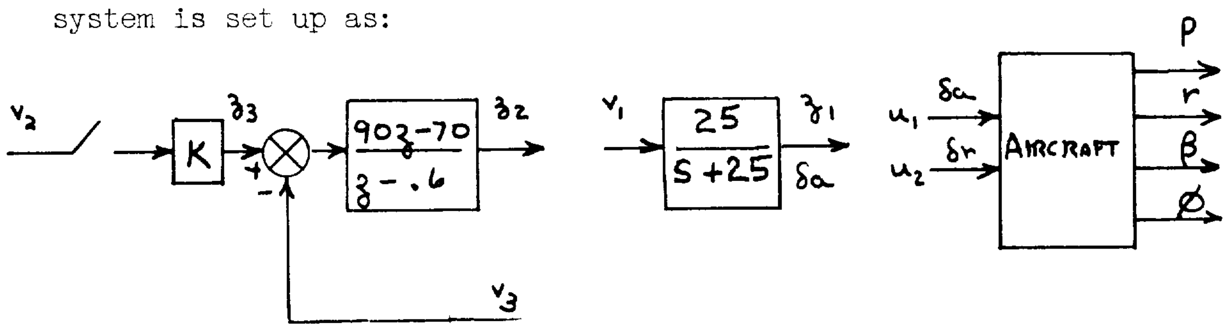
and K1, K3 would generate a root locus grid.

The formulation of the sampled-data system is illustrated in the following examples.

example: A lateral-directional aircraft plant with a roll rate feedback to a digital controller is to be modeled. The block diagram of the system is:



The block diagram is comprised of a pilot input gain, a digital filter, a zero-order-hold, and the aileron actuator transfer function. The aircraft state vector and output vector is $y = x = (p\ r\ \beta\ \phi)^T$ and the aircraft equations of motion are input to CONTROL in STEP 1. The system is set up as:



STEP 1 defines the aircraft with $u = (\delta a\ \delta r)^T$. In STEP 2 the actuator block input and output must be numbered first since it is part of the plant. The appropriate data for STEP 2 is:

NBLOCK	3
GRAPH	$\begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 2 & 3 & 0 & 0 & -3 \\ 3 & 0 & 0 & 0 & 2 \end{bmatrix}$
BLOCK	$\begin{bmatrix} 1 & 1 & 2 \\ 2 & 2 & 2 \\ 3 & 1 & 1 \end{bmatrix}$
NUMER	$\begin{bmatrix} 25. & & \\ -70. & 90. & \\ 1. & & \end{bmatrix}$
DENOM	$\begin{bmatrix} 25. & 1. & \\ -.6 & 1. & \\ 1. & & \end{bmatrix}$
GAIN	$\begin{bmatrix} 1. & 1. & K \end{bmatrix}$
ITHINY	$\begin{bmatrix} 1 & 2 & 3 & 4 \end{bmatrix}$
ITHINU	$\begin{bmatrix} 3 & 4 \end{bmatrix}$
NYTOV, NZTOU, NYZTOK	$\begin{bmatrix} 1 & 1 & 1 \end{bmatrix}$

YTOV [1 3]

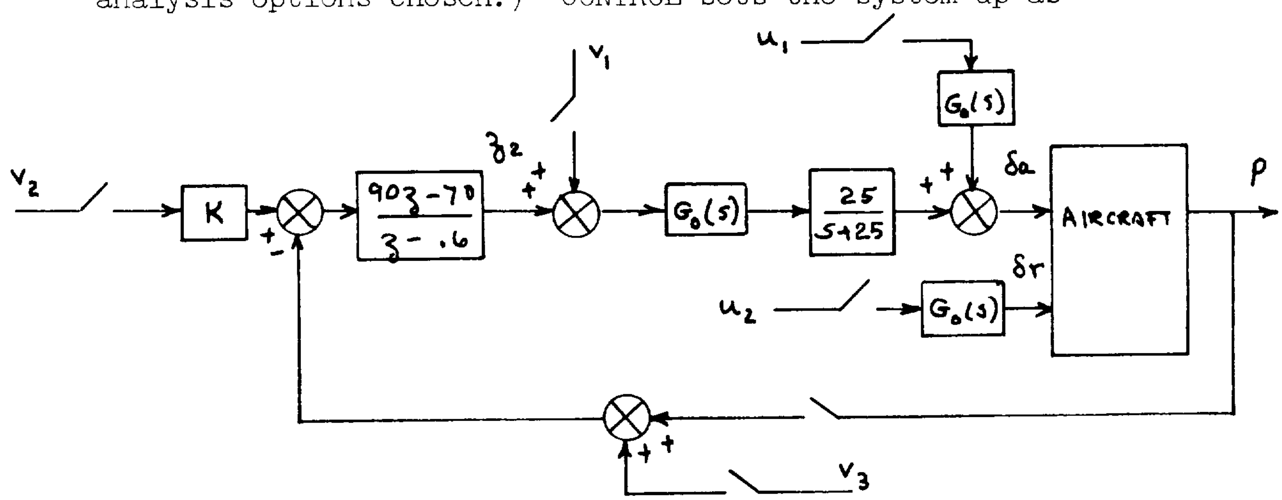
ZTOU [1 1]

YZTOK [6 3]

The pertinent namelist parameters are

DIGITL = 1, NXC = 5, NUC = 3, ZOH = 3, ...

(Other parameters are required to specify STEP 1 and the analysis options chosen.) CONTROL sets the system up as



The connection from z_2 to the summing junction before the zero-order-hold is constructed as a feedback control law

$$u = \begin{bmatrix} \delta a \\ \delta r \\ v_1 \\ v_2 \\ v_3 \end{bmatrix} = K1\, x = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -90. & 0. & 0. & 0. & 0. & -16. \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} p \\ r \\ \beta \\ \phi \\ \delta a \\ x \end{bmatrix}$$

If SYSTEM = 2, this "feedback" connection is completed and closed-loop z-transfer functions, w-plane frequency responses, or transient responses may be obtained. If SYSTEM = 3, the feedback gain matrix is used to calculate the z-plane root locus.

The ITHINU vector in the above example specifies that only the 3rd and 4th elements of the augmented input vector will be retained. The 3rd element (v_1) must be retained if SYSTEM = 3 since a feedback is defined to this input. If v_1 is not retained the root locus could not be obtained.

COMPUTATIONAL DELAY AND MODIFIED z-TRANSFORMS

The digital controller requires a finite time, ϵ_1, to compute the updated command signals to the plant (fig. 8(a)). The preceding analysis has assumed that $\epsilon_1 << T$. If this condition is not met the computational delay may be critical to the system stability. The modified z-transform allows this case to be analyzed using open-loop frequency response techniques. A linear analysis of a sampled-data system requires that all events pertinent to the system (state, input, output) be defined at one instant in time, the sampling instant. But if $\epsilon \lesssim T$, the digital filter computes commands based on the system output at time $nT-\epsilon_1$, while the plant state is defined only at time nT. The situation is shown in figure 9. At $t=(n+m-1)T$, the digital controller samples the plant output, $y^c_n(m)$, and inputs

u_n^d . The digital controller then computes the updated plant input u_n^c . This requires $(1-m)T$ seconds where $0 \leq m \leq 1$. If $m = 1$ there is no delay and if $m = 0$ there is a one sample period delay.

The output $y_n^c(m)$ is dependent upon the state of the plant at $t = (n-1)T$ and the form of the input u^c from $t = (n-1)T$ to $t = (n+m-1)T$. If the input to the plant is from a sampler then

$$y_n^c(m) = H x^c[(n+m-1)T]$$

$$= H\left[\Phi(mT)\, x_{n-1}^c + \phi(mT) B u_{n-1}^c\right] \qquad (20a)$$

where $$\phi(mT) = \int_0^{mT} e^{-A(mT-\tau)} d\tau$$

If the input to the plant is from a zero-order-hold then

$$y_n^c(m) = H\phi(mT)\, x_{n-1}^c + \left[H \Theta(mT) B + F\right] u_{n-1}^c \qquad (20b)$$

where $$\Theta(mT) = \int_0^{mT} \phi(mT-\tau)\, d\tau$$

In either case, $y_n^c(m)$ is described by (20a) or (20b) as a linear combination of x_{n-1}^c and u_{n-1}^c . Modified z-transform analysis is performed by idealizing the time sequence model of figure 9 and considering $y_n^c(m)$ and the digital controller update that it generates to occur instantaneously with the plant update at $t = nT$. The resulting system model for sampled inputs is

$$x^c_{n+1} = \phi(T)\, x^c_n + \phi(T) B\, u^c_n \tag{21a}$$

$$y^c_n(m) = H\,\phi(mT)\, x_{n-1} + H\,\phi(mT)\, u^c_{n-1} \tag{21b}$$

The z-transform of (21) yields the transfer function matrix $G(z,m)$ where

$$\begin{aligned} Y_m(z) &\equiv G(z,m)\; U(z) \\ &= \frac{1}{z}\left\{ H\,\phi(mT)\left[(zI-\phi(T))^{-1}\phi(T)B + B\right]\right\} U(z) \end{aligned}$$

Thus the model of equations (21) will generate modified z-transfer functions with the identifications

$$\begin{aligned} A &\longleftarrow \phi(T) \\ B &\longleftarrow \phi(T)B \\ H &\longleftarrow H\phi(mT) \\ F &\longleftarrow H\phi(mT)B \end{aligned}$$

A similar transfer matrix may be derived for zero-order-hold inputs.

The resulting z-transfer functions which the CONTROL program generates must be multiplied by z^{-1} to account for the sample period delay in the output equation (21b).

example: find $G(z,m)$ for $G(s) = \dfrac{1}{s+a}$

The plant equations are

$$\dot{x} = -ax + u$$

$$y = x$$

then $\phi(T) = e^{-aT}$, $\phi(mT) = e^{-amT}$ and

$$x_{n+1} = e^{-aT} x_n + e^{-aT} u_n$$

$$y_n(m) = e^{-amT} x_{n-1} + e^{-amT} u_{n-1}$$

$$Y_m(z) = \frac{1}{z}\left\{ e^{-amT} \frac{e^{-aT}}{z - e^{-aT}} + e^{-amT} \right\} U(z)$$

$$= \frac{1}{z} \frac{z e^{-amT}}{z - e^{-aT}} U(z)$$

or $$G(z,m) = \frac{e^{-amT}}{z - e^{-aT}}$$

To obtain modified z-transforms of open-loop sampled-data systems the parameter m must be specified in the namelist. If m = 1. the standard z-transform will result if $y_n^{c+} = y_n^{c-}$. Numerical errors limit m to $m >$ .2. All other namelist parameters required for sampled-data system analysis are unchanged. Only open-loop analysis can be accomplished with $m \neq$ 0. Digital filters may be cascaded with the "open loop" plant using the MIXED option as described above. If the digital filter output drives the plant, recall that a quasi "closed-loop" system is set up with YZTOK defining a "feed-back" law and SYSTEM must be set to 2. Table VII(c) lists the modified z-transform models.

METHOD OF ANALYSIS

The methods of analysis used by the CONTROL program are summarized in this section.

Frequency Response and Power Spectra

The basic system equations ((1.) or (2.)) may be transformed to yield

$$p X(p) = A X(p) + B U_{com}(p) \tag{22a}$$

$$Y(p) = H X(p) + F U_{com}(p) \tag{22b}$$

where $p = s$ or z depending on the type of system. Equation (22) is rewritten to display the system transfer matrix,

$$Y(p) = G(p) U_{com}(p) \tag{23}$$

where

$$G(p) = H(pI-A)^{-1}B + F$$

The transfer matrix, $G(p)$, is an $NY \times NU$ matrix of transfer functions. If transfer functions and/or frequency responses are requested, CONTROL computes these $(NY)\cdot(NU)$ functions. Frequency responses are generated at discrete frequencies in the following manner:

1. Continuous systems - $G(p) = G(s)$. The frequency response of the ith output due to the jth input is generated by setting $s = j\omega$ in $g_{ij}(s)$ and allowing ω to take on discrete values as specified in Appendix 2.
2. Discrete and sampled-data systems - $G(p) = G(z)$ Frequency responses of z-transformed functions are

accomplished either in the w-plane or the z-plane under the control of FRPS. If FRPS = 1, $G(z)$ is transformed to a w-plane transfer matrix, $G(w)$, by the transformation

$$z = \frac{1+w}{1-w}$$

The frequency response is accomplished by the substitution $w = j\nu$ at discrete points along the positive imaginary axis in the w-plane.

If FRPS = -1, the frequency response is accomplished by the substitution $z = \cos \omega T + j \sin \omega T$ at discrete points along the upper unit semicircle in the z-plane. The advantage of the w-plane frequency response is that asymptotic Bode plot methods may be used. (This is due to the frequency response being a polynomial function of the frequency.)

3. Continuous power spectra - $G(p) = G(s)$

Power spectra are computed for continuous systems from the relation

$$S_{y_i}(\omega) = |g_{ij}(\omega)|^2 S_{u_j}(\omega)$$

where $S_{y_i}(\omega)$ and $S_{u_j}(\omega)$ are the power spectra of the ith output and jth input, respectively, and $g_{ij}(s)$ is the corresponding transfer function. CONTROL assumes that

$$S_{u_j}(\omega) = 1$$

i.e., the input is unity variance white noise. Thus, to compute power spectra, a "shaping filter" will usually be added to the system dynamics and driven by the white noise input. The output of the filter then drives the system with the desired spectral content.

<u>Eigenvalues</u>

CONTROL uses the QR algorithm to determine the system eigenvalues. HESSEN transforms the matrix to upper Hessenburg form. QREIG then determines the eigenvalues via calls to QRT. The subroutines QREIG, HESSEN, and QRT are contained in the IBM Share Program No. 3006.01 written by P. Imiad Fawzi and J. E. VanNess, Northwestern University. The QR algorithm is discussed in reference 1.

<u>Transfer Function Numerators</u>

CONTROL determines the transfer function numerators as the eigenvalues of a matrix derived from the A, B, H, and F matrices. Details may be found in reference 2.

<u>Transient Responses and Discretization of Sampled-Data Systems</u>

To compute transient responses of continuous systems and to discretize sampled-data systems, the transition matrix and its integral are required. They are computed in the EAT subroutine by summing the partial series

$$\phi(t) = e^{At} = I + At + \frac{1}{2!}A^2t^2 + \frac{1}{3!}A^3t^3 + \cdots + \frac{1}{n!}A^n t^n$$

$$\Theta(t) = \int_0^t e^{A(t-\tau)}d\tau = It + \frac{1}{2!}At^2 + \frac{1}{3!}A^2t^3 + \cdots + \frac{1}{n!}A^{(n-1)}t^n$$

The series are terminated when the last terms in both series cause changes to each element of both series less than 10^{-3} times the respective element or when the series has not converged in 24 terms.

In the computation of ϕ for sampled-data systems, it is common to have eigenvalues whose magnitudes are comparable to the half-sample frequency resulting in slow convergence of the series. In this case, the user does not have the flexibility of using a smaller integration step size since the sample period is fixed. To help alleviate this problem, CONTROL computes $\phi(T/8)$ and $\Theta(T/8)$ and then finds $\phi(T)$ and $\Theta(T)$ as

$$\phi(T) = \left[\phi(T/8)\right]^8$$

$$\Theta(T) = \Theta(T/8)\left[\sum_{i=0}^{7} \phi(iT/8)\right]$$

Details may be found in reference 3.

Transient responses for continuous systems are calculated using $\phi(T)$ and $\Theta(T)$ as

$$x[(n+1)T] = \phi(T)x(nT) + \Theta(T)Bu(nT)$$

$$y(nT) = Hx(nT) + Fu(nT)$$

where $u(nT)$ is defined in the INPUT subroutine. The input, $u(nT)$, is held constant between sample periods.

Transient responses for discrete and sampled-data systems are computed in a similar manner from the difference equations given in Table VII.

For sampled-data systems, the MULTRT option allows the user to compute the intersample response of the system. The system is then described by:

$$x_{n+1} = A x_n + B u_n$$
$$y_n = H x_n + F u_n$$
$$u_n = K1 x_n + D u_{com_n}$$

where A and B are obtained by discretizing the plant for the time period, T/MULTRT and u_n is updated every T seconds. That is, the plant is discretized as though the sample period was T/MULTRT but u_n is held constant over T seconds. Thus, MULTRT intersample transient response points will be computed. Only transient responses are allowed with this option.

Digital Filtering

In synthesizing sampled-data systems, much time and effort can go into the computation of digital filter coefficients to give desired filtering to a signal. The CONTROL program allows the user to choose from a table of standard filters (Table VI) the filtering action he desires. The filter may be specified in the s, z, or w-plane. The transformation of s- and w-plane filters to z-plane filters can be carried out automatically by the program, allowing the user to draw upon experience in analog filtering techniques. The transformation of a w-plane filter to a z-plane filter is accomplished by replacing w by

$$w = \frac{z-1}{z+1}$$

The transformation of an s -plane filter to a w -plane filter is

$$u = \tanh\left(\frac{aT}{2}\right)$$

where a is the s -plane first order pole or zero and u is the corresponding w -plane pole or zero. For complex poles and zeroes

$$\left(1 + \frac{2\zeta}{\omega} s + s^2/\omega^2\right)$$

the transformation is

$$\left(1 + \frac{2\zeta_w}{\omega_w} w + w^2/\omega_w^2\right)$$

where

$$\omega_w = \sqrt{u^2 + \nu^2}$$

$$\zeta_w = -u/\omega_w$$

$$u = \frac{\sinh(\alpha T)}{\cosh(\alpha T) + \cos(\beta T)}$$

$$\nu = \frac{\sin(\alpha T)}{\cosh(\alpha T) + \cos(\beta T)}$$

with

$$\omega^2 = \alpha^2 + \beta^2$$

$$\alpha = -\zeta\omega$$

Digital filters derived from this two-step process (called the bilinear transformation with frequency prewarping) maintain a close resemblance of the original s -plane filters over a wide range of the half-sample frequency. References 4 and 5 give discussions of digital filters.

Model Following - If MODEL = 1, CONTROL computes frequency responses appropriate to the evaluation of model following systems. Let y_1 be the model output, y_2 be the model follower output, and let the model have inputs u_1, and u_2. The CONTROL program will compute the frequency responses (with FRPS set appropriately)

1 $\quad \frac{y_1}{u_1}(j\omega)$

2 $\quad \frac{y_2}{u_1}(j\omega) \quad ; \quad \frac{y_2/u_1}{y_1/u_1}(j\omega)$

3 $\quad \frac{y_1}{u_2}(j\omega)$

4 $\quad \frac{y_2}{u_2}(j\omega) \quad ; \quad \frac{y_2/u_2}{y_1/u_2}(j\omega)$

Thus, with MODEL set, CONTROL will provide the frequency responses

$$\frac{y_{2i+1}/u_l}{y_{2i}/u_l}(j\omega) \qquad \begin{cases} i = 1,2,\ldots,NY/2 \\ l = 1,2,\ldots,NU \end{cases}$$

in addition to the standard frequency responses.

Similarity Transformation - Numerical problems in calculating eigenvalues can sometimes be traced to the eigenvalues of a matrix being small compared to its norm. In this event, diagonal similarity transformations may aid in eigenvalue computation. For the autonomous system

$$\dot{x} = Ax \qquad (24)$$

a similarity transformation is defined as the change of variables

$$z = Px$$

for P nonsingular. The system (24) becomes

$$\dot{z} = P\dot{x} = PAP^{-1}z = A'z$$

with $A' = PAP^{-1}$. The matrix A' has the same eigenvalues as A and if P is chosen properly, A' will have a smaller norm than A .

The CONTROL program includes an option (NSCALE) which the user may select if numerical problems are suspected in eigenvalue computations. In order to maintain the same input-output relationship, the program performs the following operations when the A matrix is scaled.

$$PB \longrightarrow B$$
$$HP^{-1} \longrightarrow H$$
$$K1P^{-1} \longrightarrow K1$$
$$K3P^{-1} \longrightarrow K3$$

The scaling technique is described in references 6 and 7.

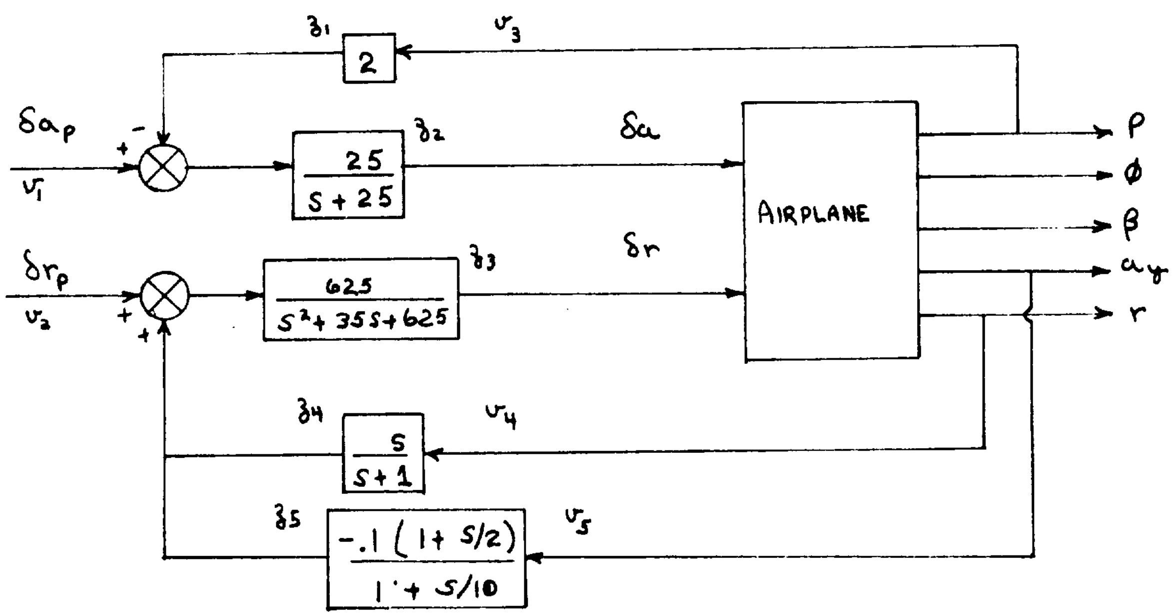
PROGRAM SIZE AND TIMING

The CONTROL program requires 131 K_8 words of computer memory. It has operated on a CDC CYBER 70 computer utilizing a segmented structure which reduced the memory requirement to 72 K_8 words. Included in these size requirements is memory allocated to data matrices for maximum state, output, and input vector dimensions of 15, 15, and 10, respectively. The data matrix storage requirements are a function of the system dimensions.

The example program of the next section was executed on the CDC CYBER 70 and required 17 sec. of CPU execution time to generate the problem setup and calculate ten transfer functions, ten frequency responses, and a transient response.

EXAMPLE PROBLEM

An example problem is given to illustrate the problem formulation, data deck, and output listing. The input and output listings are given in Appendix 3. The problem involves a lateral-directional airplane model with a control system consisting of aileron and rudder actuators, a roll rate feedback to δa, and yaw rate and side force feedback to δr through a washout and lead-lag filter, respectively. The system is shown in the block diagram.



The airplane equations of motion are

$$\begin{bmatrix} \dot{p} \\ \dot{r} \\ \dot{\beta} \\ \dot{\phi} \end{bmatrix} = \begin{bmatrix} L_p & L_r & L_\beta & 0 \\ N_p & N_r & N_\beta & 0 \\ \alpha_t & -1 & Y_\beta & g/V \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} p \\ r \\ \beta \\ \phi \end{bmatrix} + \begin{bmatrix} L_{\delta a} & L_{\delta r} \\ N_{\delta a} & N_{\delta r} \\ 0 & Y_{\delta r} \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \delta a \\ \delta r \end{bmatrix}$$

$$\begin{bmatrix} p \\ r \\ \beta \\ \phi \\ a_y \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -V/g\,\alpha_t & V/g & 0 & -1 \end{bmatrix} \begin{bmatrix} p \\ r \\ \beta \\ \phi \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & V/g & 0 \end{bmatrix} \begin{bmatrix} \dot{p} \\ \dot{r} \\ \dot{\beta} \\ \dot{\phi} \end{bmatrix}$$

the control system is described using the MIXED option and frequency responses and transient responses are obtained for roll rate and yaw rate.

CONCLUDING REMARKS

A FORTRAN digital computer program for the analysis of linear continuous and sampled-data systems has been described. The program features a flexible input format allowing the program user to define systems in a variety of representations. All systems are analyzed using state variable techniques. Analysis options of the program are: transfer functions, frequency responses, power spectra, root loci, root contours, and transient responses.

Dryden Flight Research Center
National Aeronautics and Space Administration
Edwards, Calif., January 12, 1976

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APPENDIX 1

FORTRAN LISTING OF CONTROL

A brief description of the various subroutines of CONTROL follows:

CONTROL - is the MAIN subroutine as described on page 5.

ADD - performs matrix addition.

ASCALE - scales the A matrix with a diagonal similarity transformation.

CARD - is described on page 4.

CHANGE - is described on page 6.

CLASS - is described on page 4.

CNTRLR - serves as the executive routine for CONTROL.

CPMT - computes complex roots.

EAT - computes the transition matrix and its integral.

EIGEN - is described on page 4

FRQRSP - is described on page 4.

HESSEN - transforms a matrix to the upper Hessenburg form.

INPUTV - is the INPUT subroutine described on page 6.

INVR - determines the inverse of a matrix.

LOAD - is described on page 4.

LOAD1 - is used in conjunction with LOAD to load the system matrices.

MAKE - makes two matrices equivalent.

MATRIX - is described on page 4.

MULT - performs matrix multiplication.

NMRATR - is described on page 4.

PSP - is described on page 4.

OREIG - determines the system eigenvalues.

QRT - is used in conjunction with OREIG.

RDISC - reads input matrices from the disc storage units.

RDISC1 - is used in conjunction with RDISC.

REDUCE - determines the irreducible submatrices of a matrix (used with ASCALE).

ROOT - is described on page 4.

SETUP - is described on page 4.

SPIT - outputs matrices on the printer.

SPIT1 - is used in conjunction with SPIT.

THIST - is described on page 5.
(starts at label SPIT1 16)

SWZ - transforms s-and w-plane filters to z-plane filters.

TANG - computes complex arc tangents.

WDISC - writes input matrices on to disc storage.

WDISC1 - is used in conjunction with WDISC.

ZOT - initializes the system matrices to zero.

ZOT1 - is used in conjunction with ZOT.

ZTOW - converts z-plane transfer functions to w-plane transfer functions.

COPO - plots data on CALCOMP plotter.

READO - plots zeros for a root locus.

CSTAR - contains envelope curves for the C* options.

SUBSCL - computes the scaling factor for root locus plots.

```
      PROGRAM CONTROL (INPUT=65,OUTPUT=65,TAPE1=INPUT,TAPE3=OUTPUT,TAPE5 CONTROL
     1=65,TAPE6=65,TAPE7=65,TAPE8=65,TAPE9=65)                          CONTROL
      REAL K1,K2,K3,K4                                                  CONTROL
      DIMENSION W1(15,15),W2(15,15),W3(15,15),ROOTR(15),ROOTI(15),      CONTROL
     1ROTR(15),ROTI(15),SAV1(200),SAV2(200),U(15),V(15)                CONTROL
      DIMENSION A(15,15),B(15,10),C(15,15),H(15,15),G(15,1 ),F(1',10),  CONTROL
     1K1(10,15),K2(10,15),K3(10,15),K4(10,15),D(10,10)                 CONTROL
      COMMON/SUBWRIT/ ISUBNAM                                           CONTROL
      DATA ISUBNAM/0/                                                   CONTROL
C                                                                       CONTROL
C     CONTROL MAIN PROGRAM.  ABSOLUTE DIMENSIONS FOR ALL ARRAYS ARE     CONTROL
C     DECLARED HERE AND PASSED THROUGHOUT THE PROGRAM IN THE UDIM       CONTROL
C     COMMON BLOCK.  TO CHANGE DIMENSIONS OF ARRAYS REQUIRES CHANGES ONL CONTROL
C     IN THIS ROUTINE.  MX MUST BE SET EQUAL TO \NX^1' WHERE NX IS THE  CONTROL
C     MAXIMUM DIMENSION OF THE STATE VECTOR.                            CONTROL
C                                                                       CONTROL
      IF (ISUBNAM .GE. 2) WRITE (3,990)                                 CONTROL
  990 FORMAT(1X,*MAIN*)                                                 CONTROL
      MX=15                                                             CONTROL
      MY=10                                                             CONTROL
      MU=10                                                             CONTROL
      MS=200                                                            CONTROL
      CALL       CNTRLR (A,B,C,H,G,F,K1,K2,K3,K4,D,W1,W2,W3,ROOTR,ROOTI, CONTROL
     1ROTR,ROTI,SAV1,SAV2,U,V,                                          CONTROL
     2MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                        CONTROL
      STOP                                                              CONTROL
      END                                                               CONTROL
```

```
      SUBROUTINE ADD (X,A,Y,B,C,N,M,                                  ADD    2
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                      ADD    3
      DIMENSION   A(MAT1,MAT2),B(MAT3,MAT4),C(MAT5,MAT6)             ADD    4
      COMMON/SUBWRIT/ ISUBNAM                                         ADD    5
      IF(ISUBNAM.GE.2) WRITE(3,990)                                   ADD    6
  990 FORMAT(1X,*ADD*)                                                ADD    7
      DO 10 I=1,N                                                     ADD    8
      DO 10 J=1,M                                                     ADD    9
      C(I,J)=X*A(I,J)+Y*B(I,J)                                        ADD   10
   10 CONTINUE                                                        ADD   11
      RETURN                                                          ADD   12
      END                                                             ADD   13
```

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```
      SUBROUTINE ASCALE (N,J,M,MM,P,A,B,C,DIBAR,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
C
C        THIS SUBROUTINE SCALES THE MATRIX A (OF DIMENSION N) WITH
C        A DIAGONAL SIMILARITY TRANSFORMATION. SUBROUTINE REDUCE IS
C        CALLED TO DETERMINE THE IRREDUCIBLE SUBMATRICES OF A.
C
C          J- NUMBER OF IRREDUCIBLE SUBMATRICES
C      MM(I)- DIMENSION OF THE ITH SUBMATRIX
C          M - MATRIX WHOSE ITH ROW CONTAINS THE ORIGINAL ROW AND COLUMN
C                NUMBERS OF THE ITH SUBMATRIX
C                TRANSFORMATION MATRIX
C          P - VECTOR CONTAINING THE DIAGONAL ELEMENTS OF THE
C
C          THE ROUTINE PRODUCES THE SCALED A MATRIX
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CONTUR,NUMERS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     2IGC,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KOUNT
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRPS,TRESP
      INTEGER DIGITL,SCAPLT,ZOH
      DIMENSION DIBAR (MX)
      DIMENSION A(MX,MX),B(MX,MX),C(MX,MX)
      DIMENSION M(10,20),MM(20),P(20)
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*SCALE*)
      NSCALE=0
      ITEST=0
      CALL REDUCE (N,J,MM,M,A,B,C,ITEST,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (ITEST.EQ.0) GO TO 110
      DO 111 I=1,N
      P(I)=1.0
  111 CONTINUE
      WRITE (3,112)
  112 FORMAT (/*    SIMILARITY TRANSFORMATION MATRIX SET EQUAL TO IDENTI
     1TY*/)
      RETURN
  110 CONTINUE
      DO 75 I=1,N
      P(I)=0.0
   75 CONTINUE
      STOP=1.0
      DO 100 I=1,J
      NI=MM(I)
      IF (NI.NE.1) GO TO 70
      P(M(I,1))=1.0
      GO TO 100
   70 CONTINUE
      DO 50 II=1,NI
      DO 51 JJ=1,NI
      B(II,JJ)=A(M(I,II),M(I,JJ))
   51 CONTINUE
      DIBAR(II)=1.0
      P(M(I,II))=1.0
   50 CONTINUE
      ICTCC=0
```

```
      K=0
    4 DO 10 II=1,NI
      SAPI=0.0
      RAIP =0.0
      DO 20 IP=1,NI
      IF (II.EQ.IP)GO TO 20
      RAIP=RAIP+B(II,IP)**2
      SAPI=SAPI+B(IP,II)**2
   20 CONTINUE
      DITTY=SQRT(SAPI/RAIP)
      DIBAR(II)=SQRT(DITTY)
      DIBARI=1.0/DIBAR(II)
      P(M(I,II))=P(M(I,II))*DIBAR(II)
      DO 30 L=1,NI
      B(II,L)=B(II,L)*DIBAR(II)
   30 CONTINUE
      DO 40 L=1,NI
      B(L,II)=B(L,II)*DIBARI
   40 CONTINUE
      K=K+1
      IF ((DIBAR(II)).LE.(1.+STOP))ICTCO=ICTCO+1
      IF ((DIBAR(II)).GT.(1.+STOP))ICTCO=0
      IF (ICTCO.EQ.NI) GO TO 3
   10 CONTINUE
      IF (K.LT.40) GO TO 4
    3 CONTINUE
  100 CONTINUE
      DO 60 I=1,N
      DO 60 L=1,N
      A(I,L)=P(I)*A(I,L)/P(L)
   60 CONTINUE
      IF (IPT.LT.1) GO TO 200
      WRITE (3,201) (P(I),I=1,N)
  201 FORMAT (/10X,* THE DIAGONAL TRANSFORMATION MATRIX IS*/40X,(E20.8))
  200 CONTINUE
      RETURN
      END
```

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```
      SUBROUTINE CARD                                                   CARD       2
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,     CARD       3
     1CONTUR,NUMERS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,         CARD       4
     1IGO,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KOUNT                  CARD       5
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRPS,TRESP CARD       6
      INTEGER DIGITL, SCAPLT, ZOH                                       CARD       7
      COMMON/ACOND/DELT,FINALT,IFREQ,FFREQ,DELFRQ, GAIN1,GAIN2,M        CARD       8
      COMMON/LABEL/INPT,OUTPT,TITLE                                     CARD       9
      COMMON/SUBWRIT/ ISUBNAM                                           CARD      10
      REAL   INPT(10), OUTPT(20),TITLE(8)                               CARD      11
      REAL IFREQ,M                                                      CARD      12
      NAMELIST/CODE/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,   CARD      13
     1CONTUR,NUMERS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,IGO,     CARD      14
     2FORM,IPT,READ3,KOUNT,DELT,FINALT,IFREQ,FFREQ,DELFRQ,GAIN1,GAIN2,  CARD      15
     3MIXED,MULTRT,SCAPLT,                                              CARD      16
     4ZOH,M,ISUBNAM                                                     CARD      17
      IF(ISUBNAM.GE.2) WRITE(3,990)                                     CARD      18
      DATA RST/10HROCO      /,PLOT/10HPLOT      /                       CARD      19
  990 FORMAT(1X,*CARD*)                                                 CARD      20
    1 FORMAT (8A10)                                                     CARD      21
    2 FORMAT (40I2)                                                     CARD      22
      IF (KOUNT.NE.1) GO TO 10                                          CARD      23
      WRITE (3,11)                                                      CARD      24
   11 FORMAT (/,"     CONTROL PROGRAM PERMANENT FILE JWELIB,CYCLE 13, JA CARD      25
     1NUARY 1,1976 ",/)                                                 CARD      26
   10 CONTINUE                                                          CARD      27
      IF (CONTUR.EQ.1.AND.KOUNT.GT.1) GO TO 5                           CARD      28
      READ (1,1) TITLE                                                  CARD      29
      IF (TITLE(1).EQ.PLOT) GO TO 300                                   CARD      30
      IF (EOF(1).NE.0) STOP                                             CARD      31
      WRITE (3,3) TITLE                                                 CARD      32
    3 FORMAT (1H1,8A10)                                                 CARD      33
      IF (IFLAG .EQ.1.AND.KOUNT.GT.1) RETURN                            CARD      34
      READ (1,CODE)                                                     CARD      35
  140 FORMAT (10X,*CONTINUOUS SYSTEM*)                                  CARD      36
  141 FORMAT (10X,*SAMPLED-DATA SYSTEM*)                                CARD      37
  142 FORMAT (10X,*DISCRETE SYSTEM*)                                    CARD      38
  243 FORMAT (10X,*MIXED OPTION*)                                       CARD      39
  143 FORMAT (10X,*OPEN LOOP*)                                          CARD      40
  144 FORMAT (10X,*CLOSED LOOP*)                                        CARD      41
  145 FORMAT (10X,*ROOT LOCUS*)                                         CARD      42
  245 FORMAT (10X,*ROOT CONTOUR*)                                       CARD      43
  146 FORMAT (10X,*LOAD ROUTINE INPUT*)                                 CARD      44
  147 FORMAT (10X,*MATRIX ROUTINE INPUT*)                               CARD      45
  148 FORMAT (10X,*CHANGE ROUTINE INPUT*)                               CARD      46
  149 FORMAT (10X,*CLASS ROUTINE INPUT*)                                CARD      47
  151 FORMAT (10X,*TRANSFER FUNCTIONS*)                                 CARD      48
  152 FORMAT (10X,*EIGENVALUES*)                                        CARD      49
  153 FORMAT (10X,*FREQUENCY RESPONSES*)                                CARD      50
  154 FORMAT (10X,*POWER SPECTRA*)                                      CARD      51
  155 FORMAT (10X,*TRANSIENT RESPONSES*)                                CARD      52
      IS=DIGITL+1                                                       CARD      53
      GO TO (170,171,172),IS                                            CARD      54
  170 WRITE (3,140)                                                     CARD      55
      GO TO 200                                                         CARD      56
  171 WRITE (3,141)                                                     CARD      57
      GO TO 200                                                         CARD      58
```

```
  172 WRITE (3,142)                                                     CARD      59
  200 IF (MIXED .EQ. 1) WRITE (3,243)                                   CARD      60
      GO TO (173,174,175),SYSTEM                                        CARD      61
  173 WRITE (3,143)                                                     CARD      62
      GO TO 201                                                         CARD      63
  174 WRITE (3,144)                                                     CARD      64
      GO TO 201                                                         CARD      65
  175 WRITE (3,145)                                                     CARD      66
  201 GO TO (176,177,178,179),READ                                      CARD      67
  176 WRITE (3,146)                                                     CARD      68
      GO TO 202                                                         CARD      69
  177 WRITE (3,147)                                                     CARD      70
      GO TO 202                                                         CARD      71
  178 WRITE (3,148)                                                     CARD      72
      GO TO 202                                                         CARD      73
  179 WRITE (3,149)                                                     CARD      74
  202 IF (NUMERS.EQ.0.AND.SYSTEM.NE.3.AND.CONTUR.EQ.0) WRITE (3,151)    CARD      75
      IF (NUMERS .EQ. 1) WRITE (3,152)                                  CARD      76
      IF (CONTUR .EQ. 1) WRITE (3,245)                                  CARD      77
      IF (FRPS .EQ. 1 .OR. FRPS .EQ. -1) WRITE (3,153)                  CARD      78
      IF (FRPS .EQ. 2) WRITE (3,154)                                    CARD      79
      IF (TRESP .NE. 0) WRITE (3,155)                                   CARD      80
      WRITE (3,150) NX,READ,TRESP,CMAT,DELT,NY,SYSTEM,FRPS,NK2,FINALT,  CARD      81
     1NU,MIXED,NUMERS,IFLAG,IFREQ,NXC,OUTPUT,FORM,IGO,DELFRQ,NUC,DIGITL, CARD     82
     2CONTUR,READ3,FFREQ,ZOH,IPT,MULTRT,SAV,GAIN1,N1,KOUNT,MODEL,NSCALE, CARD     83
     3GAIN2,N2,M                                                        CARD      84
  150 FORMAT (//10X,*NX    =*,I4,11X,*READ    =*,I4,8X,*TRESP   =*,I4,8X, CARD    85
     1*CMAT   =*,I4,8X,*DELT    =*,F7.3/10X,*NY   =*,I4,11X,*SYSTEM =*,  CARD     86
     2I4,8X,*FRPS    =*,I4,8X,*NK2     =*,I4,8X,*FINALT =*,F7.3/10X,     CARD     87
     3*NU   =*,I4,11X,*MIXED   =*,I4,8X,*NUMERS =*,I4,8X,*IFLAG   =*,I4, CARD     88
     48X,*IFREQ   =*,F7.3/10X,*NXC =*,I4,11X,*OUTPUT =*,I4,8X,*FORM    =*, CARD   89
     5I4,8X,*IGO     =*,I4,8X,*DELFRQ =*,F7.3/10X,*NUC =*,I4,11X,       CARD      90
     6*DIGITL =*,I4,8X,*CONTUR =*,I4,8X,*READ3   =*,I4,8X,*FFREQ   =*,  CARD      91
     7F7.3/10X,*ZOH =*,I4,11X,*IPT     =*,I4,8X,*MULTRT =*,I4,8X,       CARD      92
     8*SAV     =*,I4,8X,*GAIN1   =*,F7.3/10X,*N1   =*,I4,11X,*KOUNT  =* CARD      93
     9I4,8X,*MODEL   =*,I4,8X,*NSCALE =*,I4,8X,*GAIN2   =*,F7.3/10X,    CARD      94
     1*N2   =*,I4,71X,*M        =*,F7.3)                                CARD      95
      IF (MULTRT.GT.0) DELT=DELT/MULTRT                                 CARD      96
      IF (NY.EQ.0) GO TO 50                                             CARD      97
      IF (MIXED.NE.0.AND.NY.LT.8) GO TO 50                              CARD      98
      READ (1,1)(OUTPT(I),I=1,NY)                                       CARD      99
      IF (EOF(1).NE.0) STOP                                             CARD     100
      GO TO 51                                                          CARD     101
   50 READ (1,1)(OUTPT(I),I=1,8)                                        CARD     102
      IF (EOF(1).NE.0) STOP                                             CARD     103
   51 IF (NU.EQ.0) GO TO 52                                             CARD     104
      IF (MIXED.NE.0.AND.NU.LT.8) GO TO 52                              CARD     105
      READ (1,1) (INPT(I),I=1,NU)                                       CARD     106
      IF (EOF(1).NE.0) STOP                                             CARD     107
      GO TO 53                                                          CARD     108
   52 READ(1,1)(INPT(I),I=1,8)                                          CARD     109
      IF (EOF(1).NE.0) STOP                                             CARD     110
   53 CONTINUE                                                          CARD     111
      RETURN                                                            CARD     112
  300 CALL COPO                                                         CARD     113
      STOP                                                              CARD     114
    5 READ (1,1) TITLE                                                  CARD     115
```

ORIGINAL PAGE IS
OF POOR QUALITY

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      IF (EOF(1).NE.0) GO TO 98
      WRITE (3,8) TITLE
    8 FORMAT (/8A10/)
      RETURN
   98 IF (FORM.EQ.0) GO TO 99
      ND=3
      XYX=-1.
      WRITE (7) ND,XYX,XYX,XYX
   99 STOP
      END
```

```
      SUBROUTINE CHANGE (A,B,C,H,G,F,K1,K2,K3,K4,D,W1,W2,W3,         CHANGE     2
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                     CHANGE     3
      DIMENSION W1(MX,MX),W2(MX,MX),W3(MX,MX)                        CHANGE     4
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,  CHANGE     5
     1CONTUR,NUMERS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,      CHANGE     6
     1IGC,FORM,IPT,READ3,MIXED,MULTPT,SCAPLT,ZOH,KOUNT               CHANGE     7
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRPS,TRESP CHANGE  8
      INTEGER DIGITL, SCAPLT, ZOH                                    CHANGE     9
      COMMON/ACOND/DELT,FINALT,IFREQ,FFREQ,DELFREQ,GAIN1,GAIN2,M     CHANGE    10
      REAL K1, K2, K3, K4, IFREQ,M                                   CHANGE    11
      DIMENSION A(MX,MX),B(MX,MU),C(MX,MX),H(MY,MX),G(MY,MX),F(MY,MU), CHANGE  12
     1K1(MU,MX),K2(MU,MX),K3(MU,MX),K4(MU,MX),D(MU,MU)               CHANGE    13
      COMMON/BLKDAT/NUMER,DENOM,GAIN,GRAPH,BLOCK,STATE,YTOV,ZTOU,YZTOK, CHANGE 14
     1ITHINY,ITHINU,NBLOCK,NYTOV,NZTOU,NXYU,NYZTOK,NXT,NYT,NUT,NY1,NU1 CHANGE  15
      REAL NUMER                                                     CHANGE    16
      INTEGER GRAPH,BLOCK,STATE,YTOV,ZTOU,YZTOK                      CHANGE    17
      DIMENSION GRAPH(20,5),BLOCK(20,3),NUMER(20,5),DENOM(20,5),     CHANGE    18
     XGAIN(20),STATE(20,4),ITHINY(30),ITHINU(20),YTOV(20,2),         CHANGE    19
     X  ZTOU(20,2),NXYU(8),YZTOK(20,2)                               CHANGE    20
C                                                                    CHANGE    21
C     USER WRITTEN SUBROUTINE TO CHANGE SYSTEM PARAMETERS SET UP IN  CHANGE    22
C     PREVIOUS CASE                                                  CHANGE    23
C                                                                    CHANGE    24
      COMMON/SUBWRIT/ ISUBNAM                                        CHANGE    25
      IF(ISUBNAM.GE.2) WRITE(3,990)                                  CHANGE    26
  990 FORMAT(1X,*CHANGE*)                                            CHANGE    27
      RETURN                                                         CHANGE    28
      END                                                            CHANGE    29
```

```
      SUBROUTINE CLASS (A,B,C,H,G,F,D,W1,W2,W3,                         CLASS     2
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                         CLASS     3
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,     CLASS     4
     1CONTUR,NUMERS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,         CLASS     5
     2IGO,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KOUNT                  CLASS     6
      COMMON/ACOND/DELT,FINALT,IFREQ,FFREQ,DELFRQ, GAIN1,GAIN2,MMM      CLASS     7
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRPS,TRESP CLASS     8
      INTEGER DIGITL,SCAPLT,ZOH                                         CLASS     9
      DIMENSION A(MX,MX),B(MX,MU),C(MX,MX),H(MY,MX),G(MY,MX),F(MY,MU),  CLASS    10
     1D(MU,MU)                                                          CLASS    11
      DIMENSION W1(MX,MX),W2(MX,MX),W3(MX,MX)                           CLASS    12
      REAL IFREQ,NUMER,MMM                                              CLASS    13
      COMMON/BLKDAT/NUMER,DENOM,GAIN,GRAPH,BLOCK,STATE,YTOV,ZTOU,YZTOK, CLASS    14
     1ITHINY,ITHINU,NBLOCK,NYTOV,NZTOU,NXYU,NYZTOK,NXT,NYT,NUT,NY1,NU1  CLASS    15
      INTEGER GRAPH,BLOCK,STATE,YTOV,ZTOU,YZTOK                         CLASS    16
      DIMENSION GRAPH(20,5),BLOCK(20,3),NUMER(20,5),DENOM(20,5),        CLASS    17
     XGAIN(20),STATE(20,4),ITHINY(30),ITHINU(20),YTOV(20,2),            CLASS    18
     X   ZTOU(20,2),NXYU(8),YZTOK(20,2)                                 CLASS    19
    1 FORMAT (16I5)                                                     CLASS    20
      COMMON/SUBWRIT/ ISUBNAM                                           CLASS    21
      IF(ISUBNAM.GE.2) WRITE(3,990)                                     CLASS    22
  990 FORMAT(1X,*CLASS*)                                                CLASS    23
    2 FORMAT (8F10.4)                                                   CLASS    24
      NIN=3                                                             CLASS    25
      NX1=NX                                                            CLASS    26
      NY1=NY                                                            CLASS    27
      NU1=NU                                                            CLASS    28
      NXT=NX                                                            CLASS    29
      NYT=NY                                                            CLASS    30
      NUT=NU                                                            CLASS    31
      IF (IGO.EQ.1) GO TO 224                                           CLASS    32
      NYTOV=0                                                           CLASS    33
      NZTOU=0                                                           CLASS    34
      NYZTOK=0                                                          CLASS    35
  224 IF (MIXED.EQ.1) GO TO 210                                         CLASS    36
      NX1=0                                                             CLASS    37
      NY1=0                                                             CLASS    38
      NU1=0                                                             CLASS    39
  210 CONTINUE                                                          CLASS    40
      IF (IGO.EQ.1.AND.KOUNT.GT.1) GO TO 86                             CLASS    41
      DO 222 I=1,30                                                     CLASS    42
      ITHINY(I)=0                                                       CLASS    43
  222 CONTINUE                                                          CLASS    44
      DO 223 I=1,20                                                     CLASS    45
      ITHINU(I)=0                                                       CLASS    46
  223 CONTINUE                                                          CLASS    47
      READ (1,1) NBLOCK,NIT                                             CLASS    48
      IF (EOF(1).NE.0) STOP                                             CLASS    49
      IF (NBLOCK.EQ.0) GO TO 230                                        CLASS    50
      IF (NIT .EQ. 0) GO TO 736                                         CLASS    51
      CALL SWZ (DELT,IGO,                                               CLASS    52
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                         CLASS    53
      GO TO 86                                                          CLASS    54
  736 DO 91 I=1,NBLOCK                                                  CLASS    55
      READ (1,1) (GRAPH(I,J),J=1,5)                                     CLASS    56
      IF (EOF(1).NE.0) STOP                                             CLASS    57
   91 CONTINUE                                                          CLASS    58
```

```
      DO 92 I=1,NBLOCK
      READ (1,1) (BLOCK(I,J),J=1,3)
      IF (EOF(1).NE.0) STOP
   92 CONTINUE
      DO 93 I=1,NBLOCK
      READ (1,2) (NUMER(I,J),J=1,5)
      IF (EOF(1).NE.0) STOP
   93 CONTINUE
      DO 94 I=1,NBLOCK
      READ (1,2) (DENOM(I,J),J=1,5)
      IF (EOF(1).NE.0) STOP
   94 CONTINUE
      READ (1,2) (GAIN(I),I=1,NBLOCK)
      IF (EOF(1).NE.0) STOP
   95 CONTINUE
      DO 5 I=1,NBLOCK
      DO 5 J=1,4
      STATE (I,J)=0.0
    5 CONTINUE
      NX=0
      DO 20 I=1,NBLOCK
      STATE(I,1)=GRAPH(I,1)
      IF (BLOCK(I,2).EQ.1.AND.BLOCK(I,3).EQ.1) GO TO 21
      IF (BLOCK(I,2).GT.BLOCK(I,3)) GO TO 22
      IF (BLOCK(I,2).EQ.BLOCK(I,3)) GO TO 23
      STATE(I,3)=1
      GO TO 24
   23 STATE(I,3)=2
   24 STATE(I,2)=NX+1
      STATE(I,4)=BLOCK(I,3)-1
      NX=NX+BLOCK(I,3)-1
      GO TO 20
   21 STATE(I,3)=4
      GO TO 20
   22 STATE(I,3)=3
   20 CONTINUE
      NU=0
      DO 25 K=1,NBLOCK
      IF (IABS(GRAPH(K,5)).GT.NU) NU=IABS(GRAPH(K,5))
   25 CONTINUE
      NXT=NX+NX1
      NYT=NBLOCK+NY1
      NUT=NU+NU1
      IF (IGC.EQ.1.AND.KOUNT.GT.1) GO TO 271
      READ (1,1) (ITHINY(I),I=1,NYT)
      IF (EOF(1).NE.0) STOP
   87 FORMAT (/19X,*ITHINY*/)
      IF (READ.EQ.4.AND.SYSTEM.EQ.3) GO TO 232
      IF (MIXED.NE.1) GO TO 243
  232 READ (1,1)(ITHINU(I),I=1,NUT)
      IF (EOF(1).NE.0) STOP
  230 READ (1,1) NYTOV,NZTOU,NYZTOK
      IF (EOF(1).NE.0) STOP
      IF (NYTOV.EQ.0) GO TO 231
      DO 212 I=1,NYTOV
      READ (1,1)(YTOV(I,J),J=1,2)
      IF (EOF(1).NE.0) STOP
```

```
  212 CONTINUE
  231 IF (NZTOU.EQ.0) GO TO 211
      DO 213 I=1,NZTOU
      READ (1,1)(ZTOU(I,J),J=1,2)
      IF (EOF(1).NE.0) STOP
  213 CONTINUE
  211 IF (NYZTOK.EQ.0) GO TO 243
      DO 219 I=1,NYZTOK
      READ (1,1) (YZTOK(I,J),J=1,2)
      IF (EOF(1).NE.0) STOP
  219 CONTINUE
      IF (SYSTEM.EQ.1) SYSTEM=2
  243 CONTINUE
      IF (NBLOCK.EQ.0) GO TO 241
  214 FORMAT (/10X,*ITHINU*/)
  215 FORMAT (/10X,*YTOV*/)
  217 FORMAT (/10X,*ZTOU*/)
  220 FORMAT (/10X,*YZTOK*/)
      GO TO 272
  271 CONTINUE
      NX1=NXYU(1)
      NY1=NXYU(2)
      NU1=NXYU(3)
      NXT=NXYU(4)
      NYT=NXYU(5)
      NUT=NXYU(6)
      NX=NXYU(7)
      NU=NXYU(8)
      GO TO 273
  272 NXYU(1)=NX1
      NXYU(2)=NY1
      NXYU(3)=NU1
      NXYU(4)=NXT
      NXYU(5)=NYT
      NXYU(6)=NUT
      NXYU(7)=NX
      NXYU(8)=NU
  273 CONTINUE
      IF (NIT .EQ. 1) GO TO 340
      WRITE (3,95)
   95 FORMAT (//* BLOCK DIAGRAM INPUT PARAMETERS ARE*//)
      WRITE (3,96)
   96 FORMAT (10X,* GRAPH*/)
      DO 97 I=1,NBLOCK
      WRITE (3,1) (GRAPH(I,J),J=1,5)
   97 CONTINUE
      WRITE (3,98)
   98 FORMAT (/10X,*BLOCK*/)
      DO 99 I=1,NBLOCK
      WRITE (3,1) (BLOCK(I,J),J=1,3)
   99 CONTINUE
      WRITE (3,81)
   81 FORMAT (/10X,*NUMER*/)
      DO 82 I=1,NBLOCK
      WRITE (3,2) (NUMER(I,J),J=1,5)
   82 CONTINUE
      WRITE (3,83)
```


C.2

```
   83 FORMAT (/10X,*DENOM   */)
      DO 84 I=1,NBLOCK
      WRITE (3,2) (DENOM(I,J),J=1,5)
   84 CONTINUE
      WRITE (3,85)
   85 FORMAT (/10X,*GAIN*/)
      WRITE (3,2) (GAIN(I),I=1,NBLOCK)
  340 WRITE (3,87)
      WRITE (3,1)(ITHINY(I),I=1,NYT)
      IF (READ.EQ.4.AND.SYSTEM.EQ.3) GO TO 341
      IF (MIXED.NE.1) GO TO 242
  341 WRITE (3,214)
      WRITE (3,1)(ITHINU(I),I=1,NUT)
      IF (NYTOV.EQ.0) GO TO 240
      WRITE (3,215)
      DO 216 I=1,NYTOV
      WRITE (3,1)(YTOV(I,J),J=1,2)
  216 CONTINUE
  240 IF (NZTOU.EQ.0) GO TO 241
      WRITE (3,217)
      DO 218 I=1,NZTOU
      WRITE (3,1)(ZTOU(I,J),J=1,2)
  218 CONTINUE
  241 IF (NYZTOK.EQ.0) GO TO 242
      WRITE (3,220)
      DO 221 I=1,NYZTOK
      WRITE (3,1) (YZTOK(I,J),J=1,2)
  221 CONTINUE
  242 CONTINUE
      IF (NBLOCK.EQ.0) RETURN
      DO 440 I=1,NBLOCK
      IF (DENOM(I,BLOCK(I,3)).EQ.1.) GO TO 440
      N9= BLOCK(I,3)
      XX=DENOM(I,N9)
      IF (XX.NE. 0.0) GO TO 442
      WRITE (3,443) I
  443 FORMAT (/10X,* LEADING COEFFICIENT OF NO.*,I5,* BLOCK IS ZERO*/)
      GO TO 440
  442 CONTINUE
      DO 441 J=1,N9
      DENOM(I,J)= DENOM(I,J)/XX
  441 CONTINUE
      GAIN(I)= GAIN(I)/XX
  440 CONTINUE
      DO 30 I=1,NBLOCK
      IF (STATE(I,3).NE.4) GO TO 40
      DO 31 J=1,NIN
      IF (GRAPH(I,J+1).EQ.0) GO TO 31
      C(I+NY1,IABS(GRAPH(I,J+1))+NY1)=-ISIGN(1,GRAPH(I,J+1))*GAIN(I)
     1*NUMER(I,1)/DENOM(I,1)
   31 CONTINUE
      IF (GRAPH(I,5).EQ.0) GO TO 30
      F(I+NY1,IABS(GRAPH(I,5))+NU1)=ISIGN(1,GRAPH(I,5))*GAIN(I)
     1*NUMER(I,1)/DENOM(I,1)
      GO TO 30
   40 IF (STATE(I,3).EQ.3) GO TO 50
      NOST1=STATE(I,4)+1
```

```
      NOST=NOST1-1
      IF (NOST.NE.0) GO TO 45
      WRITE (3,46)
   46 FORMAT (/10X,*INCONSISTENT DATA IN CLASS*)
      GO TO 30
   45 DO 42 J=1,NOST
      H(I+NY1,STATE(I,2)+J-1+NX1)=GAIN(I)*(NUMER(I,J)-DENOM(I,J)*NUMER
     1(I,NOST1))
   42 CONTINUE
      IF (STATE(I,3).EQ.1) GO TO 41
      IF (GRAPH(I,5).EQ.0) GO TO 43
      F(I+NY1,IABS(GRAPH(I,5))+NU1)=ISIGN(1,GRAPH(I,5))*GAIN(I)*NUMER
     1(I,BLOCK(I,2))
   43 CONTINUE
      DO 44 J=1,NIN
      IF (GRAPH(I,J+1).EQ.0) GO TO 44
      C(I+NY1,IABS(GRAPH(I,J+1))+NY1)=-ISIGN(1,GRAPH(I,J+1))*GAIN(I)
     1*NUMER(I,BLOCK(I,2))
   44 CONTINUE
   41 CONTINUE
      GO TO 30
   50 CONTINUE
      DO 60 J=1,NIN
      IF (GRAPH(I,J+1).EQ.0) GO TO 60
      NOST=STATE(IABS(GRAPH(I,J+1)),4)
      IF (NOST.GE.2) GO TO 47
      WRITE (3,48)
   48 FORMAT (/10X,*DIFFERENTIATOR INPUT NOT ALLOWED*)
      GO TO 60
   47 DO 72 L=2,NOST
      H(I+NY1,STATE(IABS(GRAPH(I,J+1)),2)+L-1+NX1)=H(I+NY1,STATE(IABS
     1(GRAPH(I,J+1)),2)+L-1+NX1)+ISIGN(1,GRAPH(I,J+1))*GAIN(I)*GAIN(IABS
     2(GRAPH(I,J+1)))*(NUMER(IABS(GRAPH(I,J+1)),L-1)-NUMER(IABS(GRAPH
     3(I,J+1)),NOST)*DENOM(IABS(GRAPH(I,J+1)),L))
   72 CONTINUE
      IF (BLOCK(IABS(GRAPH(I,J+1)),2)+1.LT.BLOCK(IABS(GRAPH(I,J+1)),3)
     1)GO TO 60
      H(I+NY1,STATE(IABS(GRAPH(I,J+1)),2)+NX1)=H(I+NY1,STATE(IABS(GRAPH
     1(I,J+1)),2)+NX1)+GAIN(I)*GAIN(IABS(GRAPH(I,J+1)))*ISIGN(1,GRAPH
     2(I,J+1))*(-1.)*NUMER(IABS(GRAPH(I,J+1)),NOST)*DENOM(IABS(GRAPH
     3(I,J+1)),1)
      IF (GRAPH(IABS(GRAPH(I,J+1)),5).EQ.0) GO TO 73
      F(I+NY1,IABS(GRAPH(IABS(GRAPH(I,J+1)),5))+NU1)=ISIGN(1,GRAPH(IABS
     1(GRAPH(I,J+1)),5))*GAIN(I)*GAIN(IABS(GRAPH(I,J+1)))*NUMER(IABS
     2(GRAPH(I,J+1)),BLOCK(IABS(GRAPH(I,J+1)),2)-1)*ISIGN(1,GRAPH(I,J+1)
     3)+F(I+NY1,IABS(GRAPH(IABS(GRAPH(I,J+1)),5))+NU1)
   73 DO 74 L=1,NIN
      C(I+NY1,IABS(GRAPH(IABS(GRAPH(I,J+1)),L+1))+NY1)=C(I+NY1,IABS(GRAP
     1H(IABS(GRAPH(I,J+1)),L+1))+NY1)-ISIGN(1,GRAPH(IABS(GRAPH(I,J+1)),
     2L+1))*ISIGN(1,GRAPH(I,J+1))*GAIN(I)*GAIN(IABS(GRAPH(I,J+1)))
   74 CONTINUE
   60 CONTINUE
   30 CONTINUE
      II1=NY1+1
      II2=NBLOCK+NY1
      DO 80 II=II1,II2
      C(II,II)=C(II,II)+1.0
```

```
   80 CONTINUE
      CALL INVR (C,W1,NYT,1,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MX
      MAT2=MX
      MAT3=MY
      MAT4=MX
      MAT5=MX
      MAT6=MX
      CALL MULT (W1,H,W2,NYT,NYT,NXT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MY
      MAT3=MX
      CALL MAKE (H,W2,NYT,NXT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MY
      MAT3=MY
      MAT4=MU
      CALL MULT (W1,F,W2,NYT,NYT,NUT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MY
      MAT2=MU
      MAT3=MX
      MAT4=MX
      CALL MAKE (F,W2,NYT,NUT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      DO 200 I=1,NBLOCK
      NOST=STATE(I,4)
      IF (NOST.EQ.0) GO TO 200
      DO 201 J=1,NOST
      A(STATE(I,2)+NOST-1+NX1,STATE(I,2)+J-1+NX1)=-DENOM(I,J)
      IF (J.EQ.NOST) GO TO 201
      A(STATE(I,2)-1+J+NX1,STATE(I,2)+J+NX1)=1.0
  201 CONTINUE
      IF (IABS(GRAPH(I,5)).EQ.0) GO TO 110
      B(STATE(I,2)+NOST-1+NX1,IABS(GRAPH(I,5))+NU1)=ISIGN(1,GRAPH(I,5))
  110 CONTINUE
      DO 120 J=1,NIN
      IF (GRAPH(I,J+1).EQ.0) GO TO 120
      DO 121 K=1,NX
      A(STATE(I,2)+NOST-1+NX1,K+NX1)=A(STATE(I,2)+NOST-1+NX1,K+NX1)
     1+H(IABS(GRAPH(I,J+1))+NY1,K+NX1)*ISIGN(1,GRAPH(I,J+1))
  121 CONTINUE
      DO 122 K=1,NU
      IF (F(I,K).NE.0.0) OUTPUT=3
      B(STATE(I,2)+NOST-1+NX1,K+NU1)=B(STATE(I,2)+NOST-1+NX1,K+NU1)
     1+F(IABS(GRAPH(I,J+1))+NY1,K+NU1)*ISIGN(1,GRAPH(I,J+1))
  122 CONTINUE
  120 CONTINUE
  200 CONTINUE
      DO 280 I=1,NX
      DO 281 J=1,NX
      C(I+NX1,J+NX1)=0.0
  281 CONTINUE
      C(I+NX1,I+NX1)=1.0
  280 CONTINUE
      DO 90 I=1,NUT
```

```
      DO 191 J=1,NUT                                    CLASS   344
      D(I,J)=0.0                                        CLASS   345
  191 CONTINUE                                          CLASS   346
      D(I,I)=1.0                                        CLASS   347
   90 CONTINUE                                          CLASS   348
      DO 522 I=1,NYT                                    CLASS   349
      DO 522 J=1,NUT                                    CLASS   350
      IF (F(I,J).EQ.0.0) GO TO 522                      CLASS   351
      OUTPUT=3                                          CLASS   352
      GO TO 523                                         CLASS   353
  522 CONTINUE                                          CLASS   354
      OUTPUT=1                                          CLASS   355
  523 CONTINUE                                          CLASS   356
      NU=NUT                                            CLASS   357
      NX=NXT                                            CLASS   358
      NY=NYT                                            CLASS   359
      RETURN                                            CLASS   360
      END                                               CLASS   361
```

```
      SUBROUTINE CNTRLR (A,B,C,H,G,F,K1,K2,K3,K4,D,W1,W2,W3,ROOTR,ROOTI,
C    1ROTR,ROTI,SAV1,SAV2,U,V,
     1ROTR,ROTI,Z,ZZ,U,V,
     2MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
C
C         THIS SUBROUTINE SERVES AS THE EXECUTIVE ROUTINE FOR THE
C         CONTROL PROGRAM. THE CONTROL PROGRAM IS CAPABLE OF PERFORMING
C         ,FOR LINEAR SYSTEMS, THE FOLLOWING OPERATIONS
C
C           1. ROOT LOCII AS A FUNCTION OF TWO FEEDBACK GAINS
C
C           2. DETERMINATION OF SYSTEM EIGENVALUES FOR OPEN AND
C              CLOSED-LOOP SYSTEMS
C
C           3. DETERMINATION OF SYSTEM TRANSFER FUNCTIONS FOR
C              ARBITRARY INPUT-OUTPUT VARIABLES
C
C           4. CALCULATION OF TABULATED FREQUENCY RESPONSES
C
C           5. CALCULATION OF TABULATED POWER SPECTRAL DENSITY
C              FUNCTIONS.
C
C           6. TABULATED TIME HISTORY RESPONSE
C
C        COMPUTATIONS ARE PERFORMED USING STATE VARIABLE MATRIX
C        NOTATION.
C
C      CORRECTION MADE BY G. NORRIS JULY 5 73
C      Z AND SAV1, ZZ AND SAV2 ARE SAME MATRIX
C
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CONTUR,NUMERS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     1IGC,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KOUNT
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRPS,TRESP
      INTEGER DIGITL,SCAPLT,ZOH
      COMMON/RCOND/ DELT,FINALT,IFREQ,FFREQ,DELFRQ,GAIN1,GAIN2,MN
      REAL   INPT(10), OUTPT(20),TITLE(8)
      COMMON/LABEL/INPT,OUTPT,TITLE
      REAL IFREQ,K1,K2,K3,K4,MN
      DIMENSION A(MX,MX),B(MX,MU),C(MX,MX),H(MY,MX),G(MY,MY),F(MY,MU),
     1K1(MU,MX),K2(MU,MX),K3(MU,MX),K4(MU,MX),D(MU,MU),
     2W1(MX,MY),W2(MX,MX),W3(MX,MX),ROOTR(MX),ROOTI(MX),ROTR(MX),
     3ROTI(MX),U(MX),V(MX),Z(MS),ZZ(MS)
C     DIMENSION A(15,15), B(15,10), C(15,15), H(15,15), G(15,15),
C    1 F(15,10), K1(10,15), K2(10,15), K3(10,15), K4(10,15), D(10,10)
C     DIMENSION W1(15,15), W2(15,15), W3(15,15), ROOTR(15), ROOTI(15),
C    1 ROTR(15), ROTI(15), U(15), V(15), Z(200), ZZ(200)
      DIMENSION M(10,20),MM(20),P(20),ICOND(29),JCOND(29),RCOND(8)
      EQUIVALENCE (READ,ICOND(1)),(DELT,RCOND(1))
      COMMON/BLKDAT/NUMER,DENOM,GAIN,GRAPH,BLOCK,STATE,YTOV,ZTOU,YZTOK,
     1ITHINY,ITHINU,NBLOCK,NYTOV,NZTOU,NXYU,NYZTOK,NXT,NYT,NUT,NY1,NU1
      DIMENSION GRAPH(20,3),BLOCK(20,3),NUMER(20,5),DENOM(20,5),
     XGAIN(20),STATE(20,4),ITHINY(30),ITHINU(20),YTOV(20,2),
     X  ZTOU(20,2),NXYU(8),YZTOK(20,2)
      INTEGER GRAPH,BLOCK,STATE,YTOV,ZTOU,YZTOK
      REAL NUMER
      COMMON/SUBWRIT/ ISUBNAM
```

```
      DATA  RCON/10HRCON      /
      IF(ISUBNAM.GE.2) WRITE(3,930)
  930 FORMAT(1X,*CNTRLR*)
      KOUNT=0
      ISAV=0
  500 CONTINUE
      ITT=0
      DO 202 I=1,29
      JCOND(I)=0
  202 CONTINUE
      DO 203 I=1,8
      BCOND(I)=0.0
  203 CONTINUE
  501 CONTINUE
      REWIND 8
      KOUNT=KOUNT+1
      DO 200 I=1,29
      ICOND(I)=JCOND(I)
  200 CONTINUE
      CALL CARD
      IF(READ.NE.3) ISAV=0
      DO 201 I=1,29
      JCOND(I)=ICOND(I)
  201 CONTINUE
      IF((CONTUR.EQ.1).AND.(FORM.GT.0).AND.(ITT.EQ.0)) GO TO 91
      GO TO 92
   91 NPLOT=1
      WRITE (7) NPLOT
      WRITE (7) RCON,TITLE,SYSTEM,MODEL,DIGITL,SCAPLT
   92 IF (CONTUR.EQ.1) ITT=1
      CALL ZOT (A,B,C,H,G,F,K1,K2,K3,K4,D,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      GO TO (30,40,50,55),READ
   30 CALL LOAD    (A,B,C,H,G,F,K1,K2,K3,K4,D,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      GO TO 60
   40 CALL MATRIX (A,B,C,H,G,F,K1,K2,K3,K4,D,W1,W2,W3,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
C
      DO 45 I=1,29
   45 JCOND(I)=ICOND(I)
C
      GO TO 60
   50 IF (ISAV.EQ.0) GO TO 51
      CALL RCTSC (A,B,C,H,G,F,K1,K2,K3,K4,D,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
   51 CALL CHANGE (A,B,C,H,G,F,K1,K2,K3,K4,D,W1,W2,W3,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (MIXED.EQ.0.0.AND.ISAV.EQ.0) GO TO 555
      GO TO 60
   55 IGO =0
  555 CONTINUE
      CALL CLASS        (A,B,C,H,G,F,D,W1,W2,W3,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
   60 CONTINUE
      IF (READ3.EQ.1) JCOND(1)=3
      IF (ISAV.EQ.1)ISAV=1
```

```
      IF (CONTUR.EQ.1.AND.KOUNT.GT.1) GO TO 69                           CNTRLR  116
      CALL OPTT    (A,B,C,H,G,F,K1,K2,K3,K4,D,                           CNTRLR  117
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                         CNTRLR  118
   69 IF (SAV.EQ.0) GO TO 70                                             CNTRLR  119
      CALL NOISC   (A,B,C,H,G,F,K1,K2,K3,K4,D,                           CNTRLR  120
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                         CNTRLR  121
      JCONP(18)=0                                                        CNTRLR  122
   70 CONTINUE                                                           CNTRLR  123
      CALL       SETUP (J,M,MM,P,A,B,C,H,G,F,K1,K2,K3,K4,D,W1,W2,W3,     CNTRLR  124
     1 ROOTR,                                                            CNTRLR  125
     2 MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                        CNTRLR  126
      IF (TRESP.GT.0) NPLOT=1                                            CNTRLR  127
      IF (TRESP.GT.0) NPLOT=TRESP                                        CNTRLR  128
      IF (FRPS.NE.0) NPLOT=NY*NU                                         CNTRLR  129
      IF (FRPS.GT.0.AND.TRESP.GT.0) NPLOT=NY*NU+1                        CNTRLR  130
      IF (FRPS.NE.0.AND.TRESP.GT.0) NPLOT=NY*NU+TRESP                    CNTRLR  131
      IF (SYSTEM.EQ.3) NPLOT=1                                           CNTRLR  132
      IF (FORM.GT.0.AND.CONTUR.EQ.0) WRITE (7) NPLOT                     CNTRLR  133
      IF (MULTRT.NE.0) GO TO 101                                         CNTRLR  134
      IF (SYSTEM.NE.3) GO TO 80                                          CNTRLR  135
      CALL ROOT (A,B,C,H,G,F,K1,K2,K3,K4,D,W1,W2,W3,ROOTR,ROOTI,U,V,     CNTRLR  136
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                         CNTRLR  137
      GO TO 90                                                           CNTRLR  138
   80 CONTINUE                                                           CNTRLR  139
      WRITE (3,81)                                                       CNTRLR  140
   81 FORMAT   (//10X,*THE EIGEN VALUES OF THE SYSTEM ARE*//20X,         CNTRLR  141
     1*REAL PART*,15X,* IMAGINARY PART*/)                                CNTRLR  142
      CALL EIGEN (NX,W1,W2,W3,ROOTR,ROOTI,U,V,                           CNTRLR  143
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                         CNTRLR  144
      IF (IFLAG.EQ.0.AND.CONTUR.EQ.1) GO TO 499                          CNTRLR  145
      IF (CONTUR.EQ.1) GO TO 501                                         CNTRLR  146
      GO TO 502                                                          CNTRLR  147
  499 IF (FORM.EQ.0) GO TO 500                                           CNTRLR  148
      NO=1                                                               CNTRLR  149
      XYX=-1.0                                                           CNTRLR  150
      WRITE(7)NO,XYX,XYX                                                 CNTRLR  151
      GO TO 500                                                          CNTRLR  152
  502 CONTINUE                                                           CNTRLR  153
      CALL OPMT (Z,ROOTR,ROOTI,NX,                                       CNTRLR  154
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                         CNTRLR  155
      WRITE (3,82)                                                       CNTRLR  156
   82 FORMAT (//10X,*THE COEFFICIENTS OF THE CHARACTERISTIC EQUATION ORD CNTRLR  157
     1ERED FROM THE LOWEST POWER OF S*//)                                CNTRLR  158
      NX1=NX+1                                                           CNTRLR  159
      WRITE (3,83) (Z(I),I=1,NX1)                                        CNTRLR  160
   83 FORMAT (E20.8)                                                     CNTRLR  161
   90 CONTINUE                                                           CNTRLR  162
      IF (NUMERS.EQ.1) GO TO 100                                         CNTRLR  163
      NN=NX                                                              CNTRLR  164
C     CALL       NMRATR (NN,A,B,C,H,G,F,D,ROOTR,ROOTI,ROTR,ROTI,Z,V,     CNTRLR  165
      CALL       NMRATR (NN,A,B,C,H,G,F,D,ROOTR,ROOTI,ROTR,ROTI,U,V,     CNTRLR  166
C    1W1,W2,W3,SAV1,SAV2,                                                CNTRLR  167
     1W1,W2,W3,Z,ZZ,                                                     CNTRLR  168
     2MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                         CNTRLR  169
  100 CONTINUE                                                           CNTRLR  170
      IF(TRESP.EQ.0) GO TO 507                                           CNTRLR  171
  101 CONTINUE                                                           CNTRLR  172
```

```
      CALL        THIST (A,B,C,H,F,W1,W2,W3,ROOTR,ROOTI,U,K1,D,Z,V,        CNTRLR   173
      CALL        THIST (A,B,C,H,F,W1,W2,W3,ROOTR,ROOTI,U,K1,C,ROTI,ROTR, CNTRLR   174
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                           CNTRLR   175
  507 IF (SCAPLT.EQ.2) JCOND(28)=1                                         CNTRLR   176
      IF (IFLAG.EQ.0) GO TO 100                                            CNTRLR   177
      GO TO 501                                                            CNTRLR   178
      END                                                                  CNTRLR   179
```

```
      SUBROUTINE CPMT(C,ROOTR,ROOTI,N,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      COMPLEX A,B,D,E
      DIMENSION A(25),B(25),C(MX),ROOTR(MX),ROOTI(MX),D(25),E(25)
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*CPMT*)
      IF (N.GT.1) GO TO 10
      C(1)=-ROOTR(1)
      C(2)=1.0
      RETURN
   10 CONTINUE
      A(1)=CMPLX(-ROOTR(1),ROOTI(1))
      A(2)=CMPLX(1.0,0.0)
      NX=2
      DO 4 II=2,N
      NY=NX+1
      DO 1 I=1,NY
      D(I)=CMPLX(0.0,0.0)
    1 CONTINUE
      B(1)=CMPLX(-ROOTR(II),ROOTI(II))
      B(2)=CMPLX(1.0,0.0)
      DO 3 I=1,2
      DO 3 J=1,NX
      K=I+J-1
      D(K)=A(J)*B(I)+D(K)
    3 CONTINUE
      NX=NX+1
      DO 5 JJ=1,NX
      A(JJ)=D(JJ)
    5 CONTINUE
    4 CONTINUE
      DO 7 I=1,NX
      E(I)=D(I)
    7 CONTINUE
      DO 6 I=1,NX
      C(I)=REAL(D(I))
    6 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE EAT (T,A,W1,W2,W3,C,N,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
C
C     THIS SUBROUTINE COMPUTES THE TRANSITION MATRIX AND IT@S INTEGRAL.
C     THE SERIES IS TRUNCATED WHEN THE LARGEST ELEMENT OF THE LAST TERM
C     THE SERIES IS LESS THAN 1.E-03 TIMES THE SMALLEST ELEMENT OF THE S
C     SERIES.  WRITTEN BY R. MAINE  8/17/71
C
      DIMENSION A(MX,MX),W1(MX,MX),W2(MX,MX),W3(MX,MX),C(MX,MX)
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CONTUR,NUMERS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     1IGO,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KCUNT
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRPS,TRESP
      INTEGER DIGITL
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*EAT*)
      MAT1=MX
      MAT2=MX
      MAT3=MX
      MAT4=MX
      MAT5=MX
      MAT6=MX
      NT=24
      CALL ZCT1(W1,N,N,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL MAKE (W2,W1,N,N,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      DO 1 I=1,N
      W1(I,I)=1.0
    1 CONTINUE
      CALL MAKE (W3,W1,N,N,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      G=1.0
      W3MAX= 1.E+50
      T= T/8.
      DO 7 I=1,NT
      BB=I
      G=G*T/BB
      W1MIN= 1.E+50
      W2MIN= 1.E+50
      DO 30 J=1,NX
      DO 30 K=1,NX
      IF (W1(J,K).NE.0.0.AND.ABS(W1(J,K)).LT. W1MIN) W1MIN=ABS(W1(J,K))
      IF (W2(J,K).NE.0.0.AND.ABS(W2(J,K)).LT. W2MIN) W2MIN=ABS(W2(J,K))
   30 CONTINUE
      W3MAX1= W3MAX*T/BB
      CALL ADD (1.0,W2,G,W3,W2,N,N,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL MULT (A,W3,C,N,N,N,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL MAKE (W3,C,N,N,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      W3MAX =0.0
      DO 40 J=1,NX
      DO 40 K=1,NX
      IF (ABS(W3(J,K)).GT.W3MAX) W3MAX= (ABS(W3(J,K)))
```

```
   40 CONTINUE                                                            EAT
      W3MAX= W3MAX*G                                                      EAT
      CALL ADD (1.0, W1, G, W3, W1, N, N,                                 EAT
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                          EAT
      IF (W3MAX1.LT.W2MIN* 1.0E-03 .AND.W3MAX.LT.W1MIN* 1.0E-03) GO TO 70 EAT
    7 CONTINUE                                                            EAT
      WRITE (3,1000) W1MIN, W3MAX, W2MIN, W3MAX1                          EAT
 1000 FORMAT(* ERROR IN EAT*,5X,*W1MIN =*,E15.6,5X,*W3MAX =*,E15.6,/* *,  EAT
     117X,*W2MIN =*,E15.6,5X,*W3MAX1 =*,E15.6)                            EAT
   70 CONTINUE                                                            EAT
      DO 90 K=1,3                                                         EAT
      CALL MAKE (W3, W1, N, N,                                            EAT
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                          EAT
      CALL MULT (W1, W3, C, N, N, N,                                      EAT
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                          EAT
      CALL MAKE (W1, C, N, N,                                             EAT
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                          EAT
      DO 80 J=1,N                                                         EAT
      W3(J,J)= W3(J,J)+1.                                                 EAT
   80 CONTINUE                                                            EAT
      CALL MULT (W2, W3, C, N, N, N,                                      EAT
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                          EAT
      CALL MAKE (W2, C, N, N,                                             EAT
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                          EAT
   90 CONTINUE                                                            EAT
      I= I*3,                                                             EAT
      WRITE (3,51) I                                                      EAT
   51 FORMAT (/*     THE TRANSITION MATRIX *,I5,*  TERMS*/)               EAT
      CALL SPIT1 (W1,NX,NX,                                               EAT
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                          EAT
      RETURN                                                              EAT
      END                                                                 EAT
```

```
      SUBROUTINE EIGEN (N,W1,W2,W3,ROOTR,ROOTI,ROTR,ROTI,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CONTUR,NUMERS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     1IGO,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KOUNT
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRPS,TRESP
      INTEGER DIGITL,SCAPLT,ZOH
      DIMENSION M(10,20),MM(20),P(20),KD(25)
      DIMENSION W1(MX,MX),W2(MX,MX),W3(MX,MX)
      DIMENSION ROOTR(MX),ROOTI(MX),ROTR(MX),ROTI(MX)
      COMMON/UDIM/MX,MY,MU,MS
C
C
C       THIS SUBROUTINE FINDS THE EIGENVALUES OF THE INPUT MATRIX (W1)
C
C       NSCALE=0  NO PRECONDITIONING OF THE INPUT MATRIX IS DONE
C
C       NSCALE=1  SCALE IS CALLED TO SCALE THE INPUT MATRIX BY A
C                 DIAGONAL SIMILARITY TRANSFORMATION. THEN THE
C                 EIGENVALUES OF THE IRREDUCIBLE SUBMATRICES ARE
C                 DETERMINED.
C       NSCALE=2  REDUCE IS CALLED TO DETERMINE THE IRREDUCIBLE
C                 SUBMATRICES OF W1. THEN THE EIGENVALUES OF THE
C                 INDIVIDUAL SUBMATRICES ARE DETERMINED.
C
C
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*EIGEN*)
      IPRNT=0
      IF (NSCALE.EQ.0) GO TO 50
      IF (NSCALE.EQ.2) GO TO 100
      CALL ASCALE (N,J,M,MM,P,W1,W2,W3,ROOTR,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      GO TO 101
  100 CALL REDUCE (N,J,MM,M,W1,W2,W3,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      GO TO 101
   50 DO 51 I=1,N
      M(1,I)=I
   51 CONTINUE
      MM(1)=N
      J=1
  101 CONTINUE
      KRUNT=0
      DO 200 I=1,J
      N5=MM(I)
      DO 110 K=1,N5
      DO 110 L=1,N5
      W2(K,L)=W1(M(I,K),M(I,L))
  110 CONTINUE
      CALL HESSEN (W2,N5,ROTR,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL QREIG (N5,ROTR,ROTI,IPRNT,W2,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF(SYSTEM.EQ.3) GO TO 3
      IF(CONTUR.EQ.1) GO TO 3
      GO TO 5
```

```
    4 IF(FORM.EQ.3) GO TO 5
      J3=0
      DO 418 J4=1,N5
      IF(ROTI(J4).LT.0.) GO TO 418
      J3=J3+1
      KC(J3)=J4
  418 CONTINUE
      WRITE(7) J3,(ROTR(KC(K)),ROTI(KC(K)),K=1,J3)
      IF(FORM.EQ.2) GO TO 7
    5 WRITE (3,300) (ROTR(II),ROTI(II),II=1,N5)
    7 CONTINUE
  300 FORMAT (/(2E30.8))
      DO 120 K=1,N5
      ROOTR(KRUNT+K)=ROTR(K)
      ROOTI(KRUNT+K)=ROTI(K)
  120 CONTINUE
      KRUNT=KRUNT+N5
  200 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FRQRSP (NNUM,NN,GAIN,IMOD,ROOTR,ROOTI,ROTR,ROTI,SAV1,   FRQRSP
     1SAV2,INY,INU,                                                      FRQRSP
     2MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                         FRQRSP
      REAL IFREQ,M                                                       FRQRSP
      DIMENSION ROOTR(MX),ROOTI(MX),ROTR(MX),ROTI(MX),SAV1(MS),SAV2(MS)  FRQRSP
      COMPLEX RN1,RN2,RD1,RD2                                            FRQRSP
      INTEGER TWO, FOUR                                                  FRQRSP
      COMMON/LABEL/INPT,OUTPT,TITLE                                      FRQRSP
      REAL    INPT(10), OUTPT(20),TITLE(8)                               FRQRSP
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,      FRQRSP
     1CONTUR,NUMERS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,          FRQRSP
     1IGO,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KOUNT                   FRQRSP
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRPS,TRESP  FRQRSP
      INTEGER DIGITL, SCAPLT, ZOH                                        FRQRSP
      COMMON/ACOND/ DELT,FINALT,IFREQ,FFREQ,DELFRQ,GAIN1,GAIN2,M         FRQRSP
      COMMON/SUBWRIT/ ISUBNAM                                            FRQRSP
      REAL PST                                                           FRQRSP
      DATA TWO/2/,FOUR/4/                                                FRQRSP
      DATA PST/10HFREQ      /                                            FRQRSP
      IF(ISUBNAM.GE.2) WRITE(3,999)                                      FRQRSP
  999 FORMAT(1X,*FRQRSP*)                                                FRQRSP
      IF(FORM.GT.0) WRITE(7)PST,TITLE,SYSTEM,MODEL,DIGITL,SCAPLT         FRQRSP
      J=1                                                                FRQRSP
      IF (IMOD.EQ.2) GO TO 70                                            FRQRSP
      IF (DIGITL.NE.0) GO TO 200                                         FRQRSP
      WRITE (3,71) OUTPT(INY),INPT(INU)                                  FRQRSP
   71 FORMAT (//5X,A10*/*A10,*FREQUENCY RESPONSE  S-PLANE*//* FREQUENCY  FRQRSP
     1*,6X,*AMPLITUDE RATIO*,9X,*PHASE ANGLE*/*  RAD/SEC*,12X,*DB*,17X,* FRQRSP
     2DEGREES*/)                                                         FRQRSP
      GO TO 75                                                           FRQRSP
  200 WRITE (3,76) OUTPT(INY),INPT(INU)                                  FRQRSP
   76 FORMAT (//5X,A10,*/*A10,* FREQUENCY RESPONSE  W-PLANE*//*  W-PLANE FRQRSP
     1   S-PLANE*/* FREQUNCY     FREQUENCY        AMPLITUDE RATIO        FRQRSP
     2PHASE ANGLE*/12X,*  RAD/SEC*,12X,*DB*,17X,*DEGREES*/)              FRQRSP
   75 IF (FORM.GT.0) WRITE (7)TWO,OUTPT(INY),INPT(INU)                   FRQRSP
      GO TO 72                                                           FRQRSP
   70 IF (DIGITL.NE.0) GO TO 201                                         FRQRSP
      WRITE (3,73)  OUTPT(INY),INPT(INU),OUTPT(INY),OUTPT(INY-1)         FRQRSP
   73 FORMAT (//6X,*S-PLANE*,A10,*/*,A10,* FREQUENCY RESPONSE*3X,A10,*/* FRQRSP
     1A10,*FREQUENCY RESPONSE*/* FREQUENCY      AMPLITUDE RATIO*9X,*PHASE FRQRSP
     2ANGLE  AMPLITUDE RATIO*9X,*PHASE ANGLE*/*  RAD/SEC*10X,*DB*17X,*DE FRQRSP
     3GREES*,13X,*DB*,17X,*DEGREES*/)                                    FRQRSP
      GO TO 77                                                           FRQRSP
  201 WRITE (3,78) OUTPT(INY),INPT(INU),OUTPT(INY),OUTPT(INY-1)          FRQRSP
   78 FORMAT (//6X,*W-PLANE  *,A10,*/*,A10,* FREQUENCY RESPONSE*3X,A10,* FRQRSP
     1/*,A10,* FREQUENCY RESPONSE*/* W-PLANE   S-PLANE*/* FREQUENCY      FRQRSP
     2AMPLITUDE RATIO*9X,*PHASE ANGLE  AMPLITUDE RATIO*9X,*PHASE ANGLE*/ FRQRSP
     3*  RAD/SEC*10X,*DB*17X,*DEGREES*,13X,*DB*,18X,*DEGREES*/)          FRQRSP
   77 IF (FORM.GT.0) WRITE(7)FOUR,OUTPT(INY),INPT(INU),OUTPT(INY),OUTPT  FRQRSP
     1(INY-1)                                                            FRQRSP
   72 CONTINUE                                                           FRQRSP
      FREQ=.1/1.15                                                       FRQRSP
      IF (DIGITL.EQ.0.OR.INY.GT.1.OR.INU.GT.1.OR.FRPS.EQ.-1) GO TO 91    FRQRSP
      IF (IFREQ.EQ.0) GO TO 90                                           FRQRSP
      IFREQ= TAN(IFREQ*DELT*.5)                                          FRQRSP
      FFREQ= TAN(FFREQ*DELT*.5)                                          FRQRSP
      GO TO 91                                                           FRQRSP
```

```
   40 FFREQ= TAN(87./57.3)
      IFREQ= TAN(FREQ     * DELT*.5)
      DELFRQ= 1.15
   91 CONTINUE
  101 CONTINUE
      IF (IFREQ.EQ.0..AND.DIGITL.EQ.0) GO TO 80
      IF (IFREQ.NE.0..AND.DIGITL.EQ.0) GO TO 81
      IF (IFREQ.EQ.0..AND.DIGITL.NE.0) GO TO 82
      IF (IFREQ.NE.0..AND.DIGITL.NE.0) GO TO 83
   80 FREQ=1.15*FREQ
      IF (J.EQ.1) FFREQ=150.
      GO TO 84
   81 IF (J.EQ.1) GO TO 85
      FREQ=FREQ*DELFRQ
      GO TO 84
   85 FREQ=IFREQ
      GO TO 84
   82 IF (FRPS.EQ.-1) GO TO 80
      IF (J.EQ.1) GO TO 85
      FREQ=1.15*FREQ
      GO TO 84
   86 FREQ=TAN(FREQ     *DELT*.5)
      GO TO 84
   83 IF (J.EQ.1) GO TO 85
      FREQ=FREQ*DELFRQ
   84 CONTINUE
      RN1=CMPLX (1.0,0.0)
      RD1=CMPLX (1.0,0.0)
      XR= 0.0
      XI= FREQ
      DO 20 I=1,NN
      IF (FRPS.NE.-1) GO TO 21
      XR= COS(FREQ*DELT)
      XI= SIN(FREQ*DELT)
   21 IF (I.GT.NNUM) GO TO 5
      RN2= CMPLX(XR-ROTR(I), XI-ROTI(I))
      RN1= RN1*RN2
    5 RD2= CMPLX(XR-ROOTR(I), XI-ROOTI(I))
      RD1=RD1*RD2
   20 CONTINUE
      RD1=GAIN*RN1/RD1
      PHI=TANG(RD1)
      REAL1=REAL(RD1)
      AMAG=AIMAG(RD1)
      AMPRAT =SQRT(AMAG**2+REAL1**2)
      DB=20.*ALOG10(AMPRAT)
      IF (IMCO.EQ.0) GO TO 30
      IF (IMCO.EQ.2) GO TO 40
      SAV1(J)=DB
      SAV2(J)=PHI
   30 IF(FORM.EQ.2) GO TO 6
      IF (DIGITL.NE. 0    .AND. FRPS .NE. -1) GO TO 79
      WRITE (3,50) FREQ,DB,PHI
      GO TO 11
   79 OMEGA= ATAN(FREQ)*2./DELT
      WRITE (3,51) FREQ,OMEGA,DB,PHI
   11 CONTINUE
```

```
      IF(FORM.EQ.0) GO TO 60
    6 WRITE (7) FREQ,DB,PHI
  121 CONTINUE
      GO TO 60
   40 A=DB-SAV1(J)
      B=PHI-SAV2(J)
      IF(FORM.EQ.2) GO TO 7
      IF (DIGITL.NE. 0   .AND. FRPS .NE. -1) GO TO 12
      WRITE (3,50) FREQ,DB,PHI,A,B
      GO TO 13
   12 WRITE (3,51) FREQ,OMEGA,DB,PHI,A,B
   13 CONTINUE
      IF(FORM.EQ.0) GO TO 60
    7 WRITE(7) FREQ,DB,PHI,A,B
  131 CONTINUE
   50 FORMAT (F10.4,4E20.5)
   51 FORMAT (2F10.4,4E20.5)
   60 J=J+1
      IF (FREQ.LE.FFREQ) GO TO 100
   10 CONTINUE
      IF(FORM.EQ.0) GO TO 8
      JD=99
      IF(IMOD.EQ.2) WRITE(7) JD,DB,PHI,A,B
      IF(IMOD.NE.2) WRITE(7)JD,DB,PHI
    8 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE HESSEN (A,M,B,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      DIMENSION B(MX),A(MX,MX)
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*HESSEN*)
      IF (M-2) 30,30,32
   32 DO 40 LC = 3,M
      N = M - LC + 3
      N1 = N - 1
      N2 = N - 2
      NI = N1
      DIV= ABS(A(N,N-1))
      DO 2 J = 1,N2
      IF( ABS(A(N,J))-DIV) 2,2,1
    1 NI = J
      DIV=  ABS(A(N,J))
    2 CONTINUE
      IF(DIV) 3,40,3
    3 IF(NI - N1) 4, 7,4
    4 DO 5 J = 1,N
      DIV = A(J,NI)
      A(J,NI) = A(J,N1)
      A(J,N1) = DIV
    5 CONTINUE
      DO 6 J = 1,M
      DIV = A(NI,J)
      A(NI,J) = A(N1,J)
      A(N1,J) = DIV
    6 CONTINUE
    7 DO 26 K = 1, N1
      B(K) = A(N,K)/A(N,N-1)
   26 CONTINUE
      DO 45 J = 1,M
      SUM = 0.0
      IF (J - N1) 46,43,43
   46 IF(B(J))  41,43,41
   41 A(N,J) = 0.0
      DO 42 K = 1,N1
      A(K,J) = A(K,J) - A(K,N1)*B(J)
      SUM = SUM + A(K,J)*B(K)
   42 CONTINUE
      GO TO 45
   43 DO 44 K = 1,N1
      SUM = SUM + A(K,J)*B(K)
   44 CONTINUE
   45 A(N1,J) = SUM
   40 CONTINUE
   30 RETURN
      END
```

```
      SUBROUTINE INPUTV(DELT,T,U,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NYC,NUC,N1,N2,DIGITL,
     1CONTUR,NUMERS,ERRS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     2IGO,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KOUNT
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, ERRS,TRESP
      INTEGER DIGITL,SCAPLT,ZOH
      DIMENSION U(MX)
C
C     USER WRITTEN SUBROUTINE CONSTRUCTING INPUT VECTOR FOR TRANSIENT
C     RESPONSE.
C
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*INPUTV*)
      IF (T.GT.0.0) RETURN
      READ (1,1) (U(I),I=1,NU)
      IF (EOF(1).NE.0) STOP
    1 FORMAT (8F10.4)
      RETURN
      END
```

```
      SUBROUTINE INVR (A,B,JJJ,IT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
C  PROGRAM AUTHORS R.E. FUNDERIC AND R.G. EDWARDS,
C  COMPUTING TECHNOLOGY CENTER, UNION CARBIDE CORP., NUCLEAR DIV.,
C  OAK RIDGE, TENN.
C
C  CTC ORD PROGRAM NO. 9067.1
      DIMENSION A(MX,MX),B(MX,MX)
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CONTUR,NUMBRS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     1IGO,FORM,IPT,READ3,MIXSQ,MULTRT,SCAPLT,ZOH,KOUNT
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRPS,TRESP
      INTEGER DIGITL, SCAPLT, ZOH
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*INVR*)
      MAT1=MX
      MAT2=MX
      IF (IPT.LT.1) GO TO 70
      WRITE (3,71)
   71 FORMAT (/*    MATRIX ENTERING INVR AND ITS INVERSE*/)
      CALL SPIT1 (A,JJJ,JJJ,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
   70 CONTINUE
      IF (JJJ.NE.1) GO TO 50
      B(1,1)=1./A(1,1)
      RETURN
   50 CONTINUE
      DO 21 I=1,JJJ
      DO 20 J=1,JJJ
      B(I,J)=0.0
   20 CONTINUE
      B(I,I)=1.0
   21 CONTINUE
      KK=JJJ
      NV=JJJ
      D=1.
      IF (JJJ.LT.0)D=0.
      KKM=KK-1
      DO 9 I=1,KKM
      S=0.0
      DO 1 J=I,KK
      R=ABS(A(J,I))
      IF (R.LT.S) GO TO 1
      S=R
      L=J
    1 CONTINUE
      IF (L.EQ.I) GO TO 5
      DO 2 J=I,KK
      S=A(I,J)
      A(I,J)=A(L,J)
      A(L,J)=S
    2 CONTINUE
      IF(NV.LE.0)GO TO 4
      DO 3 J=1,NV
      S=B(I,J)
      B(I,J)=B(L,J)
```

```
      B(L,J)=0
    3 CONTINUE
    4 D=-D
    5 IF(A(I,I).EQ.0.)GO TO 9
      IPO=I+1
      DO 8 J=IPO,KK
      IF (A(J,I).EQ.0.) GO TO 8
      S=A(J,I)/A(I,I)
      A(J,I)=0.0
      DO 6 K=IPO,KK
      A(J,K)=A(J,K)-A(I,K)*S
    6 CONTINUE
      IF (NV.LE.0) GO TO 8
      DO 7 K=1,NV
      B(J,K)=B(J,K)-B(I,K)*S
    7 CONTINUE
    8 CONTINUE
    9 CONTINUE
      DO 10 I=1,KK
      D=D*A(I,I)
   10 CONTINUE
      IF(NV.LE.0)GO TO 13
      KMO=KK-1
      DO 12 K=1,NV
      B(KK,K)=B(KK,K)/A(KK,KK)
      DO 12 I=1,KMO
      N=KK-I
      DO 11 J=N,KMO
      B(N,K)=B(N,K)-A(N,J+1)*B(J+1,K)
   11 CONTINUE
      B(N,K)=B(N,K)/A(N,N)
   12 CONTINUE
   13 DMAT=Q=D
      IF (IPT.LT.1) GO TO 72
      CALL SPIT1 (B,JJJ,JJJ,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
   72 CONTINUE
      IF (IT.EQ.0) RETURN
      DO 30 I=1,JJJ
      DO 30 J=1,JJJ
      IF (ABS(B(I,J)).LT.1.E-5)B(I,J)=0.
   30 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE LOAD     (A,B,C,H,G,F,K1,K2,K3,K4,D,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
C
C       THIS SUBROUTINE LOADS ALL MATRICES ACCORDING TO THE
C       PARAMETERS, SYSTEM AND OUTPUT, USING THE SUBROUTINE LOAD1
C
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CONTUR,NUMERS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     1IGO,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KOUNT
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRPS,TRESP
      INTEGER DIGITL, SCAPLT, ZOH
      REAL K1,K2,K3,K4
      DIMENSION A(MX,MX),B(MX,MU),C(MX,MX),H(MY,MX),G(MY,MX),F(MY,MU),
     1K1(MU,MX),K2(MU,MX),K3(MU,MX),K4(MU,MX),D(MU,MU)
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*LOAD*)
      MAT1=MX
      MAT2=MX
      NMAT=0
      CALL LOAD1 (A,NX,NX,NMAT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MU
      CALL LOAD1 (B,NX,NU,NMAT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (CMAT.EQ.0) GO TO 20
      MAT1=MX
      MAT2=MX
      CALL LOAD1 (C,NX,NX,NMAT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      GO TO 40
   20 MAT2=MX
      CALL ZCT1(C,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      DO 21 I=1,NX
   21 C(I,I)=1.0
   40 CONTINUE
      IF (MIXED.EQ.1) GO TO 50
      GO TO  (50,50,60),SYSTEM
   60 MAT1=MU
      MAT2=MX
      CALL LOAD1 (K1,NU,NX,NMAT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (NK2.EQ.0) GO TO 62
      CALL LOAD1 (K2,NU,NX,NMAT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
   62 CONTINUE
      IF (N2.EQ.0) GO TO 64
      CALL LOAD1 (K3,NU,NX,NMAT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (NK2.EQ.0) GO TO 64
      CALL LOAD1 (K4,NU,NX,NMAT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
   64 CONTINUE
      GO TO 200
   50 MAT1=MY
      MAT2=MX
```

```
      CALL LOAD1 (H,NY,NX,NMAT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      GO TO(100,56,57,58),OUTPUT
   56 CALL LOAD1 (G,NY,NX,NMAT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      GO TO 100
   57 MAT2=MU
      CALL LOAD1 (F,NY,NU,NMAT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      GO TO 100
   58 CALL LOAD1 (G,NY,NX,NMAT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MU
      CALL LOAD1 (F,NY,NU,NMAT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
  100 IF (MIXED .EQ. 1) GO TO 200
      GO TO (200,110,200),SYSTEM
  110 MAT1=MU
      MAT2=MX
      CALL LOAD1 (K1,NU,NX,NMAT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (NK2.EQ.0) GO TO 66
      CALL LOAD1 (K2,NU,NX,NMAT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
   66 CONTINUE
      MAT2=MU
      CALL LOAD1 (D,NU,NU,NMAT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
  200 RETURN
      END
```

```
      SUBROUTINE LOAD1 (A,N,M,NMAT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      DIMENSION A(MAT1,MAT2)
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*LOAD1*)
      NMAT=NMAT+1
   10 FORMAT (2I10)
      READ (1,10) N1,N2
      IF (EOF(1).NE.0) STOP
      IF (N1.EQ.N.AND.N2.EQ.M) GO TO 20
      WRITE (3,100) NMAT,N,M,N1,N2
  100 FORMAT (///,10X,* WARNING  DIMENSION OF NUMBER*,I2,* MATRIX SHOULD
     1 BE *,I5,* BY*,I2,*  BUT IS*,I5,* BY*,I2,//)
   20 DO 30 I=1,N
      READ (1,200) (A(I,J),J=1,M)
      IF (EOF(1).NE.0) STOP
   30 CONTINUE
  200 FORMAT (8F10.4)
      RETURN
      END
```

```
      SUBROUTINE MAKE (A,B,N,M,                                       MAKE       2
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                      MAKE       3
      DIMENSION A(MAT1,MAT2),B(MAT3,MAT4)                             MAKE       4
      COMMON/SUBWRIT/ ISUBNAM                                         MAKE       5
      IF(ISUBNAM.GE.2) WRITE(3,990)                                   MAKE       6
  990 FORMAT(1X,*MAKE*)                                               MAKE       7
      DO 10 I=1,N                                                     MAKE       8
      DO 10 J=1,M                                                     MAKE       9
      A(I,J)=B(I,J)                                                   MAKE      10
   10 CONTINUE                                                        MAKE      11
      RETURN                                                          MAKE      12
      END                                                             MAKE      13
```

```
      SUBROUTINE MATRIX (A,B,C,H,G,F,K1,K2,K3,K4,D,W1,W2,W3,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CONTUR ,NUMERS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NX2,IFLAG,
     1IGC,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KOUNT
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,FRPS,TRESP,READ3
      INTEGER DIGITL, SCAPLT, ZOH
      COMMON/ACOND/ DELT,FINALT,IFREQ,FFREQ,DELFRQ,GAIN1,GAIN2,M
      REAL K1,K2,K3,K4,IFREQ,M
      DIMENSION A(MX,MX),B(MX,MU),C(MX,MX),H(MY,MX),G(MY,MX),F(MY,MU),
     1K1(MU,MX),K2(MU,MX),K3(MU,MX),K4(MU,MX),D(MU,MU),
     2W1(MX,MX),W2(MX,MX),W3(MX,MX)
      DIMENSION GRAPH(20,5),BLOCK(20,3),NUMER(20,5),DENOM(20,5),
     XGAIN(20),STATE(20,4),ITHINY(30),ITHINU(20),YTOV(20,2),
     X  ZTOU(20,2),NXYU(8),YZTOK(20,2)
      REAL NUMER
      INTEGER GRAPH,BLOCK,STATE,YTOV,ZTOU,YZTOK
      COMMON /BLKDAT/ NUMER,DENOM,GAIN,GRAPH,BLOCK,STATE,YTOV,
     X  ZTOU,YZTOK,ITHINY,ITHINU,NBLOCK,NYTOV,NZTOU,NXYU,NYZTOK,
     X  NXT,NYT,NUT,NY1,NU1
C
C     USER WRITTEN SUBROUTINE TO CONSTRUCT SYSTEM MATRICES UNDER CONTROL
C     OF CONDITION CODES
C
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*MATRIX SUB 2*)
      RETURN
      END
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
      SUBROUTINE MULT (A,B,C,N,M,K,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      DIMENSION A(MAT1,MAT2),B(MAT3,MAT4),C(MAT5,MAT6)
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*MULT*)
      DO 10 I=1,N
      DO 10 L=1,K
      XX=0.0
      DO 11 J=1,M
      XX=XX+A(I,J)*B(J,L)
   11 CONTINUE
      C(I,L)=XX
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE NMRATR (NN,A,B,C,H,G,F,D,ROOTR,ROOTI,ROTR,ROTI,Z,V,
     1W1,W2,W3,SAV1,SAV2,
     2MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
C
C     THIS SUBROUTINE DETERMINES THE NUMERATORS OF TRANSFER
C     FUNCTIONS BY FINDING THE MATRIX WHOSE EIGENVALUES ARE
C    THE DESIRED Z ROOTS. SUBROUTINE EIGEN IS CALLED TO FIND
C     THE EIGENVALUES
C     CORRECTION MADE BY G. NORRIS JULY 5 73
C     V AND ROTR, AND Z AND ROTI ARE SAME MATRIX
C
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CONTUR,NUMERC,FRES,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     2IGO,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KCUNT
      INTEGER READ, SYSTEM, OUTPUT, FORM, CONTUR, SAV, CMAT, READ3,
     1 FRES, TRESP
      INTEGER DIGITL,SCAPLT,ZOH
      COMMON/ACOND/ DELT,FINALT,IFREQ,FFREQ,DELFRQ,GAIN1,GAIN2,MN
      REAL    INPT(10), OUTPT(20),TITLE(8)
      COMMON/LABEL/INPT,OUTPT,TITLE
      REAL IFREQ,MN
      DIMENSION A(MX,MX),B(MX,MU),C(MX,MX),H(MY,MX),G(MY,MX),F(MY,MU),
     1D(MU,MU),
     2W1(MX,MX),W2(MX,MX),W3(MX,MX),ROOTR(MX),ROOTI(MX),ROTR(MX),
     3ROTI(MX),Z(MX),V(MX),SAV1(MS),SAV2(MS)
C     DIMENSION A(15,15), B(15,10), C(15,15), H(15,15), G(15,15),
C    1 F(15,10), D(10,10)
C     DIMENSION W1(15,15), W2(15,15), W3(15,15)
C     DIMENSION ROOTR(15), ROOTI(15), ROTR(15), ROTI(15)
C     DIMENSION SAV1(200), SAV2(200)
C     DIMENSION V(15), Z(15)
      COMMON/SUBWRIT/ ISUBNAM
      INTEGER ONE
      DATA ONE /1/,DUMY/0.0/
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*NMRATR*)
      DO 300 JJ=1,NU
      IMOD=0
      DO 300 I=1,NY
      N=NN
      DO 500 IX=1,NX
      IF (H(I,IX).NE.0.0) GO TO 501
  500 CONTINUE
      WRITE (3,502)I
  502 FORMAT (//10X,*ROW *,I2,* OF H MATRIX IS NULL *//)
      WRITE(7)ONE,DUMY,DUMY
      GO TO 300
  501 CONTINUE
      IF (F(I,JJ).EQ.0.0) GO TO 410
      NNUM=NN
      GO TO 431
  410 DO 420 K=1,NN
      ROTR(K)=0.
      IF (H(I,K).NE.0.0)ROTR(K)=1.
  420 CONTINUE
      DO 430 LL=1,NN
      DO 421 K=1,NN
```

```
      IF (ROTR(K).EQ.0.0.OR.B(K,JJ).EQ.0.0) GO TO 421
      NNUM=NN-LL
      GO TO 431
  421 CONTINUE
      ITEST=0
      DO 442 K=1,NN
      ROTI(K)=0.
  442 CONTINUE
      DO 422 K=1,NN
      DO 422 L=1,NN
      IF (K.EQ.L) GO TO 422
      IF (ROTR(K).EQ.0.0.OR.A(K,L).EQ.0.0) GO TO 422
      ROTI(L)=1.
      ITEST=1
  422 CONTINUE
      IF (ITEST.EQ.0) GO TO 440
      DO 423 K=1,NN
      ROTR(K)=ROTI(K)
  423 CONTINUE
  430 CONTINUE
  440 WRITE (3,441) JJ,I
  441 FORMAT (/10X,*NUMBER*,I4,*  INPUT DOES NOT EXCITE NUMBER*,I4,*  OU
     1TPUT*/)
      GO TO 300
  431 W2(1,1)=F(I,JJ)
      MM=N+1
      DO 5 K=2,MM
      W2(1,K)=-H(I,K-1)
      W2(K,1)=B(K-1,JJ)
      DO 4 L=2,MM
      W2(K,L)=-A(K-1,L-1)
    4 CONTINUE
    5 CONTINUE
      IF (IPT.LT.2) GO TO 240
      WRITE (3,241)
  241 FORMAT (/* NUMERATOR MATRICES*/)
      MAT1=MX
      MAT2=MX
      CALL SPIT1 (W2,MM,MM,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
  240 CONTINUE
      II=0
      IF (W2(1,1)) 181,8,181
    8 DO 180 II=1,LL
      DO 10 K=2,MM
      IF (W2(K,1).NE.0.0) GO TO 22
   10 CONTINUE
      GO TO 200
   22 M=K
      Z(II)=W2(M,1)
      DO 20 K=1,N
      DO 15 L=1,N
      W3(K,L)=-(W2(K+1,1)/Z(II))*(W2(1,L+1)+W2(M,L+1))
   15 CONTINUE
   20 CONTINUE
      DO 30 K=1,N
      DO 25 L=1,N
```

```
               W3(K,L)=W3(K,L)+W2(K+1,L+1)
            20 CONTINUE
            30 CONTINUE
               IF (M-2) 32,42,32
            32 DO 40 K=1,N
               STORE=W3(1,K)
               W3(1,K)=W3(M-1,K)
               W3(M-1,K)=STORE
            40 CONTINUE
            42 DO 50 K=1,N
               G1=0.0
               DO 45 L=1,N
               G1=W3(K,L)*(W2(L+1,1)/Z(II))+G1
            45 CONTINUE
               W3(K,M-1)=G1
            50 CONTINUE
               IF (M-2) 52,62,52
            52 DO 60 K=1,N
               STORE=W3(K,1)
               W3(K,1)=W3(K,M-1)
               W3(K,M-1)=STORE
            60 CONTINUE
            62 G1=0.0
               DO 71 KKK=1,N
               G1=-W2(1,KKK+1)*W2(KKK+1,1)+G1
            71 CONTINUE
               DO 70 K=1,N
               DO 70 L=1,N
               W2(K,L)=W3(K,L)
            70 CONTINUE
               W2(1,1)=G1/Z(II)
               N=N-1
               MM=N+1
               IF (IPT.LT.2) GO TO 180
               CALL SPIT1 (W2,MM,MM,
              1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
           180 CONTINUE
           181 CONTINUE
C      FOLLOWING STATEMENT ADDED  SEPT 1972 DUE TO CDC IBM DO LOOP
C      INDEX DIFFERENCE
               IF(II.NE.0) II=II-1
C      IN THE FORM---
C       DO 182 II=1,LL    WHERE LL=1
C      II TERMINAL VALUE IS 2 ON CDC
C      II TERMINAL VALUE IS 1 ON IBM
               IF (N.EQ.0) GO TO 197
               DO 190 K=1,N
               DO 185 L=1,N
               W3(K,L)=-W2(K+1,L+1)+ ((W2(K+1,1)*W2(1,L+1))/W2(1,1))
           185 CONTINUE
           190 CONTINUE
           197 DE= W2(1,1)
               IF (II) 193,196,193
           193 DO 195 KJ=1,II
               DE=DE*Z(KJ)
           195 CONTINUE
           196 CONTINUE
```

```
      IF (N.NE.0) GO TO 199
      WRITE (3,210) OUTPT(I), INPT(JJ),DE
  210 FORMAT (//10X,*THE*,A10,*/*,A10,*NUMERATOR GAIN IS * ,E12.4,
     1*THERE ARE NO ZEROES*/)
      GO TO 198
  199 DO 400 K=1,N
      DO 400 J=1,N
      W1(K,J)=W3(K,J)
  400 CONTINUE
      IF (IPT.LT.2) GO TO 243
      CALL SPIT1(W1,N,N,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
  243 CONTINUE
      WRITE (3,209) OUTPT(I),INPT(JJ),DE
  209 FORMAT (//10X,,*THE *,A10,*/*A10,* NUMERATOR GAIN IS*,F12.4//* THE
     1 ZEROES OF THE TRANSFER FUNCTION ARE*//20X,*REAL PART*,15X,*IMAGIN
     2ARY PART*/)
      IF (MN.NE.0.AND. SYSTEM .NE. 3)  WRITE (3,1000)
 1000 FORMAT (/ * FOR MODIFIED Z-TRANSFORMS, ADD Z=0. POLE*/)
      CALL EIGEN (N,W1,W2,W3,ROTR,ROTI,Z,V,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL CPMT (Z,ROTR,ROTI,N,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      WRITE (3,82)
   82 FORMAT (//10X,* THE COEFFICIENTS OF THE NUMERATOR  POLYNOMIAL ORDE
     1RED FROM THE LOWEST POWER OF S*//)
      NX1=N+1
      WRITE (3,83) (Z(IA),IA=1,NX1)
   83 FORMAT (E20.8)
  198 CONTINUE
      IF (DIGITL.EQ.0) GO TO 110
      IF (MN .EQ. 0) GO TO 113
      NSAV=NX
      NN=NN+1
      NX=NX+1
      IF (I .GT. 1 .OR. JJ .GT. 1) GO TO 113
      ROOTR(NX)= 0.0
      ROOTI(NX)= 0.0
  113 CONTINUE
      IF (DIGITL .EQ. 0 .OR. SYSTEM .EQ. 3 .OR. FRPS .EQ. -1) GO TO 110
      IF (I .GT. 1 .OR. JJ .GT. 1) GO TO 110
      CALL ZTOW(N,NN,DE,1,1,ROOTR,ROOTI,ROTR,ROTI,L1,DEE,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      WRITE (3,111)
  111 FORMAT (/10X,*  THE W-PLANE POLES ARE *//)
      WRITE (3,112) (ROOTR(K),ROOTI(K),K=1,NN)
  112 FORMAT (/(2E30.8))
  110 CONTINUE
      IF (DIGITL.EQ.0.OR.SYSTEM.EQ.3.OR.FRPS.EQ.-1) GO TO 120
      CALL ZTOW (N,NN,DE,2,2,ROOTR,ROOTI,ROTR,ROTI,L1,DEE,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      WRITE (3,121) DE
  121 FORMAT (//10X,*  THE W-PLANE TRANSFER FUNCTION GAIN IS    *,E12.4/*
     1              THE ZEROES ARE*//)
      WRITE (3,112) (ROTR(K),ROTI(K),K=1,N)
  120 CONTINUE
      IF (FRPS.EQ.-1) GO TO 301
```

```
      IFR=FRPS+1
      GO TO (311,310,320) IFR
  310 IF (MODEL.EQ.0) GO TO 301
      IF((MOD(I,2)).EQ.1) GO TO 302
      IF (IMOD.EQ.2) GO TO 302
      IMOD=2
      GO TO 301
  302 IMOD=1
  301 CALL FRQRSP (N,NN,DE,IMOD,ROOTR,ROOTI,ROTR,ROTI,SAV1,SAV2,
     1I,JJ,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      GO TO 311
  320 CALL PSD (N,NN,DE,ROOTR,ROOTI,ROTR,ROTI,SAV1,SAV2,I,JJ,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      GO TO 311
  200 WRITE (3,211) JJ
  211 FORMAT (//10X,*COLUMN *,I2,*  OF THE B MATRIX IS NULL*/)
  311 IF (MN.EQ.0) GO TO 300
      NX=NSAV
      NN=NSAV
  300 CONTINUE
      END
```

```
      SUBROUTINE PSD (NNUM,NN,GAIN,ROOTR,ROOTI,ROTR,ROTI,SAV1,SAV2,
     1INY,INU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
C
C       THIS SUBROUTINE COMPUTES THE POWER SPECTRUM CORRESPONDING
C       TO THE TRANSFER FUNCTION WHOSE POLES ARE (ROOTR,ROOTI) AND
C       WHOSE ZEROES ARE (ROTR,ROTI). IT IS ASSUMED THAT THE INPUT
C       TO THE TRANSFER FUNCTION IS A WHITE NOISE PROCESS OF UNITY
C       VARIANCE AND HENCE THE PSD IS GIVEN BY THE SQUARE OF THE
C       MODULUS OF THE TRANSFER FUNCTION. THUS ANY CORRELATION
C       DESIRED IN THE RANDOM PROCESS EXCITING THE SYSTEM SHOULD
C       BE INCLUDED AS A SHAPING FILTER IN THE *A* MATRIX WHICH
C       IS EXCITED BY WHITE NOISE. NOTE THAT ONLY EXPONENTIALLY
C       CORRELATED PROCESSES MAY BE SO STRUCTURED.
C
      DIMENSION ROOTR(MX),ROOTI(MX),ROTR(MX),ROTI(MX),SAV1(MS),SAV2(MS)
      COMPLEX RN1,RN2,RD1,RD2
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CONTUR,NUMERS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     2IGC,FORM,IPT,READ3,MIXED,MULTPT,SCAPLT,ZOH,KOUNT
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRPS,TRESP
      COMMON/ACOND/ DELT,FINALT,IFREQ,FFREQ,DELFRQ,GAIN1,GAIN2,M
      INTEGER DIGITL, SCAPLT, ZOH
      REAL IFREQ,M
      REAL PST
      COMMON/LABEL/INPT,OUTPT,TITLE
      REAL   INPT(10), OUTPT(20),TITLE(8)
      COMMON/SUBWRIT/ ISUBNAM
      DATA PST/10HSPEC      /
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*PSD*)
      IF(FORM.GT.0) WRITE(7)PST,TITLE,SYSTEM,MODEL,DIGITL,SCAPLT
      VAR=0.0
      X=0.0
      J=1
      IF(FORM.GT.0) WRITE(7)OUTPT(INY),INPT(INU)
      WRITE (3,60) OUTPT(INY),INPT(INU)
   60 FORMAT (/10X,A10,*/*A10,* POWER SPECTRAL DENSITY*/10X,*FREQUENCY,R
     1AD/SEC*4X,*PSD MAGNITUDE*/)
      FREQ=IFREQ
      IF (IFREQ.NE.0.) GO TO 70
      FREQ=.1
      FFREQ=150.
   70 CONTINUE
  100 CONTINUE
      IF (IFREQ.NE.0.) GO TO 71
      FREQ=1.15*FREQ
      GO TO 72
   71 FREQ=DELFRQ*FREQ
   72 CONTINUE
      RN1=CMPLX (1.0,0.0)
      RD1=CMPLX (1.0,0.0)
      DO 20 I=1,NN
      IF (I.GT.NNUM) GO TO 5
      RN2=CMPLX (-ROTR(I),FREQ     -ROTI(I))
      RN1=RN1*RN2
      RN2=CMPLX (-ROTR(I),-FREQ     -ROTI(I))
```

```
      RN1=RN1*RN2
      RD2=CMPLX (-ROOTR(I),FREQ    -ROOTI(I))
      RD1=RD1*RD2
      RD2=CMPLX (-ROOTR(I),-FREQ    -ROOTI(I))
      RD1=RD1*RD2
   20 CONTINUE
      SAV1(J)=GAIN**2*RN1/RD1
      VAR=VAR+SAV1(J)*(FREQ    -X)
      IF(FORM.EQ.2) GO TO 6
      WRITE (3,50) FREQ    ,SAV1(J)
      IF(FORM.EQ.0) GO TO 40
    6 WRITE(7)FREQ    ,SAV1(J)
   40 CONTINUE
   50 FORMAT (14X,F8.4.12X,E12.4)
      X=FREQ
      J=J+1
      IF (FREQ.LE.FFREQ) GO TO 100
   10 CONTINUE
      WRITE (3,30) VAR
   30 FORMAT (10X,*THE VARIANCE IS*E12.4)
      JD=99
      WRITE(7) JD,SAV1(I)
      RETURN
      END
```

```
      SUBROUTINE QREIG (M,ROOTR,ROOTI,IFRNT,A,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      DIMENSION A(MX,MY),ROOTR(MX),RCOTI(MX)
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*QREIG*)
      N = M
      IF(IFRNT)   80,81,80
   80 WRITE (3,104)
   81 ZERO = 0.0
      JJ=1
  177 XNN=0.0
      XN2=0.0
      AA = 0.0
      B = 0.0
      C = 0.0
      DD = 0.0
      R=0.0
      SIG=0.0
      ITER = 0
   17 IF(N-2)     13,14,12
   13 IF(IFRNT)   82,83,82
   82 WRITE (3,105)A(1,1)
   83 ROOTR(1) = A(1,1)
      ROOTI(1) = 0.0
    1 CONTINUE
      RETURN
   14 JJ=-1
   12 X = (A(N-1,N-1) - A(N,N))**2
      S = 4.0*A(N,N-1)*A(N-1,N)
      ITER = ITER + 1
C     IF (X.EQ.0.0.OR. ABS(S/X) .GT. 1.0E-8) GO TO 15
      IF(X.EQ.0.0)GO TO 15
      IF(ABS(S/X).GT.1.0E-8) GO TO 15
   16 IF ( ABS(A(N-1,N-1))- ABS(A(N,N))) 32,32,31
   31 E = A(N-1,N-1)
      G = A(N,N)
      GO TO 33
   32 G = A(N-1,N-1)
      E = A(N,N)
   33 F = 0.
      H = 0.
      GO TO 24
   15 S = X + S
      X = A(N-1,N-1) + A(N,N)
      IF(S)     18,19,19
   19 SQ= SQRT(S)
      F=0.0
      H=0.0
      IF (X) 21,21,22
   21 E=(X-SQ)/2.0
      G=(X+SQ)/2.0
      GO TO 24
   22 G=(X-SQ)/2.0
      E=(X+SQ)/2.0
      GO TO 24
   18 F= SQRT (-S)/2.0
```

```
      E=X/2.0
      G=E
      H=-F
   24 IF(JJ)  28,70,70
   70 D=1.0E-10*( ABS(G)+F)
      IF( ABS(A(N-1,N-2)).GT. D) GO TO 26
   28 IF(IPRNT)  84,85,84
   84 WRITE (3,105)E,F,ITER
      WRITE (3,105)G,H
   85 ROOTR(N) = E
      ROOTI(N) = F
      ROOTR(N-1) = G
      ROOTI(N-1) = H
      N=N-2
      IF(JJ)  1,177,177
   26 IF( ABS(A(N,N-1)) .GT. 1.0E-10* ABS(A(N,N))) GO TO 50
   29 IF(IPRNT)  86,87,86
   86 WRITE (3,105)A(N,N),ZERO,ITER
   87 ROOTR(N) = A(N,N)
      ROOTI(N) = 0.0
      N=N-1
      GO TO 177
   50 IF( ABS( ABS(XNN/A(N,N-1))-1.0)-1.0E-6) 63,63,62
   62 IF( ABS( ABS(XN2/A(N-1,N-2))-1.0)-1.0E-6) 63,63,700
   63 V0= ABS(A(N,N-1))- ABS(A(N-1,N-2))
      IF (ITER-15) 53,164,64
  164 IF(V0) 165,165,166
  165 P = A(N-1,N-2)**2
      SIG = 2.0*A(N-1,N-2)
      GO TO 60
  166 P = A(N,N-1)**2
      SIG = 2.0*A(N,N-1)
      GO TO 60
   64 IF(V0)   67,67,66
   66 IF(IPRNT)  88,85,88
   88 WRITE (3,107)A(N-1,N-2)
      GO TO 84
   67 IF(IPRNT)  89,87,89
   89 WRITE (3,107)A(N,N-1)
      GO TO 86
  700 IF(ITER .GT. 50) GO TO 63
      IF(ITER .GT. 5 ) GO TO 53
  701 ET=E*E+F*F
      IF (ET) 702,601,702
  702 GT=G*G+H*H
      IF (GT) 703,601,703
  703 CONTINUE
      Z1=          ((E-AA)**2+(F-B)**2)/(E*E+F*F)
      Z2=        ((G-C)**2+(H-DD)**2)/(G*G+H*H)
      IF(Z1-0.25)  51,51,52
   51 IF(Z2-0.25)    53,53,54
   53 P=E*G-F*H
      SIG=E+G
      GO TO 60
   54 P=E*E
      SIG=E+E
      GO TO 60
```

```
   57 IF(ZZ-0.25) 55,57,601
   55 R=0.0
      SIG=0.0
      GO TO 60
  601 R = 0.0
      SIG = 0.0
   60 XNN=A(N,N-1)
      XN2=A(N-1,N-2)
      CALL QRT (N,2,SIG,0,A,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      AA=
      B=F
      C=G
      DD=H
      GO TO 12
  104 FORMAT(////1X, 9HREAL PART  6X  14HIMAGINARY PART, 25X
     1  13HTAKEN AS ZERO 5X 4HITER //)
  105 FORMAT(1X,E15.8,3X,E15.8, 42X I3)
  107 FORMAT (74X, E15.8)
      END
```

```
      SUBROUTINE QRT (N,R,SIG,D,A,
     1MX,MY,MU,MC,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      DIMENSION A(MX,MX),PSI(2),G(3)
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*QRT*)
      N1 = N - 1
      IA = N - 2
      IP = IA
      IF(N-3) 101,10,60
   60 DO 12 J = 3,N1
      J1 = N - J
      IF( ABS(A(J1+1,J1))-D) 10,10,11
   11 DEN = A(J1+1,J1+1)*(A(J1+1,J1+1)-SIG)+A(J1+1,J1+2)*A(J1+2,J1+1)+R
      IF(DEN) 61,12,61
   61 IF( ABS(A(J1+1,J1)*A(J1+2,J1+1)*( ABS(A(J1+1,J1+1)+A(J1+2,J1+2)
     1-SIG)+ ABS(A(J1+3,J1+2)))/DEN)-D) 10,10,12
   12 IP= J1
   10 DO  14  J=1,IP
      J1=IP-J+1
      IF ( ABS(A(J1+1,J1))-D) 13,13,14
   14 IQ= J1
   13 DO  100  I=IP,N1
      IF(I-IP)    16,15,16
   15 G(1)=A(IP,IP)*(A(IP,IP)-SIG)+A(IP,IP+1)*A(IP+1,IP)+R
      G(2)=A(IP+1,IP)*(A(IP,IP)+A(IP+1,IP+1)-SIG)
      G(3)=A(IP+1,IP)*A(IP+2,IP+1)
      A(IP+2,IP)=0.0
      GO TO 19
   16 G(1)=A(I,I-1)
      G(2)=A(I+1,I-1)
      IF(I-IA)    17,17,18
   17 G(3)=A(I+2,I-1)
      GO TO 19
   18 G(3)=0.0
   19 XK=  SIGN( SQRT(G(1)**2+G(2)**2+G(3)**2), G(1))
   22 IF(XK)    23,24,23
   23 AL=G(1)/XK+1.0
      PSI(1)=G(2)/(G(1)+XK)
      PSI(2)=G(3)/(G(1)+XK)
      GO TO 25
   24 AL=2.0
      PSI(1)=0.0
      PSI(2)=0.0
   25 IF(I-IQ)    26,27,26
   26 IF(I-IP)     29,28,29
   28 A(I,I-1)=-A(I,I-1)
      GO TO 27
   29 A(I,I-1)=-XK
   27 DO 30  J=I,N
      IF(I-IA)   31,31,32
   31 C=PSI(2)*A(I+2,J)
      GO TO 33
   32 C=0.0
   33 E=AL*(A(I,J)+PSI(1)*A(I+1,J)+C)
      A(I,J)=A(I,J)-E
      A(I+1,J)=A(I+1,J)-PSI(1)*E
```

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```
      IF(I-IA)   34,34,30
   34 A(I+2,J)=A(I+2,J)-PSI(2)*E
   30 CONTINUE
      IF(I-IA)   35,35,36
   35 L=I+2
      GO TO  37
   36 L=N
   37 DO  40  J=I0,L
      IF(I-IA)  38,38,39
   38 C=PSI(2)*A(J,I+2)
      GO TO  41
   39 C=0.0
   41 E=AL*(A(J,I)+PSI(1)*A(J,I+1)+C)
      A(J,I)=A(J,I)-E
      A(J,I+1)=A(J,I+1)-PSI(1)*E
      IF(I-IA)  42,42,40
   42 A(J,I+2)=A(J,I+2)-PSI(2)*E
   40 CONTINUE
      IF(I-N+3)   43,43,100
   43 E=AL*PSI(2)*A(I+3,I+2)
      A(I+3,I)=-E
      A(I+3,I+1)=-PSI(1)*E
      A(I+3,I+2)=A(I+3,I+2)-PSI(2)*E
  100 CONTINUE
  101 RETURN
       END
```

```
      SUBROUTINE RDISC  (A,B,C,H,G,F,K1,K2,K3,K4,D,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
C
C       THIS SUBROUTINE READS ALL INPUT MATRICES FROM DISCS ACCORDING
C       TO THE  PARAMETERS, SYSTEM AND OUTPUT, USING SUBROUTINE RDISC1
C
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CONTUR,NUMER,EPPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     2IGO,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KOUNT
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, EPPS,TRESP
      INTEGER       DIGITL,SCAPLT, ZOH
      DIMENSION A(MX,MX),B(MX,MU),C(MX,MX),H(MY,MX),G(MY,MX),F(MY,MU),
     1K1(MU,MX),K2(MU,MX),K3(MU,MX),K4(MU,MX),D(MU,MU)
      REAL K1,K2,K3,K4
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT (1X,*RDISC*)
      MAT1=MX
      MAT2=MX
      CALL RDISC1 (A,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MU
      CALL RDISC1 (B,NX,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MX
      CALL RDISC1 (C,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MU
      CALL RDISC1 (K1,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL RDISC1 (K2,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL RDISC1 (K3,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL RDISC1 (K4,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MY
      CALL RDISC1 (H,NY,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL RDISC1 (G,NY,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MU
      CALL RDISC1 (F,NY,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MU
      CALL RDISC1 (D,NU,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      REWIND 8
      RETURN
      END
```

```
      SUBROUTINE RDISC1 (A,N,M,                                          RDISC1     2
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                         RDISC1     3
      DIMENSION A(MAT1,MAT2)                                             RDISC1     4
      COMMON/SUBWRIT/ ISUBNAM                                            RDISC1     5
      IF(ISUBNAM.GE.2) WRITE(3,940)                                      RDISC1     6
  940 FORMAT(1X,*RDISC1*)                                                RDISC1     7
      DO 10 I=1,N                                                        RDISC1     8
      READ (8) (A(I,J),J=1,M)                                            RDISC1     9
      IF(EOF(8).NE.0) STOP1                                              RDISC1    10
   10 CONTINUE                                                           RDISC1    11
      RETURN                                                             RDISC1    12
      END                                                                RDISC1    13
```

```
      SUBROUTINE REDUCE (N,J,MM,M,A,B,C,ITEST,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
C
C        THIS SUBROUTINE DETERMINES THE IRREDUCIBLE SUBMATRICES OF
C        THE MATRIX A WITH DIMENSION N.
C
C         J- NUMBER OF IRREDUCIBLE SUBMATRICES (1-5)
C     MM(I)- DIMENSION OF THE ITH SUBMATRIX
C        M - MATRIX WHOSE ITH ROW CONTAINS THE ORIGINAL ROW AND COLUMN
C               NUMBERS OF THE ITH SUBMATRIX
C
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CONTUR,NUMERS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     2IGO,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KOUNT
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRPS,TRESP
      INTEGER DIGITL,SCAPLT,ZOH
      DIMENSION A(MX,MX),B(MX,MX),C(MX,MX)
      INTEGER SCAN
      DIMENSION M(10,20),MM(20),SCAN(20)
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*REDUCE*)
      DO 60 I=1,20
      DO 61 J=1,10
      M(J,I)=0
   61 CONTINUE
      MM(I)=0
   60 CONTINUE
      DO 10 I=1,N
      DO 11 J=1,N
      B(I,J)=0.0
      C(I,J)=0.0
      IF (A(I,J).NE.0.0) B(I,J)=1.0
   11 CONTINUE
      B(I,I)=1.0
   10 CONTINUE
      KRUNT=1
   22 CONTINUE
      DO 20 I=1,N
      DO 20 J=1,N
      DO 21 K=1,N
      IF (B(I,K).EQ.0.0.OR.B(K,J).EQ.0.0) GO TO 21
      C(I,J)=1.0
      GO TO 20
   21 CONTINUE
   20 CONTINUE
      KRUNT=2*KRUNT
      IF (KRUNT.GE.N-1) GO TO 23
      DO 24 I=1,N
      DO 24 J=1,N
      B(I,J)=C(I,J)
   24 CONTINUE
      GO TO 22
   23 CONTINUE
      DO 30 I=1,N
      SCAN(I)=I
   30 CONTINUE
```

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```
      K=N                                                           REDUCE  59
      DO 35 J=1,10                                                  REDUCE  60
      MM(J)=0                                                       REDUCE  61
      NK=1                                                          REDUCE  62
      JJ=1                                                          REDUCE  63
      DO 36 I=1,K                                                   REDUCE  64
      IF (C(SCAN(1),SCAN(I)).EQ.1.0.AND.C(SCAN(I),SCAN(1)).EQ.1.0)  REDUCE  65
     1 GO TO 37                                                     REDUCE  66
      GO TO 36                                                      REDUCE  67
   37 M(J,JJ)=SCAN(I)                                               REDUCE  68
      MM(J)=MM(J)+1                                                 REDUCE  69
      NK=NK+1                                                       REDUCE  70
      JJ=JJ+1                                                       REDUCE  71
   36 CONTINUE                                                      REDUCE  72
      K=K-NK                                                        REDUCE  73
      IF (K.LE.0) GO TO 38                                          REDUCE  74
      LL=1                                                          REDUCE  75
      KRUNT=0                                                       REDUCE  76
      KONT=0                                                        REDUCE  77
      JX=K+NK                                                       REDUCE  78
      DO 39 L=1,JX                                                  REDUCE  79
      IF (SCAN(L).NE.M(J,LL)) GO TO 40                              REDUCE  80
      KRUNT=KRUNT+1                                                 REDUCE  81
      LL=LL+1                                                       REDUCE  82
      GO TO 39                                                      REDUCE  83
   40 KRUNT=KRUNT+1                                                 REDUCE  84
      KONT=KONT+1                                                   REDUCE  85
      SCAN(KONT)=SCAN(KRUNT)                                        REDUCE  86
   39 CONTINUE                                                      REDUCE  87
   35 CONTINUE                                                      REDUCE  88
   38 CONTINUE                                                      REDUCE  89
      IF (K.GT.0)WRITE (3,100)                                      REDUCE  90
  100 FORMAT (//,* MORE THAN 10 REDUCIBLE SUBMATRICES*//)           REDUCE  91
      IF (K.GT.0) ITEST=1                                           REDUCE  92
      IF (IPT.LT.2) GO TO 200                                       REDUCE  93
      WRITE (3,201)                                                 REDUCE  94
  201 FORMAT (/* MATRIX M IN REDUCE*/)                              REDUCE  95
C    IN STATEMENT DO 35 J=1,10 IF THE LOOP GOES TO COMPLETION       REDUCE  96
C    J WILL = 11 ON CDC                                             REDUCE  97
C    J WILL = 10 ON IBM                                             REDUCE  98
      IF(J.GE.11) J=J-1                                             REDUCE  99
      DO 202 I=1,J                                                  REDUCE 100
      MMM=MM(I)                                                     REDUCE 101
      WRITE (3,203) (M(I,L),L=1,MMM)                                REDUCE 102
  202 CONTINUE                                                      REDUCE 103
  203 FORMAT (20I5)                                                 REDUCE 104
  200 CONTINUE                                                      REDUCE 105
      RETURN                                                        REDUCE 106
      END                                                           REDUCE 107
```

```
      SUBROUTINE ROOT (A,B,C,H,G,F,K1,K2,K3,K4,D,W1,W2,W3,ROOTR,ROOTI,
     1U,V,
     2MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
C
C       THIS SUBROUTINE COMPUTES ROOT LOCII AS A FUNCTION OF TWO
C       FEEDBACK GAINS DEFINED BY K1,K2 AND K3,K4. THE OPEN LOOP
C       SYSTEM IS SCALED BY A SIMILARITY TRANSFORMATION. AT THE
C       CONCLUSION OF THE ROOT LOCII COMPUTATIONS THE NUMERATOR
C       ZEROES AND GAINS CORRESPONDING TO THE OPEN LOOP SYSTEM
C       ARE CALCULATED.
C
C        N1- NUMBER OF ROOT LOCUS POINTS FOR THE K1,K2 GAIN
C        N2- NUMBER OF ROOT LOCUS POINTS FOR THE K3,K4 GAIN
C
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CONTUR,NUMERS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     2IGO,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KCUNT
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRPS,TRESP
      INTEGER DIGITL,SCAPLT,ZOH
      REAL IFREQ,K1,K2,K3,K4,MN
      COMMON/ACOND/ DELT,FINALT,IFREQ,FFREQ,DELFRQ,GAIN1,GAIN2,MN
      DIMENSION A(MX,MX),B(MX,MU),C(MX,MX),H(MY,MX),G(MY,MX),F(MY,MU),
     1K1(MU,MX),K2(MU,MX),K3(MU,MX),K4(MU,MX),D(MU,MU)
      DIMENSION W1(MX,MX),W2(MX,MX),W3(MX,MX)
      DIMENSION ROOTR(MX),ROOTI(MX),U(MX),V(MX)
      DIMENSION M(10,20),MM(20),P(20)
      COMMON/LABEL/INPT,OUTPT,TITLE
      REAL   INPT(10), OUTPT(20),TITLE(8)
      COMMON/SUBWRIT/ ISUBNAM
      DATA BLANK/8H        /
      DATA PST/10HRCLD      /
      IF(ISUBNAM.GE.2) WRITE(3,990)
      IF (ISUBNAM .EQ. 2) WRITE (3,990)
  990 FORMAT(1X,*ROOT*)
      IF (GAIN1.EQ.0.0) GAIN1=1.0
      IF (GAIN2.EQ.0.0) GAIN2=1.0
      WRITE (3,300) GAIN1,GAIN2
  300 FORMAT (/10X,*GAIN1 = *F10.4,10X,*GAIN2 = *F10.4/)
      MAT1=MX
      MAT2=MX
      MAT3=MX
      MAT4=MX
      MAT5=MX
      MAT6=MX
      IF(FORM.GT.0) WRITE(7)PST,TITLE,SYSTEM,MODEL,DIGITL,SCAPLT
      IF(FORM.GT.0) WRITE(7)N2,N1
      KK=1
      N1A=IABS(N1)
      RR=0.0
      TT=0.0
      II=0
      JJ=0
      NK3=NK3+1
      DO 40 I=1,N2
      IF (N1.LT.0) GO TO 141
      II=I-1
      RR=(I-1)*GAIN2
```

```
      GO TO 142
  141 RR=2.*RR
      II=2*II
      IF (I.EQ.1)II=0
      IF (I.EQ.2)II=1
      IF (I.EQ.1) RR=0.0
      IF (I.EQ.2)RR=GAIN2
  142 CONTINUE
      DO 40 J=1,N1A
      IF (N1.LT.0) GO TO 41
      JJ= J-1
      TT=  (J-1) * GAIN1
      GO TO 42
   41 TT=2. * TT
      JJ=2* JJ
      IF (J.EQ.1) JJ=0
      IF (J.EQ.2) JJ=1
      IF (J.EQ.1) TT=0.0
      IF (J.EQ.2) TT=GAIN1
   42 CONTINUE
      GO TO (101,100),NK3
  100 MAT1=MU
      MAT2=MX
      MAT3=MU
      MAT4=MX
      CALL ADD (TT,K2,RR,K4,W1,NU,NL,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MX
      MAT3=MX
      DO 43 IA=1,NU
      DO 44 JA=1,NU
      W1(IA,JA)=-W1(IA,JA)
   44 CONTINUE
      W1(IA,IA)=1.0+W1(IA,IA)
   43 CONTINUE
      CALL INVR (W1,W2,NU,D,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MU
      MAT3=MU
      CALL ADD (TT,K1,RR,K3,W1,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MX
      MAT3=MX
      CALL MULT (W2,W1,W3,NU,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      GO TO 102
  101 MAT1=MU
      MAT2=MX
      MAT3=MU
      MAT4=MX
      CALL ADD (TT,K1,RR,K3,W3,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
  102 CONTINUE
      IF (J.EQ.2.AND.I.EQ.1) GO TO 200
      IF (J.EQ.1.AND.I.EQ.2) GO TO 201
      GO TO 202
  200 DO 203 IX=1,NU
```

```
      DO 205 JX=1,NX
      IF (NK2.EQ.1) GO TO 209
      H(KK,JX)=W3(IX,JX)/TT
      GO TO 205
  209 H(KK,JX)=W1(IX,JX)/TT
  205 CONTINUE
      IF (NK2.EQ.1) GO TO 203
      DO 207 JX=1,NU
      F(KK,JX)=K2(IX,JX)
  207 CONTINUE
  203 KK=KK+1
      NY=NU
      GO TO 202
  201 DO 204 IX=1,NU
      DO 206 JX=1,NX
      IF (NK2.EQ.1) GO TO 210
      H(KK,JX)=W3(IX,JX)/TT
      GO TO 206
  210 H(KK,JX)=W1(IX,JX)/RR
  206 CONTINUE
      IF (NK2.EQ.0) GO TO 204
      DO 208 JX=1,NU
      F(KK,JX)=K4(IX,JX)
  208 CONTINUE
  204 KK=KK+1
      NY=2*NU
  202 CONTINUE
      MAT1=MX
      MAT2=MU
      MAT3=MX
      MAT4=MY
      CALL MULT (B,W3,W2,NX,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MX
      CALL ADD (1.0,A,1.0,W2,W1,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (N2.NE.0) GO TO 220
      WRITE (3,221) J, TT
  221 FORMAT (//,10X,*NO. *,I5,* ITERATION, 1ST GAIN =*,E12.4/
     120X,* REAL PART*,15X,*IMAGINARY PART*/)
      GO TO 222
  220 WRITE (3,7) J, TT, I, RR
    7 FORMAT (//,10X,*NO. *,I5,* ITERATION, 1ST GAIN =*,E12.4,10X,*NO. *
     1,I5,* ITERATION, 2ND GAIN =*,E12.4/20X,*REAL PART*,15X,
     2*IMAGINARY PART*/)
  222 CONTINUE
      CALL EIGEN (NX,W1,W2,W3,ROOTR,ROOTI,U,V,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
   45 CONTINUE
      DO 74 I=1,NU
      DO 74 J=1,NU
      D(I,J)=0.0
   74 CONTINUE
      OUTPUT=3
      IF (NK2.EQ.0) OUTPUT=1
      ERRS=0
      NUMERS=0
```

```
      OUTPT(1)=BLANK
      INPT(1)=BLANK
      NUU=NU*2
      DO 50 I=1,NUU
      DO 51 J=1,NX
      IF (H(I,J).EQ.0.0) GO TO 51
      GO TO 52
   51 CONTINUE
   50 CONTINUE
   52  IF (I.EQ.1) GO TO 54
      IF (I.GT.NU) I=NUU-NU
      DO 53 J=1,NX
      H(1,J)=H(I,J)
      B(J,1)=B(J,I)
   53 CONTINUE
      DO 56 J=1,NU
      F(1,J) =F(I,J)
   56 CONTINUE
   54 NY=1
      NU=1
      WRITE (3,55)
   55 FORMAT (//,10X,*ROOT LOCUS OPTION COMPUTES THE ZEROES OF THE FIRST
     1 NON ZERO ROW*/10X,*OF K1 OR K3 RESPECTIVELY DUE TO INDICATED
     2 INPUT*/)
      RETURN
      END
```

```
      SUBROUTINE SETUP (J,M,MM,P,A,B,C,H,G,F,K1,K2,K3,K4,D,W1,W2,W3,
     1 ROOTR,
     2 MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
C
C       THIS SUBPROGRAM REDUCES THE ORIGINAL INPUT MATRICES FOR
C       THE OPEN AND CLOSED LOOP SYSTEMS TO STANDARD FORM AND
C       SCALES THE RESULTING SYSTEM WITH A DIAGONAL SIMILARITY
C       TRANSFORMATION.
C      CORRECTION MADE BY G. NORRIS JULY 5 73
C
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CONTUR,NUMERS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     2IGC,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KOUNT
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRPS,TRESP
      INTEGER DIGITL,SCAPLT,ZOH
      COMMON/ACOND/ DELT,FINALT,IFREQ,FFREQ,DELFRQ,GAIN1,GAIN2,MMM
      REAL K1, K2, K3, K4, IFREQ, MMM
      DIMENSION M(10,20),MM(20),P(20)
      DIMENSION A(MX,MX),B(MX,MU),C(MX,MX),H(MY,MX),G(MY,MX),F(MY,MU),
     1K1(MU,MX),K2(MU,MX),K3(MU,MX),K4(MU,MX),D(MU,MU),
     2W1(MX,MX),W2(MX,MX),W3(MX,MX),ROOTR(MX)
C     DIMENSION W1(15,15), W2(15,15), W3(15,15)
C     DIMENSION A(15,15), B(15,10), C(15,15), H(15,15), G(15,15)
C     DIMENSION F(15,10), D(10,10), ROOTR(15),
C    1 K1(10,15), K2(10,15), K3(10,15), K4(10,15)
      COMMON/BLKDAT/NUMER,DENOM,GAIN,GRAPH,BLOCK,STATE,YTOV,ZTOU,YZTOK,
     1ITHINY,ITHINU,NBLOCK,NYTOV,NZTOU,NXYU,NYZTOK,NXT,NYT,NUT,NY1,NU1
      REAL NUMER
      INTEGER GRAPH,BLOCK,STATE,YTOV,ZTOU,YZTOK
      DIMENSION GRAPH(20,5),BLOCK(20,3),NUMER(20,5),DENOM(20,5),
     XGAIN(20),STATE(20,4),ITHINY(30),ITHINU(20),YTOV(20,2),
     X  ZTOU(20,2),NXYU(8),YZTOK(20,2)
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*SETUP*)
      IMIX=0
      ICK=0
      MAT1=MX
      MAT2=MX
      MAT3=MX
      MAT4=MX
      MAT5=MX
      MAT6=MX
      IF (CMAT.EQ.0) GO TO 5
C
C       ELIMINATE C MATRIX
C
      CALL INVR (C,W2,NX,1,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL MULT (W2,A,W1,NX,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL MAKE (A,W1,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT4=MU
      CALL MULT (W2,B,W1,NX,NX,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MU
```

```
      MAT4=MX
      CALL MAKE (B,W1,NX,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CMAT=0
    5 GO TO (50,10,10),SYSTEM
   10 IF (NK2.EQ.0) GO TO 40
C
C     ELIMINATE K2,K4 MATRICES
C
      IF (SYSTEM.EQ.3.AND.MIXED.NE.1) GO TO 660
      MAT1=MU
      MAT2=MX
      MAT4=MU
      CALL MULT(K2,B,W1,NU,NX,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      DO 12 I=1,NU
      DO 13 J=1,NU
      W2(I,J)=-W1(I,J)
   13 CONTINUE
      W2(I,I)=1.0+W2(I,I)
   12 CONTINUE
      IF (DICITL .NE. 1) GO TO 838
      DO 839 I=1,NU
      DO 839 J=1,NUC
      W2(I,J)= 0.0
      IF (I .EQ. J) W2(I,I)= 1.0
  839 CONTINUE
  838 CALL INVR (W2,W1,NU,0,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MU
      MAT4=MX
      CALL MULT (K2,A,W2,NU,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL ADD  (1.0,K1,1.0,W2,W3,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MX
      CALL MULT (W1,W3,W2,NU,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT3=MU
      MAT4=MU
      CALL MULT (W1,D,W3,NU,NU,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MU
      MAT2=MU
      MAT3=MX
      MAT4=MX
      CALL MAKE (D,W3,NU,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MX
      CALL MAKE (K1,W2,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      NK2=0
      GO TO 40
  660 MAT1=MU
      MAT2=MX
      CALL MULT (K2,A,W1,NU,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
```

```
      CALL MULT (K4,A,W2,NU,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL ADD (1.0,K1,1.0,W1,W3,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL ADD (1.0,K3,1.0,W2,W1,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL MAKE (K1,W3,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL MAKE (K3,W1,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT4=MU
      CALL MULT (K2,B,W1,NU,NX,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL MULT (K4,B,W2,NU,NX,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT4=MX
      CALL MAKE (K2,W1,NU,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL MAKE (K4,W2,NU,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
   40 CONTINUE
   50 IF (OUTPUT.EQ.1.OR.OUTPUT.EQ.3) GO TO 51
C
C     ELIMINATE G MATRIX
C
      MAT1=MY
      MAT2=MX
      MAT3=MY
      MAT4=MU
      CALL MULT (G,B,W1,NY,NX,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MU
      MAT4=MX
      MAT3=MX
      CALL ADD (1.0,F,1.0,W1,W2,NY,NU,
     1MX,MY,MU,MS,MAT1,MAT3,MAT4,MAT5,MAT6)
      CALL MAKE (F,W2,NY,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MX
      CALL MULT (G,A,W1,NY,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL ADD (1.0,H,1.0,W1,W2,NY,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL MAKE (H,W2,NY,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (OUTPUT.EQ.2) OUTPUT=3
      IF (OUTPUT.EQ.4) OUTPUT=3
   51 IF (MIXED.NE.1.OR.READ.EQ.4) GO TO 210
C
C     AUGMENT SYSTEM WITH CONTROL SYSTEM MODELED IN CLASS
C
      MAT1=MX
      MAT2=MX
      CALL ZOT1 (C,MX,MX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      DO 211 I=1,NY
      C(I,I)=1.0
```

```
  211 CONTINUE
      CALL CLASS       (A,B,C,H,G,F,D,W1,W2,W3,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
  21  CONTINUE
      MAT1=MX
      MAT2=MX
      MAT3=MX
      MAT4=MX
      CALL MAKE (W1,A,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (NSCALE.EQ.0) GO TO 52
      IF (NSCALE.EQ.2) GO TO 52
C
C     SYSTEM SCALED BY A DIAGONAL SIMILARITY TRANSFORMATION
C
      ICK=1
      CALL ASCALE (NX,J,M,MM,P,W1,W2,W3,ROCTR,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      DO 60 I= 1,NX
      DO 60 K= 1,NU
      K1(K,I)=K1(K,I)/F(I)
      IF (SYSTEM.NE.3.AND.NK2.NE.1) GO TO 661
      K3(K,I)=K3(K,I)/F(I)
  661 B(I,K)=B(I,K)*P(I)
   60 CONTINUE
      IF (SYSTEM.EQ.3.OR.MIXED.EQ.1) GO TO 662
      DO 70 I=1,NY
      DO 70 K=1,NX
      H(I,K)=H(I,K)/P(K)
   70 CONTINUE
  662 MAT1=MX
      MAT2=MX
      CALL MAKE (A,W1,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (IPT.LT.1) GO TO 52
      WRITE (3,110)
  110 FORMAT (1H1,10X,*THE REDUCED AND SCALED SYSTEM IS*)
      CALL SPIT (A,B,C,H,G,F,K1,K2,K3,K4,D,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
   52 IF (DIGITL.NE.1) GO TO 80
      IF(NZTOU.EQ.0.AND.NYTOV.EQ.0) GO TO 465
      IMIX=1
      GO TO 80
C
C     DISCRETIZE CONTINUOUS PORTION OF SAMPLED-DATA SYSTEM
C
  465 IF (MMM.EQ.0.0) GO TO 455
      IF (SYSTEM.NE.1) GO TO 456
      GO TO 457
  456 WRITE (3,458)
  458 FORMAT (/,* ROOT LOCUS AND CLOSED LOOP OPTIONS NOT ALLOWED WITH MO
     -DIFIED Z-TRANSFORMS*/)
  457 XM=MMM*DELT
      CALL EAT (XM,A,W1,W2,W3,C,NXC,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (ZOH.EQ. 0) GO TO 459
      OUTPUT=3
```

```
      MAT1=MY
      CALL MULT (H,W2,W3,NY,NXC,NXC,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT4=MU
      MAT1=MX
      CALL MULT (W3,P,C,NY,NXC,NUC,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MY
      MAT3=MY
      MAT4=MU
      MAT5=MY
      MAT6=MU
      CALL ADD (1.,C,1.,F,F,NY,NUC,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
  459 MAT1=MY
      MAT3=MX
      MAT4=MX
      MAT5=MY
      MAT6=MX
      CALL MULT (H,W1,W3,NY,NXC,NXC,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT5)
      CALL MAKE (H,W3,NY,NXC,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (ZOH.EQ.NUC) GO TO 455
      NN1=ZOH+1
      DO 460 I=1,NY
      DO 460 J=NN1,NUC
      IF (F(I,J).NE.0) GO TO 461
  460 CONTINUE
      GO TO 462
  461 WRITE (3,448)
  462 DO 463 I=1,NY
      DO 463 J=NN1,NUC
      XX=0.0
      DO 464 K=1,NXC
      XX=XX+H(I,K)*B(K,J)
  464 CONTINUE
      F(I,J)=XX
  463 CONTINUE
      OUTPUT=3
  455 CONTINUE
      CALL EAT (DELT,A,W1,W2,W3,C,NXC,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      NN1=ZOH+1
      DO 7 I=1,NXC
      DO 7 J=1,NXC
      A(I,J)= W1(I,J)
    7 CONTINUE
      IF (ZOH.EQ.0) GO TO 441
      MAT1=MX
      MAT4=MU
      CALL MULT (W2, B, W3, NXC, NXC, ZOH,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MU
      MAT4=MX
      CALL MAKE (B,W3,NXC,ZOH,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
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```
  441 IF (ZOH.EQ.NUC) GO TO 442
      IF (ZOH.LT.NUC) GO TO 443
      WRITE (3,444)
  444 FORMAT (/,* ZOH GREATER THAN NUC*/)
  443 DO 445 I=1,NY
      DO 445 J=NN1,NUC
      IF (F(I,J).NE.0.) GO TO 446
  445 CONTINUE
      GO TO 447
  446 WRITE (3,448)
  448 FORMAT (/* F MATRIX NOT NULL *)
  447 DO 449 I=1,NXC
      DO 449 J=NN1,NUC
      XX=0.0
      DO 450 K=1,NXC
      XX=XX+W1(I,K)*B(K,J)
  450 CONTINUE
      W3(I,J)= XX
  449 CONTINUE
      IF (MMM.NE.0.0) GO TO 470
      DO 452 I=1,NY
      DO 452 J=NN1,NUC
      XX=0.0
      DO 453 K=1,NXC
      XX=XX+H(I,K)* B(K,J)
  453 CONTINUE
      F(I,J) = XX
  452 CONTINUE
  470 DO 451 I=1,NXC
      DO 451 J=NN1,NUC
      B(I,J)= W3(I,J)
  451 CONTINUE
      OUTPUT=3
  442 CONTINUE
   15 IF (IPT.LT.1) GO TO 80
      WRITE (3,111)
  111 FORMAT (1H1,10X,* THE DESCRETIZED SYSTEM IS*)
      CALL SPIT (A, B, C, H, G, F, K1, K2, K3, K4, D,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
   80 CONTINUE
      IF (MIXED.NE.1) GO TO 500
      IF (IMIX.EQ.2) GO TO 500
C
C     SUBSYSTEMS DESCRIBED IN STEP1 AND STEP2 OF MIXED LOADING OPTION
C     ARE COUPLED USING YTOV AND ZTOU
C
      IF (NBLOCK.EQ.0) GO TO 500
      MAT1=MX
      MAT2=MY
      MAT3=MX
      MAT4=MY
      CALL ZCT1(W1,NUT,NYT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (NZTOU.EQ.0) GO TO 300
      DO 301 I=1,NZTOU
      W1(ZTOU(I,2),ZTOU(I,1)+NY1)=1.0
  301 CONTINUE
```

```
  300 IF (NYTOV.EQ.0) GO TO 302
      DO 303 I=1,NYTOV
      W1(YTOV(I,2)+NU1,YTOV(I,1))=1.0
  303 CONTINUE
      MAT1=MY
      MAT2=MU
  302 CALL MULT (F,W1,W3,NYT,NUT,NYT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      DO 306 I=1,NYT
      DO 307 J=1,NYT
      W3(I,J)=-W3(I,J)
  307 CONTINUE
      W3(I,I)=1.0+W3(I,I)
  306 CONTINUE
      CALL INVR(W3,C,NYT,1,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MX
      MAT2=MX
      MAT3=MY
      CALL MULT (C,H,W1,NYT,NYT,NXT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MY
      MAT3=MX
      CALL MAKE (H,W3,NYT,NXT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (ICK.NE.1) GO TO 312
      DO 313 I=1,NY
      DO 313 J=1,NX
      H(I,J)=H(I,J)/P(J)
  313 CONTINUE
  312 CONTINUE
      MAT1=MX
      MAT2=MX
      MAT3=MY
      MAT4=MU
      CALL MULT (C,F,W3,NYT,NYT,NUT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MY
      MAT2=MU
      MAT3=MX
      MAT4=MX
      CALL MAKE(F,W3,NYT,NUT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MX
      MAT2=MU
      CALL MULT (B,W1,W3,NXT,NUT,NYT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MX
      MAT3=MY
      CALL MULT (W3,H,W1,NXT,NYT,NXT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT5)
      MAT3=MX
      CALL ADD (1.0,A,1.0,W1,A,NXT,NXT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT3=MY
      MAT4=MU
      CALL MULT (W3,F,W1,NXT,NYT,NUT,
```

```
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (ICK.NE.1) GO TO 310
      DO 311 I=1,NX
      DO 311 J=1,NY
      W1(I,J)=W1(I,J)/P(J)
  311 CONTINUE
  310 CONTINUE
      MAT3=MX
      MAT4=MX
      MAT1=MX
      MAT2=MU
      CALL ADD (1.0,P ,1.0,W1,W2,NXT,NUT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MU
      CALL MAKE (U,W2,NXT,NUT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
  500 CONTINUE
      IF (IMIX.NE. 1) GO TO 466
      IMIX=2
      GO TO 465
  456 IF (READ.EQ.4.OR.MIXED.EQ.1) GO TO 728
      GO TO 720
  728 IF (NYZTOK.EQ.0) GO TO 720
C
C     CONSTRUCT FEEDBACK MATRICES K1 AND K3 FROM YZTOK
C
      IF (SYSTEM.EQ.1) SYSTEM=2
      K=1
      I=1
  716 MAT1=MX
      MAT2=MX
      CALL ZCT1(W1,NUT,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL ZCT1(W2,NUT,NUT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
  713 CONTINUE
      DO 714 J=1,NX
      W1(YZTOK(I,2),J)= H(YZTOK(I,1),J) +W1(YZTOK(I,2),J)
  714 CONTINUE
      DO 713 J=1,NUT
      W2(YZTOK(I,2),J)= F(YZTOK(I,1),J) +W2(YZTOK(I,2),J)
  715 CONTINUE
      I=I+1
      IF (SYSTEM .EQ. 2) GO TO 730
      DO 800 J=1,NYZTOK
      DO 801 L=1,20
      IF (YZTOK(J,2) .EQ. ITHINU(L)) GO TO 800
  801 CONTINUE
      WRITE (3,804) YZTOK(J,2)
  804 FORMAT (/10X,*NO. *,I5,* INPUT MUST BE SAVED FOR FEEDBACK*/)
      DO 802 L=1,20
      IF (ITHINU(21-L).EQ.0)  GO TO 802
      IF (YZTOK(J,2).GT.ITHINU(21-L)) GO TO 803
      ITHINU(22-L)=ITHINU(21-L)
  802 CONTINUE
  803 ITHINU(22-L)=YZTOK(J,2)
  800 CONTINUE
```

```
      MAT1=MU
      MAT2=MU
      IF (K .EQ. 2) GO TO 731
      CALL MAKE (K1,W1,NUT,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL MAKE (K2,W2,NUT,NUT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (NY2TOK .EQ. 1) GO TO 732
      K=2
      GO TO 710
  731 CALL MAKE (K3,W1,NUT,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL MAKE (K4,W2,NUT,NUT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (NY2TOK .GT. 2) WRITE (3,722)
  722 FORMAT (/*ONLY 2 LOOPS ALLOWED*)
  732 DO 733 L=1,NUT
      DO 733 J=1,NUT
      IF (K2(L,J) .NE. 0.0) GO TO 734
      IF (K4(L,J) .NE. 0.0) GO TO 734
  733 CONTINUE
      GO TO 720
  734 NK2=1
      GO TO 720
  730 IF (I .LE. NY2TOK) GO TO 713
      DO 736 J=1,NUT
      DO 737 L=1,NUT
      W2(J,L)=-W2(J,L)
  737 CONTINUE
      W2(J,J)=1.0+W2(J,J)
  736 CONTINUE
      MAT1=MX
      MAT2=MX
      CALL INVR (W2,W3,NUT,1,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MU
      MAT2=MU
      MAT3=MX
      MAT4=MX
      CALL MAKE (D,W3,NUT,NUT,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MX
      MAT2=MX
      CALL MULT (W3,W1,W2,NUT,NUT,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MU
      CALL MAKE (K1,W2,NUT,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
  720 CONTINUE
      IF (DIGITL .NE. 1) GO TO 6
      DO 837 I=1,NU
      DO 837 J=1,NUC
      K2(I,J)=0.0
      K4(I,J)=0.0
  837 CONTINUE
    6 CONTINUE
      IF (MULTPT .NE. 0) GO TO 727
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      IF (SYSTEM .NE. 2) GO TO 727
C
C     FOR CLOSED LOOP ANALYSIS, INCORPORATE FEEDBACK MATRX,K1
C     AND FEEDFORWARD MATRIX,D
C
      MAT1=MX
      MAT2=MU
      MAT3=MU
      MAT4=MY
      CALL MULT (B,K1,W1,NX,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MX
      MAT3=MX
      CALL ADD (1.0,A,1.0,W1,W2,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL MAKE (A,W2,NX,NX,
     1MX,MU,MY,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MU
      MAT3=MU
      MAT4=MU
      CALL MULT (B,D,W1,NX,NU,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT3=MX
      MAT4=MX
      CALL MAKE (B,W1,NX,NU,
     1MX,MU,MY,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MY
      MAT2=MU
      MAT3=MU
      CALL MULT (F,K1,W1,NY,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MX
      MAT3=MX
      CALL ADD (1.0,H,1.0,W1,W2,NY,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL MAKE (H,W2,NY,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MU
      MAT3=MU
      MAT4=MU
      CALL MULT (F,D,W1,NY,NU,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT3=MX
      MAT4=MX
      CALL MAKE (F,W1,NY,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      SYSTEM=1
  727 CONTINUE
      IF (READ.EQ.4.AND.SYSTEM.EQ.3) GO TO 828
      IF (MIXED.NE.1) GO TO 721
  828   IF (NBLOCK.EQ.0) GO TO 520
C
C     THIN THE INPUT VECTOR (MIXED LOADING OPTION)
C
      DO 394 I=1,10
      DO 321 J=1,NX
      B(J,I)=B(J,ITHINU(I))
```

```
 321  CONTINUE
      DO 323 J=1,NY
      F(J,I)=F(J,ITHINU(I))
 323  CONTINUE
      IF (SYSTEM .EQ. 3 .OR.  MULTOT .NE. 0) GO TO 322
      GO TO 305
 322  DO 325 J=1,NX
      K1(I,J)=K1(ITHINU(I),J)
      K3(I,J)=K3(ITHINU(I),J)
 325  CONTINUE
      DO 326 J=1,NUT
      D(J,I)=D(J,ITHINU(I))
 326  CONTINUE
      DO 327 J=1,NUT
      E(I,J)=D(ITHINU(I),J)
 327  CONTINUE
 305  IF (ITHINU(I+1) .EQ. 0) GO TO 320
 304  CONTINUE
 320  IF (I.LT.NUT) NU=I
 721  CONTINUE
      IF (READ.EQ.4.OR.MIXED.EQ.1.OR.READ.EQ.3) GO TO 729
      GO TO 520
 729  CONTINUE
C
C     THIN THE OUTPUT VECTOR (MIXED LOADING OPTION)
C
      DO 501 I=1,30
      DO 502 J=1,NXT
      H(I,J)=H(ITHINY(I),J)
 502  CONTINUE
      DO 503 J=1,NUT
      F(I,J)=F(ITHINY(I),J)
 503  CONTINUE
      IF (ITHINY(I+1) .EQ. 0) GO TO 521
 501  CONTINUE
 521  IF (I.LT.NY) NY=I
      IF (IMIX.NE.1) GO TO 520
      IMIX=2
      GO TO 465
 520  MAT1=MX
      MAT2=MX
      MAT3=MX
      MAT4=MX
      CALL MAKE (H1,A,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (MIXED.EQ.1)                    GO TO 102
      IF (IPT.LT.1) GO TO 200
 102  WRITE (3,100)
 100  FORMAT(1H1,10X,* THE FINAL REDUCED SYSTEM IS*//)
      CALL SPIT (A,B,C,H,G,F,K1,K2,K3,K4,D,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
 200  CONTINUE
      END
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
      SUBROUTINE SPIT    (A,B,C,H,G,F,K1,K2,K3,K4,D,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
C
C       THIS SUBROUTINE PRINTS ALL MATRICES ACCORDING TO THE
C       PARAMETERS, SYSTEM AND OUTPUT, USING SUBROUTINE SPIT1
C
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CONTUR,NUMBRS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     2IGO,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOM,KCUNT
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRPS,TRESP
      INTEGER DIGITL,SCAPLT,ZOM
      DIMENSION A(MX,MX),B(MX,MU),C(MX,MX),H(MY,MX),G(MY,MX),F(MY,MU),
     1K1(MU,MX),K2(MU,MX),K3(MU,MX),K4(MU,MX),D(MU,MU)
      REAL K1,K2,K3,K4
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*SPIT*)
      MAT1=MX
      MAT2=MX
      WRITE (3,10)
   10 FORMAT (// 10X,*THE A MATRIX IS*/)
      CALL SPIT1 (A,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      WRITE (3,11)
   11 FORMAT (// 10X,*THE B MATRIX IS*/)
      MAT2=MU
      CALL SPIT1 (B,NX,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MX
      IF (CMAT.EQ.0) GO TO 21
      WRITE (3,20)
   20 FORMAT (//10X,*THE C MATRIX IS*/)
      CALL SPIT1 (C,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
   21 CONTINUE
      GO TO (50,50,60),SYSTEM
   60 WRITE (3,12)
   12 FORMAT (// 10X,*THE K1 MATRIX IS*/)
      MAT1=MU
      CALL SPIT1 (K1,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (NK2.EQ.0) GO TO 62
      WRITE (3,13)
   13 FORMAT (// 10X,*THE K2 MATRIX IS*/)
      CALL SPIT1 (K2,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
   62 CONTINUE
      IF (N2.EQ.0)GO TO 64
      WRITE (3,14)
   14 FORMAT (// 10X,*THE K3 MATRIX IS*/)
      CALL SPIT1 (K3,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (NK2.EQ.0) GO TO 64
      WRITE (3,15)
   15 FORMAT (// 10X,*THE K4 MATRIX IS*/)
      CALL SPIT1 (K4,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
```

```
   64 CONTINUE
      IF (MIXED.EQ.1) GO TO 50
      GO TO 200
   50 WRITE (3,16)
   16 FORMAT (// 10X,*THE H MATRIX IS*/)
   17 FORMAT (// 10X,*THE G MATRIX IS*/)
   18 FORMAT (//10X,*THE F MATRIX IS*/)
   19 FORMAT (//10X,*THE D MATRIX IS*/)
      MAT1=MY
      CALL SPIT1 (H,NY,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      GO TO (100,56,57,58),OUTPUT
   56 WRITE (3,17)
      CALL SPIT1 (G,NY,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      GO TO 100
   57 WRITE (3,18)
      MAT2=MU
      CALL SPIT1 (F,NY,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      GO TO 100
   58 WRITE (3,17)
      CALL SPIT1 (G,NY,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      WRITE (3,18)
      MAT2=MU
      CALL SPIT1 (F,NY,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
  100 GO TO (200,110,200),SYSTEM
  110 WRITE (3,12)
      MAT1=MU
      MAT2=MX
      CALL SPIT1 (K1,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      IF (NK2.EQ.0) GO TO 66
      WRITE (3,13)
      CALL SPIT1 (K2,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
   66 CONTINUE
      WRITE (3,19)
      MAT2=MU
      CALL SPIT1 (D,NU,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
  200 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SPIT1 (A,N,M,                                          SPIT1     2
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                        SPIT1     3
      DIMENSION A(MAT1,MAT2)                                            SPIT1     4
      COMMON/SUBWRIT/ ISUBNAM                                           SPIT1     5
      IF(ISUBNAM.GE.2) WRITE(3,990)                                     SPIT1     6
  990 FORMAT(1X,*SPIT1*)                                                SPIT1     7
      WRITE (3,10) N,M                                                  SPIT1     8
   10 FORMAT (2I10/)                                                    SPIT1     9
      DO 20 I=1,N                                                       SPIT1    10
      WRITE (3,30) (A(I,J),J=1,M)                                       SPIT1    11
   20 CONTINUE                                                          SPIT1    12
   30 FORMAT (10E12.4)                                                  SPIT1    13
      RETURN                                                            SPIT1    14
      END                                                               SPIT1    15
```

```
      SUBROUTINE THIST (A,B,C,H,F,W1,W2,W3,ROOTR,ROOTI,U,K1,D,Z,V,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
C
C       THIS SUBROUTINE COMPUTES A TABULATED TIME HISTORY RESPONSE
C       OF THE SYSTEM.  INPUT TO THE SYSTEM IS UNDER USER CONTROL
C       THROUGH A CALL TO SUBROUTINE INPUT (DELT,T,U) WHERE DELT IS
C       THE TIME INCREMENT, T IS THE TIME, AND U IS THE INPUT VECTOR
C       OF DIMENSION MX.  THE RESPONSE IS COMPUTED USING THE STATE
C       TRANSITION MATRIX.  THE TRANSITION MATRIX IS COMPUTED BY THE
C       SUBROUTINE EAT USING THE SERIES EXPANSION TECHNIQUE.  TEN TERMS
C       OF THE SERIES ARE USED.
C     CORRECTION MADE BY G. NORRIS JULY 5 73
C
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CCNTUR,NUMERS,FRES,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     2IGC,FORM,IPT,READ3,MIXEC,MULTRT,SCAPLT,ZOH,KCLNT
      COMMON/ACOND/ DELT,FINALT,IFREQ,FFREQ,DELFRQ,GAIN1,GAIN2,M
      INTEGER READ,SYSTEM,OUTPUT,FORM,CCNTUR,SAV,CMAT,READ3, FRES,TRESP
      INTEGER DIGITL,SCAPLT,ZOH
      REAL K1, IFREQ, M
      COMMON/LABEL/INPT,OUTPT,TITLE
      REAL   INPT(10), OUTPT(20),TITLE(8)
      DIMENSION A(MX,MX),B(MX,MU),C(MX,MX),H(MY,MX),F(MY,MU),
     1W1(MX,MX),W2(MX,MX),W3(MX,MX),ROOTR(MX),ROOTI(MX),U(MX),
     2K1(MU,MX),D(MU,MU),Z(MX),V(MX)
C     DIMENSION A(15,15), B(15,10), C(15,15), H(15,15)
C     DIMENSION F(15,10),K1(10,15), D(10,10), Z(15), V(15), U(15)
C     DIMENSION W1(15,15), W2(15,15), W3(15,15)
C     DIMENSION ROOTR(15), ROOTI(15)
C     DIMENSION K2(10,15), K3(10,15), K4(10,15)
      REAL PST
      COMMON/SUBWRIT/ ISUBNAM
      DATA PST/10HTIME      /
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*THIST*)
      IF (DIGITL.NE.0) GO TO 60
      IF (MULTRT.GT.0) GO TO 60
      CALL EAT (DELT,A,W1,W2,W3,C,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MX
      MAT2=MX
      MAT3=MX
      MAT4=MX
      MAT5=MX
      MAT6=MX
      CALL MAKE (A,W1,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT4=MU
      CALL MULT (W2,B,W3,NX,NX,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MU
      MAT4=MX
      CALL MAKE (B,W3,NX,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
   60 CONTINUE
      DO 400 IS=1,TRESP
      T=0.0
```

```
      DO 1 I=1,NX
      ROOTR(I)=0.0
      ROOTI(I)=0.0
      Z(I)=0.0
      V(I)=0.0
      W1(I,1)=0.0
      U(I)=0.0
    1 CONTINUE
      NXX=NXC+1
      NUU=NUC+1
      IF(FORM.GT.0) WRITE(7)PST,TITLE,SYSTEM,MODEL,DIGITL,SCAPLT
      NYU=NY+NU
      IF (MULTRT.EQ.1) NYU=NY+NUC
      IF(FORM.GT.0) WRITE(7)NYU,(OUTPT(I),I=1,NY),(INPT(J),J=1,NU)
      WRITE (3,13) (OUTP T(I),I=1,NY),(INP T(J),J=1,NU)
   13 FORMAT (//*     TIME     *(11(2X,A10))//)
      IF (MULTRT.NE.0) GO TO 98
   20 CONTINUE
      CALL INPUTV(DELT,T,U,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      DO 31 I=1,NY
      ROOTI(I)=0.0
      DO 30 J=1,NX
      ROOTI(I)=ROOTI(I)+H(I,J)*ROOTR(J)
   30 CONTINUE
      DO 31 I=1,NY
      DO 31 J=1,NU
      ROOTI(I)=ROOTI(I)+F(I,J)*U(J)
   31 CONTINUE
      IF(FORM.EQ.2) GO TO 6
      WRITE (3,10) T,(ROOTI(I),I=1,NY),(U(J),J=1,NU)
      IF(FORM.EQ.0) GO TO 7
    6 WRITE(7)T,(ROOTI(I),I=1,NY),(U(J),J=1,NU)
    7 CONTINUE
   10 FORMAT (11E12.3)
      DO 40 I=1,NX
      W1(I,1)=0.0
      DO 40 J=1,NX
      W1(I,1)=W1(I,1)+A(I,J)*ROOTR(J)
   40 CONTINUE
      DO 41 I=1,NX
      DO 41 J=1,NU
      W1(I,1)=W1(I,1)+B(I,J)*U(J)
   41 CONTINUE
      DO 42 I=1,NX
      ROOTR(I)=W1(I,1)
   42 CONTINUE
      T=T+DELT
      IF (T.LE.FINALT) GO TO 20
      GO TO 96
   98 KCT=1
      ICK=0
  120 CONTINUE
      IF (ICK.EQ.1) GO TO 70
      CALL INPUTV(DELT,T,U,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      DO 75 I=1,NXC
```

```
      V(I)=ROOTR(I)
   75 CONTINUE
      DO 71 I=1,NU
      XX=0.
      DO 72 J=1,NU
      XX=XX+D(I,J)*U(J)
   72 CONTINUE
      Z(I)=XX
   71 CONTINUE
      DO 73 I=1,NU
      XX=0.
      DO 74 J=1,NX
      XX=XX+K1(I,J)*ROOTR(J)
   74 CONTINUE
      Z(I)=Z(I)+XX
   73 CONTINUE
      ICK=1
   70 CONTINUE
      DO 80 I=1,NY
      XX=0.
      DO 81 J=1,NXC
      XX=XX+H(I,J)*ROOTR(J)
   81 CONTINUE
      ROOTI(I)=XX
   80 CONTINUE
      DO 82 I=1,NY
      XX=0.
      DO 83 J=1,NUC
      XX=XX+F(I,J)*Z(J)
   83 CONTINUE
      ROOTI(I)=ROOTI(I)+XX
   82 CONTINUE
      IF (FORM.EQ.2) GO TO 16
      WRITE (3,10) T,(ROOTI(I),I=1,NY),(Z(J),J=1,NUC)
      IF (FORM.EQ.0) GO TO 17
   16 WRITE (7) T, (ROOTI(I),I=1,NY), (Z(J),J=1,NUC)
   17 CONTINUE
      DO 85 I=1,NXC
      XX=0.
      DO 86 J=1,NXC
      XX=XX+A(I,J)*ROOTR(J)
   86 CONTINUE
      W1(I,1)=XX
   85 CONTINUE
      DO 87 I=1,NXC
      XX=0.
      DO 88 J=1,NUC
      XX=XX+B(I,J)*Z(J)
   88 CONTINUE
      W1(I,1)=W1(I,1)+XX
   87 CONTINUE
      DO 89 I=1,NXC
      ROOTR(I)=W1(I,1)
   89 CONTINUE
      T=T+DELT
      KCT=KCT+1
      IF (T.GT.FINALT) GO TO 96
```

```
      IF (KCT.LE.MULTPT) GO TO 120
      KCT=1
      ICK=0
      IF (NXX.GT.NX) GO TO 120
      DO 90 I=NXX,NX
      XX=0.
      DO 91 J=NXX,NX
      XX=XX+A(I,J)*RCOTR(J)
   91 CONTINUE
      W1(I,1)=XX
   90 CONTINUE
      DO 92 I=NXX,NX
      XX=0.
      DO 93 J=1,NXC
      XX=XX+A(I,J)*V(J)
   93 CONTINUE
      W1(I,1)=W1(I,1)+XX
   92 CONTINUE
      IF (NUU.GT.NU) GO TO 130
      DO 94 I=NXX,NX
      XX=0.
      DO 95 J=NUU,NU
      XX=XX+B(I,J)*Z(J)
   95 CONTINUE
      RCOTR(I)=W1(I,1)+XX
   94 CONTINUE
      GO TO 120
  130 DO 131 I=NXX,NX
      ROOTR(I)=W1(I,1)
  131 CONTINUE
      GO TO 120
   96 TT=-1.0
      IF(FORM.GT.0) WRITE(7)TT,TT,TT,TT,TT,TT,TT,TT,TT,TT,TT,TT,TT,
     XTT,TT,TT,TT,TT,TT,TT,TT,TT,TT
  400 CONTINUE
      END
```

```
      SUBROUTINE SWZ (DELT,IGO,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
C     UPDATED 1-9-73 TO INCLUDE DIFFERENTIATOR BLOCK
C     UPDATED 2-13-73 TO CORRECT GAIN COMPUTATION WITH MOD=1
C     UPDATED 4-25-73
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CONTUR,NUMERS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     2IGOO,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KOUNT
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRPS,TRESP
      INTEGER DIGITL,SCAPLT,ZOH
      COMMON/BLKDAT/NUMER,DENOM,GAIN,GRAPH,BLOCK,STATE,YTOV,ZTOU,YZTOK,
     1ITHINY,ITHINU,NBLOCK,NYTOV,NZTOU,NXYU,NYZTOK,NXT,NYT,NUT,NY1,NU1
      REAL NUMER
      INTEGER GRAPH,BLOCK,STATE,YTOV,ZTOU,YZTOK
      DIMENSION GRAPH(20,5),BLOCK(20,3),NUMER(20,5),DENOM(20,5),
     XGAIN(20),STATE(20,4),ITHINY(30),ITHINU(20),YTOV(20,2),
     X  ZTOU(20,2),NXYU(8),YZTOK(20,2)
      DIMENSION NIP(20,7),PARAM(20,5),CARAM(20,5)
   11 FORMAT (I2,I3,5I5,5F10.4)
      DO 300 I=1,NBLOCK
      DO 300 K=1,5
      DENOM(I,K)=0.
  300 NUMER(I,K)=0.
      IF(IGO.EQ.1.AND.KOUNT.GT.1) GO TO 310
C     IF (IGO.EQ.1) GO TO 310
      WRITE (3,500)
   14 FORMAT (7I5,7F10.4)
  500 FORMAT (  //* BLOCK DIAGRAM INPUT PARAMETERS*//* NO. TYPE*,7X,*CON
     1NEC*,5X,*MOD*,19X,*PARAM*/)
      DO 10 J=1,NBLOCK
      READ (1,11) (NIP(J,L),L=1,7),(CARAM(J,K),K=1,5)
      WRITE (3,14) (NIP(J,L),L=1,7),(CARAM(J,K),K=1,5)
   10 CONTINUE
  310 DO 311 I=1,NBLOCK
      DO 311 K=1,5
  311 PARAM(I,K)=CARAM(I,K)
      DO 12 J=1,NBLOCK
      GAIN(NIP(J,1))=PARAM(J,1)
      GRAPH(NIP(J,1),1)=NIP(J,1)
      DO 13 K=3,6
   13 GRAPH (NIP(J,1),K-1)=NIP(J,K)
   12 BLOCK(NIP(J,1),1)=NIP(J,1)
      DO 100 I=1,NBLOCK
      L=NIP(I,1)
      II=NIP(I,2)
      GO TO (101,102,103,104,105,106,107,108,108,108,108),II
  101 BLOCK(         L,2)=1
      BLOCK(         L,3)=1
      NUMER(L,1)=1.
      DENOM(         L,1)=1.
      GO TO 100
  102 IF (NIP(I,7).NE.0) WRITE (3,15)
   15 FORMAT (/* THIS DIGITAL DIFFERENTIATOR IS NO GOOD*/)
      BLOCK(L,2)=2
      NUMER(L,1)=0.
      NUMER(L,2)=1.
      DENOM(L,1)=1.
```

```
      GO TO 100
  103 IF (NIP(I,7).EQ.1) GO TO 120
      IF (NIP(I,7).EQ.2) GO TO 121
      BLOCK(L,2)=1
      BLOCK(L,3)=2
      NUMER(L,1)=1.
      DENOM(L,1)=0.
      DENOM(L,2)=1.
      GO TO 100
  120 GAIN(L)=GAIN(L)*.5*DELT
  121 BLOCK(L,2)=2
      BLOCK(L,3)=2
      NUMER(L,1)=1.
      NUMER(L,2)=1.
      DENOM(L,1)=-1.
      DENOM(L,2)=1.
      GO TO 100
  104 IF (NIP(I,7).EQ.1) GO TO 141
      IF (NIP(I,7).EQ.2) GO TO 142
      BLOCK(L,2)=1
      BLOCK(L,3)=2
      NUMER(L,1)=1.
      DENOM(L,1)=1.
      DENOM(L,2)=1./PARAM(I,2)
      GO TO 100
  141 PARAM(I,2)=TANH(.5*PARAM(I,2)*DELT)
  142 XNU=PARAM(I,2)
      BLOCK(L,2)=2
      BLOCK(L,3)=2
      NUMER(L,1)=XNU/(1.+XNU)
      NUMER(L,2)=NUMER(L,1)
      DENOM(L,2)=1.
      DENOM(L,1)=(XNU-1.)/(XNU+1.)
      GO TO 100
  105 BLOCK(L,2)=2
      BLOCK(L,3)=2
      IF (NIP(I,7).EQ.1) GO TO 151
      IF (NIP(I,7).EQ.2) GO TO 152
      NUMER(L,1)=1.
      NUMER(L,2)=1./PARAM(I,3)
      DENOM(L,1)=1.
      DENOM(L,2)=1./PARAM(I,2)
      GO TO 100
  151 PARAM(I,2)=TANH(.5*PARAM(I,2)*DELT)
      PARAM(I,3)=TANH(.5*PARAM(I,3)*DELT)
  152 XNU=PARAM(I,2)
      XN=PARAM(I,3)
      DENOM(L,1)=(XNU-1.)/(XNU+1.)
      DENOM(L,2)=1.
      NUMER(L,1)=(XNU*(XN-1.))/(XN*(XNU+1.))
      NUMER(L,2)=(XNU*(XN+1.))/(XN*(XNU+1.))
      GO TO 100
  106 BLOCK(L,2)=2
      BLOCK(L,3)=2
      IF (NIP(I,7).EQ.1) GO TO 161
      IF (NIP(I,7).EQ.2) GO TO 162
      NUMER(L,1)=0.
```

```
      NUMER(L,2)=1.
      DENOM(L,1)=PARAM(I,2)
      DENOM(L,2)=1.
      GO TO 100
  161 PARAM(I,2)=TANH(.5*PARAM(I,2)*DELT)
  162 XN=PARAM(I,2)
      NUMER(L,1)=-1./(1.+XN)
      NUMER(L,2)=-NUMER(L,1)
      DENOM(L,1)=(XN-1.)/(XN+1.)
      DENOM(L,2)=1.
      GO TO 100
  107 IF (NIP(I,7).EQ.1) GO TO 171
      IF (NIP(I,7).EQ.2) GO TO 172
      BLOCK(L,2)=1
      BLOCK(L,3)=3
      NUMER(L,1)=1.
      DENOM(L,3)=1./(PARAM(I,2)*PARAM(I,3))
      DENOM(L,2)=1./PARAM(I,2)+1./ PARAM(I,3)
      DENOM(L,1)=1.
      GO TO 100
  171 PARAM(I,2)=TANH(.5*PARAM(I,2)*DELT)
      PARAM(I,3)=TANH(.5*PARAM(I,3)*DELT)
  172 XNU=PARAM(I,2)
      XN=PARAM(I,3)
      GAIN(L)=GAIN(L)*XN*XNU/((XN+1.)*(XNU+1.))
      BLOCK(L,2)=3
      BLOCK(L,3)=3
      NUMER(L,1)=1.
      NUMER(L,2)=2.
      NUMER(L,3)=1.
      DENOM(L,1)=((XN-1.)*(XNU-1.))/((XN+1.)*(XNU+1.))
      DENOM(L,2)=(XN-1.)/(XN+1.)+(XNU-1.)/(XNU+1.)
      DENOM(L,3)=1.
      GO TO 100
  108 IF (NIP(I,7).EQ.1) GO TO 181
      IF (NIP(I,7).EQ.2) GO TO 182
      BLOCK(L,2)=1
      BLOCK(L,3)=3
      NUMER(L,1)=1.
      DENOM(L,3)=1./(PARAM(I,2)**2)
      DENOM(L,2)=2.*PARAM(I,3)/PARAM(I,2)
      DENOM(L,1)=1.
      GO TO 109
  181 ALFA=-PARAM(I,2)*       PARAM(I,3)
      BETA=SQRT(PARAM(I,2)**2-ALFA**2)
      A=ALFA*DELT
      B=BETA*DELT
      D=(EXP(A)*COS(B)+1.)**2+SIN(B)**2*EXP(2.*A)
      U=(EXP(2.*A)                    -1.)/D
      V=2.*SIN(B)*EXP(A)/D
      W=SQRT(U**2+V**2)
      OMEGA=PARAM(L,2)
      ZETA=PARAM(L,3)
      PARAM(I,2)=W
      PARAM(I,3)=-U/W
  182 BLOCK(L,2)=3
      BLOCK(L,3)=3
```

```
      XN=PARAM(I,2)
      DENOM(L,1)=(1.-2.*PARAM(I,3)*XN+XN**2)/(1.+2.*PARAM(I,3)*XN+XN**2)
      DENOM(L,2)=2.*(XN**2-1.)/(1.+2.*PARAM(I,3)*XN+XN**2)
      DENOM(L,3)=1.
      GAIN(L)=GAIN(L)*XN**2/(1.+2.*PARAM(I,3)*XN+XN**2)
  109 IF (NIP(I,7).NE.0) GO TO 110
      II=NIP(I,2)-7
      GO TO (100,221,222,223),II
  221 BLOCK(L,2)=3
      NUMER(L,3)=1./PARAM(I,4)**2
      NUMER(L,2)=2.*PARAM(I,5)/PARAM(I,4)
      NUMER(L,1)=1.
      GO TO 100
  222 BLOCK(L,2)=2
      NUMER(L,2)=1./PARAM(I,4)
      NUMER(L,1)=1.
      GO TO 100
  223 BLOCK(L,2)=2
      NUMER(L,1)=0.
      NUMER(L,2)=1.
      GO TO 100
  110 II=NIP(I,2)-7
      GO TO (230,232,231,230),II
  231 IF (NIP(I,7).EQ.2) GO TO 230
      PARAM(I,4)=TANH(.5*PARAM(I,4)*DELT)
      GO TO 230
  232 IF (NIP(I,7).EQ.2) GO TO 230
      ALFA=-PARAM(I,4)*       PARAM(I,5)
      BETA=SQRT(PARAM(I,4)**2-ALFA**2)
      A=ALFA*DELT
      B=BETA*DELT
      D=(EXP(A)*COS(B)+1.)**2+SIN(B)**2*EXP(2.*A)
      U=(EXP(2.*A)                   -1.)/D
      V=2.*SIN(B)*EXP(A)/D
      W=SQRT(U**2+V**2)
      PARAM(I,4)=W
      PARAM(I,5)=-U/W
  230 GO TO (240,241,242,243),II
  240 NUMER(L,1)=1.
      NUMER(L,2)=2.
      NUMER(L,3)=1.
      GO TO 100
  241 YN=PARAM(I,4)
      NUMER(L,2)=2.*(YN**2-1.)/(1.+2.*PARAM(I,5)*YN+YN**2)
      NUMER(L,1)=(1.-2.*PARAM(I,5)*YN+YN**2)/(1.+2.*PARAM(I,5)*YN+YN**2)
      NUMER(L,3)=1.
      GAIN(L)=GAIN(L)*(1.+2.*PARAM(I,5)*YN+YN**2)/YN**2
      GO TO 100
  242 YN=PARAM(I,4)
      NUMER(L,1)=(YN-1.)/(YN+1.)
      NUMER(L,2)=2.*YN/(YN+1.)
      NUMER(L,3)=1.
      GAIN(L)=GAIN(L)*(1.+YN)/YN
      GO TO 100
  243 NUMER(L,1)=-1.
      NUMER(L,2)=0.
      NUMER(L,3)=1.
```

```
      IF (NIP(I,7).EQ.2) GO TO 100
      GAIN(L)=GAIN(L)*(1.+2.*PARAM(I,3)*XN+XN**2)/XN**2
      GAIN(L)=GAIN(L)*(1.+DENOM(L,1)+DENOM(L,2))
     1/(2.*DELT)
  100 CONTINUE
      RETURN
      END
```

```
      FUNCTION TANG (A)                                                 TANG   2
      COMPLEX A,C                                                       TANG   3
      EQUIVALENCE (C,B(1))                                              TANG   4
      DIMENSION B(2)                                                    TANG   5
      C=A                                                               TANG   6
      PHI=ATAN2 (B(2),B(1))*57.3                                        TANG   7
      IF (B(2).GT.0.0.AND.B(1).LT.0.0) GO TO 10                         TANG   8
      TANG=PHI                                                          TANG   9
      GO TO 20                                                          TANG  10
   10 TANG=PHI-360.                                                     TANG  11
   20 RETURN                                                            TANG  12
      END                                                               TANG  13
```

```
      SUBROUTINE WDISC    (A,B,C,H,G,F,K1,K2,K3,K4,D,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
C
C       THIS SUBROUTINE WRITES ALL INPUT MATRICES ON DISCS ACCORDING
C       TO THE PARAMETERS,SYSTEM AND OUTPUT, USING SUBROUTINE WDISC1
C
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CONTUR,NUMERS,FRES,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     2IGO,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KOUNT
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRES,TRESP
      INTEGER DIGITL,SCAPLT,ZOH
      DIMENSION A(MX,MX),B(MX,MU),C(MX,MX),H(MY,MX),G(MY,MX),F(MY,MU),
     1K1(MU,MX),K2(MU,MX),K3(MU,MX),K4(MU,MX),D(MU,MU)
      REAL K1,K2,K3,K4
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*WDISC*)
      MAT1=MY
      MAT2=MX
      CALL WDISC1 (A,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MU
      CALL WDISC1 (B,NX,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MX
      CALL WDISC1 (C,NX,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MU
      CALL WDISC1 (K1,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL WDISC1 (K2,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL WDISC1 (K3,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL WDISC1 (K4,NU,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MY
      CALL WDISC1 (H,NY,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL WDISC1 (G,NY,NX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MU
      CALL WDISC1 (F,NY,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MU
      CALL WDISC1 (D,NU,NU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      REWIND 8
      RETURN
      END
```

```
      SUBROUTINE WDISC1 (A,N,M,                                         WDISC1     2
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)                        WDISC1     3
      DIMENSION A(MAT1,MAT2)                                            WDISC1     4
      COMMON/SUBWRIT/ ISUBNAM                                           WDISC1     5
      IF(ISUBNAM.GE.2) WRITE(3,990)                                     WDISC1     6
  990 FORMAT(1X,*WDISC1*)                                               WDISC1     7
      DO 10 I=1,N                                                       WDISC1     8
      WRITE (8) (A(I,J),J=1,M)                                          WDISC1     9
   10 CONTINUE                                                          WDISC1    10
      RETURN                                                            WDISC1    11
      END                                                               WDISC1    12
```

```
      SUBROUTINE ZOT (A,B,C,H,G,F,K1,K2,K3,K4,D,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      COMMON/COND/READ,SYSTEM,OUTPUT,NX,NY,NU,NXC,NUC,N1,N2,DIGITL,
     1CONTUR,NUMERS,FRPS,TRESP,MODEL,NSCALE,SAV,CMAT,NK2,IFLAG,
     2IGC,FORM,IPT,READ3,MIXED,MULTRT,SCAPLT,ZOH,KCUNT
      INTEGER DIGITL,SCAPLT,ZOH
      INTEGER READ,SYSTEM,OUTPUT,FORM,CONTUR,SAV,CMAT,READ3, FRPS,TRESP

      REAL K1,K2,K3,K4
      DIMENSION A(MX,MX),B(MX,MU),C(MX,MX),H(MY,MX),G(MY,MX),F(MY,MU),
     1K1(MU,MY),K2(MU,MX),K3(MU,MX),K4(MU,MX),D(MU,MU)
C
C       THIS SUBROUTINE INITIALIZES THE SYSTEM MATRICES TO ZERO
C       USING ZOT1
C
C
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*ZOT*)
      MAT1=MX
      MAT2=MX
      CALL ZOT1 (A,MX,MX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL ZOT1 (C,MX,MX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MY
      CALL ZOT1 (H,MY,MX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL ZOT1 (G,MY,MX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MU
      CALL ZOT1 (F,MY,MU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MX
      CALL ZOT1 (B,MX,MU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT1=MU
      MAT2=MX
      CALL ZOT1 (K1,MU,MX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL ZOT1 (K2,MU,MX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL ZOT1 (K3,MU,MX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      CALL ZOT1 (K4,MU,MX,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      MAT2=MU
      CALL ZOT1 (D,MU,MU,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      RETURN
      END
```

```
      SUBROUTINE ZOT1 (A,N,M,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
      DIMENSION A(MAT1,MAT2)
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*ZOT1*)
      DO 10 I=1,N
      DO 10 J=1,M
      A(I,J)=0.0
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ZTOW (N,NN,DE,I,JJ,ROOTR,ROOTI,ROTR,ROTI,L1,DEE,
     1MX,MY,MU,MS,MAT1,MAT2,MAT3,MAT4,MAT5,MAT6)
C
C       THIS SUBROUTINE CONVERTS Z-PLANE TRANSFER FUNCTIONS TO
C        W-PLANE TRANSFER FUNCTIONS
C
      DIMENSION ROOTR(MX),ROOTI(MX),ROTR(MX),ROTI(MX)
      COMMON/SUBWRIT/ ISUBNAM
      IF(ISUBNAM.GE.2) WRITE(3,990)
  990 FORMAT(1X,*ZTOW*)
      L2=0
      K=1
      IF (I.GT.1.OR.JJ.GT.1) GO TO 1
      DEE=1.0
      L1=0
    2 IF (ABS((ROOTR(K)-1.)    +ROOTI(K)    ).GT.10.**(-6)) GO TO 10
      L1=L1+1
      DEE=DEE/2.
      ROOTR(K)=0.0
      ROOTI(K)=0.0
      K=K+1
      GO TO 11
   10 IF (ROOTI(K).NE.0.0) GO TO 12
      DEE=DEE/(1.+ROOTR(K))
      ROOTR(K)=-(1.-ROOTR(K))/(1.+ROOTR(K))
      K=K+1
      GO TO 11
   12 A=ROOTR(K)**2
      B=ROOTI(K)**2
      G=(1.+ROOTR(K))**2
      DEE=DEE/(G+B)
      ROOTR(K)=(A+B-1.)/(G+B)
      ROOTR(K+1)=ROOTR(K)
      ROOTI(K)=(2.*ROOTI(K))/(G+B)
      ROOTI(K+1)=-ROOTI(K)
      K=K+2
   11 IF (K.LE.NN) GO TO 2
      RETURN
    1 DE=DE*DEE
      NSAV=0
   13 IF (ABS((ROTR(K)+1.)+ROTI(K)).LT.10.**(-6)) GO TO 18
      IF (ABS((ROTR(K)-1.)+ROTI(K)).GT.10.**(-6)) GO TO 14
      DE=DE*2.
      L2=L2+1
      ROTR(K)=0.
      ROTI(K)=0.
      K=K+1
      GO TO 15
   18 DE=DE*2.
      ROTR(K)=-1000.
      ROTI(K)=0.
      K=K+1
      NSAV=NSAV+1
      GO TO 15
   14 IF (ROTI(K).NE.0.) GO TO 16
      DE=DE*(1.+ROTR(K))
      ROTR(K)=-(1.-ROTR(K))/(1.+ROTR(K))
```

```
      K=K+1
      GO TO 15
   13 A=ROTR(K)**2
      B=ROTI(K)**2
      G=(1.+ROTR(K))**2
      DE=DE*(G+B)
      ROTR(K)=(A+B-1.)/(G+B)
      ROTR(K+1)=ROTR(K)
      ROTI(K)=(2.*ROTI(K))/(G+B)
      ROTI(K+1)=-ROTI(K)
      K=K+2
   15 IF (K.LE.N) GO TO 13
      LMN=NN-N
      DE=DE*(-1.)**LMN
      II=1
      DO 20 I=1,N
      IF (ROTR(II).NE.-1000.) GO TO 22
      K=II
      DO 21 L=K,N
      ROTR(L)=ROTR(L+1)
      ROTI(L)=ROTI(L+1)
   21 CONTINUE
      GO TO 20
   22 II=II+1
   20 CONTINUE
      N=N-NSAV
      IF (N.EQ.NN)RETURN
      N1=N+1
      N=NN-NSAV
      IF (N.LE.N1)RETURN
      DO 17 I=N1,N
      ROTR(I)=1.0
      ROTI(I)=0.
   17 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE COPO                                                   COPO
C                                                                       COPO
C---------------------------------------------------------------------- COPO
C***********        SUBROUTINE  C O P O  PLOTS DATA GENERATED BY THE  C O N  COPO
C                   PROGRAM. THE FOLLOWING TYPES OF PLOTS ARE AVAILABLE.    COPO
C                         1. TIME HISTORY                               COPO
C                         2. TIME HISTORY WITH CSTAR ENVELOPE           COPO
C                         3. FREQUENCY RESPONSE                         COPO
C                         4. POWER SPECTRAL DENSITY                     COPO
C                         5. ROOT LOCUS                                 COPO
C                         6. Z-PLANE ROOT LOCUS                         COPO
C                         7. ROOT CONTOUR                               COPO
C                                                                       COPO
C                   THE MAXIMUM NUMBER OF POINTS FOR ANY ONE PLOT IS 998. TH COPO
C                   MAXIMUM NUMBER OF TIME HISTORY PLOTS IS 25. AN AUTOMATIC COPO
C                   PLOT REQUEST IS GENERATED AT THE END OF TH  JOB     COPO
C---------------------------------------------------------------------- COPO
C                                                                       COPO
      EXTERNAL CSTAR                                                    COPO
      DOUBLE PRECISION SNAME                                            COPO
      COMMON/CSTARC/CTML,CTMU,CENVL,CENVU/CSTARP/PTML,PTMU,PENVL,PENVU  COPO
C                                                                       COPO
C     ARRAYS IN FOLLOWING DIMENSION STATEMENT DEFINE THE POWER AND CURVED COPO
C     APPROACH CSTAR OPTION ENVELOPES FOR TIME HISTORY PLOTS.           COPO
C                                                                       COPO
      DIMENSION CTML(20),CTMU(20),CENVL(20),CENVU(20),                  COPO
     X          PTML(12),PTMU(23),PENVL(12),PENVU(23)                   COPO
      REAL UNCLE(1024),VP(1000) ,TM,FR,VP2(1000),                       COPO
     XBIG(10),YLOG(4,9),LOG(9),NOTA,PTITLE(8),COMMENT(12),              COPO
     X    PS,RL,TIME(1000),V(25),S10(1000),S20(1000)                    COPO
      INTEGER ORDER(10),LOW,HIGH,LOWY,HIGHY                             COPO
      INTEGER YEP                                                       COPO
      INTEGER TWO,FOUR,SYSTEM                                           COPO
      EQUIVALENCE (FREQ,IFRE)                                           COPO
      INTEGER REMUS,TITLE(8),LAB(4),ONE,NAME(25),ENV,CSCRUV,CSPOA       COPO
      DATA ORDER/1,0,2,5,10,14,12,11,3,7/,                              COPO
     XCSCRUV/10HCSTARC    /,                                            COPO
     XCSPOA/10HCSTARP    /                                              COPO
      DATA TWO/2/,FOUR/4/,REMUS/1024/,                                  COPO
     XRC/10HROCO      /,                                                COPO
     XFR/10HFREQ      /,                                                COPO
     XPS/10HSPEC      /,                                                COPO
     XTM/10HTIME      /,                                                COPO
     XRL/10HPOLO      /,                                                COPO
     XNOPLOTS/0/,NOTA/10HNOT APP   /,                                   COPO
     XPTITLE/"          *","*****  PLEA","SE READJUS","T PEN EVER",     COPO
     X"Y FIVE TO ","TEN PLOT P","AGES  *****","*         "/,            COPO
     XCOMMENT/"   ****** "," P L E A S"," E  U S E ","  ******   ",     COPO
     X"   * P E R"," F O R A T"," E D  P A ","P E R *   ",               COPO
     X"          ","          ","          ","          "/,             COPO
     X     BIG/2*.18,.25,.20,.18,.20,.18,.25,.18,.20/,                   COPO
     X          YLOG/.1139,.1761,.2304,.2788,.3617,.3979,.4314,          COPO
     X                     .4624,.5185,.5441,.5682,.5911,.6335,.6532,    COPO
     X                     .6721,.6902,.7243,.7404,0.,0.,.7993,.8129,    COPO
     X                     0.,0.,.8633,.8751,0.,0.,.9191,.9294,0.,0.,    COPO
     X                     .9685,.9777,0.,0./,                          COPO
     X     LOG/.3010,.4771,.6021,.6990,.7782,.8451,.9031,.9542,1./,     COPO
```

```
     XLABEL/10H MAG-DB    /,LABEL1/10HPHI-DEG   /,LABEL2/10H  DUE TO  /
C
C    SET UP PLOT FACTORS AND READ DATA FOR AUTO PLOT REQUEST
C
      HALF=2./2.54
      CM=10./25.4
      CALL PLOTS (UNCLE,REMUS,6)
      CALL FACTOR (1.)
C     READ(1,504)SNAME,SUBTASK
      READ(1,504) IVSN,SNAME,SUBTASK
C 504 FORMAT (15X,2A10,5X,I4)
  304 FORMAT (I4,11X,2A10,5X,I4)
      WRITE (3,806)
  806 FORMAT ("1",10X," PLOTTING HAS BEGUN")
C
C    DATA SET 7 CONTAINS PLOT DATA WRITTEN BY  C O N T R O L  PROGRAM
C    FOR EACH CASE RUN IN THE CONTROL PROGRAM THE FOLLOWING IS WRITTEN O
C                RECORD ONE  NPLOT=NO. OF PLOTS
C                RECORD TWO  TYPE=TYPE OF PLOT (MUST BE TIME,FREQ,SPEC,ROL
C                            TITLE=80 CHARACTER PLOT TITLE
C                            SYSTEM=3 IMPLIES ROOT LOCUS
C                            MODEL=NOT USED
C                            IDIG=1 INDICATES Z-PLANE ROOT LOCUS
C                            SCAPLT=NOT USED
C
      YEP=0
      KLP=0
      NCKP=0
      NOKP=0
      NNKP=0
 9061 CONTINUE
      NCKP=NOKP+1
      IF ((YEP.NE.1).AND.(NOKP.EQ.2)) GO TO 99
      IF (NOKP.EQ.2) REWIND 9
      IF (NOKP.EQ.2) GO TO 113
      IF(NCKP.EQ.3) GO TO 99
      REWIND 7
  113 CONTINUE
      NCO=0
  999 IF(NCO.NE.0) GO TO 18
      IF (NOKP.NE.2) GO TO 1115
      READ(9) NPLOT
      IF (EOF(9).NE.0) GO TO 99
      IF (NOKP.EQ.2) GO TO 114
 1115 CONTINUE
      READ(7)NPLOT
      IF (EOF(7) .NE. 0) GO TO 8061
  114 CONTINUE
      IF (NOKP.EQ.2) NCKP=1
      IF (NOKP.EQ.2) NNKP=KLP
      IF (NOKP.EQ.1) KLP=KLP+1
   18 NCO=NCO+1
      IF(NCO.EQ.NPLOT) NCO=0
      IF (NCKP.NE.2) GO TO 111
                  READ (9) TYPE,TITLE,SYSTEM,MODEL,IDIG,SCAPLT
      IF (EOF(9).NE.0) GO TO 99
      IF (NOKP.EQ.2) GO TO 116
```

```
  111 READ (7) TYPE,TITLE,SYSTEM,MODEL,IDIG,SCAPLT
      IF (EOF(7) .NE. 0) GO TO 99
      IF((TYPE.EQ.PL).AND.(IDIG.EQ.1)) WRITE(9) NPLOT
      IF((TYPE.EQ.PL).AND.(IDIG.EQ.1)) WRITE(9) TYPE,TITLE,SYSTEM,MODEL,
     1IDIG,SCAPLT
  115 CONTINUE
      IF((TYPE.EQ.TM).OR.(TYPE.EQ.FR).OR.(TYPE.EQ.PS).OR.(TYPE.EQ.RL).OR
     X.(TYPE.EQ.PC)) GO TO 1
      WRITE (3,905)
  905 FORMAT (10X,"TYPE FIELD DOES NOT CONTAIN VALID OPTION--WILL CONTIN
     XUE SEARCHING FOR RECORD WITH VALID TYPE FIELD")
      GO TO 999
    1 CONTINUE
      IF((NCO.EQ.0).OR.(NCO.EQ.1)) WRITE(3,500)TITLE
  500 FORMAT (/5X,8A10)
C
C     IS THIS A TIME HISTORY PLOT?
      IF(TYPE.NE.TM) GO TO 2
C***************** TIME HISTORY PLOT SECTION ******************
      READ(7)NYU,(NAME(J),J=1,NYU)
      M=1
    4 READ(7)TIME(M),(V(K),K=1,NYU)
      IF(TIME(M).LT.0.) GO TO 3
C
C     DATA SET 5 IS A TEMPORARY TIME HISTORY DATA STORAGE
C
      WRITE(5) (V(K),K=1,NYU)
      M=M+1
      GO TO 4
    3 M=M-1
      REWIND 5
      CALL SCALE (TIME,8.5,M,1)
      TCM=TIME(M+2)
C
C---------------------------------------------------------------------
C----DO LOOP 90 WILL PLOT  NYU  TIME HISTORY PLOTS----------
      DO 90 KK=1,NYU
      ENV=0
      DO 10 KC=1,M
      READ(5) (V(K),K=1,NYU)
   10 VP(KC)=V(KK)
C
C     CHECK FOR A CSTAR TYPE TIME HISTORY
C
      IF((NAME(KK).NE.CSCRUV).AND.(NAME(KK).NE.CSFOA)) ENV=1
      IF(ENV.EQ.1) GO TO 9
C
C     IF CSTAR OPTION, NORMALIZE DATA BY DIVIDING BY LAST DATA VALUE.
C
      DO 25 KC=1,M
   25 VP(KC)=VP(KC)/VP(M)
    9 REWIND 5
      IF(MOD(KK,4).NE.1) GO TO 31
      IF(KK.EQ.1) GO TO 32
C
C     SPACE TO NEXT PLOT PAGE
      CALL PLOT(28.4950*CM,-2.*CM,-3)
```

```
   32 CALL PLOT (2.*CM,2.*CM,-3)
      CALL FACTOR(HALF)
      CALL AX90 (0.,0.,"TIME HISTORY---SECONDS",-22,8.5,0.,TIME(M+1),
     XTCM)
      CALL FACTOR(1.)
      IF(KK.EQ.1) TIME(M+2)=TIME(M+2)*1.27
      YO=-20.
      YN=13.
      CALL SYMBOL (.5*CM,23.2*CM,.20*CM,TITLE,0.,80)
      GO TO 33
   31 YN=-6.
      YO=YO+6.
   33 CALL PLOT (0.,YN*CM,-3)
      CALL SCALE (VP,2.5,M,1)
C
C     IF ENV NOT EQUAL TO ONE, GENERATE APPROFRIATE CSTAR ENVELOPE
C
      IF(ENV.EQ.1) GO TO 29
      IF((NAME(KK).EQ.CSCRUV).AND.(VP(M+2).LT..8)) VP(M+2)=.8
      IF((NAME(KK).EQ.CSPOA).AND.(VP(M+2).LT.1.)) VP(M+2)=1.
   29 CONTINUE
      CALL FACTOR(HALF)
      CALL AX90 (0.,0.,NAME(KK),10,2.5,90.,VP(M+1),VP(M+2))
      VP(M+2)=VP(M+2)*1.27
      CALL FACTOR(1.)
C
C     IF ENV NOT EQUAL TO ONE, GENERATE APPPROPRIATE CSTAR ENVELOPE
C
      IF(ENV.EQ.1) GO TO 26
      IF(NAME(KK).NE.CSCRUV) GO TO 28
      CTML(20)=TIME(M+2)
      CENVL(19)=VP(M+1)
      CENVL(20)=VP(M+2)
      CALL LINE (CTML,CENVL,18,1,0,0)
      CTMU(20)=CTML(20)
      CENVU(19)=CENVL(19)
      CENVU(20)=CENVL(20)
      CALL LINE (CTMU,CENVU,18,1,0,0)
      GO TO 26
   28 PTML(12)=TIME(M+2)
      PENVL(11)=VP(M+1)
      PENVL(12)=VP(M+2)
      CALL LINE(PTML,PENVL,10,1,0,0)
      PTMU(23)=PTML(12)
      PENVU(22)=PENVL(11)
      PENVU(23)=PENVL(12)
      CALL LINE (PTMU,PENVU,21,1,0,0)
   26 CONTINUE
      CALL LINE (TIME,VP,M,1,0,0)
C
C     NOPLOTS KEEPS TRACK OF NUMBER OF PLOTS
      NOPLOTS=NOPLOTS+1
      WRITE(3,502)NAME(KK)
  502 FORMAT (10X,A10," TIME HISTORY PLOT COMPLETED")
   90 CONTINUE
C--------------------------- END OF DO LOOP 90 ---------------------------
C
```

```
C     SPACE TO NEXT PLOT PAGE
      CALL PLOT (24.4950*CM,YO*CM,-3)
      GO TO 999
C
C     IS THIS A FREQUENCY RESPONSE PLOT?
    2 IF(TYPE.NE.FR) GO TO 5
C
C-----------------------------------------------------------------------
C***** FREQUENCY RESPONSE AND POWER SPECTRAL DENSITY PLOT SECTION *****
C
      READ(7)NUDE,(NAME(J),J=1,NUDE)
      K=1
C
C----READ AND CONVERT FREQUENCY RESPONSE DATA----------
C     CHECK TO SEE IF THERE ARE TWO OR FOUR PLOTS
C
    7 IF(NUDE.EQ.TWO) READ(7)FREQ,VP(K),VP2(K)
      IF(NUDE.EQ.FOUR) READ(7)FREQ,VP(K),VP2(K),S10(K),S20(K)
      IF(IFRE.EQ.99) GO TO 6
      TIME(K)=ALOG10(FREQ)
      K=K+1
      GO TO 7
    6 K=K-1
      GO TO 17
C
C     IS THIS A POWER SPECTRAL DENSITY PLOT?
    5 IF(TYPE.NE.PS) GO TO 23
C
C----THIS SECTION WILL READ AND CONVERT POWER SPECTRAL DENSITY DATA
C
      READ(7) (NAME(J),J=1,2)
      YI=16.
      YA=-18.
      K=1
   16 READ(7)FREQ,VALUE
      IF(IFRE.EQ.99) GO TO 13
      FREQ=FREQ/6.2832
      TIME(K)=ALOG10(FREQ)
      IF(K.EQ.1) GO TO 35
      IF(TIME(K).LE.PTIME) GO TO 13
   35 PTIME=TIME(K)
      IF(VALUE)14,24,34
   14 VP(K)=ALOG10(-VALUE)
      GO TO 44
   34 VP(K)=ALOG10(VALUE)
      GO TO 44
   24 VP(K)=0
   44 IF((VP(K)).LT.YI) YI=VP(K)
      IF((VP(K)).GT.YA) YA=VP(K)
   15 K=K+1
      GO TO 16
   13 K=K-1
C-----------------------------------------------------------------------
C
C      DETERMINE X AXIS MINIMUM AND INCREMENT
   17 DO 20 J=1,11
      IF(TIME(1).LT.FLOAT(6-J))LOW=FLOAT(5-J)
```

```
      IF(TIME(K).GT.FLOAT(J-8))HIGH=FLOAT(J-7)
   20 CONTINUE
      S=LOW
      DO 30 J=1,5
      L=J
      S=S+1
      IF(S.EQ.HIGH) GO TO 8
   30 CONTINUE
    8 XLEN=17.
      IF(TYPE.EQ.PS) XLEN=18.
      XDIST=(XLEN/L)*CM
      TIME(K+1)=LOW
      TIME(K+2)=1./XDIST
      NUDIF=1
C
C----DO LOOP 101 WILL PLOT ONE PSD  OR TWO FREQ. RESPONSE PLOTS---------
C
   55 DO 101 KK=1,2
      X=2.*CM
      Y=13.*CM
      IF(KK.EQ.1) GO TO 221
      X=0.
      Y=-13.*CM
      IF(TYPE.NE.PS) GO TO 221
      X=0.0
      Y=13.*CM
  221 IF(KK.NE.2) GO TO 703
      CALL PLOT(X,Y,-3)
      GO TO     11
C
C     GENERATE X AXIS (LOG) FOR PSD OR FREQUENCY RESPONSE
C
  703 IF(TYPE.EQ.FR) GO TO 700
      CALL PLOT(CM,0.,-3)
      CALL SYMBOL(.5*CM,25.2*CM ,.20*CM,TITLE,0.,80)
      GO TO 701
  700 CALL PLOT(X,Y,-3)
      CALL SYMBOL (.5*CM,12.2*CM,.20*CM,TITLE,0.,80)
  701 XN=0.
      YN=0.
      IF(TYPE.EQ.FR)YN=-13.*CM
      LK=L+1
      PL=1.
      DO 40 J=1,LK
      CALL SYMBOL (XN,YN,.65*CM,13,0.,-1)
      IF(J.EQ.LK) GO TO 40
      DO 50 J1=1,8
      XP=XN+XDIST*LOG(J1)
      CALL SYMBOL (XP,YN,.2*CM,13,0.,-1)
      PL=PL+1.
      XPO=XP-.05*CM
      CALL NUMBER (XPO,YN-.30*CM,.15*CM,PL,0.,-1)
   50 CALL PLOT (XP,YN,3)
      PL=1.
   40 XN=XN+XDIST
      CALL PLOT (0.,YN,2)
      XPM=-.2*CM
```

```
      XEM=.4*CM
      XNO=LOW
      DO 60 J=1,LK
      CALL NUMBER (XBM,YN-.70*CM,.25*CM,10.,0.,-1)
      CALL NUMBER (XEM,YN-.50*CM,.125*CM,XNO,0.,-1)
      XNO=XNO+1.
      XBM=XBM+XDIST
   60 XEM=XEM+XDIST
C
C     IS THIS A PSD PLOT?
      IF(TYPE.EQ.PS) GO TO 19
C
C    GENERATE Y AXIS (CM) FOR FREQUENCY RESPONSE AND PLOT DATA LINE
C
      CALL SYMBOL (5.5*CM,YN-1.15*CM,.25*CM,"FREQUENCY RESPONSE--RADIANS
     X/SEC",0.,31)
  901 FORMAT (F10.5)
      READ (1,901) DDB
      IF (EOF(1) .NE. 0)                                  GO TO 902
      IF (DDB .EQ. 0.)                                    GO TO 902
      VMAX=-100.
      DO 904 IJK=1,K
         IF (VP(IJK) .GT. VMAX)    VMAX=VP(IJK)
  904    CONTINUE
      VMAX=FLOAT(IFIX(VMAX+DDB/2.))
      VP(K+1)=VMAX-6.0*DDB
      VP(K+2)=DDB
      VMIN=VMAX-11.5*DDB
      DO 906 JKL=1,K
         IF (VP(JKL) .LT. VMIN)    VP(JKL)=VMIN
  906    CONTINUE
                                                          GO TO 903
  902 CALL SCALE (VP,6.0,K,1)
  903 CONTINUE
      LAB(1)=LABEL
      LAB(3)=LABEL2
      J=2
      IF(NUDIE.EQ.1) J=J-2
      LAB(2)=NAME(J+1)
      LAB(4)=NAME(J+2)
      CALL FACTOR(HALF)
      CALL AX9C (0.,0.,LAB,40,6.,90.,VP(K+1),VP(K+2))
      VP(K+2)=VP(K+2)*1.27
      CALL FACTOR(1.)
      NOPLOTS=NOPLOTS+1
      CALL LINE (TIME,VP,K,1,0,0)
      GO TO 12
C
C    GENERATE Y AXIS (LOG) FOR PSD
C
   19 CALL SYMBOL (5.25*CM,-1.15*CM,.25*CM,"POWER SPECTRAL DENSITY--CYCL
     XES/SEC",0.,34)
      DO 70 J=1,32
      IF(YI.LT.FLOAT(16-J))LOWY=FLOAT(15-J)
      IF(YA.GT.FLOAT(J-18))HIGHY=FLOAT(J-17)
   70 CONTINUE
      S=LOWY
```

```
      DO 80 J=1,10
      LY=J
      S=S+1
      IF(S.EQ.HIGHY) GO TO 21
    8 CONTINUE
   21 YDIST=(25./LY)*CM
      INO=25./LY
      VP(K+1)=LOWY
      VP(K+2)=1./YDIST
      YN=0.
      LKY=LY+1
      PL=1.
      DO 140 J=1,LKY
      CALL SYMBOL (0.,YN,.3*CM,13,90.,-1)
      IF(J.EQ.LKY) GO TO 140
      DO 100 J1=1,9
      IF(INO.LT.4) GO TO 76
      IF(INO.LT.6) GO TO 77
      IF(INO.LE.8) GO TO 78
      IF(INO.LE.12) GO TO 79
      IF(J1.GT.5) GO TO 73
      DO 110 J2=1,4
      YQ=YN+YDIST*YLOG(J2,J1)
  110 CALL SYMBOL (0.,YQ,.2*CM,13,90.,-1)
      GO TO 76
   77 IF(J1.GT.3) GO TO 76
      GO TO 79
   78 IF(J1.GT.6) GO TO 76
   79 DO 120 J2=1,2
      YQ=YN+YDIST*YLOG(J2,J1)
  120 CALL SYMBOL (0.,YQ,.2*CM,13,90.,-1)
   76 IF(J1.EQ.9) GO TO 100
      YQ=YN+YDIST*LOG(J1)
      CALL SYMBOL (0.,YQ,.3*CM,13,90.,-1)
      IF(INO.LT.4) GO TO 100
      PL=PL+1.
      CALL NUMBER (-.25*CM,YQ,.15*CM,PL,0.,-1)
  100 CONTINUE
      PL=1.
  140 YN=YN+YDIST
      CALL PLOT (0.,0.,2)
      YNO=LOWY
      YEM=.4*CM
      YBM=-.2*CM
      DO 130 J=1,LKY
      CALL NUMBER (-.5*CM,YBM,.3*CM,10.,90.,-1)
      CALL NUMBER (-.8*CM,YEM,.2*CM,YNO,90.,-1)
      YNO=YNO+1.
      YBM=YBM+YDIST
  130 YEM=YEM+YDIST
      LAB(1)=NAME(1)
      LAB(2)=LABEL2
      LAB(3)=NAME(2)
      CALL SYMBOL (-1.3*CM,10.3*CM,.3*CM,LAB,90.,30)
      GO TO 22
C
C     GENERATE SECOND FREQUENCY RESPONSE Y AXIS AND PLOT DATA LINE
```

```
      11 VP2(K+1)=-270.
         VP2(K+2)=60.*1.27
         LAB(1)=LABEL1
         LAB(3)=LABEL2
         J=2
         IF(NUDIE.EQ.1) J=J-2
         LAB(2)=NAME(J+1)
         LAB(4)=NAME(J+2)
         CALL FACTOR(HALF)
         CALL AX90 (0.,0.,LAB,40,6.,90.,-270.,60.)
         CALL FACTOR(1.)
         NOPLOTS=NOPLOTS+1
         CALL LINE (TIME,VP2,K,1,0,0)
C
C     SPACE TO NEXT PLOT PAGE
      12 IF(KK.EQ.2) CALL PLOT (28.4950*CM,0.,-3)
         IF(KK.EQ.1) GO TO 101
         GO TO 101
C
C     PLOT PSD DATA LINE
C
      22 CALL LINE (TIME,VP,K,1,0,0)
         NOPLOTS=NOPLOTS+1
      42 IF(IFPF.EQ.99) GO TO 36
         READ(7)FREQ,VALUE,VALUE
         GO TO 42
      36 CONTINUE
C
C     SPACE TO NEXT PLOT PAGE
         CALL PLOT (29.4950*CM,0.,-3)
         WRITE(3,1113)
    1113 FORMAT(/10X,"P S D  PLOTS COMPLETED"/)
         GO TO 98
     101 CONTINUE
C
C-------------------------- END OF CC LOOP 101 -------------------------
C
         WRITE(3,1112)
    1112 FORMAT (/11X,"FREQUENCY RESPONSE PLOTS COMPLETED"/)
C
C     CHECK FOR MORE THAN TWO FREQUENCY RESPONSE PLOTS
C
         IF(TYPE.EQ.PS) GO TO 999
         IF(NUDC.EQ.TWO) GO TO 999
         IF(NUDIE.EQ.2) GO TO 999
         NUDIE=2
         DO 200 JKS=1,K
         VP(JKS)=S10(JKS)
     200 VP2(JKS)=S20(JKS)
         GO TO 66
C
C-----------------------------------------------------------------------
C******ROOT LOCUS AND ROOT CONTOUR SECTION**********
C
C
C     IS THIS A ROOT LOCUS PLOT?
```

```
   23 IF(TYPE.EQ.RL) READ(7)N,M
      M=IABS(M)
C
C     CHECK FOR A Z-PLANE ROOT LOCUS (IDIG=1)
C
      IF(NOKP.-0.2) GO TO 1901
      IF(IDIG.NE.1) GO TO 201
      YER= 1

C-----------------------------------------------------------------------
C*****Z-PLANE ROOT LOCUS SECTION**********
C     GENERATE HALF CIRCLE AND EACH AXES
C
      CALL PLOT (17.*CM,2.*CM,-3)
      CALL PLOT (0.,20.*CM,2)
      Z=1.
      Y=20.*CM
      DO 202 J=1,5
      CALL SYMBOL (0.,Y,.2*CM,13,90.,-1)
      CALL NUMBER (.5*CM,Y-.3*CM,.25*CM,Z,90.,1)
      Z=Z-.5
  202 Y=Y-5.*CM
      CALL SYMBOL (2.*CM,6.*CM,.3*CM,"Z - PLANE ROOT LOCUS    (.1 UNIT/CM
     X)",90.,35)
      Y=10*CM
      CALL PLOT (0.,Y,3)
      X=-12.*CM
      CALL PLOT (X,Y,2)
      Z=1.2
      DO 203 J=1,3
      CALL PLOT (X,Y,3)
      CALL PLOT (X,Y,2)
      CALL SYMBOL (X,Y,.2*CM,13,0.,-1)
      CALL NUMBER (X,Y+.15*CM,.125*CM,Z,90.,1)
      CALL PLOT (X,Y+.15*CM,3)
      Z=Z-.4
  203 X=X+4.*CM
      CALL SYMBOL (-16.0*CM,.5*CM,.24*CM,TITLE(1),90.,80)
C
C     FOR ROOT LOCUS EACH GAIN INCREMENT HAS A DIFFERENT SYMBOL PLOTTED
C
      CALL SYMBOL (-15.*CM,3.*CM,.24*CM,"GAIN INCREMENT ORDER---",
     X90.,23)
      Y=9.1*CM
      X=-15.15*CM
      DO 204 J=1,12
      CALL SYMBOL (X,Y,BIG(J)*CM*1.2,ORDER(J),0.,-1)
  204 Y=Y+.85*CM
      S1=1.01
      DO 205 J=1,100
      S1=S1-.01
      S10(J)=S1
  205 TIME(J)=-SQRT(1-S10(J)**2)
      S10(101)=-1.2
      S10(102)=.254
      TIME(101)=-1.2
      TIME(102)=.254
```

```
      CALL PLOT (-12.*CM,0.,-3)
      CALL LINE (TIME,S1J,100,1,0,0)
      S1 =-1.01
      DO 206 J=1,100
      S1=S1+.01
  206 S10(J)=S1
      CALL LINE (TIME,S10,100,1,0,0)
      XDT=.1*2.54
      YCREY=.1*2.54
      XMIN=-1.3
      XMAX=1.4
      YMIN=0.
      YMAX=1.0
      GO TO 207
C
C-----------------------------------------------------------------------
C
C***** FOLLOWING SECTION INVOLVES ROOT LOCUS OR ROOT CONTOUR
C
C     READ MAXIMUM AND MINIMUM VALUES FOR Y AXIS AND X AXIS GENERATION
C
  201 READ (1,900)YMIN,YMAX
  900 FORMAT (2F10.0)
      IF (EOF(1) .NE. 0) GO TO 998
      WRITE(3,803)YMIN,YMAX
  803 FORMAT (10X,"YMIN=",F6.1,5X,"YMAX=",F6.1)
C
C     GENERATE X AXIS
C
      CALL SUBSCL(YMAX,YMIN,25.0,1.,10.,YCREY)
      XDT=YCREY
      XMIN=-14.*XDT
      XMAX=4.*XDT
      CALL FACTOR(HALF)
      IF(TYPE.EQ.RL) CALL AXIS (0.,0.,"ROOT LOCUS",-10,9.,0.,XMIN,
     XXDT*2.)
      IF(TYPE.NE.RL) CALL AXIS (0.,0.,"ROOT CONTOUR",-12,9.,0.,XMIN,
     XXDT*2.)
      CALL FACTOR(1.)
      CALL PLOT (14.*CM,0.,3)
      CALL PLOT (14.*CM,25.*CM,2)
      CALL SYMBOL (CM,25.2*CM,.20*CM,TITLE(1),0.,80)
C
C     IS THIS A ROOT CONTOUR PLOT
      IF(TYPE.NE.RL) GO TO 61
C
C     FOR ROOT LOCUS EACH GAIN INCREMENT HAS A DIFFERENT SYMBOL PLOTTED
C
      CALL SYMBOL (CM,26.1*CM,.24*CM,"GAIN INCREMENT ORDER---",0.,23)
      XN=7.10*CM
      YN=25.15*CM
      DO 170 J=1,10
      CALL SYMBOL (XN,YN,.24*CM,ORDER(J),0.,-1)
  170 XN=XN+.85*CM
   61 CONTINUE
      XN=18.3*CM
      YN=25.*CM
```

```
      Y5=YCREY*5.                                                       COPO     629
      YDO=YMIN+25.*YCREY                                                COPO     630
      DO 180 J=1,6                                                      COPO     631
      CALL PLOT (19.*CM,YN,3)                                           COPO     632
      CALL SYMBOL (18.*CM,YN,.4*CM,13,90.,-1)                           COPO     633
      CALL NUMBER (XN,YN,.26*CM,YDO,0.,1)                               COPO     634
      CALL PLOT (18.*CM,YN,3)                                           COPO     635
      YN=YN-5.*CM                                                       COPO     636
  180 YDO=YDO-Y5                                                        COPO     637
      YCREY=YCREY*2.54                                                  COPO     638
      XDT=XDT*2.54                                                      COPO     639
      IF(TYPE.NE.RL) GO TO 62                                           COPO     640
  207 CONTINUE                                                          COPO     641
C                                                                       COPO     642
C---------------------------------------------------------------------- COPO     643
C----DO LOOP 190 WILL READ THE ROOTS WITH N BEING THE NO. OF GAIN INCREM COPO     644
C----AND M BEING THE NO. OF ROOTS TO BE PLOTTED WITHIN EACH GAIN INCREME COPO     645
C----         BOTH Z-PLANE AND REGULAR ROOT LOCUS ARE PLOTTED HERE      COPO     646
C                                                                       COPO     647
      DO 190 J=1,N                                                      COPO     648
      DO 190 K=1,M                                                      COPO     649
      IF(K.EQ.1) PTF=1.                                                 COPO     650
      IF (NOKP.NE.2) GO TO 1555                                         COPO     651
      READ (9) I,(TIME(L),VP(L),L=1,I)                                  COPO     652
      IF (EOF(9).NE.0)  GO TO 1900                                      COPO     653
      IF (NOKP.EQ.2) GO TO 115                                          COPO     654
 1555 CONTINUE                                                          COPO     655
      READ(7)I,(TIME(L),VP(L),L=1,I)                                    COPO     656
      IF (IDIG.EQ.1) WRITE(9)I,(TIME(L),VP(L),L=1,I)                    COPO     657
  115 CONTINUE                                                          COPO     658
      LL=0                                                              COPO     659
      DO 160 L=1,I                                                      COPO     660
C                                                                       COPO     661
C     THROW OUT ALL POINTS OUTSIDE X AND Y BOUNDS                       COPO     662
C                                                                       COPO     663
      IF(((VP(L)).GT.YMAX).OR.((VP(L)).LT.YMIN).OR.((TIME(L)).GT.XMAX).O COPO     664
     XR.((TIME(L)).LT.XMIN)) GO TO 160                                  COPO     665
      IF(((VP(L)).EQ.0.).AND.((TIME(L)).EQ.0.)) GO TO 160               COPO     666
      IF((J.NE.1).OR.(K.NE.1)) GO TO 27                                 COPO     667
      XN=(TIME(L)-XMIN)/XDT                                             COPO     668
      YN=(VP(L)-YMIN)/YCREY                                             COPO     669
      IF(IDIG.EQ.1) XN=(1.2-VP(L))/XDT                                  COPO     670
      IF(IDIG.EQ.1) YN=(1.+TIME(L))/YCREY                               COPO     671
      IF(NOKP.EQ.2) XN=-VP(L)/XDT                                       COPO     672
      IF(NOKP.EQ.2) YN=(16.+(TIME(L)-1.)/.005)/2.54                     COPO     673
      CALL SYMBOL (XN,YN,.35*CM,4,0.,-1)                                COPO     674
      GO TO 160                                                         COPO     675
   27 LL=LL+1                                                           COPO     676
      TIME(LL)=TIME(L)                                                  COPO     677
      VP(LL)=VP(L)                                                      COPO     678
  160 CONTINUE                                                          COPO     679
      L=LL                                                              COPO     680
      IF(IDIG.NE.1) GO TO 208                                           COPO     681
      DO 209 JJ=1,L                                                     COPO     682
      VT=VP(JJ)                                                         COPO     683
      VP(JJ)=TIME(JJ)                                                   COPO     684
  209 TIME(JJ)=-VT                                                      COPO     685
```

```
            VP(L+1)=-1.
            VP(L+2)=YCREY
            TIME(L+1)=-1.2
            TIME(L+2)=XDT
            IF (NOKP.NE.2) GO TO 211
            VP(L+1)=.92
            TIME(L+1)=0.0
            GO TO 211
        228 VP(L+1)=YMIN
            VP(L+2)=YCREY
            TIME(L+1)=XMIN
            TIME(L+2)=XDT
        211 KD=K
            IF(K.GT.10) KD=K-10
            CALL LINE (TIME,VP,L,1,-1,ORDER(KD))
        190 CONTINUE
       1901 CONTINUE
            IF(IDIG.NE.1) GO TO 1900
            IF (KLP.NE.NNKP) GO TO 1900
            IF (NOKP.EQ.1) GO TO 1900
            CALL PLOT (17.*CM,2.*CM,-3)
            CALL FACTOR(.7874)
            CALL AXIS(0.,0.,16HZ-PLANE EXPANDED,-16,10.,90.,.92,.01)
            CALL AXIS(0.,8.,9HIMAG AXIS,-9,6.,180.,0.,.01)
            CALL SYMBOL(-7.5,0.,.14,TITLE(1),90.,80)
            CALL SYMBOL (-7.,.5,.14,"GAIN INCREMENT ORDER ---",90.,24)
            YY=4.55
            DO 2044 J=1,10
            CALL SYMBOL (-7.1,YY,.14,ORDER(J),0.,-1)
       2044 YY=YY+.425
            CALL FACTOR(1.0)
            XMIN=.91
            XMAX=1.03
            YMIN=0.
            YMAX=.07
            XDT=.0127
            YCREY=.0127
            KLP=KLP+1
            WRITE (3,1111)
       1111 FORMAT(20X,"EXPANDED ROOT LOCUS COMPLETED")
            GO TO 207
       1900 CONTINUE
C
C-----------------------------------------------------------------
C
C           CALL SUBROUTINE TO PLOT ZEROES
C
            CALL READO(YMAX,YMIN,XMAX,XMIN,XDT,YCREY,IDIG ,TIME,VP,NOKP)
            IF(IDIG.NE.1) WRITE(3,1118)
            IF(IDIG.EQ.1) WRITE(3,1117)
       1117 FORMAT (20X,"Z PLANE ROOT LOCUS PLOT COMPLETED")
C
C        SPACE TO NEXT PLOT PAGE
            IF(IDIG.NE.1) CALL PLOT (30.4950*CM,0.,-3)
            IF(IDIG.EQ.1) CALL PLOT (25.4950*CM,-2.*CM,-3)
            NOPLOTS=NOPLOTS+1
            IF (NOKP.EQ.2) CALL PLOT (-12.*CM,0.,-3)
```

```
   99 GO TO 999
C
C-----------------------------------------------------------------------
C*****ROOT CONTOUR PLOT SECTION**********
C
   62 IFS=0
      GO TO 67
   66 IFS=1
   67 READ(7)I,(TIME(L),VP(L),L=1,I)
      IF((TIME(1).EQ.-1.).AND.(VP(1).EQ.-1.)) GO TO 63
      LL=0
      DO 260 L=1,I
      IF(((VP(L)).GT.YMAX).OR.((VP(L)).LT.YMIN).OR.((TIME(L)).GT.XMAX).O
     XR.((TIME(L)).LT.XMIN)) GO TO 260
      IF(((VP(L)).EQ.0.).AND.((TIME(L)).EQ.0.)) GO TO 260
      XN=(TIME(L)-XMIN)/XDT
      YN=(VP(L)-YMIN)/YCREY
      IF(IFS.GT.0) GO TO 65
      CALL SYMBOL (XN,YN,.30*CM,4,0.,-1)
      GO TO 260
   65 CALL SYMBOL (XN,YN,.10*CM,1,0.,-1)
  260 CONTINUE
      IF(IFS.EQ.0) GO TO 66
      GO TO 67
   63 IDIG=0
      WRITE (3,1119)
 1118 FORMAT (20X,"ROOT LOCUS PLOT COMPLETED")
 1119 FORMAT (20X,"ROOT CONTOUR PLOT COMPLETED")
C
C-----------------------------------------------------------------------
C
C     SPACE TO NEXT PLOT PAGE
      CALL PLOT (30.+950*CM,0,-3)
      NOPLOTS=NOPLOTS+1
      GO TO 999
  991 WRITE (3,1000)
 1000 FORMAT (/10X,"N O   P L O T S   R E Q U E S T E D")
      GO TO 99
C
C     MUST BE A LIMIT CARD FOR EACH REGULAR ROOT LOCUS OR ROOT CONTOUR
C
  998 WRITE(3,503)
  503 FORMAT (10X,"E R R O R - - NO DATA CARD FOR ROOT LOCUS OR ROOT CON
     XTOUR PLOT")
      GO TO 999
   99 CONTINUE
      CALL PLOT (0.,0.,999)
C
C     GENERATE AUTOMATIC PLOT REQUEST
C
      CALL PLOTREQ(SNAME,SUBTASK,0,0,0,0,0,NOTA,NOTA,0,0,0,
     XPTITLE,NOPLOTS,0,IVSN,COMMENT)
C    XPTITLE,NOPLOTS,0,0,COMMENT)
      END
```

```
      SUBROUTINE READO(YMAX,YMIN,XMAX,XMIN,YCREX,YCREY,IDIG,TIME,VP,NOKP READO
     1)                                                                 READO
C                                                                       READO
C---------------------------------------------------------------------- READO
C     THIS SUBROUTINE READS AND PLOTS THE ZEROES OF THE TRANSFER        READO
C     FUNCTION FOR A ROOT LOCUS                                         READO
C---------------------------------------------------------------------- READO
C                                                                       READO
      DIMENSION TIME(1),VP(1)                                           READO
      IF  ((NOKP.NE.2) .OR.(IDIG.NE.1)) GO TO 1234                      READO
      READ (9) I,(TIME(L),VP(L),L=1,I)                                  READO
      IF(EOF(9).NE.0) GO TO 161                                         READO
      IF((NOKP.EQ.2).AND.(IDIG.EQ.1)) GO TO 11                          READO
 1234 CONTINUE                                                          READO
      READ(7) I,(TIME(L),VP(L),L=1,I)                                   READO
      IF (IDIG.EQ.1      ) WRITE (9) I,(TIME(L),VP(L),L=1,I)            READO
   11 CONTINUE                                                          READO
      DO 160 L=1,I                                                      READO
      IF((VP(L).GT.YMAX).OR.(VP(L).LT.YMIN).OR.(TIME(L).GT.XMAX).OR.(TIM READO
     -E(L).LT.XMIN)) GO TO 160                                          READO
      XN=(TIME(L)-XMIN)/YCREX-.039                                      READO
      YN=(VP(L)-YMIN)/YCREY-.049                                        READO
      IF(IDIG.NE.1) GO TO 159                                           READO
      XN=(1.2-VP(L))/YCREX-.039                                         READO
      YN=(1.+TIME(L))/YCREY-.049                                        READO
      IF (YCREY.EQ..0127) XN=-VP(L)/YCREY -.039                         READO
      IF (YCREY.EQ..0127) YN=(16.+(TIME(L)-1.)/.005)/2.54 -.049         READO
  159 CALL SYMBOL(XN,YN,.140   ,54,0.,-1)                               READO
  160 CONTINUE                                                          READO
  161 CONTINUE                                                          READO
      RETURN                                                            READO
      END                                                               READO
```

```
      SUBROUTINE CSTAR                                                  CSTAR
C                                                                       CSTAR
C---------------------------------------------------------------------- CSTAR
C     THIS SUBROUTINE CONTAINS THE ENVELOPE CURVES FOR CSTAR OPTIONS    CSTAR
C     CRUISE AND POWER APPROACH                                         CSTAR
C---------------------------------------------------------------------- CSTAR
C                                                                       CSTAR
      COMMON/CSTARC/CTML,CTMU,CENVL,CENVU/CSTARP/PTML,PTMU,PENVL,PENVU  CSTAR
      DIMENSION CTML(20),CTMU(20),CENVL(20),CENVU(20),                  CSTAR
     X          PTML(12),PTMU(23),PENVL(12),PENVU(23)                   CSTAR
      DATA CTML/  0.00,   .20,   .40,   .50,   .60,   .70,   .80,   .90, CSTAR
     X            1.00,  1.10,  1.20,  1.30,  1.50,  1.70,  1.80,  1.90, CSTAR
     X            2.00,  5.00,  0.00,  0.00/,                           CSTAR
     XCENVL/.00,  .000,  .775,  .855,   .890, .890,  .885,  .855,  .800, CSTAR
     X            .785,  .795,  .810,   .855, .905,  .926,  .940,  .950, CSTAR
     X            .950,  .000,  .000/,                                  CSTAR
     XCTMU/0.0,  .020,  .075,  .113,  .180,  .200,  .300,  .340,  .400,  CSTAR
     X            .600,  .800, 1.000, 1.100, 1.200, 1.300, 1.400, 1.500, CSTAR
     X           5.000, 0.000, 0.000/,                                  CSTAR
     XCENVU/0.0,  .800, 1.200, 1.400, 1.600, 1.645, 1.730, 1.735, 1.720, CSTAR
     X           1.555, 1.355, 1.200, 1.145, 1.105, 1.070, 1.055, 1.050, CSTAR
     X           1.050, 0.000, 0.000/                                   CSTAR
      DATA PTML/  0.00,   .20,   .60,  1.40,  2.25,  2.50,  2.75,  3.00, CSTAR
     X            3.25,  3.50,  0.00,  0.00/,                           CSTAR
     XPENVL/0.0,  0.00,   .55,   .85,   .89,   .76,   .69,   .69,   .73, CSTAR
     X             .85,   .00,   .00/,                                  CSTAR
     XPTMU/0.0,   .01,   .06,   .10,   .16,   .20,   .30,   .42,   .50,  CSTAR
     X      .60,   .70,   .80,   .90,  1.00,  1.20,  1.33,  1.50,  2.00, CSTAR
     X     2.50,  3.00,  3.50,  0.00,  0.00/,                           CSTAR
     XPENVU/0.0,   .50,  1.00,  1.20,  1.50,  1.62,  1.84,  2.00,  2.08, CSTAR
     X     2.16,  2.21,  2.23,  2.24,  2.21,  2.08,  2.00,  1.92,  1.71,  CSTAR
     X     1.55,  1.39,  1.17,  0.00,  0.00/                            CSTAR
      END                                                               CSTAR
```

```
      SUBROUTINE SUBSCL(XMAX,XMIN,S,KFAC,DIV,SCALE)
C
C-------------------------------------------------------------------
C     THIS SUBROUTINE COMPUTES THE SCALING FACTOR FOR ROOT LOCUS PLOTS
C-------------------------------------------------------------------
C
      DIMENSION X(1)
      REAL FAC(4)
      DATA FAC/1.,2.,5.,10./
      A=XMAX-XMIN
      IF(A.EQ.0.) GO TO 17
      SLEN=S*DIV/10.
      B=A/SLEN
      IF(B.GT..5.AND.B.LE.1.) GO TO 401
      IF(B.LE.5.) GO TO 38
      GO TO 41
   17 WRITE(3,20)
   20 FORMAT("  DATUM MAXIMUM AND MINIMUM ARE THE SAME"  )
   40 SCALE=.01
      GO TO 5
  401 SCALE=1.
      GO TO 5
   41 DO 4 I=1,999
      DO 4 J=1,3
      IF(B.GE.FAC(J)*10.**(I-1)) GO TO 4
      SCALE=FAC(J)*10.**(I-1)
      GO TO 5
    4 CONTINUE
      GO TO 5
   38 DO 39 I=1,999
      DO 39 J=1,3
      IF(B.LE.FAC(4-J)*10.**(-I+1))    GO TO39
      SCALE=FAC(5-J)*10.**(-I+1)
      GO TO 5
   39 CONTINUE
    5 A=AMOD(XMIN,SCALE)
   19 IF(XMIN.GT.0.)XMIN=XMIN-A
      IF(XMIN.LT.0.)XMIN=XMIN-SCALE-A
      IF(KFAC.GT.0) GOT 050
      XMIN=XMIN+SCALE*SLEN
      SCALE=-SCALE
   50 CONTINUE
      RETURN
      END
```

APPENDIX 2

NAMELIST CODE

THE CONDITION CODES AND INPUT DATA ARE CONTAINED IN THE NAMELIST CODE AND ARE LISTED BELOW. ALL OF THE CODES AND DATA ARE INITIALIZED TO ZERO AT THE START OF EACH CASE UNLESS THE SAV OPTION IS SET

CONDITION_CODES (INTEGER VARIABLES)
READ,SYSTEM,OUTPUT,MIXED,DIGITL,FRPS,NUMERS,TRESP,NX,NY,NU,NXC,NUC, ZOH,N1,N2,CONTUR,MULTRT,MODEL,NSCALE,CMAT,NK2,FORM,IPT,IGO,SAV, IFLAG,READ3

INPUT_DATA (REAL VARIABLES)
DELT,FINALT,IFREQ,FFREQ,DELFRQ,M,GAIN1,GAIN2

CONDITION_CODE_DESCRIPTION (INTEGER VARIABLES)

READ	1	DATA MATRICES INPUT THROUGH LOAD SUBROUTINE
	2	DATA MATRICES CONSTRUCTED IN USER WRITTEN MATRIX SUBROUTINE
	3	DATA FROM PREVIOUS CASE ALTERED IN USER WRITTEN CHANGE SUBROUTINE
	4	DATA MATRICES CONSTRUCTED FROM BLOCK DIAGRAM INFORMATION IN CLASS SUBROUTINE
SYSTEM	1	OPEN LOOP SYSTEM ANALYSIS
	2	CLOSED LOOP SYSTEM ANALYSIS
	3	ROOT LOCUS ANALYSIS
OUTPUT	1	$y = Hx$
	2	$y = Hx + G\dot{x}$
	3	$y = Hx + Fu$
	4	$y = Hx + G\dot{x} + Fu$
MIXED	0	NO ACTION
	1	MIXED SYSTEM ANALYSIS (SEE TABLE V.) SYSTEM MATRICES ARE CONSTRUCTED IN A TWO-STEP PROCESS, STEP 1 SPECIFIES OPEN LOOP PLANT (I.E. SPECIFY A,B, C,H,G,F REGARDLESS OF VALUE OF SYSTEM). STEP 2 AUGMENTS PLANT WITH CONTROL SYSTEM DESCRIBED BY BLOCK DIAGRAM USING CLASS. SYSTEM SPECIFIES THE TYPE OF ANALYSIS FOR THE AUGMENTED SYSTEM.
DIGITL	0	CONTINUOUS SYSTEM ANALYSIS
	1	SAMPLED-DATA SYSTEM ANALYSIS
	2	DISCRETE SYSTEM ANALYSIS
		IF DIGITL $\neq$ 0, DELT SPECIFIES THE SAMPLE PERIOD OF THE DISCRETE OR SAMPLED-DATA SYSTEM.

FRPS
- 0 NOT APPLICABLE
- 1 FREQUENCY RESPONSE CALCULATED FOR EACH TRANSFER FUNTION
  - S-PLANE IF DIGITL = 0
  - W-PLANE IF DIGITL = 1,2 (DELT REQUIRED)
- -1 S-PLANE FREQUENCY RESPONSES CALCULATED FROM Z-TRANSFER FUNCTIONS WITH DIGITL = 1,2 (DELT REQUIRED)
- 2 S-PLANE POWER SPECTRA CALCULATED (DIGITL= 0)

NUMERS
- 0 NUMERATOR ZEROES OF S- OR Z-TRANSFER FUNCTIONS CALCULATED
- 1 NUMERATOR ZEROES NOT CALCULATED

CONTROL WILL COMPUTE TRANSFER FUNCTION NUMERATOR ZEROES FOR ALL INPUT-OUTPUT PAIRS DEFINED BY THE INPUT AND OUTPUT VECTORS. FOR MIXED SYSTEM ANALYSIS, THE ITHINU AND ITHINY OPTIONS ALLOW UNWANTED TRANSFER FUNCTIONS TO BE ELIMINATED.

TRESP
- 0 NO ACTION
- N N TRANSIENT RESPONSES CALCULATED. 'DELT SPECIFIES INTEGRATION STEP SIZE. IF DISC INPUT ROUTINE IS USED, THERE MUST BE N INPUT CARDS AT THE END OF THE DATA CASE GIVING THE INPUT STEP FUNCTION.

NX,NY,NU — DIMENSIONS OF X, Y, AND U VECTORS. IF MIXED = 1, NX, NY, AND NU SPECIFY DIMENSIONS OF THE OPEN LOOP PLANT (STEP 1). STATES ADDED IN STEP 2 OF THE MIXED OPTION AUTOMATICALLY INCREMENT NX, NY, AND NU.

NXC,NUC — DIMENSIONS OF STATE AND INPUT VECTORS CORRESPONDING TO THE CONTINUOUS SUBSYSTEM (PLANT) OF A SAMPLED-DATA SYSTEM. THE PLANT MUST BE PARTITIONED IN THE UPPER LEFT POSITION OF THE SYSTEM MATRICES (A,B,H,F,ETC.) $NXC \leq NX$, $NUC \leq NU$

ZOH — FOR SAMPLED-DATA SYSTEMS, THE NUMBER OF INPUTS TO THE PLANT WHICH ARE OUTPUTS OF ZERO-ORDER-HOLD DEVICES. THESE MUST BE THE FIRST ZOH COMPONENTS OF THE INPUT VECTOR, U.

N1,N2 — THE ROOT LOCUS OPTION ALLOWS TWO FEEDBACK GAINS ITO BE SPECIFIED. N1 IS THE NUMBER OF ITERATIONS OF THE FIRST VARIABLE (K1,K2) AND N2 IS THE NUMBER OF ITERATIONS OF THE SECOND VARIABLE (K3,K4). (COMMONLY, N2 =0).
- IF N1 > 0, GAIN INCREMENTS ARE ARITHMETIC (0,1,2,3,..)
- IF N1 < 0, GAIN INCREMENTS ARE GEOMETRIC (0,1,2,4,8,.)

Gain increments of second variable are the same as the first; N2 must be >0.

CONTUR
- 0 NOT APPLICABLE
- 1 ROOT CONTOUR OPTION FOR PARAMETER VARIATION STUDIES CONTROL DETERMINES ONLY SYSTEM EIGENVALUES AND RETURNS TO TOP OF PROGRAM FOR NEXT VARIATION. CONTINUES UNTIL CONTUR SET TO ZERO. (USED WITH IFLAG,READ3,SAV,AND CHANGE)

MULTRT — FOR SAMPLED-DATA SYSTEMS, COMPUTES MULTRT TRANSIENT RESPONSE POINTS FOR EACH SAMPLE PERIOD SO THAT INTERSAMPLE RESPONSE MAY BE INVESTIGATED. ONLY TRANSIENT RESPONSES ARE CALCULATED IF MULTRT IS SET.

MODEL	0	NOT APPLICABLE
	1	MODEL FOLLOWING ON CONSECUTIVE FREQUENCY RESPONSES
NSCALE	0	NOT APPLICABLE
	1	STATE VECTOR TRANSFORMED TO IMPROVE NUMERICAL CONDITIONING IN DETERMINATION OF EIGENVALUES. A MATRIX SCALED BY A DIAGONAL SIMILARITY TRANSFORMATION.
CMAT	0	C MATRIX IS THE IDENTITY MATRIX (C NOT REQUIRED)
	1	$C \neq I$ (C REQUIRED)
NK2	0	K2 = 0 , K4 = 0 (K2,K4 NOT REQUIRED)
	1	$K2 \neq 0$ OR $K4 \neq 0$ (K2,K4 REQUIRED)
FORM	0	PRINT ONLY FOR OUTPUT
	1	PRINT AND PLOT OUTPUT
	2	PLOT ONLY FOR OUTPUT THE CONTROL PLOTTER PROGRAM AUTOMATICALLY SCALES ALL PLOTS EXCEPT ROOT LOCUS PLOTS (WHICH REQUIRE AN EXTRA DATA CARD).
IPT		CODE FOR EXTRA PRINTOUT FOR DEBUGGING
	0	NO EXTRA PRINTING
	1,2	EXTRA PRINTING
IGO		CODE FOR DATA REQUIRED BY CLASS SUBROUTINE
	0	INPUT DATA REQUIRED BY CLASS (TABLE V, STEP 2)
	1	CLASS USES DATA FROM PREVIOUS CASE
SAV	0	DATA MATRICES NOT SAVED
	1	DATA MATRICES SAVED FOR SUBSEQUENT CASES. IF MIXED = 1, CONTROL SAVES MATRICES DEFINED IN STEP 1 (CLASS INPUT DATA, STEP 2, IS NOT DESTROYED AND IS AVAILABLE FOR SUBSEQUENT CASES).
IFLAG	0	ON SUBSEQUENT CASE THE CONDITION CODES AND INPUT DATA ARE ZEROED BEFORE THE CALL TO CARD. CARD READS TITLE,NAMELIST, OUTPUT LABEL,AND INPUT LABEL CARDS
	1	ON SUBSEQUENT CASES THE CONDITION CODES AND INPUT DATA OF THE PRESENT CASE WILL BE USED. CARD READS ONLY A TITLE CARD FOR ALL SUBSEQUENT CASES. (THE OPTION MAY BE CANCELED BY SETTING IFLAG = 0 OR BY END OF DATA DECK).
READ3	0	NO ACTION
	1	ON SUBSEQUENT CASES, READ DEFAULTS TO 3 TO FORCE PROGRAM TO THE CHANGE SUBROUTINE. THE OPTION IS USED WITH IFLAG FOR PARAMETER VARIATION STUDIES.

INPUT DATA DESCRIPTION (REAL VARIABLES)

```
DELT          TIME INCREMENT FOR TRANSIENT RESPONSES AND/OR SAMPLE PERIOD
              FOR SAMPLED-DATA SYSTEMS, SECONDS

FINALT        FINAL TIME FOR TRANSIENT RESPONSES, SECONDS

IFREQ,FFREQ,DELFRQ
              INITIAL,FINAL, AND INCREMENTAL FREQUENCIES FOR FREQUENCY
              RESPONSES OR POWER SPECTRA.  DELFRQ = 1.1 IS GOOD FOR
              MOST APPLICATIONS. FREQUENCIES MUST BE SPECIFIED IN
              (DELFRQ CANNOT EQUAL 1.0)
              RADIANS/SEC. (S-PLANE) EVEN FOR DISCRETE AND SAMPLED-DATA
              SYSTEMS.  IF IFREQ  = 0., PROGRAM DEFAULTS TO AN INTERNAL
              SET OF FREQUENCY POINTS SPACED BETWEEN .1 AND 150. RAD/SEC.
              FOR SAMPLED-DATA FREQUENCY RESPONSES CONTROL DEFAULTS
              IN THE FOLLOWING MANNER,
              IF DIGITL≠0 AND FRPS ≠-1 AND IFREQ=0
                    IFREQ = TAN (.1*DELT*.5)
                    FFREQ = TAN (.9*3.14*.5)
              IF DIGITL≠0 AND FRPS ≠-1 AND IFREQ≠0
                    IFREQ= TAN (IFREQ*DELT*.5)
                    FFREQ = TAN (FFREQ*DELT*.5)

M             CODE FOR MODIFIED Z-TRANSFER FUNCTION COMPUTATION FOR
              SAMPLED-DATA SYSTEMS.  M IS THE FRACTIONAL SAMPLE PERIOD
              DELAY AND IS IN THE RANGE  0.≤ M ≤ 1.    M = 1.GIVES THE
              STANDARD Z-TRANSFORM  IF THE SIGNAL HAS NO JUMP DISCONTIN-
              UITY AT THE SAMPLE INSTANT.   M = 0. GIVES THE Z-TRANSFORM
              WITH A ONE  SAMPLE PERIOD DELAY. HOWEVER, NUMERICAL ERRORS
              LIMIT  M  TO   M ≥ .2 .  THEREFORE, IF M=0., THE PROGRAM
              DEFAULTS TO STANDARD Z-TRANSFORM ANALYSIS. ONLY OPEN LOOP
              CALCULATIONS (MODIFIED Z-TRANSFER FUNCTIONS AND FREQUENCY
              RESPONSES) MAY BE PERFORMED WITH THIS OPTION.

GAIN1,GAIN2   ROOT LOCUS GAIN INCREMENTS FOR THE TWO FEEDBACK GAIN
              VARIABLES ALLOWED WITH THE ROOT LOCUS OPTION.  IF NOT SET,
              PROGRAM DEFAULTS TO GAIN1= 1.0, GAIN2=  1.0.
```


C·3

APPENDIX 3

INPUT AND OUTPUT LISTINGS OF EXAMPLE PROBLEM

A. INPUT LISTING

```
   EXAMPLE PROBLEM    LATERAL-DIRECTIONAL AIRPLANE & CONTROL SYSTEM
$CODE READ=1,MIXED=1,SYSTEM=1,OUTPUT=2,NX=4,NY=5,NU=2,NSCALE=0,SAV=0,
CMAT=1,IPT=0,FRPS=1,IFLAG=0,READ3=0,DELT=.05,FINALT=3.,
TRESP=1,FORM=C,IFREQ=.1,FFREQ=20.,DELFRQ=1.11,$END
ROLLRATE YAWRATE   BETA      PHI       AY
DELTAAC DELTARC
          4          4
-5.9       1.7        -15.
-.4       -1.         10.
-.004     -1.         -.25        .11
1.
          4          2
14.        3.
-.6       -6.
           .07

          4          4
1.        -.02
-.02       1.
                      1.
                                 1.
          5          4
1.
           1.
                       1.
                                  1.
-.0348      8.7                   -1.
          5          4



                      8.7
     5      1
1    1                          3       -2.
2    4                          1        1.          25.
3    8      4      5            2        1.          25.          .7
4    6                          4         1.          1.
5    5                          5       -.1          10.          2.
     1      2      3      4     5
     3      4
     3      2      1
     1      3
     2      4
     5      5
     2      1
     3      2
     6      3
             1.
```

B. OUTPUT LISTING

```
EXAMPLE PROBLEM  LATERAL-DIRECTIONAL AIRPLANE AND CONTROL SYSTEM
        CONTINUOUS SYSTEM
        MIXED OPTION
        OPEN LOOP
        LOAD ROUTINE INPUT
        TRANSFER FUNCTIONS
        FREQUENCY RESPONSES
        TRANSIENT RESPONSES

        NX  =   4        READ   =  1      TRESP  =  1      CMAT   =  1      DELT   =   .050
        NY  =   5        SYSTEM =  1      FRPS   =  1      NK2    =  0      FINALT =  3.000
        NU  =   2        MIXED  =  1      NUMERS =  0      IFLAG  =  0      IFREQ  =   .100
        NXC =   0        OUTPUT =  2      FORM   =  0      IGC    =  0      DELFRQ =  1.110
        NUC =   0        DIGITL =  0      CONTUP =  0      READ3  =  0      FFREQ  = 20.000
        ZOH =   0        IPT    =  0      MULTRT =  0      SAV    =  0      GAIN1  =  0.000
        N1  =   0        KOUNT  =  1      MODEL  =  0      NSCALE =  0      GAIN2  =  0.000
        N2  =   0                                                            M      =  0.000

        THE A MATRIX IS

       4          4

 -.[illegible]980E+01   .1700E+01  -.1500E+02 -0.
 -.4000E+00  -.1000E+01   .1000E+02 -0.
 -.4000E-02  -.1000E+01  -.2500E+00   .1100E+00
  .1000E+01 -0.          -0.          -0.

        THE B MATRIX IS

       4          2

  .1400E+02   .3000E+01
 -.6000E+00  -.6000E+01
-0.           .7000E-01
-0.          -0.

        THE C MATRIX IS

       4          4

  .1000E+01  -.2000E-01 -0.          -0.
 -.2000E-01   .1000E+01 -0.          -0.
-0.          -0.          .1000E+01 -0.
-0.          -0.          -0.          .1000E+01

        THE F MATRIX IS

       5          4

  .1000E+01 -0.          -0.          -0.
-0.           .1000E+01 -0.          -0.
-0.          -0.          .1000E+01 -0.
-0.          -0.          -0.          .1000E+01
 -.3480E-01   .8700E+01 -0.          -.1000E+01
```

ORIGINAL PAGE IS
OF POOR QUALITY

THE G MATRIX IS

5 4

-0.	-0.	-0.	-0.
-0.	-0.	-0.	-0.
-0.	-0.	-0.	-0.
-0.	-0.	-0.	-0.
-0.	-0.	-0.	.8700E+01

BLOCK DIAGRAM INPUT PARAMETERS

NO.	TYPE	CONNEC			MOD		PARAM				
1	1	-0	-0	-0	3	-0	-2.0000	-0.0000	-0.0000	-0.0000	-0.0000
2	4	-0	-0	-0	1	-0	1.0000	25.0000	-0.0000	-0.0000	-0.0000
3	8	4	5	-0	2	-0	1.0000	25.0000	.7000	-0.0000	-0.0000
4	6	-0	-0	-0	4	-0	1.0000	1.0000	-0.0000	-0.0000	-0.0000
5	5	-0	-0	-0	5	-0	-1.0000	10.0000	2.0000	-0.0000	-0.0000

ITHINY

1	2	3	4	5	-0	-0	-0	-0	-0

ITHINU

3	4	-0	-0	-0	-0	-0

YTOV

1	3
2	4
5	5

ZTOU

2	1
3	2

YZTOK

5	3

THE FINAL REDUCED SYSTEM IS

THE A MATRIX IS

9 9

-.5910E+01	.1681E+01	-.1441E+02	0.	.3498E+03	.1801E+04	0.	0.	0.
-.5182E+00	-.9664E+00	.9704E+01	0.	-.8003E+01	-.7714E+04	0.	0.	0.
-.4000E-02	-.1000E+01	-.2500E+00	.1100E+00	0.	.4375E+02	0.	0.	0.
.1000E+01	0.	0.	0.	0.	0.	0.	0.	0.
-.2000E+01	0.	0.	0.	-.2500E+02	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	.1000E+01	0.	0.
-.4333E+02	-.4250E+02	0.	.5000E+01	0.	-.6250E+03	-.3500E+02	-.1000E+01	.4000E+02
0.	.1000E+01	0.	0.	0.	0.	0.	-.1000E+01	0.
.8665E+01	.9700E+01	0.	-.1000E+01	0.	0.	0.	0.	-.1000E+02

THE B MATRIX IS

9 2

0.	0.
0.	0.
0.	0.
0.	0.
.1000E+01	0.
0.	0.
0.	.1000E+01
0.	0.
0.	0.

THE H MATRIX IS

5 9

.1000E+01	0.	0.	0.	0.	0.	0.	0.	0.
0.	.1000E+01	0.	0.	0.	0.	0.	0.	0.
0.	0.	.1000E+01	0.	0.	0.	0.	0.	0.
0.	0.	0.	.1000E+01	0.	0.	0.	0.	0.
.8665E+01	.8700E+01	0.	-.1000E+01	0.	0.	0.	0.	0.

THE F MATRIX IS

5 2

0.	0.
0.	0.
0.	0.
0.	0.
0.	0.

THE EIGEN VALUES OF THE SYSTEM ARE

REAL PART	IMAGINARY PART
-.38510438E+02	-.34711706E+02
-.38510438E+02	.34711706E+02
-.14860487E+02	-.36751121E+02
-.14860487E+02	.36751121E+02
.31861414E+02	0.
-.13418070E+01	0.
-.16901707E+01	0.
-.22354764E+00	0.
.92094333E-02	0.

THE COEFFICIENTS OF THE CHARACTERISTIC EQUATION ORDERED FROM THE LOWEST POWER OF S

.62837635E+06
-.54570633E+08
-.39345278E+09
-.44325784E+09
-.14167525E+09
-.21935520E+07
.27156306E+04
.33936257E+04
.78126751E+02
.10000000E+01

THE ROLL RATE/ DELTA AC NUMERATOR GAIN IS .3498E+03

THE ZEROES OF THE TRANSFER FUNCTION ARE

REAL PART	IMAGINARY PART
-.40837930E+02	-.48392089E+02
-.40837930E+02	.48392089E+02
.37439375E+02	0.
-.12398563E+01	0.
-.17439393E+01	0.
.48342766E-01	0.
.53467247E-11	0.

THE COEFFICIENTS OF THE NUMERATOR POLYNOMIAL ORDERED FROM THE LOWEST POWER OF S

-.84165208E-07
.15745192E+05
-.30410208E+06
-.43963165E+06
-.14722565E+06
.10837823E+04
.47177938E+02
.10000000E+01

ROLL RATE/ DELTA AC FREQUENCY RESPONSE S-PLANE

FREQUENCY RAD/SEC	AMPLITUDE RATIO DB	PHASE ANGLE DEGREES
.1000	-.15460E+02	.86549E+02
.1110	-.14868E+02	.82507E+02
.1232	-.14283E+02	.78420E+02
.1368	-.13710E+02	.74304E+02
.1518	-.13156E+02	.70173E+02

.1695	-.12628E+02	.66047E+02
.1870	-.12131E+02	.61946E+02
.2076	-.11668E+02	.57894E+02
.2305	-.11243E+02	.53916E+02
.2558	-.10857E+02	.50038E+02
.2839	-.10510E+02	.46286E+02
.3152	-.10202E+02	.42681E+02
.3498	-.99311E+01	.39244E+02
.3883	-.96946E+01	.35989E+02
.4310	-.94893E+01	.32925E+02
.4785	-.93118E+01	.30057E+02
.5311	-.91586E+01	.27384E+02
.5895	-.90264E+01	.24902E+02
.6544	-.89120E+01	.22603E+02
.7263	-.88124E+01	.20474E+02
.8062	-.87254E+01	.18504E+02
.8949	-.86488E+01	.16679E+02
.9934	-.85811E+01	.14982E+02
1.1026	-.85211E+01	.13401E+02
1.2239	-.84677E+01	.11921E+02
1.3585	-.84205E+01	.10531E+02
1.5080	-.83788E+01	.92195E+01
1.6739	-.83422E+01	.79763E+01
1.8580	-.83104E+01	.67930E+01
2.0624	-.82828E+01	.56612E+01
2.2892	-.82590E+01	.45732E+01
2.5410	-.82383E+01	.35210E+01
2.8206	-.82203E+01	.24961E+01
3.1308	-.82042E+01	.14899E+01
3.4752	-.81896E+01	.49278E+00
3.8575	-.81757E+01	-.50526E+00
4.2818	-.81619E+01	-.15151E+01
4.7528	-.81477E+01	-.25485E+01
5.2756	-.81324E+01	-.36183E+01
5.8559	-.81153E+01	-.47387E+01
6.5001	-.80955E+01	-.59255E+01
7.2151	-.80722E+01	-.71969E+01
8.0088	-.80443E+01	-.85739E+01
8.8897	-.80105E+01	-.10081E+02
9.8676	-.79691E+01	-.11750E+02
10.9530	-.79182E+01	-.13616E+02
12.1579	-.78556E+01	-.15726E+02
13.4952	-.77783E+01	-.18139E+02
14.9797	-.76832E+01	-.20932E+02
16.6275	-.75667E+01	-.24207E+02
18.4565	-.74255E+01	-.28099E+02
20.4867	-.72589E+01	-.32793E+02

THE YAW RATE / DELTA AC NUMERATOR GAIN IS -.8003E+01

THE ZEROES OF THE TRANSFER FUNCTION ARE

REAL PART	IMAGINARY PART
-.11898556E+03	-.16589430E+03
-.11898556E+03	.16589430E+03
.16616361E+03	0.
-.10000000E+01	0.
-.19927576E+01	0.
-.61133543E-02	-.65198013E-01
-.61133543E-02	.65198013E-01

THE COEFFICIENTS OF THE NUMERATOR POLYNOMIAL ORDERED FROM THE LOWEST POWER OF S

-.59179687E+05
-.25759641E+06
-.14083768E+08
-.20806513E+08
-.53188814E+07
.23541571E+04
.74812500E+02
.10000000E+01

YAW RATE / DELTA AC FREQUENCY RESPONSE S-PLANE

FREQUENCY RAD/SEC	AMPLITUDE RATIO DB	PHASE ANGLE DEGREES
.1000	-.21300E+02	-.13061E+03
.1110	-.19472E+02	-.12982E+03
.1232	-.17959E+02	-.12999E+03
.1368	-.16674E+02	-.13080E+03
.1518	-.15566E+02	-.13205E+03
.1685	-.14600E+02	-.13364E+03
.1870	-.13754E+02	-.13548E+03
.2076	-.13010E+02	-.13749E+03
.2305	-.12357E+02	-.13963E+03
.2558	-.11783E+02	-.14183E+03
.2839	-.11281E+02	-.14405E+03
.3152	-.10842E+02	-.14626E+03
.3498	-.10458E+02	-.14841E+03
.3883	-.10121E+02	-.15050E+03
.4310	-.98262E+01	-.15249E+03
.4785	-.95655E+01	-.15438E+03
.5311	-.93335E+01	-.15616E+03
.5895	-.91250E+01	-.15785E+03
.6544	-.89360E+01	-.15944E+03
.7263	-.87630E+01	-.16095E+03
.8062	-.86039E+01	-.16240E+03
.8949	-.84573E+01	-.16380E+03
.9934	-.83228E+01	-.16516E+03
1.1026	-.82006E+01	-.16649E+03
1.2239	-.80913E+01	-.16780E+03
1.3585	-.79956E+01	-.16908E+03
1.5080	-.79139E+01	-.17034E+03
1.6739	-.78463E+01	-.17156E+03
1.8580	-.77923E+01	-.17274E+03
2.0624	-.77510E+01	-.17388E+03
2.2892	-.77209E+01	-.17497E+03
2.5410	-.77004E+01	-.17601E+03
2.8206	-.76876E+01	-.17700E+03
3.1308	-.76808E+01	-.17795E+03
3.4752	-.76785E+01	-.17886E+03
3.8575	-.76795E+01	-.17975E+03
4.2818	-.76826E+01	-.18059E+03
4.7528	-.76873E+01	-.18147E+03
5.2756	-.76929E+01	-.18236E+03
5.8559	-.76991E+01	-.18328E+03
6.5001	-.77058E+01	-.18425E+03
7.2151	-.77129E+01	-.18530E+03
8.0088	-.77202E+01	-.18643E+03
8.8897	-.77278E+01	-.18770E+03
9.8676	-.77355E+01	-.18912E+03
10.9530	-.77433E+01	-.19074E+03
12.1579	-.77509E+01	-.19262E+03
13.4952	-.77580E+01	-.19484E+03
14.9797	-.77640E+01	-.19750E+03

16.6275	-.77689E+01	-.20070E+03
18.4565	-.77730E+01	-.20465E+03
20.4867	-.77790E+01	-.20955E+03

THE BETA / DELTA AC NUMERATOR GAIN IS .6604E+01

THE ZEROES OF THE TRANSFER FUNCTION ARE

REAL PART	IMAGINARY PART
-.30001356E+03	0.
.31081002E+03	0.
-.88070229E+02	0.
-.97466335E+00	0.
-.20036076E+01	0.
.84457968E-02	0.

THE COEFFICIENTS OF THE NUMERATOR POLYNOMIAL ORDERED FROM THE LOWEST POWER OF S

.13896621E+06
-.15160948E+08
-.25077612E+08
-.86602900E+07
-.35285104E+05
.86245561E+02
.10000000E+01

BETA / DELTA AC FREQUENCY RESPONSE S-PLANE

FREQUENCY RAD/SEC	AMPLITUDE RATIO DB	PHASE ANGLE DEGREES
.1000	.32188E+01	-.23476E+02
.1110	.30589E+01	-.25631E+02
.1232	.28696E+01	-.27927E+02
.1368	.26474E+01	-.30356E+02
.1518	.23889E+01	-.32901E+02
.1685	.20911E+01	-.35542E+02
.1870	.17515E+01	-.38253E+02
.2076	.13684E+01	-.41006E+02
.2305	.94098E+00	-.43769E+02
.2558	.46964E+00	-.46510E+02
.2839	-.44257E-01	-.49198E+02
.3152	-.59833E+00	-.51805E+02
.3498	-.11894E+01	-.54308E+02
.3883	-.18135E+01	-.56688E+02
.4310	-.24666E+01	-.58936E+02
.4785	-.31443E+01	-.61046E+02
.5311	-.38426E+01	-.63021E+02
.5895	-.45578E+01	-.64869E+02
.6544	-.52868E+01	-.66601E+02
.7263	-.60275E+01	-.68235E+02
.8062	-.67785E+01	-.69785E+02
.8949	-.75392E+01	-.71269E+02
.9934	-.83099E+01	-.72701E+02
1.1026	-.90915E+01	-.74091E+02
1.2239	-.98851E+01	-.75443E+02
1.3585	-.10692E+02	-.76758E+02
1.5080	-.11513E+02	-.78032E+02
1.6739	-.12348E+02	-.79257E+02
1.8580	-.13197E+02	-.80425E+02

2.0624	-.14059E+02	-.81527E+02
2.2892	-.14933E+02	-.82558E+02
2.5410	-.15816E+02	-.83515E+02
2.8206	-.16708E+02	-.84397E+02
3.1306	-.17606E+02	-.85208E+02
3.4752	-.18508E+02	-.85954E+02
3.8575	-.19414E+02	-.86643E+02
4.2818	-.20321E+02	-.87286E+02
4.7528	-.21230E+02	-.87893E+02
5.2756	-.22139E+02	-.88476E+02
5.8559	-.23048E+02	-.89048E+02
6.5001	-.23957E+02	-.89624E+02
7.2151	-.24865E+02	-.90221E+02
8.0088	-.25772E+02	-.90857E+02
8.8897	-.26678E+02	-.91558E+02
9.8676	-.27582E+02	-.92353E+02
10.9530	-.28484E+02	-.93281E+02
12.1579	-.29383E+02	-.94392E+02
13.4952	-.30277E+02	-.95753E+02
14.9797	-.31167E+02	-.97454E+02
16.6275	-.32050E+02	-.99615E+02
18.4565	-.32926E+02	-.10240E+03
20.4867	-.33796E+02	-.10603E+03

THE PHI / DELTA AC NUMERATOR GAIN IS .3498E+03

THE ZEROES OF THE TRANSFER FUNCTION ARE

REAL PART	IMAGINARY PART
-.40837930E+02	-.48392089E+02
-.40837930E+02	.48392089E+02
.37439375E+02	0.
-.12398563E+01	0.
-.17499393E+01	0.
.48342747E-01	0.

THE COEFFICIENTS OF THE NUMERATOR POLYNOMIAL ORDERED FROM THE LOWEST POWER OF S

.15745187E+05
-.30410210E+06
-.43963166E+06
-.14722565E+06
.10837823E+04
.47177938E+02
.10000000E+01

PHI / DELTA AC FREQUENCY RESPONSE S-PLANE

FREQUENCY RAD/SEC	AMPLITUDE RATIO DB	PHASE ANGLE DEGREES
.1000	.45403E+01	-.34575E+01
.1110	.42252E+01	-.74998E+01
.1232	.39043E+01	-.11586E+02
.1368	.35707E+01	-.15703E+02
.1518	.32177E+01	-.19833E+02
.1685	.28393E+01	-.23960E+02
.1870	.24304E+01	-.28061E+02
.2076	.19868E+01	-.32113E+02
.2305	.15057E+01	-.36091E+02

.2558	.98536E+00	-.39968E+02
.2839	.42551E+00	-.43721E+02
.3152	-.17309E+00	-.47325E+02
.3499	-.80864E+00	-.50762E+02
.3883	-.14785E+01	-.54018E+02
.4310	-.21797E+01	-.57082E+02
.4785	-.29087E+01	-.59950E+02
.5311	-.36620E+01	-.62622E+02
.5895	-.44362E+01	-.65104E+02
.6544	-.52282E+01	-.67404E+02
.7263	-.60352E+01	-.69532E+02
.8062	-.68546E+01	-.71502E+02
.8949	-.76845E+01	-.73328E+02
.9934	-.85232E+01	-.75024E+02
1.1026	-.93696E+01	-.76606E+02
1.2239	-.10223E+02	-.78085E+02
1.3585	-.11082E+02	-.79475E+02
1.5080	-.11947E+02	-.80787E+02
1.6739	-.12817E+02	-.82030E+02
1.8580	-.13691E+02	-.83214E+02
2.0624	-.14570E+02	-.84345E+02
2.2892	-.15453E+02	-.85433E+02
2.5410	-.16339E+02	-.86486E+02
2.8206	-.17227E+02	-.87510E+02
3.1308	-.18117E+02	-.88517E+02
3.4752	-.19009E+02	-.89514E+02
3.8575	-.19902E+02	-.90512E+02
4.2818	-.20794E+02	-.91522E+02
4.7528	-.21687E+02	-.92555E+02
5.2756	-.22578E+02	-.93625E+02
5.8559	-.23467E+02	-.94745E+02
6.5001	-.24354E+02	-.95932E+02
7.2151	-.25237E+02	-.97204E+02
8.0088	-.26116E+02	-.98580E+02
8.8897	-.26988E+02	-.10009E+03
9.8676	-.27853E+02	-.10176E+03
10.9530	-.28709E+02	-.10362E+03
12.1579	-.29553E+02	-.10573E+03
13.4952	-.30382E+02	-.10815E+03
14.9797	-.31193E+02	-.11094E+03
16.6275	-.31983E+02	-.11421E+03
18.4565	-.32749E+02	-.11811E+03
20.4867	-.33487E+02	-.12280E+03

THE AY / DELTA AC NUMERATOR GAIN IS .2962F+04

THE ZEROES OF THE TRANSFER FUNCTION ARE

REAL PART	IMAGINARY PART
-.12023271E+02	-.15019465E+02
-.12023271E+02	.15019465E+02
-.10962181E+02	0.
-.70471725E+00	-.97429378E+00
-.70471725E+00	.97429378E+00
.79864692E-02	0.
-.10000000E+02	0.

THE COEFFICIENTS OF THE NUMERATOR POLYNOMIAL ORDERED FROM THE LOWEST POWER OF S

-.46854623E+03
.58090733E+05

.71766408E+05
.66354798E+05
.11838388E+05
.10483452E+04
.46410172E+02
.10000000E+01

AY / DELTA AC FREQUENCY RESPONSE S-PLANE

FREQUENCY RAD/SEC	AMPLITUDE RATIO DB	PHASE ANGLE DEGREES
.1000	.72610E+01	-.20545E+03
.1110	.70846E+01	-.20775E+03
.1232	.68748E+01	-.21022E+03
.1368	.66273E+01	-.21283E+03
.1518	.63376E+01	-.21558E+03
.1685	.60013E+01	-.21844E+03
.1870	.56145E+01	-.22138E+03
.2076	.51737E+01	-.22437E+03
.2305	.46758E+01	-.22738E+03
.2558	.41187E+01	-.23036E+03
.2839	.35008E+01	-.23327E+03
.3152	.28210E+01	-.23606E+03
.3498	.20790E+01	-.23868E+03
.3883	.12745E+01	-.24108E+03
.4310	.40787E+00	-.24319E+03
.4785	-.51997E+00	-.24496E+03
.5311	-.15070E+01	-.24629E+03
.5895	-.25488E+01	-.24708E+03
.6544	-.36373E+01	-.24722E+03
.7263	-.47574E+01	-.24658E+03
.8062	-.58846E+01	-.24502E+03
.8949	-.69816E+01	-.24244E+03
.9934	-.80000E+01	-.23886E+03
1.1026	-.88874E+01	-.23442E+03
1.2239	-.96040E+01	-.22947E+03
1.3585	-.10140E+02	-.22444E+03
1.5080	-.10520E+02	-.21976E+03
1.6739	-.10792E+02	-.21566E+03
1.8580	-.11012E+02	-.21222E+03
2.0624	-.11222E+02	-.20934E+03
2.2892	-.11454E+02	-.20687E+03
2.5410	-.11723E+02	-.20461E+03
2.8206	-.12035E+02	-.20238E+03
3.1308	-.12387E+02	-.20002E+03
3.4752	-.12772E+02	-.19740E+03
3.8575	-.13182E+02	-.19442E+03
4.2818	-.13603E+02	-.19098E+03
4.7528	-.14023E+02	-.18703E+03
5.2756	-.14430E+02	-.18251E+03
5.8559	-.14810E+02	-.17742E+03
6.5001	-.15150E+02	-.17168E+03
7.2151	-.15436E+02	-.16529E+03
8.0088	-.15656E+02	-.15827E+03
8.8897	-.15795E+02	-.15059E+03
9.8676	-.15838E+02	-.14227E+03
10.9530	-.15765E+02	-.13331E+03
12.1579	-.15552E+02	-.12375E+03
13.4952	-.15169E+02	-.11365E+03
14.9797	-.14577E+02	-.10317E+03
16.6275	-.13734E+02	-.92598E+02
18.4565	-.12605E+02	-.82409E+02
20.4867	-.11175E+02	-.73240E+02

THE ROLL RATE/DELTA RC NUMERATOR GAIN IS .1801E+04

THE ZEROES OF THE TRANSFER FUNCTION ARE

REAL PART	IMAGINARY PART
-.10000000E+01	0.
-.25000000E+02	0.
.61123953E+01	0.
-.10000000E+02	0.
-.35026731E+01	0.
-.14030276E-12	0.

THE COEFFICIENTS OF THE NUMERATOR POLYNOMIAL ORDERED FROM THE LOWEST POWER OF S

-.75096080E-09
-.53524306E+04
-.67542014E+04
-.12645209E+04
.16964028E+03
.33390278E+02
.10000000E+01

ROLL RATE/DELTA RC FREQUENCY RESPONSE S-PLANE

FREQUENCY RAD/SEC	AMPLITUDE RATIO DB	PHASE ANGLE DEGREES
.1000	-.17819E+02	-.29895E+02
.1110	-.17975E+02	-.31742E+02
.1232	-.18162E+02	-.33797E+02
.1368	-.18383E+02	-.36047E+02
.1518	-.18642E+02	-.38473E+02
.1685	-.18941E+02	-.41056E+02
.1870	-.19284E+02	-.43767E+02
.2076	-.19672E+02	-.46577E+02
.2305	-.20105E+02	-.49456E+02
.2558	-.20585E+02	-.52371E+02
.2839	-.21109E+02	-.55293E+02
.3152	-.21676E+02	-.58193E+02
.3498	-.22283E+02	-.61051E+02
.3883	-.22927E+02	-.63849E+02
.4310	-.23603E+02	-.66577E+02
.4785	-.24310E+02	-.69232E+02
.5311	-.25042E+02	-.71816E+02
.5895	-.25798E+02	-.74337E+02
.6544	-.26574E+02	-.76805E+02
.7263	-.27371E+02	-.79232E+02
.8062	-.28187E+02	-.81631E+02
.8949	-.29022E+02	-.84010E+02
.9934	-.29876E+02	-.86374E+02
1.1026	-.30752E+02	-.88719E+02
1.2239	-.31649E+02	-.91035E+02
1.3585	-.32568E+02	-.93302E+02
1.5080	-.33507E+02	-.95492E+02
1.6739	-.34463E+02	-.97574E+02
1.8580	-.35431E+02	-.99511E+02
2.0624	-.36404E+02	-.10127E+03
2.2892	-.37373E+02	-.10282E+03
2.5410	-.38327E+02	-.10413E+03
2.8206	-.39253E+02	-.10520E+03

3.1308	-.43140E+02	-.10609E+03
3.4752	-.40974E+02	-.10653E+03
3.8575	-.41742E+02	-.10680E+03
4.2818	-.42433E+02	-.10682E+03
4.7528	-.43036E+02	-.10658E+03
5.2756	-.43542E+02	-.10611E+03
5.8559	-.43942E+02	-.10541E+03
6.5001	-.44232E+02	-.10449E+03
7.2151	-.44407E+02	-.10337E+03
8.0088	-.44463E+02	-.10208E+03
8.8897	-.44400E+02	-.10063E+03
9.8676	-.44217E+02	-.99091E+02
10.9530	-.43915E+02	-.97508E+02
12.1579	-.43498E+02	-.95962E+02
13.4952	-.42966E+02	-.94555E+02
14.9797	-.42324E+02	-.93413E+02
16.6275	-.41575E+02	-.92700E+02
18.4565	-.40725E+02	-.92624E+02
20.4867	-.39780E+02	-.93459E+02

THE YAW RATE /DELTA RC NUMERATOR GAIN IS -.3714E+04

THE ZEROES OF THE TRANSFER FUNCTION ARE

REAL PART	IMAGINARY PART
-.10000000E+01	0.
-.15581129E+02	-.24557545E+02
-.15581129E+02	.24557545E+02
-.10000000E+02	0.
-.67523717E-01	-.16816906E+00
-.67523717E-01	.16816906E+00

THE COEFFICIENTS OF THE NUMERATOR POLYNOMIAL ORDERED FROM THE LOWEST POWER OF S

.27777778E+03
.14580808E+04
.37964141E+04
.97791700E+04
.12043562E+04
.42297306E+02
.10000000E+01

YAW RATE /DELTA RC FREQUENCY RESPONSE S-PLANE

FREQUENCY RAD/SEC	AMPLITUDE RATIO DB	PHASE ANGLE DEGREES
.1000	-.19086E+02	-.90021E+02
.1110	-.20524E+02	-.86391E+02
.1232	-.22021E+02	-.81386E+02
.1368	-.23517E+02	-.74458E+02
.1518	-.24888E+02	-.65099E+02
.1685	-.25920E+02	-.53317E+02
.1870	-.26397E+02	-.40252E+02
.2076	-.26274E+02	-.27954E+02
.2305	-.25723E+02	-.18026E+02
.2558	-.24978E+02	-.10859E+02
.2839	-.24205E+02	-.60623E+01
.3152	-.23485E+02	-.30594E+01
.3498	-.22848E+02	-.13528E+01

.3883	-.22302E+02	-.57444E+00
.4310	-.21841E+02	-.46687E+00
.4745	-.21457E+02	-.85425E+00
.5311	-.21140E+02	-.16181E+01
.5835	-.20883E+02	-.26800E+01
.6544	-.20640E+02	-.39895E+01
.7263	-.20526E+02	-.55104E+01
.8062	-.20418E+02	-.72233E+01
.8949	-.20356E+02	-.91100E+01
.9934	-.20341E+02	-.11153E+02
1.1026	-.20374E+02	-.13332E+02
1.2239	-.20457E+02	-.15620E+02
1.3585	-.20595E+02	-.17992E+02
1.5080	-.20788E+02	-.20377E+02
1.6739	-.21039E+02	-.22753E+02
1.8580	-.21347E+02	-.25057E+02
2.0624	-.21712E+02	-.27234E+02
2.2892	-.22130E+02	-.29228E+02
2.5410	-.22597E+02	-.30986E+02
2.8206	-.23108E+02	-.32463E+02
3.1308	-.23657E+02	-.33620E+02
3.4752	-.24237E+02	-.34423E+02
3.8575	-.24839E+02	-.34851E+02
4.2818	-.25457E+02	-.34885E+02
4.7528	-.26083E+02	-.34518E+02
5.2756	-.26710E+02	-.33748E+02
5.8559	-.27331E+02	-.32580E+02
6.5001	-.27941E+02	-.31025E+02
7.2151	-.28533E+02	-.29099E+02
8.0088	-.29104E+02	-.26822E+02
8.8897	-.29649E+02	-.24217E+02
9.8676	-.30168E+02	-.21307E+02
10.9530	-.30657E+02	-.18114E+02
12.1579	-.31115E+02	-.14655E+02
13.4952	-.31540E+02	-.10941E+02
14.9797	-.31927E+02	-.69774E+01
16.6275	-.32265E+02	-.27709E+01
18.4565	-.32535E+02	.16525E+01
20.4867	-.32705E+02	.62035E+01

THE BETA /DELTA RC NUMERATOR GAIN IS .4375E+02

THE ZEROES OF THE TRANSFER FUNCTION ARE

REAL PART	IMAGINARY PART
-.10000000E+01	0.
-.85278345E+02	0.
-.15664379E+02	-.24652880E+02
-.15664379E+02	.24652880E+02
-.10000000E+02	0.
.38894055E-02	0.

THE COEFFICIENTS OF THE NUMERATOR POLYNOMIAL ORDERED FROM THE LOWEST POWER OF S

-.28297033E+04
.72429157E+06
.83510518E+06
.11267429E+06
.48169837E+04
.12760321E+03
.10000000E+01

BETA /DELTA RC FREQUENCY RESPONSE S-PLANE

FREQUENCY RAD/SEC	AMPLITUDE RATIO DB	PHASE ANGLE DEGREES
.1000	-.74410E+01	-.20830E+03
.1110	-.75992E+01	-.21044E+03
.1232	-.77884E+01	-.21278E+03
.1368	-.80119E+01	-.21529E+03
.1518	-.82734E+01	-.21798E+03
.1685	-.85758E+01	-.22081E+03
.1870	-.89220E+01	-.22378E+03
.2076	-.93139E+01	-.22684E+03
.2305	-.97526E+01	-.22997E+03
.2558	-.10238E+02	-.23314E+03
.2839	-.10770E+02	-.23633E+03
.3152	-.11346E+02	-.23951E+03
.3498	-.11964E+02	-.24265E+03
.3883	-.12622E+02	-.24576E+03
.4310	-.13315E+02	-.24882E+03
.4785	-.14042E+02	-.25182E+03
.5311	-.14799E+02	-.25478E+03
.5895	-.15586E+02	-.25770E+03
.6544	-.16401E+02	-.26061E+03
.7263	-.17243E+02	-.26350E+03
.8062	-.18116E+02	-.26640E+03
.8949	-.19020E+02	-.26932E+03
.9934	-.19959E+02	.87744E+02
1.1026	-.20938E+02	.84785E+02
1.2239	-.21960E+02	.81819E+02
1.3585	-.23029E+02	.78871E+02
1.5080	-.24150E+02	.75973E+02
1.6739	-.25323E+02	.73167E+02
1.8580	-.26552E+02	.70502E+02
2.0624	-.27834E+02	.68023E+02
2.2892	-.29167E+02	.65796E+02
2.5410	-.30547E+02	.63855E+02
2.8206	-.31970E+02	.62250E+02
3.1308	-.33429E+02	.61017E+02
3.4752	-.34917E+02	.60183E+02
3.8575	-.36428E+02	.59786E+02
4.2818	-.37952E+02	.59827E+02
4.7528	-.39484E+02	.60321E+02
5.2756	-.41016E+02	.61270E+02
5.8559	-.42541E+02	.62671E+02
6.5001	-.44053E+02	.64516E+02
7.2151	-.45546E+02	.66791E+02
8.0088	-.47017E+02	.69479E+02
8.8897	-.48460E+02	.72562E+02
9.8676	-.49874E+02	.76020E+02
10.9530	-.51256E+02	.79836E+02
12.1579	-.52604E+02	.83999E+02
13.4952	-.53915E+02	.88504E+02
14.9797	-.55183E+02	-.26665E+03
16.6275	-.56398E+02	-.26146E+03
18.4565	-.57538E+02	-.25595E+03
20.4867	-.58573E+02	-.25020E+03

THE PHI /DELTA RC NUMERATOR GAIN IS .1801E+04

THE ZEROES OF THE TRANSFER FUNCTION ARE

REAL PART	IMAGINARY PART
-.10000000E+01	0.
.61123953E+01	0.
-.25000000E+02	0.
-.35026731E+01	0.
-.10000000E+02	0.

THE COEFFICIENTS OF THE NUMERATOR POLYNOMIAL ORDERED FROM THE LOWEST POWER OF S

-.53524306E+04
-.57542014E+04
-.12645208E+04
.16964028E+03
.33390278E+02
.10000000E+01

PHI /DELTA RC FREQUENCY RESPONSE S-PLANE

FREQUENCY RAD/SEC	AMPLITUDE RATIO DB	PHASE ANGLE DEGREES
.1000	.21805E+01	-.11990E+03
.1110	.11181E+01	-.12175E+03
.1232	.24909E-01	-.12380E+03
.1368	-.11026E+01	-.12605E+03
.1518	-.22677E+01	-.12848E+03
.1665	-.34736E+01	-.13106E+03
.1870	-.47226E+01	-.13377E+03
.2075	-.50167E+01	-.13658E+03
.2305	-.73568E+01	-.13946E+03
.2558	-.87427E+01	-.14238E+03
.2839	-.10173E+02	-.14530E+03
.3152	-.11647E+02	-.14820E+03
.3498	-.13160E+02	-.15106E+03
.3883	-.14711E+02	-.15386E+03
.4310	-.16294E+02	-.15658E+03
.4785	-.17906E+02	-.15924E+03
.5311	-.19545E+02	-.16182E+03
.5895	-.21207E+02	-.16434E+03
.6544	-.22891E+02	-.16681E+03
.7263	-.24594E+02	-.16924E+03
.8062	-.26316E+02	-.17164E+03
.8949	-.28057E+02	-.17402E+03
.9934	-.29819E+02	-.17638E+03
1.1026	-.31601E+02	-.17873E+03
1.2239	-.33404E+02	-.18102E+03
1.3585	-.35230E+02	-.18328E+03
1.5080	-.37075E+02	-.18547E+03
1.6739	-.38938E+02	-.18755E+03
1.8580	-.40812E+02	-.18949E+03
2.0624	-.42692E+02	-.19125E+03
2.2892	-.44567E+02	-.19280E+03
2.5410	-.46427E+02	-.19411E+03
2.8206	-.48260E+02	-.19518E+03
3.1308	-.50053E+02	-.19598E+03
3.4752	-.51793E+02	-.19651E+03
3.8575	-.53468E+02	-.19678E+03
4.2818	-.55065E+02	-.19680E+03
4.7528	-.56575E+02	-.19656E+03
5.2756	-.57987E+02	-.19609E+03
5.8559	-.59294E+02	-.19539E+03
6.5001	-.60491E+02	-.19447E+03

7.2151	-.61571E+02	-.19335E+03
8.0098	-.62534E+02	-.19206E+03
8.8897	-.63377E+02	-.19061E+03
9.8676	-.64101E+02	-.18907E+03
10.9530	-.64706E+02	-.18749E+03
12.1579	-.65195E+02	-.18594E+03
13.4952	-.65570E+02	-.18453E+03
14.9797	-.65834E+02	-.18339E+03
16.6275	-.65992E+02	-.18268E+03
18.4565	-.66048E+02	-.18260E+03
20.4867	-.66009E+02	-.18344E+03

THE AY /DELTA RC NUMERATOR GAIN IS -.1671E+05

THE ZEROES OF THE TRANSFER FUNCTION ARE

REAL PART	IMAGINARY PART
-.10000000E+01	0.
-.19653147E+02	-.36396151E+02
-.19653147E+02	.36396151E+02
-.42251286E+00	0.
.54973431E-02	0.
-.10000000E+02	0.

THE COEFFICIENTS OF THE NUMERATOR POLYNOMIAL ORDERED FROM THE LOWEST POWER OF S

-.39667357E+02
.70904524E+04
.25116682E+05
.20111111E+05
.21742719E+04
.50723320E+02
.10000000E+01

AY /DELTA FC FREQUENCY RESPONSE S-PLANE

FREQUENCY RAD/SEC	AMPLITUDE RATIO DB	PHASE ANGLE DEGREES
.1000	.43855E+01	-.14732E+02
.1110	.42791E+01	-.15074E+02
.1232	.41536E+01	-.15968E+02
.1368	.40075E+01	-.16899E+02
.1518	.38408E+01	-.17846E+02
.1685	.36508E+01	-.18785E+02
.1870	.34403E+01	-.19692E+02
.2076	.32102E+01	-.20542E+02
.2305	.29630E+01	-.21310E+02
.2558	.27023E+01	-.21978E+02
.2839	.24328E+01	-.22533E+02
.3152	.21593E+01	-.22969E+02
.3498	.18873E+01	-.23293E+02
.3883	.16216E+01	-.23520E+02
.4310	.13667E+01	-.23674E+02
.4785	.11258E+01	-.23787E+02
.5311	.90055E+00	-.23899E+02
.5895	.69117E+00	-.24049E+02
.6544	.49611E+00	-.24280E+02
.7263	.31211E+00	-.24629E+02
.8062	.13440E+00	-.25128E+02

.8949	-.43125E-01	-.25803E+02
.9934	-.22755E+00	-.26663E+02
1.1026	-.42652E+00	-.27717E+02
1.2239	-.64773E+00	-.28947E+02
1.3585	-.83843E+00	-.30331E+02
1.5080	-.11848E+01	-.31830E+02
1.6739	-.15118E+01	-.33400E+02
1.8580	-.18822E+01	-.34986E+02
2.0624	-.22972E+01	-.36532E+02
2.2892	-.27561E+01	-.37982E+02
2.5410	-.32561E+01	-.39281E+02
2.8205	-.37332E+01	-.40383E+02
3.1308	-.43621E+01	-.41246E+02
3.4752	-.49566E+01	-.41838E+02
3.8575	-.55699E+01	-.42134E+02
4.2818	-.61951E+01	-.42119E+02
4.7528	-.68250E+01	-.41787E+02
5.2756	-.74527E+01	-.41140E+02
5.8559	-.80718E+01	-.40187E+02
6.5001	-.86761E+01	-.38947E+02
7.2151	-.92694E+01	-.37447E+02
8.0088	-.98205E+01	-.35721E+02
8.8897	-.10353E+02	-.33810E+02
9.8676	-.10857E+02	-.31762E+02
10.9530	-.11332E+02	-.29631E+02
12.1579	-.11778E+02	-.27476E+02
13.4952	-.12198E+02	-.25362E+02
14.9797	-.12596E+02	-.23361E+02
16.6275	-.12975E+02	-.21552E+02
18.4565	-.13340E+02	-.20031E+02
20.4867	-.13697E+02	-.18914E+02

THE TRANSITION MATRIX 11 TERMS

9 9

-.3585E+00	-.7306E+00	-.4430E+00	.9217E-01	.3458E+01	.6567E+02	.1036E+01	-.2057E-01	.7287E+00
.1734E+01	.2963E+01	.3737E+00	-.2360E+00	.6289E+01	-.2055E+03	-.2887E+01	.5190E-01	-.1947E+01
-.4516E-01	-.3990E-01	.5730E+00	.1148E-01	-.1452E+00	.7171E+01	.8679E-01	-.1306E-02	.4717E-01
.2428E-01	-.9584E-02	-.1412E-01	.1001E+01	.2046E+00	.1766E+01	.2086E-01	-.2898E-03	.1055E-01
-.1942E-01	.1528E-01	.1868E-01	-.2052E-02	.3643E-01	-.2376E+01	-.3029E-01	.4516E-03	-.1638E-01
-.2322E-01	-.2360E-01	.1563E-02	.3461E-02	-.1172E+00	.1706E+01	.2902E-01	-.7784E-03	.2666E-01
-.6350E+00	-.1014E+01	.5618E-01	.1186E+00	-.4957E+01	.5005E+02	.6899E+00	-.2824E-01	.8943E+00
.2423E-01	.7467E-01	.1060E-01	-.3172E-02	.6630E-01	-.4648E+01	-.5180E-01	.9519E+00	-.2501E-01
.3369E+00	.4729E+00	-.2312E-01	-.5424E-01	.1974E+01	-.2226E+02	-.2441E+00	.3181E-02	.4903E+00

TIME	ROLL RATE	YAW RATE	BETA	PHI	AY	DELTA AC	DELTA RC
0.	0.	0.	0.	0.	0.	-0.	.100E+01
.500E-01	.209E-01	-.525E-01	.132E-02	.293E-03	-.276E+00	-0.	.100E+01
.100E+00	.129E+00	-.415E+00	.150E-01	.346E-02	-.250E+01	-0.	.100E+01
.150E+00	.619E+00	-.219E+01	.901E-01	.191E-01	-.137E+02	-0.	.100E+01
.200E+00	.303E+01	-.110E+02	.468E+00	.950E-01	-.692E+02	-0.	.100E+01
.250E+00	.149E+02	-.542E+02	.234E+01	.468E+00	-.343E+03	-0.	.100E+01
.300E+00	.733E+02	-.267E+03	.115E+02	.230E+01	-.169E+04	-0.	.100E+01
.350E+00	.361E+03	-.131E+04	.568E+02	.113E+02	-.830E+04	-0.	.100E+01
.400E+00	.177E+04	-.645E+04	.280E+03	.557E+02	-.408E+05	-0.	.100E+01
.450E+00	.873E+04	-.317E+05	.137E+04	.274E+03	-.201E+06	-0.	.100E+01
.500E+00	.429E+05	-.156E+06	.676E+04	.135E+04	-.988E+06	-0.	.100E+01
.550E+00	.211E+06	-.768E+06	.333E+05	.663E+04	-.486E+07	-0.	.100E+01
.600E+00	.104E+07	-.378E+07	.164E+06	.326E+05	-.239E+08	-0.	.100E+01
.650E+00	.511E+07	-.186E+08	.805E+06	.160E+06	-.118E+09	-0.	.100E+01
.700E+00	.251E+08	-.914E+08	.396E+07	.789E+06	-.578E+09	-0.	.100E+01
.750E+00	.124E+09	-.450E+09	.195E+08	.388E+07	-.284E+10	-0.	.100E+01
.800E+00	.608E+09	-.221E+10	.958E+08	.191E+08	-.140E+11	-0.	.100E+01
.850E+00	.299E+10	-.109E+11	.471E+09	.939E+08	-.688E+11	-0.	.100E+01

.900E+00	.147E+11	-.535E+11	.232E+10	.462E+09	-.339E+12	-0.	.100E+01
.950E+00	.724E+11	-.263E+12	.114E+11	.227E+10	-.167E+13	-0.	.100E+01
.100E+01	.356E+12	-.129E+13	.561E+11	.112E+11	-.819E+13	-0.	.100E+01
.105E+01	.175E+13	-.637E+13	.276E+12	.550E+11	-.403E+14	-0.	.100E+01
.110E+01	.861E+13	-.313E+14	.136E+13	.270E+12	-.198E+15	-0.	.100E+01
.115E+01	.424E+14	-.154E+15	.667E+13	.133E+13	-.975E+15	-0.	.100E+01
.120E+01	.208E+15	-.758E+15	.328E+14	.654E+13	-.480E+16	-0.	.100E+01
.125E+01	.102E+16	-.373E+16	.161E+15	.322E+14	-.236E+17	-0.	.100E+01
.130E+01	.504E+16	-.183E+17	.794E+15	.158E+15	-.116E+18	-0.	.100E+01
.135E+01	.248E+17	-.902E+17	.391E+16	.778E+15	-.571E+18	-0.	.100E+01
.140E+01	.122E+18	-.444E+18	.192E+17	.383E+16	-.281E+19	-0.	.100E+01
.145E+01	.600E+18	-.218E+19	.945E+17	.188E+17	-.138E+20	-0.	.100E+01
.150E+01	.295E+19	-.107E+20	.465E+18	.926E+17	-.679E+20	-0.	.100E+01
.155E+01	.145E+20	-.528E+20	.229E+19	.456E+18	-.334E+21	-0.	.100E+01
.160E+01	.714E+20	-.260E+21	.112E+20	.224E+19	-.164E+22	-0.	.100E+01
.165E+01	.351E+21	-.128E+22	.553E+20	.110E+20	-.808E+22	-0.	.100E+01
.170E+01	.173E+22	-.628E+22	.272E+21	.542E+20	-.398E+23	-0.	.100E+01
.175E+01	.850E+22	-.309E+23	.134E+22	.267E+21	-.196E+24	-0.	.100E+01
.180E+01	.418E+23	-.152E+24	.659E+22	.131E+22	-.962E+24	-0.	.100E+01
.185E+01	.206E+24	-.748E+24	.324E+23	.645E+22	-.473E+25	-0.	.100E+01
.190E+01	.101E+25	-.368E+25	.159E+24	.317E+23	-.233E+26	-0.	.100E+01
.195E+01	.497E+25	-.181E+26	.784E+24	.156E+24	-.114E+27	-0.	.100E+01
.200E+01	.245E+26	-.890E+26	.385E+25	.768E+24	-.563E+27	-0.	.100E+01
.205E+01	.120E+27	-.438E+27	.190E+26	.378E+25	-.277E+28	-0.	.100E+01
.210E+01	.592E+27	-.215E+28	.933E+26	.186E+26	-.136E+29	-0.	.100E+01
.215E+01	.291E+28	-.106E+29	.459E+27	.914E+26	-.670E+29	-0.	.100E+01
.220E+01	.143E+29	-.521E+29	.226E+28	.450E+27	-.330E+30	-0.	.100E+01
.225E+01	.705E+29	-.256E+30	.111E+29	.221E+28	-.162E+31	-0.	.100E+01
.230E+01	.347E+30	-.126E+31	.546E+29	.109E+29	-.798E+31	-0.	.100E+01
.235E+01	.179E+31	-.620E+31	.269E+30	.535E+29	-.392E+32	-0.	.100E+01
.240E+01	.839E+31	-.305E+32	.132E+31	.263E+30	-.193E+33	-0.	.100E+01
.245E+01	.412E+32	-.150E+33	.650E+31	.129E+31	-.949E+33	-0.	.100E+01
.250E+01	.203E+33	-.738E+33	.320E+32	.637E+31	-.467E+34	-0.	.100E+01
.255E+01	.998E+33	-.363E+34	.157E+33	.313E+32	-.230E+35	-0.	.100E+01
.260E+01	.491E+34	-.179E+35	.773E+33	.154E+33	-.113E+36	-0.	.100E+01
.265E+01	.241E+35	-.878E+35	.380E+34	.758E+33	-.556E+36	-0.	.100E+01
.270E+01	.119E+36	-.432E+36	.187E+35	.373E+34	-.273E+37	-0.	.100E+01
.275E+01	.584E+36	-.213E+37	.920E+35	.183E+35	-.134E+38	-0.	.100E+01
.280E+01	.287E+37	-.105E+38	.453E+36	.902E+35	-.661E+38	-0.	.100E+01
.285E+01	.141E+38	-.514E+38	.223E+37	.444E+36	-.325E+39	-0.	.100E+01
.290E+01	.695E+38	-.253E+39	.110E+38	.218E+37	-.160E+40	-0.	.100E+01
.295E+01	.342E+39	-.124E+40	.539E+38	.107E+38	-.787E+40	-0.	.100E+01
.300E+01	.168E+40	-.612E+40	.265E+39	.528E+38	-.387E+41	-0.	.100E+01

TABLE I. CONTROL PROGRAM ANALYSIS OPTIONS

CONTINUOUS SYSTEMS	
OPEN AND CLOSED LOOP SYSTEMS	
TRANSFER FUNCTIONS	(S-PLANE)
FREQUENCY RESPONSES	(S-PLANE)
POWER SPECTRA	(S-PLANE)
TRANSIENT RESPONSES	
ROOT LOCUS	(S-PLANE)
DISCRETE SYSTEMS	
OPEN AND CLOSED LOOP SYSTEMS	
TRANSFER FUNCTIONS	(Z- OR W-PLANE)
FREQUENCY RESPONSES	(W- OR S-PLANE)
TRANSIENT RESPONSES	
ROOT LOCUS	(Z-PLANE)
SAMPLED-DATA SYSTEMS	
OPEN LOOP SYSTEMS	
STANDARD OR MODIFIED Z-TRANSFER FUNCTIONS	(Z- OR W-PLANE)
FREQUENCY RESPONSES	(W- OR S-PLANE)
TRANSIENT RESPONSES	
OPEN AND CLOSED-LOOP SYSTEMS	
STANDARD Z-TRANSFER FUNCTIONS	(Z- OR W-PLANE)
FREQUENCY RESPONSES	(W- OR S-PLANE)
TRANSIENT RESPONSES	
ROOT LOCUS	(Z-PLANE)

SYSTEMS MAY BE DEFINED BY,

1. MATRICES	(LOAD)
2. PARAMETERS	(MATRIX)
3. BLOCK DIAGRAM	(CLASS)
4. COMBINATION OF (1.,2.) AND (3.)	(MIXED)

TABLE II CONTROL PROGRAM JOB CONTROL LANGUAGE AS OF 11-1-74

```
JOB CONTROL CARDS FOR
  STANDARD CONTROL RUN
  WITHOUT SOURCE DECK
  WITHOUT PLOT TAPE

JOBN,CM720CC,T4777.
ATTACH(JWELIB,ID=JWE,PW=ADDY,MR=1)
ATTACH(OVRLY,ID=JWE)
SEGLOAD(I=OVRLY)
LOAD(JWELIB)
EXECUTE.
789 PUNCH
   DATA
6789 PUNCH     (YELLOW CARD)
--------------------------------------------------------------------------------
JOB CONTROL CARDS FOR
  STANDARD CONTROL RUN
  WITH SOURCE DECK
  WITHOUT PLOT TAPE

JOBN,CM720CC,T4777.
ATTACH(JWELIB,ID=JWE,PW=ADDY,MR=1)
FTN(LR=OUTPUT)
REWIND(LGO)
COPYL(JWELIB,LGO,JWE)
ATTACH(OVRLY,ID=JWE)
SEGLOAD(I=OVRLY)
LOAD(JWE)
EXECUTE.
789 PUNCH
   SOURCE DECKS
789 PUNCH
   DATA
6789 PUNCH     (YELLOW CARD)
--------------------------------------------------------------------------------
```

```
JOB CONTROL CARDS FOR
  STANDARD CONTROL RUN
  WITHOUT SOURCE DECK
  WITH PLOT TAPE

JOBN,CM72000,T4777,NT1.
ATTACH(JWELIB,ID=JWE,PW=ADDY,MR=1)
LABEL (CARD)  SEE DESCRIPTION
ATTACH(OVRLY,ID=JWE)
SEGLOAD(I=OVRLY)
LOAD(JWELIB)
EXECUTE.
EXIT.
BKSP(INPUT)
ATTACH(PLOTRC,ID=JWE,PW=ADDY,MR=1)
LOAD(PLOTRC)
REDUCE.
EXECUTE.
789 PUNCH
   DATA
PLOT CARDS     (SEE DESCRIPTION )
6789 PUNCH     (YELLOW CARD)
-------------------------------------------------------------------------------
```

```
JOB CONTROL CARDS FOR
  STANDARD CONTROL RUN
  WITH SOURCE DECK
  WITH PLOT TAPE

JOBN,CM72000,T4777,NT1.
ATTACH(JWELIB,ID=JWE,PW=ADDY,MR=1)
LABEL (CARD)  SEE DESCRIPTION
FTN(LR=OUTPUT)
REWIND(LGO)
COPYL(JWELIB,LGO,JWE)
ATTACH(OVRLY,ID=JWE)
SEGLOAD(I=OVRLY)
LOAD(JWE)
EXECUTE.
EXIT.
BKSP(INPUT)
ATTACH(PLOTRC,ID=JWE,PW=ADDY,MR=1)
LOAD(PLOTRC)
REDUCE.
EXECUTE.
789 PUNCH
   SOURCE DECKS
789 PUNCH
   DATA
PLOT CARDS     (SEE DESCRIPTION )
6789 PUNCH     (YELLOW CARD)
-------------------------------------------------------------------------------
```

JOB CONTROL CARDS USING UPDATE FILE
WITHOUT PLOT TAPE

```
JOBN,CM72000,T4777.
ATTACH(CONUPF,ID=JWE,PW=ADDY,MR=1)
ATTACH(OVRLY,ID=JWE,MR=1)
UPDATE(P=CONUPF)
FTN(A,I=COMPILE,LR=0)
SEGLOAD(I=OVRLY)
LOAD(LGO)
EXECUTE.
789 PUNCH
*IDENT NAME
   UPDATES
*COMPILE  CONTROL.SUBSCL
*END
789 PUNCH
   DATA
6789 PUNCH     (YELLOW CARD)
```

JOB CONTROL CARDS USING UPDATE FILE
WITH PLOT TAPE

```
JOBN,CM72000,T4777,NT1.
ATTACH(CONUPF,ID=JWE,PW=ADDY,MR=1)
ATTACH(OVRLY,ID=JWE,MR=1)
LABEL (CARD) SEE DESCRIPTION
UPDATE(P=CONUPF)
FTN(A,I=COMPILE,LR=0)
SEGLOAD(I=OVRLY)
LOAD(LGO)
EXECUTE.
EXIT.
BKSP(INPUT)
ATTACH(PLOTRC,ID=JWE,PW=ADDY,MR=1)
LOAD(PLOTRC)
REDUCE.
EXECUTE.
789 PUNCH
*IDENT NAME
   UPDATES
*COMPILE  CONTROL.SUBSCL
*END
789 PUNCH
   DATA
PLOT CARDS     (SEE DESCRIPTION )
6789 PUNCH     (YELLOW CARD)
```

THE UPDATE FILE CAN BE USED TO MODIFY SOURCE ROUTINES IN THE CONTROL PROGRAM. UPDATES ARE USED TO INSERT OR DELETE CARDS OF A SPECIFIED SUBROUTINE. EXAMPLES OF THE UPDATE DIRECTIVES CAN BE FOUND IN THE UPDATE REFERENCE MANUAL. THE SOURCE LISTING FOR THE CONTROL PROGRAM IS CONTAINED IN ROCM 2115.

```
--------------------------------------------------------------------------------

   DESCRIPTION OF LABEL CARD
CC1
LABEL(TAPE6,W,D=HD,L=XXXXXXXXXX,VSN=YYYY)*RING IN*ZZZ**
         XXXXXXXXXX=YOUR LABEL
         YYYY=VOLUME NO. OBTAINED FROM COMPUTER ROOM
         ZZZ=YOUR PAYROLL NUMBER



   DESCRIPTION OF PLOT CARDS
  PLOT CARDS
CARD ONE
CC1
PLOT
CARD TWO
CC1-4       CC 26-35                   CC 41-44
NNNN           NAME OF                    SUBTASK
               SUBMITTER                  (4 DIGIT NUMBER)
CARD THREE-N
CC1-10   CC11-20
    Y          Y
MINIMUM   MAXIMUM
(FLOATING POINT)
(ROOT LOCUS OR ROOT CONTOUR ONLY)
NNNN-VSN NUMBER
```

TABLE III. CONTROL: SYSTEM MODELS

A. CONTINUOUS SYSTEM MODELS

1. OPEN LOOP

$$C\dot{x} = Ax + Bu$$
$$y = Hx + G\dot{x} + Fu$$

2. CLOSED LOOP

$$C\dot{x} = Ax + Bu$$
$$u = K1x + K2\dot{x} + Du_{com}$$
$$y = Hx + G\dot{x} + Fu$$

3. ROOT LOCUS

$$C\dot{x} = Ax + Bu$$
$$u = (K1x + K2\dot{x}) + (K3x + K4\dot{x})$$

B. DISCRETE SYSTEM MODELS

1. OPEN LOOP

$$x_{n+1} = Ax_n + Bu_n$$
$$y_n = Hx_n + Fu_n$$

2. CLOSED LOOP

$$x_{n+1} = Ax_n + Bu_n$$
$$u_n = K1x_n + Du_{com\,n}$$
$$y_n = Hx_n + Fu_n$$

3. ROOT LOCUS

$$x_{n+1} = Ax_n + Bu_n$$
$$u_n = (K1x_n) + (K3x_n)$$

C. SAMPLED-DATA SYSTEM MODELS

1. ORIGINAL SYSTEM

$$\begin{bmatrix} \dot{x}^c \\ \hline x^d_{n+1} \end{bmatrix} = \left[\begin{array}{c|c} A_c & 0 \\ \hline 0^* & A_d \end{array}\right] \begin{bmatrix} x^c \\ \hline x^d_n \end{bmatrix} + \left[\begin{array}{c|c} B_c & 0 \\ \hline 0 & B_d \end{array}\right] \begin{bmatrix} u^c \\ \hline u^d_n \end{bmatrix}$$

$$\begin{bmatrix} y^c \\ \hline y^d_n \end{bmatrix} = \left[\begin{array}{c|c} H_c & 0 \\ \hline 0^* & H_d \end{array}\right] \begin{bmatrix} x^c \\ \hline x^d_n \end{bmatrix} + \left[\begin{array}{c|c} F_c & 0 \\ \hline 0 & F_d \end{array}\right] \begin{bmatrix} u^c \\ u^d_n \end{bmatrix}$$

2. CONNECTIONS PRIOR TO DISCRETIZATION

$$\begin{bmatrix} u^c \\ \hline u^d_n \end{bmatrix} = \begin{bmatrix} C \end{bmatrix} \begin{bmatrix} y^c \\ \hline y^d_n \end{bmatrix}$$

WHERE C IS DEFINED BY YTUV AND ZTOU AND DEFINES CONNECTIONS MADE BEFORE THE PLANT IS DISCRETIZED (SEE TABLE VII B.)

3. DISCRETIZED SYSTEM

$$\begin{bmatrix} x^c_{n+1} \\ \hline x^d_{n+1} \end{bmatrix} = \left[\begin{array}{c|c} \phi(T) & 0 \\ \hline 0^* & A_d \end{array}\right] \begin{bmatrix} x^c_n \\ x^d_n \end{bmatrix} + \left[\begin{array}{c|c|c} [\Theta(T)B_c] & [\phi(T)B_c] & 0 \\ \hline 0 & 0 & B_d \end{array}\right] \begin{bmatrix} u^c_n \\ \hline u^d_n \end{bmatrix}$$

$$\begin{bmatrix} y^c_n \\ \hline y^d_n \end{bmatrix} = \left[\begin{array}{c|c} H_c & 0 \\ \hline 0^* & H_d \end{array}\right] \begin{bmatrix} x^c_n \\ x^d_n \end{bmatrix} + \left[\begin{array}{c|c|c} [F_c] & [H_c B_c] & 0 \\ \hline 0 & 0 & F_d \end{array}\right] \begin{bmatrix} u^c_n \\ \hline u^d_n \end{bmatrix}$$

4. CONNECTIONS AFTER DISCRETIZATION

$$\begin{bmatrix} u^c_n \\ \hline u^d_n \end{bmatrix} = \begin{bmatrix} R \end{bmatrix} \begin{bmatrix} y^c_n \\ \hline y^d_n \end{bmatrix} = \begin{bmatrix} K1 \end{bmatrix} \begin{bmatrix} x^c_n \\ x^d_n \end{bmatrix}$$

WHERE R IS DEFINED BY YZTOK AND DEFINES CONNECTIONS MADE AFTER THE PLANT IS DISCRETIZED (SEE TABLE VII B.). FOR ROOT LOCUS, THE SECOND CONNECTION SPECIFIED BY YZTOK (IF ANY) WILL GENERATE K3 (SIMILAR TO K1) DEFINING A SECOND FEEDBACK VARIABLE.

5. FINAL SAMPLED-DATA SYSTEM

$$\left.\begin{aligned} x_{n+1} &= Ax_n + Bu_n \\ y_n &= Hx_n + Fu_n \end{aligned}\right\} \qquad \text{FROM 3.}$$

$$u_n = K1x_n + Du_{com_n} \qquad \text{FROM 4.} \quad (D=I)$$

* THESE SUBMATRICES MAY CONTAIN NON-ZERO ELEMENTS.

TABLE IV CONTROL PROGRAM DATA DECK FORMAT

CARD 1 TITLE CARD FORMAT (10A8)
ANY LITERAL DATA DESIRED TO LABEL ALL PRINTOUTS AND PLOTS

CARD(S) 2 TO N NAMELIST CODE (SEE APPENDIX 2)
INTEGER VARIABLES
READ, SYSTEM, OUTPUT, MIXED, DIGITL, FRPS, NUMERS, TRESP, NX, NY, NU, NXC, NUC, ZOH, N1, N2, CONTUR, MULTRT, MODEL, NSCALE, CMAT, NK2, FORM, IPT, IGO, SAV, IFLAG, READ3

REAL VARIABLES
DELT, FINALT, IFREQ, FFREQ, DELFRQ, GAIN1, GAIN2, M

CARD N+1 OUTPUT LABELS FORMAT (8A10)
LITERAL OUTPUT VARIABLE LABELS USED TO LABEL PRINTOUTS AND PLOTS. ORDERED IN SEQUENCE CORRESPONDING TO NY OUTPUTS, Y. LEAVE BLANK IF SYSTEM = 3. Will read the greater of 8 or NY outputs.

CARD N+2 INPUT LABELS FORMAT (8A10)
LITERAL INPUT VARIABLE LABELS USED TO LABEL PRINTOUTS AND PLOTS. ORDERED IN SEQUENCE CORRESPONDING TO NU INPUTS, U. LEAVE BLANK IF SYSTEM = 3. Will read the greater of 8 or NU inputs

CARD(S) (N+3) TO (M) SYSTEM DATA (SEE TABLE V AND APPENDIX 2)
SYSTEM DATA AS SPECIFIED BY LOAD, MATRIX, CHANGE, OR CLASS. IF READ =1, EACH DATA MATRIX IS READ ROW-WISE WITH FORMAT (8F10.4) AND EACH MATRIX MUST BE PRECEDED BY A DIMENSION CARD (FORMAT (2I10)) GIVING THE NUMBER OF ROWS AND COLUMNS OF THE MATRIX.

CARD M+1 TRANSIENT RESPONSE INPUT DATA
INPUT IS CALLED BY THIST TO GENERATE THE TRANSIENT RESPONSE INPUT VECTOR. THE INPUT SUBROUTINE ON THE DISC READS ONE DATA CARD FOR EACH RESPONSE DEFINING A STEP INPUT ON THE NU COMPONENTS OF THE augmented and thinned input vector, u. (format(7F10.4))

THE ABOVE CARDS DEFINE ONE CASE. AS MANY CASES AS DESIRED MAY BE STACKED TOGETHER FOR A SINGLE COMPUTER RUN.

IF A PLOT IS REQUESTED THE PLOT CARDS AS DESCRIBED IN TABLE II ARE REQUIRED

TABLE V.   DATA REQUIRED BY CONDITION CODES

<u>STEP 1</u>   READ = 1,2,3

```
SYSTEM                                   REQUIRED MATRICES
  1        OPEN LOOP                     A,B,C,H,G,F
      IF MIXED =1, THIS IS STEP 1 OF THE MIXED LOADING OPTION

  2        CLOSED LOOP                   A,B,C,H,G,F,K1,K2,D
  3        ROOT LOCUS                    A,B,C,K1,K2,K3,K4

IF CMAT    = 0       C      MATRIX NOT REQUIRED
IF NK2     = 0       K2,K4  MATRIX NOT REQUIRED
IF OUTPUT  = 1       G,F    MATRIX NOT REQUIRED
IF OUTPUT  = 2       F      MATRIX NOT REQUIRED
IF OUTPUT  = 3       G      MATRIX NOT REQUIRED
IF N2=0              K3,K4  MATRIX NOT REQUIRED
```

<u>STEP 2</u>   READ = 4 ; OR,

IF MIXED =1, THIS IS STEP 2 OF THE MIXED LOADING OPTION

```
  CARD 1   NBLOCK,NIT   FORMAT (2I5)
 IF NIT = 0   GO TO (*)

  CARDS 2-(NBLOCK+1)  ONE CARD PER BLOCK   FORMAT (I2,I3,5I5,5F10.4)

  NUM,TYPE,(CONNEC(I),I=1,4),MOD,(PARAM(I),I=1,5)

  NUM = BLOCK NUMBER
  TYPE = BLOCK TYPE  (1-10)  SEE TABLE VI
  CONNEC = SPECIFIES INPUTS TO BLOCK. FIRST THREE ELEMENTS MAY SPECIFY
         CONNECTIONS FROM OTHER BLOCKS (±).  FOURTH ELEMENT MAY
         SPECIFY EXTERNAL INPUT (±).
  MOD = SPECIFIES THAT G(P) IS S-,Z-, OR W- TRANSFORM As specified in Table VI
  PARAM = PARAMETERS DEFINING BLOCKS AS SPECIFIED IN TABLE VI
 GO TO (**)
```

	NAME	TYPE	DIMENSION	FORMAT
(*)	GRAPH	INTEGER	NBLOCK X 5	5I5
	BLOCK	INTEGER	NBLOCK X 3	3I5
	NUMER	REAL	NBLOCK X 5	5F10.4
	DENOM	REAL	NBLOCK X 5	5F10.4
	GAIN	REAL	NBLOCK	8F10.4
(**)	ITHINY	INTEGER	≤ # OF OUTPUTS	16I5

STOP IF MIXED =0 UNLESS READ=4 and SYSTEM =3

ITHINU	INTEGER	≤ # OF INPUTS	16I5
NYTOV,NZTOU,NYZTOK	INTEGER		3I5
YTOV	INTEGER	NYTOV X 2	2I5
ZTOU	INTEGER	NZTOU X 2	2I5
YZTOK	INTEGER	NYZTOK X 2	2I5

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE VI TRANSFER FUNCTION STANDARD FORMS (NIT = 1)

FOR READ = 4 OR MIXED =1 STEP 2, THE CLASS SUBROUTINE ACCEPTS BLOCK DIAGRAM TRANSFER FUNCTIONS OF THE FOLLOWING FORMS. (SEE TABLE V. STEP2)

TYPE	G(P)	PARAM(I)				
		I=1	2	3	4	5
1	K	K				
2	Kp	K				
3	$K\frac{1}{p}$	K				
4	$\frac{K}{(1+p/a)}$	K	a			
5	$\frac{K(1+p/b)}{(1+p/a)}$	K	a	b		
6	$\frac{Kp}{(p+a)}$	K	a			
7	$\frac{K}{(1+p/a)(1+p/b)}$	K	a	b		
8	$\frac{K}{1+\frac{2\zeta}{\omega}p+p^2/\omega^2}$	K	ω	ζ		
9	$\frac{K\left(1+\frac{2\zeta_2}{\omega_2}p+p^2/\omega_2^2\right)}{\left(1+\frac{2\zeta_1}{\omega_1}p+p^2/\omega_1^2\right)}$	K	ω_1	ζ_1	ω_2	ζ_2
10	$\frac{K(1+p/a)}{\left(1+\frac{2\zeta}{\omega}p+p^2/\omega^2\right)}$	K	ω	ζ	a	
11	$\frac{Kp}{1+2\frac{\zeta}{\omega}p+p^2/\omega^2}$ *	K	ω	ζ		

*Can consist of two real roots

TABLE VI (CONT.)

THE STANDARD FORM, G(P), IS INTERPRETED AS AN S-,W-, OR Z-PLANE TRANSFER FUNCTION AS SPECIFIED BELOW

DIGITL \ MOD	0	1	2
0	G(S)	---	---
1	G(S),G(Z)	G(S)	G(W)
2	G(Z)	G(S)	G(W)

IF MOD = 0 THE TRANSFER FUNCTION COEFFICIENTS ARE NOT MODIFIED

IF MOD = 1 THE TRANSFER FUNCTION CRITICAL FREQUENCIES ARE PREWARPED TO APPROXIMATE THE S-PLANE FILTER IN THE W- PLANE AND THEN TRANSFORMED TO THE Z-PLANE AS DESCRIBED BELOW. FIRST ORDER POLES AND ZEROES ARE WARPED AS

$$a = \tanh\left(\frac{aT}{2}\right)$$

COMPLEX POLES AND ZEROES ARE WARPED AS

$$\omega_w = \sqrt{u_w^2 + \nu_w^2} \qquad \zeta_w = -\frac{u_w}{\omega_w}$$

where
$$u_w = \frac{\sinh(\alpha T)}{\cosh(\alpha T) + \cos(\beta T)}$$

$$\nu_w = \frac{\sin(\beta T)}{\cosh(\alpha T) + \cos(\beta T)}$$

with
$$\omega_s^2 = \alpha^2 + \beta^2$$

$$\zeta_s = -\frac{\alpha}{\omega_s}$$

IF MOD = 2 THE TRANSFER FUNCTION IS REGARDED AS A W-PLANE TRANSFER FUNCTION AND TRANSFORMED TO THE Z-PLANE BY THE BILINEAR TRANSFORMATION

W = (Z-1)/(Z+1)

IF DIGITL = 1 AND MOD ≠ 0 THE TRANSFER FUNCTION CANNOT BE PART OF THE CONTINUOUS PLANT (I.E. THE INPUT TO THE FILTER MUST BE NUMBERED HIGHER THAN NUC AND THE FILTER STATES MUST BE NUMBERED HIGHER THAN NXC)

IF DIGITL = 1 AND MOD = 0 THE TRANSFER FUNCTION COEFFICIENTS ARE NOT MODIFIED. THE FUNCTION IS INTERPRETED AS AN S- OR Z- PLANE FUNCTION DEPENDING ON THE RELATION OF THE FILTER STATES TO NXC. IF THE FILTER STATES ARE NUMBERED LESS THEN NXC, THEN THE FILTER IS TREATED AS PART OF THE CONTINUOUS PLANT. IF THE FILTER STATES ARE NUMBERED GREATER THAN NXC THEN THE FILTER IS TREATED AS PART OF DIGITAL CONTROLLER.

TABLE VII DISCRETIZED PLANT MODELS FOR VARIOUS INPUT AND OUTPUT DEFINITIONS

	A. (*) $y_n = y_n^- \equiv y(nT-\epsilon)$	B. (**) $y_n = y_n^+ \equiv y(nT+\epsilon)$
CONTINUOUS MODEL	$\dot{x} = Ax + Bu$ $y = Hx + Fu$	
SAMPLED INPUT	$x_{n+1} = \phi(T)x_n + \phi(T)Bu_n$ $y_n = Hx_n$	$x_{n+1} = \phi(T)x_n + \phi(T)Bu_n$ $y_n = Hx_n + HBu_n \quad (F \equiv 0)$
ZOH INPUT	$x_{n+1} = \phi(T)x_n + \Theta(T)Bu_n$ $y = Hx_n$	$x_{n+1} = \phi(T)x_n + \Theta(T)Bu_n$ $y_n = Hx_n + Fu_n$

	C. (***) TIME DELAY $y_n(m) \equiv y[(n+m-1)T]$ $\quad 0 < M \leq 1$
CONTINUOUS MODEL	$\dot{x} = Ax + Bu$ $y = Hx + Fu$
SAMPLED INPUT ($F \equiv 0$)	$x_{n+1} = \phi(T)x_n + \phi(T)Bu_n$ $y_n(m) = H\phi(mT)x_{n-1} + H\phi(mT)Bu_{n-1}$
ZOH INPUT	$x_{n+1} = \phi(T)x_n + \Theta(T)Bu_n$ $y_n(m) = H\phi(mT)x_{n-1} + [H\Theta(mT)B + F]u_{n-1}$

$$\phi(t) = \int_0^t e^{-A(t-\tau)}d\tau \; ; \quad \Theta(t) = \int_0^t \phi(t-\tau)d\tau \; ; \quad x_n = x_n^- \equiv x(nT-\epsilon)$$

(*) CONTROL ASSUMES $y_n = y_n^-$ FOR ANY CONNECTIONS FROM THE PLANT TO THE DIGITAL CONTROLLER (I.E. PLANT FEEDBACK).

(**) CONTROL ASSUMES $y_n = y_n^+$ FOR FINAL SYSTEM OUTPUT CALCULATIONS (TRANSIENT RESPONSES, TRANSFER FUNCTIONS).

(***) MODIFIED Z-TRANSFORM ANALYSIS CAN ONLY BE USED WITH OPEN LOOP SAMPLED-DATA SYSTEMS.

TABLE VIII VECTOR ORDERING AND SYSTEM CONNECTION CONVENTIONS FOR SAMPLED-DATA SYSTEMS

A. VECTOR ORDERING CONVENTION

THE COMPONENTS OF THE AUGMENTED VECTORS U, X, AND Y MUST BE ORDERED IN THE FOLLOWING SEQUENCES, (IN STEP 2 OF THE MIXED OPTION, NUMBER THE EXTERNAL INPUTS AND BLOCK OUTPUTS IN THE INDICATED ORDER)

INPUT VECTOR, U

1. INPUTS TO PLANT FROM ZERO-ORDER-HOLD ELEMENTS (ZOH)
2. INPUTS TO PLANT FROM SAMPLERS (NUC-ZOH)
3. INPUTS TO DIGITAL CONTROLLER (NU-NUC)

STATE VECTOR, X

1. CONTINUOUS STATES (PLANT, NXC)
2. DISCRETE STATES (DIGITAL CONTROLLER, NX-NXC)

OUTPUT VECTOR, Y

1. PLANT OUTPUTS
2. DIGITAL CONTROLLER OUTPUTS

B. SYSTEM CONNECTION CONVENTION

CONNECTION	DEFINED IN
$\boxed{G(s)} \longrightarrow \boxed{G(s)}$	YTOV,ZTOU,GRAPH,A
$\boxed{D(z)} \longrightarrow \boxed{D(z)}$	"
$\boxed{G(s)}$ —/ $\rightarrow \boxed{D(z)}$	"
$\boxed{D(z)} \longrightarrow \boxed{G(s)}$	YZTOK
$\boxed{G(s)}$ —/ $\rightarrow \boxed{G(s)}$	"

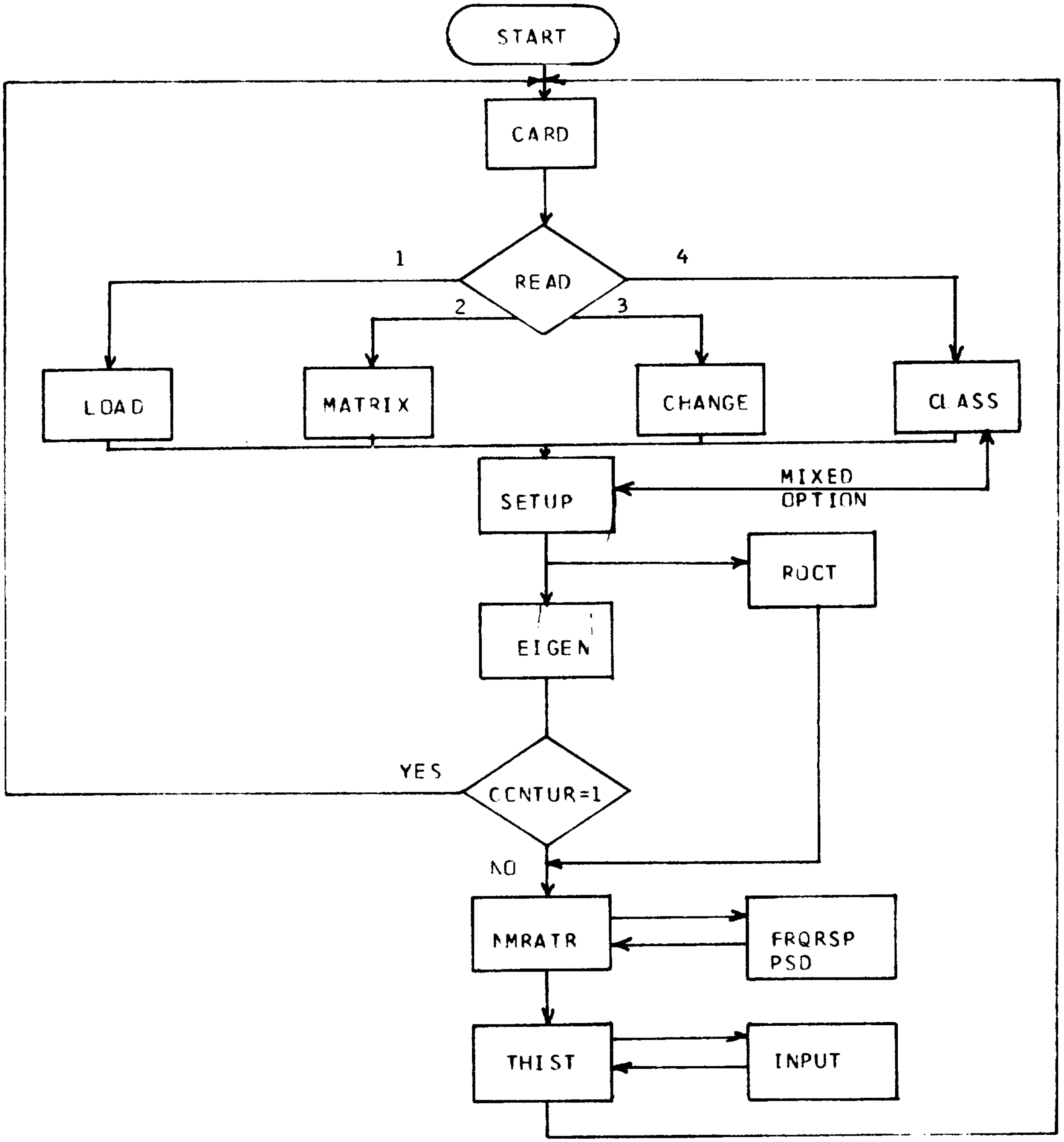
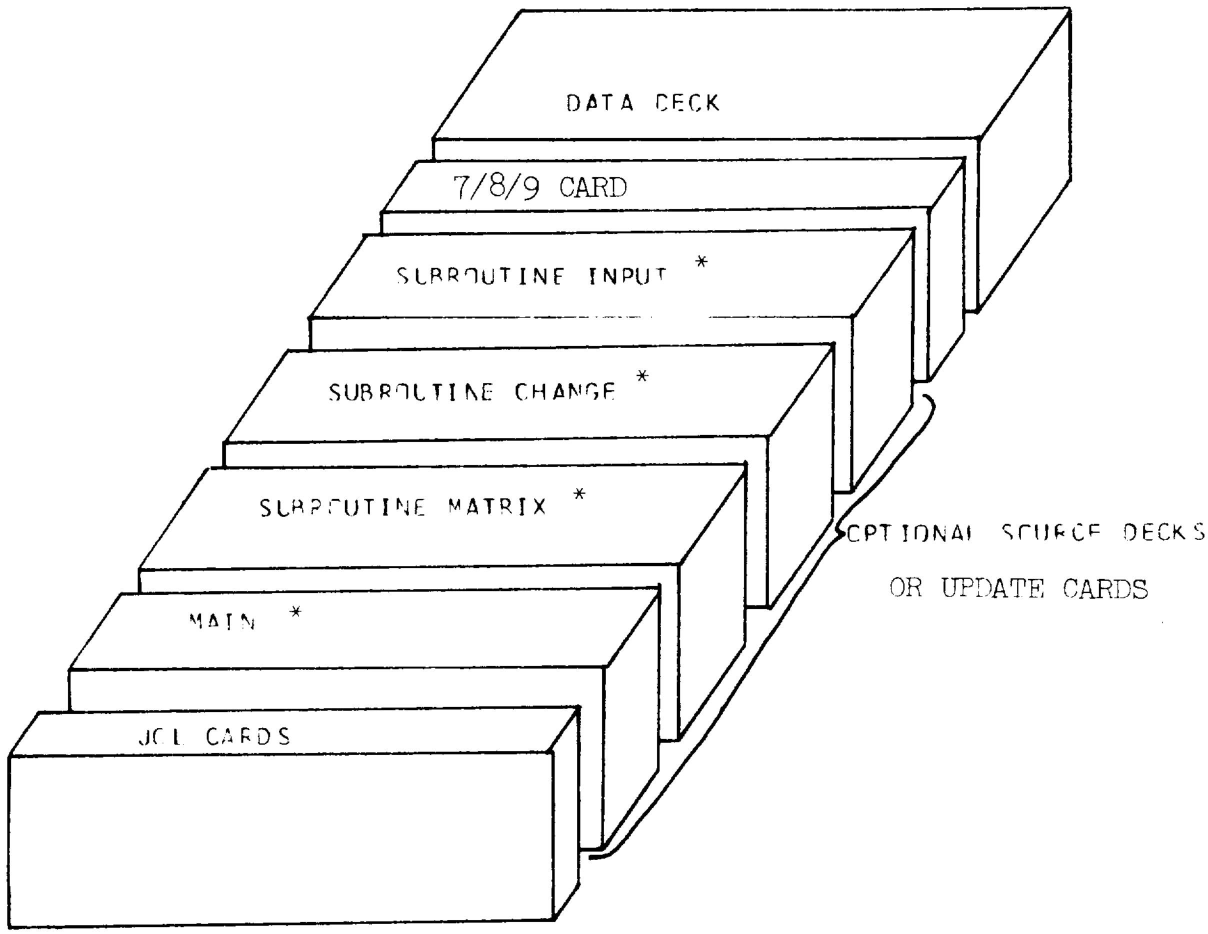


FIGURE 1   FLOW CHART OF CNTRLR SUBROUTINE



*OTHER SUBROUTINES AS DESIRED

FIGURE 2. STRUCTURE OF CONTROL DECK

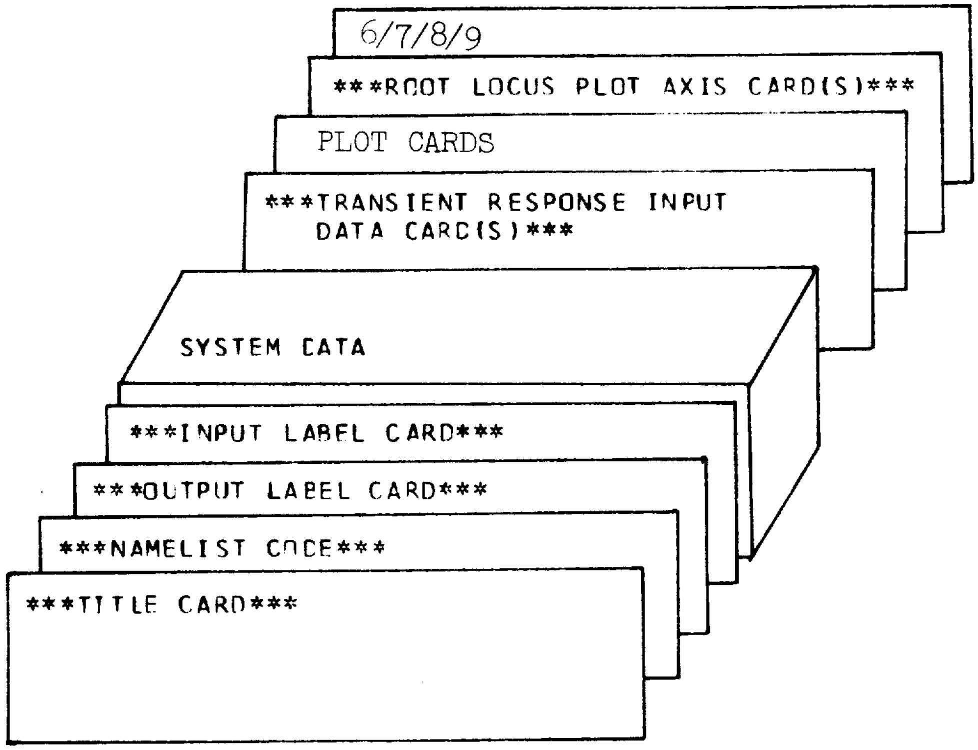


FIGURE 3. CONTROL PROGRAM DATA DECK STRUCTURE

```
CC2
 |
 v
 $CODE          READ=1,     SYSTEM=  1,OUTPUT=3,NX=4,NY=5,NU=2,
     DELT= .05 ,FINALT=10., IFREQ=.5 ,FFREQ= 100.,DELFRQ=1.11,
 IPT=2,$END
```

FIGURE 4 EXAMPLE OF DATA ENTRY USING A NAMELIST FORMAT

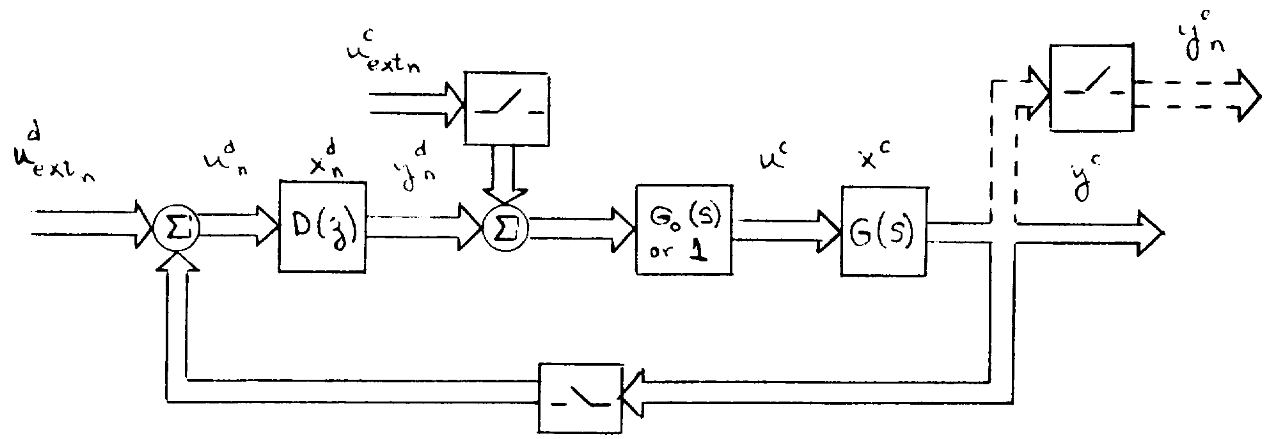


Figure 5.- Sampled-data system block diagram.

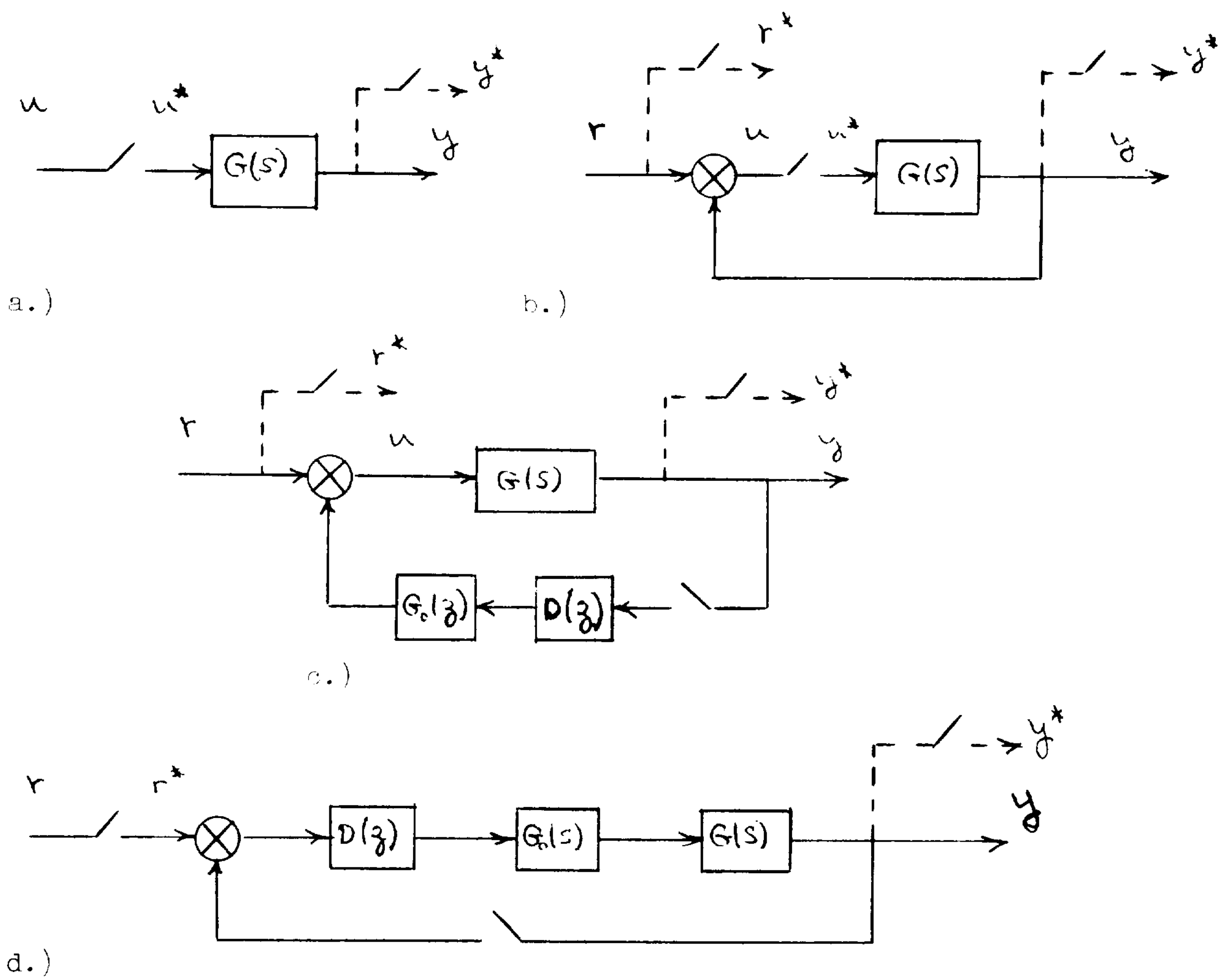


Figure 6.- Typical sampled-data systems analyzed by CONTROL.

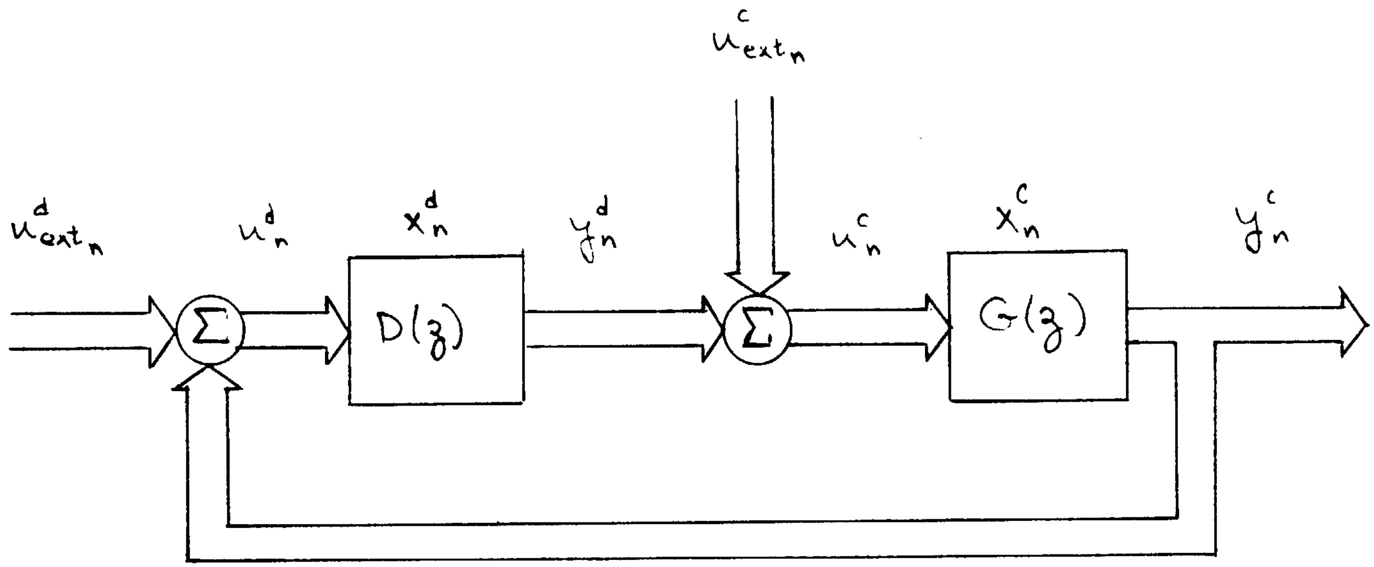
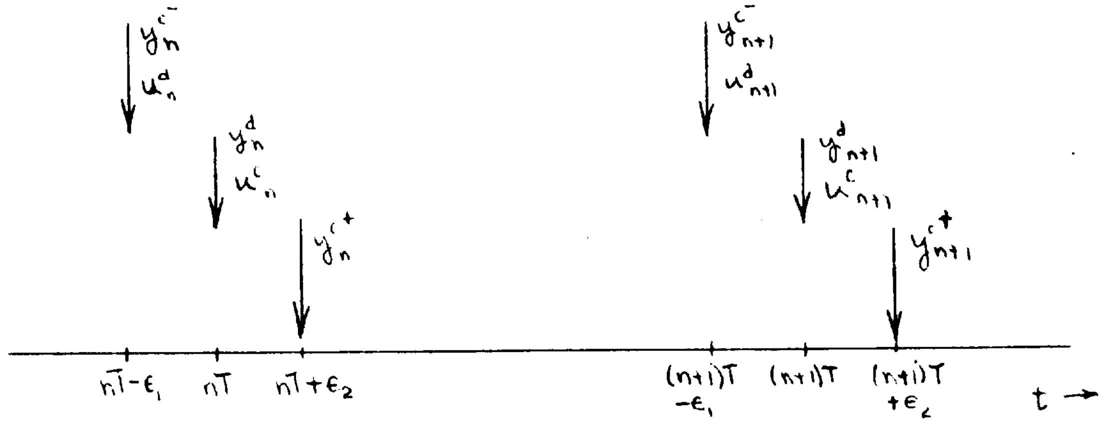


Figure 7.- Discretized sampled-data system block diagram.



a.) Time sequence of digital controller and plant.

b.) Idealized time sequence.

Figure 8.- Time sequence models for sampled-data systems.

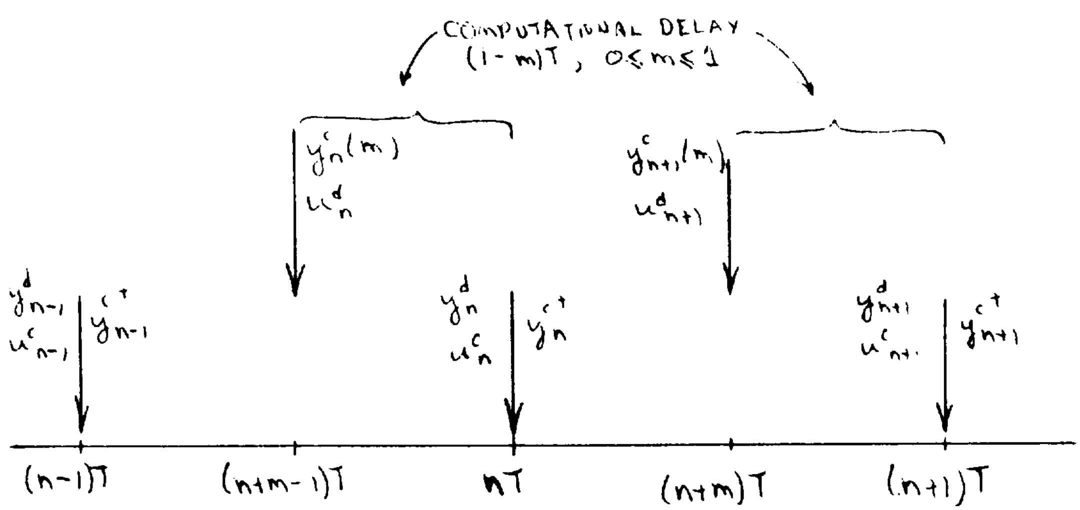


Figure 9.- Time sequence model for sampled-data systems with computational time delay.