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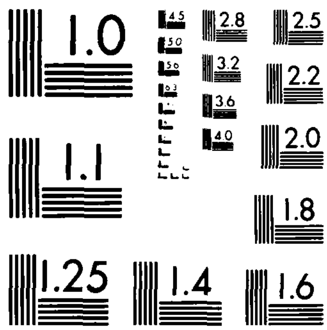

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THESIS

AN INTERACTIVE DISCRETE CONTROLS ANALYSIS
OPTION (ORACLS) FOR THE CONTROLS ANALYSIS
PACKAGE ON THE IBM 3033

by

Michael K. Brenny

June 1985

Thesis Advisor: Daniel J. Collins

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This thesis discusses the implementation of a discrete control systems analysis option, ORACLS, for the CONTROLS analysis package. The option encompasses a collection of FORTRAN programs that facilitate the design and analysis of linear, multiple input/multiple output digital feedback control systems. All programs are interactive and operate in the VM/CMS environment of the IBM 3033.

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A collection of FORTRAN subroutines, "Optimal Regulator Algorithms for the Control of Linear Systems" (ORACLS), by E.S. Armstrong of the NASA Langley Research Center, was used in the development of the ORACLSX program. Subroutines from the "Optimal Systems Control" FORTRAN program (OPTSYS), were used as the foundation for the discrete transfer function analysis program, TRANFUNC.

The ORACLS option capabilities include: analog-to-digital matrix conversion, transfer function analysis, complete eigen value analysis, modal analysis, transient response calculation, Kalman-Bucy filter synthesis, and optimal regulator synthesis. Graphical results are available for the transient analysis and transfer function analysis portions.

An Interactive Discrete Controls Analysis Option (ORACLS) for the CONTROLS Analysis Package on the IBM 3033

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Submitted in partial fulfillment of the requirements for the degree of

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LIST OF FIGURES

ORACLS Nomenclature

Name	Matrix Description & Dimension
{A}	State Weighting Matrix: (NS,NS)
{B}	Control Weighting Matrix: (NS,NC)
{GAMD}	Noise Weighting Matrix: (NS,NG)
{H}	Observables Weighting Matrix: (NO,NS)
{G}	Measurement-Feed Fwd. Dist. Matrix: (NO,NC)
{F}	Control Gain Matrix: (NC,NS)
{K}	Filter Gain Matrix: (NS,NO)
{Q}	Output Cost Matrix: (NO,NO)
{R}	Control Cost Matrix: (NC,NC)
{V1}	Process Noise Intensity (PSD) Matrix: (NG,NG)
{V2}	Measurement Noise Intensity (PSD) Matrix: (NO,NO)
{S}	Cross Product Weighting Matrix: (NS,NC)

Name	Vector Description & Dimension
X(I) -	State Vector: (NS,1)
Y(I) -	Output Vector: (NO,1)
Z(I) -	Measurement Vector: (NO,1)
V(I) -	White Measurement Noise Vectors: (NO,1)
WD(I) -	White Process Noise Vector: (NG,1)
UC(I) -	Commanded Input Vector: (NC,1)

Name	System Parameter
NS	Number of States
NC	Number of Controls
NG	Number of Process Noise Sources
NO	Number of Observations of Measurements

ACKNOWLEDGEMENT

I would like to express my sincere appreciation to Professor D.J. Collins, whose guidance and encouragement contributed immeasurably to the program development undertaken in this thesis.

I wish to dedicate this thesis to my parents and family, and to the loving memory of EAB. Without their love and support it would not have been possible.

I. INTRODUCTION

The development of "ORACLS", an interactive capability for the study, design , and analysis of digitally controlled systems on the IBM 3033, is the subject of this thesis. It gives "CONTROLS", a modern control analysis package, the ability to handle discrete systems. To that end the FORTRAN programs ORACLSX and TRANFUNC were designed. Their development and capabilities are the main focus of this thesis.

A. BACKGROUND

The completion of OPTSYSX by Hoden [Ref. 3], made an interactive multiple input/multiple output design and analysis program available for handling continuous systems. OPTSYSX was extended to graphics capable by the programs OPTGRAPH and OPTPLOT, by Laptas [Ref. 4] and Diel [Ref. 5], respectively. These programs when combined with OPTCALC by Diel [Ref. 5] and DACSAP by Cooksey [Ref. 6], became the CONTROLS analysis package. They run interactively in the VM/CMS environment of the IBM 3033. CONTROLS thus constructed, lacked ability to handle discrete systems.

Optimal Regulator Algorithms for the Control of Linear Systems (ORACLS) [Ref. 1] is a collection of FORTRAN subroutines by E.S. Armstrong of the NASA Langley Research Center. It was developed for, "constructing controllers and optimal filters for systems modeled by linear time-invariant differential or differance equations" [Ref. 1] and employes the linear-quadratic-Gaussian (LQG) techniques of modern control analysis. The ORACLS package has the capability to handle discrete system analysis. A drawback with this analysis package however, is the need for the user to code a "driver" program for each problem and to format a data file for each run.

B. PROBLEM OBJECTIVE

To overcome these problems and fill CONTROLS' discrete analysis void, a program was desired which would use ORACLS' discrete system capabilities and interact with those programs already in CONTROLS.

ORACLSX and TRANFUNC were designed and coded to meet those requirements. They can handle various design and analysis problems germane to modern control theory. The continuous system output from OPTSYSX can be used as input to ORACLSX for conversion to a discrete system. The output of ORACLSX can be used as input to either of the graphing programs OPTGRAPH or OPTPLOT. It can also be used as input to the discrete analysis program TRANFUNC.

It is assumed that the reader is familiar with sampling theory and the basic concepts of optimal control theory as applied to discrete systems. Wherever possible in this thesis and the FORTRAN programs, the nomenclature of ORACLS by Armstrong [Ref. 1] was maintained. A glossary of abbreviations and matrix notation is provided as page 9.

C. PREVIEW

An overview of the CONTROLS package and some modifications to it is presented first. The "ORACLS" option of CONTROLS will then be discussed. This encompasses the ORACLS EXEC with its program options and other available features. Discussion of the ORACLSX FORTRAN program follows next. Each option will be covered individually and its capabilities demonstrated with an example problem. The final discussion will cover the TRANFUNC FORTRAN program. An example problem will be used to show its capabilities.

II. THE CONTROLS ANALYSIS PACKAGE

A. GENERAL BACKGROUND

"CONTROLS" is a modern control analysis package available to the system user on the IBM 3033 at the Naval Postgraduate School, Monterey, California. It is accessible in the VM/CMS environment and requires only that the user's available storage be increased to the 1 mega byte (1M) limit. The system has a 2M capability for running very large systems where the capability of the 1M storage limit is exceeded. The analysis package may be accessed by simply typing; "CONTROLS" on any of the IBM 3278 terminals after having defined storage as 1M.

B. THE MANAGE EXEC (CONTROLS' OPTIONS)

The Manage Exec is used to control the program options and features available in the CONTROLS package. Figure 2.1 is a copy of the controlling menu.

1. HELP

The Manage Exec's Help option is a brief description of program names and capabilities. See figure 2.2 for the HELP menu.

2. Example Problem

Option number 5 of the Manage EXEC allows the user to obtain a sample OPTMAT data file and a documentation file to enter the OPTSYS or ORACLS program options. The instruction files OPTSAM and ORCSAM explain the program options of the respective OPTSYSX and ORACLSX FORTRAN programs. They provide the user a step by step guide to running the

```
PLOTTING IS DONE THRU DISSPLA. UP TO 20% OF YOUR DISK
    SPACE MAY BE NEEDED OTHERWISE ERROR MESSAGES
******************************************************

   CONTROLS CONSISTS OF THREE INTERACTIVE PROGRAMS

        1   DACSAP        (SISO)
        2   OPTSYS        (MIMO)
        3   ORACLS        (MIMO)

        4   HELP - PROGRAM DESCRIPTIONS
        5   SAMPLE PROBLEMS WITH PROGRAM DIRECTIONS
        6   PROGRAM DOCUMENTATION SOURCES
        7   EXIT

      ENTER  1 ,  2 ,  3 ,  4 ,  5 ,  6,  OR  7
******************************************************

   NORMALLY IN ANY FORTRAN PROGRAM TWO NULL ENTREES
  TERMINATE THE PROGRAM SENDING YOU BACK TO THE EXEC
```

Figure 2.1 CONTROLS Option Menu.

programs with the example data and also provide program results for comparison.

3. Program Documentation

The Program Documentation option lists for the user the Master's Theses which generated the programs available in CONTROLS. These are the theses as listed in references 3-6.

C. MODIFICATIONS TO THE CONTROLS PACKAGE

This section details modifications made to the OPTSYS EXEC and the FORTRAN programs of the CONTROLS package. Some of these modifications were necessary to provide the proper interface for the addition of the ORACLS option. Some were programing carryovers from the ORACLSX program. All FORTRAN programs have been updated to VS FORTRAN Release 4.0. This

```
DACSAP:
--------- CONTINUOUS & DISCRETE ANALYSIS: ------------
   TRANSFER FUNCTION INPUT          CLASSICAL ANALYSIS
   MULTIPLE LOOP, BLOCK DIAGRAM CALCULATIONS PERFORMED
   BODE, NYQUIST, NICHOLS, ROOT-LOCUS,
   TRANSIENT RESPONSE,  S  Z  W  W' PLANES

OPTSYS:
------------ CONTINUOUS SYSTEM ANALYSIS: -------------
    STATE VARIABLE INPUT, STATE VARIABLE FEEDBACK
    OPEN AND CLOSED LOOP EIGENVALUES, OPTIMAL CONTROL,
    KALMAN FILTER ANALYSIS, TRANSIENT RESPONSE,
    TRANSFER FUNCTION GENERATION,BODE, ROOT LOCUS

ORACLS:
------------- DISCRETE SYSTEM ANALYSIS: --------------
   ANALOG TO DIGITAL MATRIX CONVERSION, KALMAN-BUCY
   FILTER, OPTIMAL REGULATOR, TRANSIENT RESPONSE
   CALCULATION, EIGENVALUE AND TRANSFER FUNCTION
   ANALYSIS, MODAL MATRICES.

NOTE: PROGRAMS CAN HANDLE 32 STATES, 10 CONTROLS,
      10 OBSERVATIONS AND 10 NOISE INPUTS. TO USE
      THE LARGE SYSTEM: (98,30,30,30), OBTAIN THE
      SOURCE CODE AND CHANGE THE "COMMENTED-OUTS"
      ON THE LARGE SYSTEM DIMENSION STATEMENTS.
NOTE: OPTPLOT IS LIMITED TO 32 STATES AND 10 CONTROLS

********************** HELP ***************************

 ALL PROGRAMS HAVE HELP FACILITIES AVAILABLE IN THEM

  DACSAP:  A COMPLETE HELP FILE MAY BE PRINTED AFTER
           ACCESSING THE PROGRAM.

  OPTSYS:  A COMPLETE HELP FILE IS AVAILABLE FOR
           TERMINAL VIEWING.

  ORACLS:  A COMPLETE HELP SECTION DETAILING
           INDIVIDUAL PROGRAM OPTIONS, NOMENCLATURE
           AND EQUATIONS USED, IS AVAILABLE FOR
           TERMINAL VIEWING AND/OR DISK COPY.
```

Figure 2.2 CONTROLS HELP Menu.

update allows the use of designated "character" variables and the Block IF statement with the IF THEN, ELSE IF, ELSE structure. These changes facilitate programing allowing the removal of many confusing "GO TO" statements.

1. OPTSYS EXEC Modifications

a. Data File Protection Checks

To ensure that the user could not input a discrete system (OPTMATD) data file in the OPTSYSX program, a flag (IDOPTD) signaling the type of data, was added to the OPTMAT and OPTMATD data files. The OPTSYS EXEC was modified to check this flag for correctness. Any improper data file will be rejected and an error message issued.

b. Output Selection Option

Occasionally a user may like to make multiple runs through the OPTSYSX program saving the results from each run in a different file. An option was added to allow the selection of six different output files. The user selects to either view the program results on the screen or to have them sent to the designated listing file.

c. SHERPA Printer

The graphing programs OPTPLOT and OPTGRAPH generate a DISSPLA METAFILE which through DISSPOP can be sent to the SHERPA laser printer. An option was added to the OPTSYS EXEC which allows the user to generate thesis acceptable plots on the SHERPA printer.

2. OPTSYSX Program Modifications

Program modifications to some of the subroutines supporting the OPTSYSX program were necessary to ensure a proper interface with the ORACLSX program. ORACLSX was developed using VS FORTRAN and some of the programing ideas from it were carried over to the OPTSYSX program.

a. OPTMAT Data File

As previously mentioned the IDOPTD flag was developed to signal whether the data was continuous or discrete. IDOPTD is written as "0" to the OPTMAT data file by the subroutine WRTMAT. It is written as a "1" to the OPTMATD data file by the subroutine WRMATD. The value of IDOPTD is then checked by the OPTSYS AND ORACLS EXECs, allowing only input of proper data type. An error message is generated if a conflict arises.

The OPTMAT data file contains the system parameters and program matrices. Two changes were made to the subroutines RDMAT and WRTMAT to read and write, respectively from it. Originally all the matrices were written to the file as a single group of numbers making it hard to decipher. The first change added the corresponding matrix names to the file, separating the matrices for ease in identification. The second modification changed the two subroutines, writing and reading to and from the file only those matrices with non-zero dimensions. This modification prevents the program from writing undefined numbers to the data file which are read later as program underflows and cause error messages.

b. ORACLSX Carryovers

OPTSYSX originally had 14 different subroutines to read in the matrices and vectors. These 14 subroutine were replaced by a single subroutine READMX. READMX was modeled on the subroutine READMD from ORACLSX. It uses the matrix identification flag IMAT and the IF THEN, ELSE IF, ELSE structure of VS FORTRAN to select the proper name and matrix dimensions for the matrix desired.

3. OPTCALC and OPTPLOT Program Modifications

The program results from ORACLSX are in discrete time and those from OPTSYSX in continuous time. The OPTPLOT program has the capability to plot the results from both programs. It was desired to maintain the discreteness of the ORACLSX data even when plotting. A data flag, IPLOT, was written to the OPTPLOT data file by the OPTCALC and ORACLSX programs. A "0" for IPLOT indicates the data file is from OPTCALC and should be graphed in the continuous sense. A "1" for IPLOT indicates the data file is from the ORTRAL portion of ORACLSX and should be graphed in the discrete sense. The OPTPLOT program reads the IPLOT flag from the OPTPLOT data file. It plots the continuous results connecting the data points with a smooth line. For the discrete results it plots individual unconnected markers. The markers are spaced at integer intervals of the sampling time.

4. OPTGRAPH Program Modifications

TRANFUNC does transfer function analysis of discrete systems in the Z domain. OPTSYSX does its transfer function analysis in the S domain. The OPTGRAPH program can graph the results from either program. Data input files for OPTGRAPH are: OPTGROL, OPTGRNO, and OPTGRCM. A modification was required to indicate their source program. Use was made of a data value already available in the data files to indicate the source program. A "0" indicating the OPTSYSX program and a "1" the TRANFUNC program. The data value is read by the OPTGRAPH program and passed to the subroutine RTLO to indicate whether a Z-plane template is required on the root-locus plot. The template is a plot of lines of constant natural frequency and constant damping. See Figure 5.4 The template covers the upper half of the unit circle. Its zero damping ratio line serving as the boundary between stable and unstable systems. The subroutine TEMPLT used to generate the template was adapted from the DACSAP program by Cooksey. [Ref. 6]

III. THE ORACLS EXEC (ORACLS' OPTIONS)

A. BACKGROUND

The ORACLS EXEC is used to control the ORACLS option available in CONTROLS. It is written in the CMS EXEC and EXEC 2 languages [Ref. 8]. It was modeled after the OPTSYS EXEC and includes features similar to those available there. Flow in the ORACLS EXEC parallels that in the OPTSYS EXEC, allowing the OPTSYS user immediate familiarity with its operation. The EXEC sets up the OPTMAT and OPTMATD data files. It also performs the data file check as will be explained in Section C to follow. The selection of a FORTRAN program option causes the EXEC to set the proper filedefs and call the program module. Program execution follows shortly thereafter.

B. AVAILABLE OPTIONS

1. Program Options

A general explanation of the capabilities of the program options is included in Figure 3.1 An explanation of the program and data file connections can be found in Figure 3.4 of the HELP section to follow.

2. Output Selection

Figure 3.2 is a copy of the output selection menu from the ORACLS EXEC. It allows the user the option of sending the program results of the ORACLSX and TRANFUNC programs to 6 different listing files. Upon exiting CONTROLS, the listing file containing the input matrices and results, may be printed. The user may select to have the output redirected to the terminal screen at any time.

```
**** THE ORACLS EXEC ALLOWS THE FOLLOWING OPTIONS: ***

1 ORACLSX FORTRAN: ------DISCRETE SYSTEM ANALYSIS-----
                    (A-D CONVERSION, OPT. REG., KALMAN-
                     BUCY FILTER AND TRANSIENT ANALYSIS)

2 TRANFUNC FORTRAN: -DISCRETE TRANSFER FUNCTION ANAL.-
                     (SYSTEM EIGENVALUES, COMPENSATOR,
                      NOISE AND OPEN LOOP TRANSFER
                      FUNCTIONS, MODAL MATRICES)

3  OPTPLOT FORTRAN:  (PLOTTING OF TRANSIENT RESPONSE'S
                        STATES AND CONTROLS)

4  OPTGRAPH FORTRAN: (PLOTS: POLE-ZERO, ROOT-LOCUS)

5  OUTPUT SELECTION -- TERMINAL OR "A" DISK FILE

6  HELP: PROGRAM & DATA FILE RELATIONSHIP EXPLANATIONS

7  EXIT -- RETURN TO CMS

-SELECT AN OPTION, ANY OTHER INPUT RETURNS YOU TO MENU-
```

Figure 3.1   ORACLS EXEC Options.

```
******************* OUTPUT OPTION *******************

NOTE: "ORACLS  LISTING" OR "TRANFUN  LISTING" FILES,
       CONTAINING THE RESPECTIVE PROGRAM RESULTS OF 6
       DIFFERENT RUNS MAY BE WRITTEN TO YOUR "A" DISK.

 THE OUTPUT FILE NAME IS SELECTED FROM THE FOLLOWING:

        1  ORACLS1   LISTING  A1     (RUN 1)
        2  ORACLS2   LISTING  A1     (RUN 2)
        3  ORACLS3   LISTING  A1     (RUN 3)
        4  TRANFUN1  LISTING  A1     (RUN 1)
        5  TRANFUN2  LISTING  A1     (RUN 2)
        6  TRANFUN3  LISTING  A1     (RUN 3)
        7  DIRECT OUTPUT TO TERMINAL

ENTER: 1, 2, 3, 4, 5, OR 6, FOR YOUR OUTPUT FILE NAME
            OR 7, FOR TERMINAL OUTPUT.
```

Figure 3.2   ORACLS EXEC Output Options.

3. HELP

The ORACLS EXEC contains a "HELP" option. This option explains the data files and their program connections. It consists of three separate screens. HELP's screen "A" (Figure 3.3) shows the programs available giving a quick synopsis of each. It also lists the input and output files associated with each program. Screen "B" (Figure 3.4) is a list of the data files used in OPTSYS and ORACLS. Screen "C" (Figure 3.5) is used to inform the user of disk space limitations that may arise when using the plotting programs.

A) PROGRAMS:

"ORACLSX"	FORTRAN IS THE PRIMARY ANALYSIS PROGRAM. USES OPTMAT AND OPTMATD. GENERATES OPTMATD. ITS ORTRAL PORTION GENERATES THE OPTPLOT DATA FILE FOR THE OPTPLOT PROGRAM.
"TRANFUNC"	FORTRAN DOES TRANSFER FUNCTION ANALYSIS. IT GENERATES THE OPTGRAPH FILES: OPTGROL, OPTGRNO, AND OPTGRCM FOR OPTGRAPH PROGRAM.
"OPTPLOT"	FORTRAN PLOTS THE TRANSIENT ANALYSIS DEVELOPED IN THE ORTRAL PORTION OF ORACLS. USES OPTPLOT DATA FILE FOR PLOTTING ON TEK 618 OR VERSATEC. THESIS ACCEPTABLE PLOTS AVAILABLE VIA SHERPA PRINTER.
"OPTGRAPH"	FORTRAN PLOTS TRANSFER FUNCTION ANALYSIS DEVELOPED IN TRANFUNC PORTION OF ORACLS. USES "OPTGROL", "OPTGRNO", AND "OPTGRCM" DATA FILES FROM TRANFUNC FOR PLOTTING ON TEK618, VERSATEC PLOTTER, SHERPA PRINTER.

Figure 3.3 HELP Screen "A".

```
B) DATA FILES:

OPTMAT:   IS GENERATED BY OPTSYSX AND CONTAINS ALL INPUT
          MATRICES, AND REGULATOR AND ESTIMATOR FEEDBACK
          GAINS. CAN BE USED AS AN INPUT TO THE ORCONV
          SECTION OF ORACLS.

OPTMATD:  IS GENERATED BY ORACLS AND CONTAINS ALL INPUT
          MATRICES AND REGULATOR AND ESTIMATOR FEEDBACK
          GAINS. OPTMATD CAN BE USED TO RERUN PROBLEMS
          IN ORACLS.

OPTPLOT:  GENERATED BY TRANFUNC AND CONTAINS THE EIGEN-
          VALUE AND TRANSFER FUNCTION ANALYSIS RESULTS.
          (T.F. GAINS, POLES, ZEROS, RESIDUES, AND EIGEN
          VALUES) IT IS USED BY OPTPLOT FORTRAN FOR
          PLOTTING ON THE TEK618, VERSATEC, OR SHERPA.

OPTGROL:  OPEN LOOP TRANSFER FUNCTION
OPTGRNO:  NOISE TRANSFER FUNCTIONS THRU CLOSED LOOP SYS.
OPTGRCM:  COMPENSATOR TRANSFER FUNCTION

    THE ABOVE THREE FILES ARE GENERATED BY TRANFUNC
    AND USED BY OPTGRAPH TO DO CLASSICAL ANALYSIS.
    PLOTTING VIA THE TEK618, VERSATEC, OR SHERPA
```

Figure 3.4 HELP Screen "B".

```
C) NOTES:

    IF THE REQUIRED DATA SET IS ON YOUR "A" DISK A
    PROGRAM MAY BE RUN DIRECTLY.

    ALL PLOTTING PROGRAMS USE DISSPLA AND MAY REQUIRE
    UP TO 20% OF YOUR "A" DISK SPACE. MAKE SURE THAT
    SPACE IS AVAILABLE FOR THE DISSPLA METAFILES OR
    AN ERROR MESSAGE STATING THAT YOUR DISK IS FULL
    APPEARS.

      *****  ANY INPUT RETURNS TO MENU *****
```

Figure 3.5 HELP Screen "C".

C. THE DATA FILES

Various data files are generated by the programs contained in CONTROLS. This section looks at the the use and control of those files.

1. OPTMAT and OPTMATD Data Files

OPTMAT and OPTMATD are data control files. They contain the matrices as input by the user or as generated by the program. The OPTMAT and OPTMATD files allow the user to rerun a problem without having to reenter the matrices each time. These files are originally set up on the user's "A" disk by the ORACLS EXEC. If selected at the end of each program run, the ORACLSX program will write the system parameters and matrices to the OPTMATD file. In the beginning of the next program run, the user will be asked if he wants to use some, all, or none of the matrices that were saved.

2. Program Links

The OPTMAT, OPTMATD, and other data files serve as the links between the various programs in CONTROLS. The OPTMAT data file is the connection between the OPTSYSX and ORACLSX programs. It can be used as input for the ORCONV, analog-digital conversion option of ORACLSX. The OPTMATD data file is the link between all of the options in ORACLSX. The output from ORCONV is written to the OPTMATD file and can then be used as the input for any of the other available options. The OPTPLOT and OPTGRAPH data files are used to link the ORACLSX program to the graphing programs OPTPLOT AND OPTGRAPH.

3. Protection Features

The data file protection checks, discussed in the modifications to the OPTSYS EXEC, were also incorporated into the ORACLS EXEC. These checks prevent an improperly renamed data file from being used. See Chapter II, Section C.

IV. THE ORACLSX FORTRAN PROGRAM

A. PROGRAM OVERVIEW

ORACLSX is an interactive extension of the discrete system capabilities of Optimal Regulator Algorithms for the Control of Linear Systems (ORACLS) [Ref. 1]. It features modular programing and double precision computations. Its main program is menu driven and controls four major analysis subroutines. In addition to the ORACLS subroutines it has numerous subroutines for handling matrices and system parameters. The matrix handling subroutines are modifications of those used in OPTSYSX.

ORACLSX operates under the VS FORTRAN programing language. It makes extensive use of VS's character variables and Block IF statements. The IF THEN, ELSE IF, ELSE structure of the Block IF statement facilitates programing, allowing fewer confusing "GOTO" statements, and in fact fewer subroutines. See Section D.2.

The program has been dimensioned to handle systems with up to 32 states, 10 controls, 10 measurements/observations, and 10 noise inputs; (32,10,10,10). Larger systems, up to (98,30,30,30), can be handled by invoking the alternate dimension statements provided in the main program and major analysis subroutines. Use of the large system capabilities may exceed the storage limits of the 1M system. If so, the 2M machine must be accessed.

B. INCORPORATION OF ORACLS

The ORACLS package subroutines were set up on the system and updated to VS FORTRAN. The update involved removing the use of the Hollerith field from all statements that were not use of the Hollerith field from all statements that were not format statements. This change affected all the program calls to the subroutine PRNT [Ref. 1: pp. 8,9]. REAL declarations were replaced by CHARACTER declarations for appropriate variables in the subroutines RDTITL [Ref. 1: p. 5], and PRNT. The "IMPLICIT REAL*8 (A-H,O-Z)" statement was added to all subroutines, updating the package to double precision. Integer variables declared as REAL, were redeclared as REAL*8. Double precision function names were substituted for "ABS", "ALOG10", and "AMAX1" [Ref. 9: pp. 303,304]. After completion of the conversion to VS FORTRAN, the four example problems included in the ORACLS manual [Ref. 1], were run. Program results generated by the updated package agreed completely with those given in the manual.

C. ORACLSX'S MATRIX NOMENCLATURE

The discrete system nomenclature of ORACLS [Ref. 1] was maintained wherever possible in ORACLSX. Exceptions are the {GAMD}, {V1}, and {V2} matrices. {A} is the System, Plant, or State Weighting Matrix. {B} is the Control Weighting Matrix. {GAMD} is the Process Noise Weighting Matrix. The {H} Matrix is the Weighting of the Observations. {G} is the Measurement-Feed Forward Distribution Matrix. {F} is the Control Gain Matrix. {K} is the Filter Gain Matrix. {Q} is the Output Cost Matrix. {R} is the Control Cost Matrix. {V1} is the Process Noise Intensity (PSD) Matrix. {V2} is the Measurement Noise Intensity (PSD) Matrix. and {S} is the Cross Product Weighting Matrix.

D. SYSTEM/MODEL DESCRIPTION

ORACLSX works with discrete time systems. It bases its analysis on difference equations. In the following difference equations, "T" is the Sample Time Interval.

The SYSTEM Equation:

$$X((I+1) \cdot T) = \{A\}X(I \cdot T) + \{B\}U(I \cdot T) + \{GAMD\}WD(I \cdot T) \quad (4.1)$$

The OUTPUT Equation:

$$Y(I) = \{H\}X(I) + \{G\}U(I) \quad (4.2)$$

The MEASUREMENT Equation:

$$Z(I) = \{H\}X(I) + \{G\}U(I) + V(I) \quad (4.3)$$

The CONTROL LAW:

$$U(I) = -\{F\}X(I) \quad (4.4)$$

Where:

- X(I) - State Vector
- Y(I) - Output Vector
- Z(I) - Measurement Vector
- WD(I) - White Process Noise Vector
- V(I) - White Measurement Noise Vector

The "WD" vector has zero mean value, and a covariance matrix {V1}, where

$$E(WD) = 0 \quad (4.5)$$

and

$$\{V1\} = E(WD \cdot WD^T) \quad (4.6)$$

The "V" vector has zero mean value, and a covariance matrix {V2}, where

$$E(V) = 0 \qquad (4.7)$$

and

$$\{V2\} = E(V \bullet V^T) \qquad (4.8)$$

The quadratic performance (or Cost) index for the linear quadratic regulator is the expected value of:

The COST EQUATION:

$$J = \lim_{N \to \infty} \sum_{I=0}^{N} \Big(X^T(I \bullet T)\{V1\}X(I \bullet T) + X^T(I \bullet T)\{S\}X(I \bullet T) \ldots$$
$$\ldots + U^T(I \bullet T)\{V2\}U(I \bullet T) \Big) \qquad (4.9)$$

E. MAIN PROGRAM

1. Error Suppression

VS FORTRAN has an extensive error message library. Program execution is terminated when the number of error messages generated exceeds the default value. In ORACLSX calls to ERRSET are made to allow unlimited "Overflow", "Underflow", and "Divide Check" error messages. When these errors occur the standard corrective fix-up takes place allowing program continuation. ERRSET calls were also made to prevent "Illegal Decimal Character" and "Dimension Check" error messages from terminating the program.

2. DATA Handling

Data input into the ORACLSX program can be done interactively, one matrix at a time, or all at once, using an OPTMAT/OPTMATD file.

a. System Parameters and Save Flags

If an old OPTMAT/OPTMATD file does not exist the program will prompt the user for the system parameters. The system parameters (number of states, number of controls, number of observations/measurements, number of process noise inputs) define the size of the system to be analyzed. If there is an OPTMAT/OPTMATD file available, the user will be given a choice as to how many of the old matrices are to be saved and used again. His choices are: 1) Use all of the old matrices, 2) Use some of the old matrices, 3) Input all new matrices. If the user selects to use none of the old matrices, the program will prompt for all of the system parameters. If he selects to use some or all of the old matrices, save flags will be set for those matrices that are to be saved. The program will now prompt for those system parameters that were previously zero and are now required.

b. OPTMAT AND OPTMATD DATA Files

ORACLSX can input system parameters and matrices from either the OPTMAT or OPTMATD data files. OPTMAT is used as input to ORACLSX's ORCONV option. OPTMATD is used as input for all other options. System parameters and matrices are read from the OPTMAT and OPTMATD files using the RDMAT and RDMATD subroutines, respectively. An OPTMAT file may be written by the WRTMAT subroutine if the user wants to save the continuous matrices input into the ORCONV option. An OPTMATD file may be written by the WRMATD subroutine at the end of all program options. The OPTMATD file will contain the discrete matrices generated by the program during that run as well as those matrices input by the user.

The OPTMAT file can be used for reruns through the ORCONV option or as input to the OPTSYSX program. The OPTMATD file can be used as input to any of ORACLSX's other options or as input to the TRANFUNC program.

3. Interactive Input

The subroutines READMX and READMD were developed to handle the input of the continuous and discrete matrices, respectively. Format statements for the desired matrix are selected using a matrix identification flag, IMAT, submitted to the subroutines.

The NULL, UNITY, and SCALE subroutines of ORACLS were adapted to READMX and READMD to have the program generate the corresponding matrix. This option relieves the user of the time consuming task of entering certain matrices an element at a time. For identity matrices or those with a large number of zero elements this proves to be a valuable feature. The generation of unity and unity scaled matrices is only available if the matrices are square.

The matrix input sections of READMX and READMD are modeled after those originally used in OPTSYSX. As in OPTSYSX the user has the ability to change any matrix element before program execution.

4. Program Required User Inputs

Three subroutines; RDREAL, RDINT, and RDCHAR were borrowed from OPTSYSX [Ref. 3: p. 20] to read in program required user inputs. Subroutine RDREAL is call to input the user's response at points where a real number or zero integer may be expected. Subroutine RDINT is called to input the user's response at any point where a non-zero integer may be expected. It is used to input all program option selections. Subroutine RDCHAR is used whenever a "(Y)es" or "(N)O" answer is required. RDCHAR was updated in ORACLSX to use the character variable available in VS FORTRAN. In ORACLSX and TRANFUNC, RDCHAR is used to read the first letter of the user's input. The user may enter "Y" or "YES", or "N" or "NO" as an acceptable responses.

In each of these three subroutines a protection feature is built in. The user may enter one "null" entry without program execution halting. If this happens, a warning message will be sent to the screen and the program will recover. Two "null" entrees in a row will produce an error message and terminate the program sending the user back to the controlling EXEC. This is a handy feature as it allows an escape from the program anywhere the user is prompted for an input. Also in these subroutines is a check for correct data type. If the data input by the user is not of the correct type, an error message is sent to the screen instructing the user to enter the correct type (i.e. real, integer, character).

F. PROGRAM CAPABILITIES

This section explains the analysis capabilities of the ORACLSX program. Figures 4.1 and 4.2 show ORACLS's main and Discrete System Analysis (ORDSAL) option menus.

```
1 -- ORCONV: ANALOG TO DIGITAL MATRIX CONVERSION
2 -- ORDSAL: DISCRETE SYSTEM ANALYSIS
3 -- ORTRAL: TRANSIENT ANALYSIS OF A DISCRETE SYSTEM
4 -- HELP:   PROGRAM & EQUATION DESCRIPTIONS
5 -- EXIT:   RETURN TO ORACLS EXEC
NOTE: SELECT OPTION - 5; IF YOU ARE USING THE OUTPUT
      TO DISK OPTION AND WANT TO CHANGE FILENAMES.
NOTE: NORMALLY ANY TIME DURING THE PROGRAM TWO
      SUCCESSIVE NULL "ENTERS" TERMINATES THE PROGRAM
      SENDING YOU BACK TO THE ORACLS EXEC.
            SELECT AN OPTION: 1,2, 3, 4, OR 5.
```

Figure 4.1 ORACLSX's Main Option Menu.

```
                  ORDSAL OPTIONS:
     1 -- KBFIL : DISCRETE KALMAN-BUCY FILTER ANALYSIS
     2 -- OPTREG: DISCRETE OPTIMAL REGULATOR ANALYSIS
     3 -- EXIT:   RETURN TO ORACLS OPTIONS
     4 -- EXIT:   RETURN TO ORACLS EXEC
          SELECT AN OPTION: 1, 2, 3, OR 4.
NOTE: NORMALLY ANY TIME DURING ANY PROGRAM TWO
      SUCCESSIVE NULL "ENTERS" TERMINATES THE PROGRAM
      SENDING YOU BACK TO THE ORACLS EXEC.
```

Figure 4.2 Discrete System Analysis Option Menu.

For each of the program options a recorded terminal session demonstrating that option is available as a separate appendix. The HELP option shown in Figure 4.1 will be discussed in Section F of this chapter.

The discrete analysis subroutines of ORACLS are used as the foundations for the options in ORACLSX. In the discussions to follow references will be made to the ORACLS manual [Ref. 1] where an in depth discussion of each subroutine is provided and original references cited therein.

1. <u>ORCONV Option</u>

a. Program Operation

The purpose of the ORCONV option of ORACLSX is to perform analog to digital matrix conversion. A user entering ORACLSX with the results from the OPTSYSX program or other continuous matrices must first convert the input data to discrete values. With the discrete matrices from ORCONV the rest of the ORACLSX options maybe exercised.

ORCONV conversion capabilities are as shown in Figure 4.3 Those listed in the OPTSYS column are continuous matrices and maybe converted to the discrete matrices listed in the ORACLS column. A discrete cross product weighting matrix, {S}, will be generated if the {A} and {B} continuous matrices are converted to the discrete {Q} and {R} matrices.

MATRIX DESCRIPTION	OPTSYS NAME	ORACLS NAME
SYSTEM MATRIX:	{F}	{A}
CONTROL MATRIX:	{G}	{B}
NOISE MATRIX:	{GAM}	{GAMD}
OUTPUT COST MATRIX:	{A}	{Q}
CONTROL COST MATRIX:	{B}	{R}
PROCESS NOISE MATRIX:	{Q}	{V1}
MEASUREMENT NOISE MATRIX:	{R}	{V2}
CROSS PRODUCT WEIGHTING MATRIX:		{S}

Figure 4.3 ORCONV Conversion Capabilities.

b. Input and Output Data Files

ORCONV will accept input from the screen or allow the use of an old OPTMAT data file. The OPTMAT file may be from a previous ORCONV run or one from the OPTSYSX program. ORCONV outputs the discrete matrices generated to an OPTMATD data file which may be used in the other ORACLSX options or the TRANFUNC program.

c. Solution Algorithms

Conversion of the matrices is carried out using the subroutines EXPINT [Ref. 1: pp. 49-50] and SAMPL [Ref. 1: pp. 61-63]. EXPINT is called for conversion of the

{F} matrix. Its results are also used for conversion of the {G} matrix. SAMPL is called to compute the {Q}, {R}, and {S} matrices. It is also called to compute the {V1} and {V2} matrices.

EXPINT's computations are done using finite-series algorithms [Ref. 1: p. 49]. SAMPL uses another set of finite-series algorithms [Ref. 1: p. 61] for its computations. Both subroutines can be effectively thought of as part of a sample and hold device. Figure 4.4 shows an example of how the A/D conversion may be done using a zero-order hold device and a sampler.

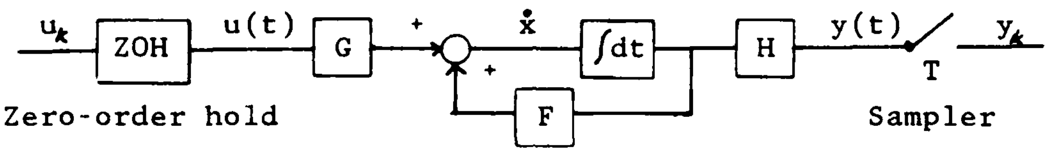


Figure 4.4 Model of the A/D Converter.

A signal is fed to the zero-order hold, (ZOH) device which "holds" the input signal for a time period equal to the sample time interval. From the ZOH the signal passes through the analog system to the sampler. Here the sampler "samples" the signal at the prescribed time interval "T" to produce a discrete signal. For ORCONV the sample time interval "T", is input by the user. Some texts refer to the sample time interval as "delta" or "delt". In this program in will be called, "delt" and in equations listed will be represented by "T".

d. ORCONV HELP

In the HELP option of ORACLSX, a section covering the ORCONV option is available. Information available there is included in Appendix A; "ORCONV Example Run".

e. Example Problem Run

To demonstrate the capabilities of the ORACLSX program an example problem from Linear Optimal Control Systems by Kwakernaak and Sivan [Ref. 2]. was used. The continuous-time positioning system of Example 2.4 [Ref. 2: pp. 133-136] is updated to a digitally controlled system in Example 6.2; 'Digital Positioning System' [Ref. 2: pp. 447-449]. The continuous-time matrices are converted to their discrete-time equivalents by the ORCONV option of ORACLSX.

Appendix A is a recording of the terminal session where the example problem data was used to exercise the ORCONV option of ORACLSX. The session begins with entry in to the CONTROLS analysis package. Here the ORACLS option is selected, placing the user in the ORACLS EXEC. From the ORACLS EXEC's options the ORACLSX FORTRAN program is selected. Before executing the ORCONV option, information comparing the OPTSYSX and ORACLSX programs is viewed. HELP information on the ORCONV program is also viewed at this time including a list of the equations used in the conversion process.

The terminal session continues as the system parameters are input defining the system. Selection of the sampling time interval is made and a status screen showing: the matrices to be converted, the sample time selected, and the system parameters, is generated. Input of the continuous matrices follows, with the user given an option to save them in an OPTMAT file. The continuous matrices input and the discrete matrices generated appear next. These are the discrete matrices as shown in equation 6-26 of [Ref. 1: p. 448]. At this point the user is given the option of saving the discrete matrices generated in an OPTMATD file. The ORCONV option is now complete and the user is sent back to ORACLSX's options from where the program is exited.

2. KBFIL Option

a. Program Operation

The purpose of KBFIL is to solve the discrete time-invariant asymptotic optimal Kalman-Bucy filter problem. The optimal filter problem is to construct an estimate of the state, X(I•T) from knowledge of the measurements, Y(I•T) and the control inputs, U(I•T) up to the time (I-1)•T.

Given the estimate of X, denoted as $\hat{X}$, the estimator equation is then written as:

$$\hat{X}(I+1) = \{A\}\hat{X}(I)+\{B\}U(I)+\{K\}(Y(I)-\{H\}\hat{X}(I)-\{G\}U(I)) \quad (4.10)$$

Solution of this problem produces the optimal filter gain matrix; {K}. Modification of format statements in ASYMFI was required. In all output statements referring to the filter gain matrix the "F" matrix was renamed the "K" matrix. All other output statements were updated to use the "V1", "V2", and "GAMD" nomenclature of ORACLSX.

b. Input and Output Data Files

KBFIL will accept input from the screen or allow use of an old OPTMATD data file. The OPTMATD file may be from a previous KBFIL run or from an ORCONV run. KBFIL outputs the computed optimal filter gain, "K" matrix, and input matrices to an OPTMATD file. This file may then be used as input to the OPTREG option which will generate the control gain matrix, "F". With these two gain matrices the Compensator analysis option of the TRANFUNC program may be exercised.

c. Solution Algorithms

Solution of the Kalman-Bucy filter problem is carried out using the ORACLS's ASYMFI subroutine. [Ref. 1:

pp. 94-99]. Duality of the Optimal Observer and the Optimal Regulator [Ref. 2: Sec 4.4] is employed in the solution, allowing ASYMFI to invoke the subroutine ASYMRE [Ref. 1: pp. 88-93] to solve the linear optimal regulator problem. In its solution of the regulator problem, ASYMRE calls the subroutine RICTNW which solves the discrete steady-state Riccati equation by the Newton Algorithm [Ref. 1: pp. 84-87].

d. KBFIL HELP

In the HELP option of ORACLSX, a section covering the KBFIL option is available. Information available there is included in Appendix B; "KBFIL Example Run".

e. Example Problem Run

The Kwakernaak and Sivan discrete control example problem data, previously discussed in the ORCONV option, was used to demonstrate the KBFIL option. Appendix B is a recording of a terminal session demonstrating the KBFIL option. It uses input from the OPTMATD data file in conjunction with new data for those matrices not previously generated. The session starts with the KBFIL HELP information. Menu screens for the Manage EXEC, and ORACLS EXEC are not shown in this session as they are duplicates of those in the beginning of the ORCONV Example Run, and may be viewed in Appendix A. Menu screens for exiting the program have also been deleted here as they are identical to those in Appendix A.

3. <u>OPTREG Option</u>

a. Program Operation

The purpose of OPTREG is to solve the discrete time-invariant asymptotic linear optimal regulator problem with noise free measurements. Solution to the problem yields the Control Gain Matrix; {F}. If the system is controlable and observable, a solution exists and is given by.

$$\{F\} = \{\{R\}+\{B\}^T\{P\}\{B\}\}^{-1}\{B\}^T\{P\}\{A\} \qquad (4.11)$$

where

$$\{P\} = \{M\}^T\{P\}\{M\}+\{F\}^T\{R\}\{F\}+\{H\}^T\{Q\}\{H\} \qquad (4.12)$$

with

$$\{M\} = \{A\}-\{B\}\{F\} \qquad (4.13)$$

During program operation the user is asked whether the system is stable or unstable. If an unstable response is entered, the matrix {A-BF} is evaluated and tested for stability relative to Alpha = .9 using the subroutine TESTST [Ref. 1: pp. 43-44]. If a stabilizing gain is required, it is computed in the subroutine DSTAB [Ref. 1: pp. 70-73].

OPTREG is set up to handle a system with or without a discrete cross product weighting matrix; {S}. If a cross product matrix is present the system will calculate a new gain matrix; {FE}, which will eliminate the cross product term in the quadratic scalar function. With the gain matrix {FE}, new "HAT" matrices are computed for use in the system equation and quadratic scalar function. These modified equations are then used and the control gain matrix; {F}, is calculated. Also output is the "FHAT" matrix which contains the control gains for the "HAT" system. If no cross product term exists, then {FHAT} = {F}.

b. Input and Output Data Files

OPTREG will accept input from the screen or allow use of an old OPTMATD data file. The OPTMATD file may be from a previous KBFIL, OPTREG, or ORCONV run. OPTREG outputs the computed optimal filter gain; "F" matrix, and input matrices to an OPTMATD file. This file may then be used as input to the transfer function analysis options available in the TRANFUNC program.

c. Solution Algorithms

The linear optimal regulator problem is solved using ORACLS's ASYMRE subroutine [Ref. 1: pp. 88-93]. ASYMRE inturn solves the discrete steady-state Riccati equation using the Newton algorithm of subroutine RICTNW [Ref. 1: pp. 84-87].

d. OPTREG HELP

In the HELP option of ORACLSX, a section covering the OPTREG option is available. Information available there is included in Appendix C; "OPTREG Example Run".

e. Example Problem Run

Kwakernaak and Sivan example 6.14 [Ref. 2: p. 494] is a continuation of Example 6.2 [Ref. 2], used in the ORCONV Example Run, and is used here to demonstrate the OPTREG option of ORACLSX. Appendix C is a recording of a terminal session demonstrating the OPTREG option. It uses input from the OPTMATD data file in conjunction with new data for those matrices not previously generated. The session starts with the OPTREG HELP information. Menu screens for the Manage EXEC, and ORACLS EXEC are not shown in this session as they are duplicates of those in the beginning of the ORCONV Example Run, and may be viewed in

Appendix A. Menu screens for exiting the program have also been deleted here as they are identical to those in Appendix A.

4. ORTRAL Option

a. Program Operation

The ORTRAL option of ORACLSX computes and prints the transient response of the time-invariant discrete system out to a desired number of stages. One stage is equal to the sampling time interval. Given a set of initial conditions; X(0), the transient response is calculated using the following:

System Equation:

$$X(I+1) = \{A\}X(I) + \{B\}U(I) \qquad (4.14)$$

Output Equation:

$$Y(I) = \{H\}X(I) + \{G\}U(I) \qquad (4.15)$$

Control Law:

$$U(I) = -\{F\}X(I) + UC(I) \qquad (4.16)$$

Where UC is the Control Input (Driving Function) and may be selected as either a Step or Ramp. Selection of the start and stop stages for the control input are selected by the user. The user is also given the option of individually selecting those control variables which he desires to drive. Normally five lines of output are generated for each stage computed. An option was added to allow the user to select only a desired number of stage results for terminal viewing. This option prevents the user from having to spend time needlessly clearing the screen when a large number of stages is used. This option does not limit the program output to the OPTPLOT data file. A transient response plot for the entire number of stages is still possible.

During program operation the user is asked whether the system is stable or unstable. If a stable response is entered, ORTRAL will compute and output the steady state value.

b. Input and Output Data Files

ORTRAL will accept input from the screen or allow use of an old OPTMATD data file. The OPTMATD file may be from a previous OPTREG or ORTRAL run. ORTRAL outputs to the OPTMATD data file the system parameters and input matrices. No results generated by the program are output to the OPTMATD file. Transient response results of the states and controls are output to the OPTPLOT data file. The OPTPLOT FORTRAN program, available in the ORACLS EXEC, uses this file. It gives the user the option of obtaining the results in graphical format.

c. Solution Algorithms

Transient response calculations are carried out using ORACLS's TRANSI subroutine [Ref. 1: pp.57-59]. Several modifications were necessary to TRANSI to incorporate the different driving functions and selectivity of controls to be driven. Output format changes were also necessary to conform to the ORACLSX nomenclature. The input control; UC was added to the list of outputs, to allow viewing of the changes in the driving function.

d. ORTRAL HELP

In the HELP option of ORACLSX, a section covering the ORTRAL option is available. Information available there is included in Appendix D; "ORTRAL Example Run".

e. Example Problem Run

Kwakernaak and Sivan example 6.13 [Ref. 2: p. 490] was used to demonstrate the ORTRAL option. It is a continuation of the digital positioning system problem of Example 6.2 [Ref. 2], discussed previously in the ORCONV example run.

Appendix D is a recording of a terminal session demonstrating the ORTRAL option. It uses input from the OPTMATD file inconjunction with control gains input separately. The session starts with the ORTRAL HELP information. Menu screens for the Manage EXEC, and ORACLS EXEC are not shown in this session as they are duplicates of those in the beginning of the ORCONV Example Run, and may be viewed in Appendix A. Menu screens for exiting the program have also been deleted here as they are identical to those in Appendix A.

Figures 4.5 and 4.6 show ORTRAL's results for the example problem as generated by the OPTPLOT FORTRAN program. They are included for comparison with those of Figure 6.12 [Ref. 1: p. 491].

G. HELP

Figure 4.7 shows the HELP feature available in ORACLSX. The menu gives the user the option of obtaining hardcopy of the information selected for viewing. HELP is meant to provide the user with sufficient insight into program operation, nomenclature, and solution methods used. It does not provide a detailed discussion of the ORACLS subroutines used and their solution techniques. An interested user should obtain ORACLS [Ref. 1] and refer to the "Solution Algorithms" discussions available in the earlier portions of this chapter.

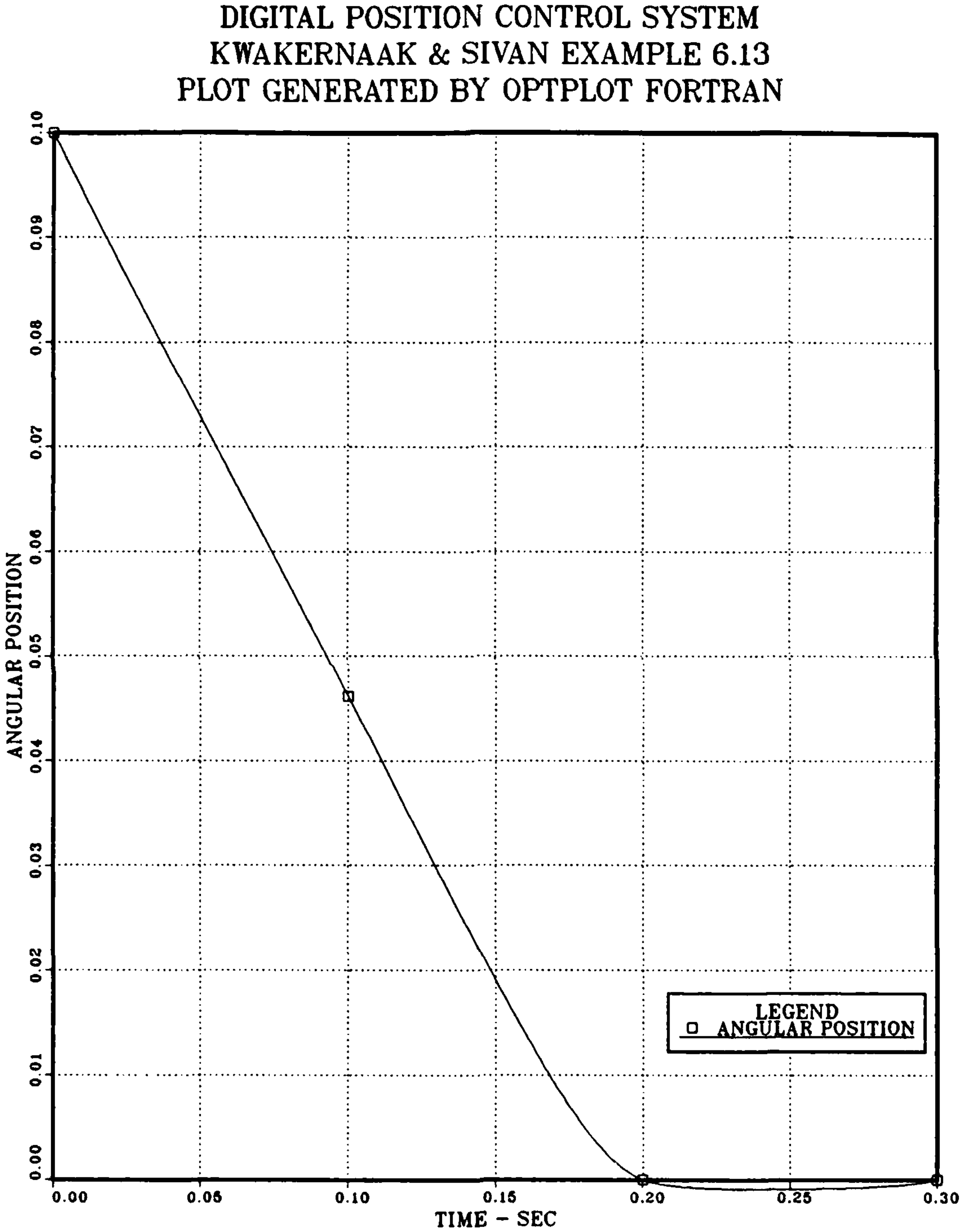


Figure 4.5 ORTRAL Example Run Plot #1.

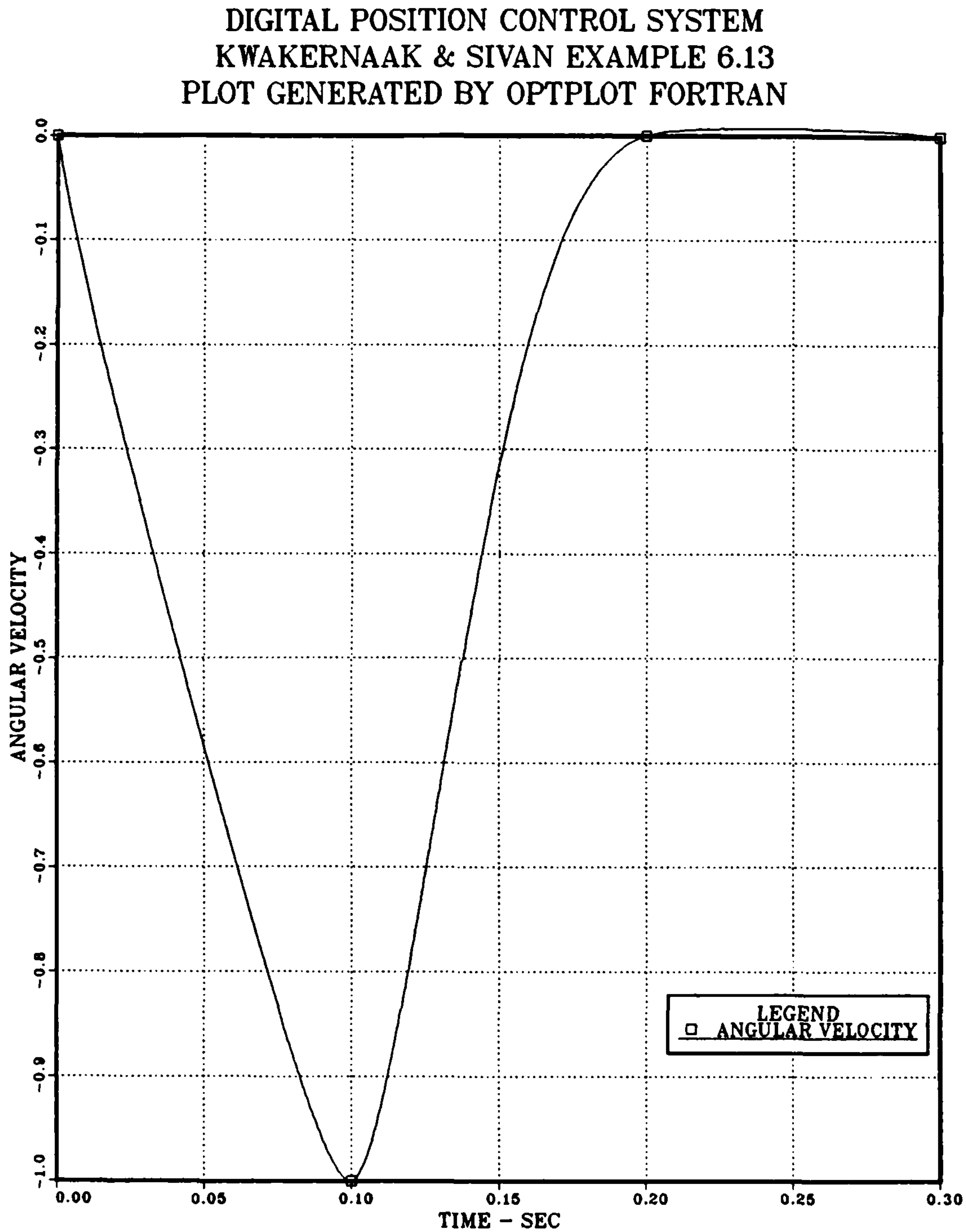


Figure 4.6 ORTRAL Example Run Plot #2.

Information available in HELP has been included in the terminal sessions which demonstrate the program options. See Appendices A-D.

```
"HELP" PROVIDES AN OVERVIEW OF THE PROGRAM OPTIONS
 AVAILABLE IN  "ORACLS"  AND SOME OF THE EQUATIONS
 USED IN THE CALCULATIONS.

 1 -- TERMINAL VIEWING OF SELECTED INFORMATION

 2 -- TERMINAL VIEWING PLUS HARDCOPY TO YOUR "A" DISK

 3 -- EXIT: RETURN TO THE ORACLS OPTIONS

NOTE:  OPTION "2" WILL PLACE THE FILE: "ORACLS HELP"
       ON YOUR "A" DISK CONTAINING THE SELECTED
       INFORMATION THAT YOU HAVE VIEWED.

             SELECT OPTION: 1, 2, OR 3
```

Figure 4.7   ORACLSX HELP Control Menu.

V. THE TRANFUNC FORTRAN PROGRAM

A. PROGRAM OVERVIEW

TRANFUNC is an interactive discrete transfer function analysis program. It features modular programing and double precision computations. Its main program is menu driven and controls four major analysis options. Additional options provide the user with HELP information or allow the MARKOV parameter to be changed (See Section E.5).

TRANFUNC operates under the VS FORTRAN programing language. It makes extensive use of VS's "Character" variable and Block IF statements. Program dimensions are similar to those in ORACLSX and have been set to handle systems with up to 32 states, 10 controls, 10 measurements/observations, and 10 noise inputs. For information on its capability to handle larger systems, see Chapter IV, Section A.

B. INCORPORATION OF ORACLS AND OPTSYS SUBROUTINES

System parameter and matrix handling subroutines used in TRANFUNC are from ORACLS and ORACLSX. Updating was required for the ORACLSX subroutines; SYSPAR, RMATFD, and INPUT, to handle the TRANFUNC options. Subroutines used in the transfer function analysis are from OPTSYSX. Formating changes were required in subroutines CNORM and MODE to maintain the discrete nomenclature used in ORACLSX.

C. TRANFUNC'S NOMENCLATURE

The discrete system nomenclature of ORACLS [Ref. 1] was maintained wherever possible in TRANFUNC. An exception was the {GAMD} matrix. {A} is the System, Plant, or State Weighting Matrix. {B} is the Control Weighting Matrix. {GAMD} is the Process Noise Weighting Matrix. The {H} Matrix is the Weighting of the Observations. {G} is the Measurement-Feed Forward Distribution Matrix. {F} is the Control Gain Matrix. {K} is the Filter Gain Matrix.

D. SYSTEM/TRANSFER FUNCTION DESCRIPTIONS

TRANFUNC works with discrete time systems. It bases its analysis on difference equations. In the following difference equations, "T" is the Sample Time Interval.

The SYSTEM Equation:

$$X((I+1)\cdot T) = \{A\}X(I\cdot T) + \{B\}U(I\cdot T) + \{GAMD\}WD(I\cdot T) \quad (5.1)$$

The OUTPUT Equation:

$$Y(I) = \{H\}X(I) + \{G\}U(I) \quad (5.2)$$

The MEASUREMENT Equation:

$$Z(I) = \{H\}X(I) + \{G\}U(I) + V(I) \quad (5.3)$$

Where:

X(I) - State Vector
Y(I) - Output Vector
Z(I) - Measurement Vector
WD(I) - White Process Noise Vector
V(I) - White Measurement Noise Vector

For more discussion of the equations and variables see Chapter 4, Section D.

TRANFUNC does its transfer function analysis in the z domain. Its transfer functions are as follows:

Open Loop Transfer Function

$$Z/U = \{H\}\{\ z\{I\}-\{A\}\ \}^{-1}\{B\} \qquad (5.4)$$

Noise Transfer Function

$$Z/U = \{H\}\{\ z\{I\}-\{A\}+\{B\}\{F\}\ \}^{-1}\{GAMD\} \qquad (5.5)$$

Compensator Transfer Function

$$U/Z = \{H\}\{\ z\{I\}-\{A\}+\{B\}\{F\}+\{K\}\{H\}\ \}^{-1}\{K\} \qquad (5.6)$$

E. MAIN PROGRAM

1. Error Suppression

VS FORTRAN has an extensive error message library. Program execution is terminated when the number of error messages generated exceeds the default value. In TRANFUNC calls to ERRSET are made to allow unlimited "Overflow", "Underflow", and "Divide Check" error messages. When these errors occur the standard corrective fix-up takes place allowing program continuation. ERRSET calls were also made to prevent "Illegal Decimal Character" and "Dimension Check" error messages from terminating the program.

2. DATA Handling

Data input into the TRANFUNC program can be done interactively, one matrix at a time, or all at once, using an OPTMATD file.

a. System Parameters and Save Flags

If an old OPTMATD file does not exist the program will prompt the user for the system parameters. The system parameters (number of states, number of controls, number of observations/measurements, number of process noise inputs) define the size of the system to be analyzed. If there is an OPTMATD file available, the user will be given a choice as to how many of the old matrices are to be saved and used again. His choices are: 1) Use all of the old matrices, 2) Use some of the old matrices, 3) Input all new matrices. If the user selects to use none of the old matrices, the program will prompt for all of the system parameters. If he selects to use some or all of the old matrices, save flags will be set for those matrices that are to be saved. The program will now prompt for those system parameters that were previously zero and are now required.

b. The OPTMATD DATA File

TRANFUNC can input the system parameters and matrices from an OPTMATD data file.System parameters and matrices are read from the OPTMATD file using the RDMATD subroutine. A OPTMATD file may be written by the WRMATD subroutine at the end of all program options. The OPTMATD file will contain only the discrete matrices input by the user during that run as all results are sent to the screen/ listing file and the OPTGRAPH data files; OPTGROL, OPTGRNO, OPTGRCM.

The OPTMATD file can be used as input to any of TRANFUNC's options or as input to the ORACLSX program. The OPTGRAPH data files can be input to the OPTGRAPH FORTRAN program to obtain pole-zero plots and root-locus plots for the respective transfer functions.

3. Interactive Input

The subroutine READMD, developed for ORACLSX, is used to handle the input of the matrices. Format statements for the desired matrix are selected using a matrix identification flag, IMAT, submitted to the subroutine by the calling program.

The NULL, UNITY, and SCALE subroutines of ORACLS were adapted to READMD to have the program generate the corresponding matrix. This option relieves the user of the time consuming task of entering certain matrices an element at a time. For identity matrices or those with a large number of zero elements this proves to be a valuable feature. The generation of unity and unity scaled matrices is only available if the matrices are square. The user is given the chance to change any matrix element before program execution.

4. <u>Program Required User Inputs</u>

Three subroutines; RDREAL, RDINT, and RDCHAR were borrowed from OPTSYSX [Ref. 3: p. 20] to read in program required user inputs. Subroutine RDREAL is call to input the user's response at points where a real number or zero integer may be expected. Subroutine RDINT is called to input the user's response at any point where a non-zero integer may be expected. It is used to input all program option selections. Subroutine RDCHAR is used whenever a "(Y)es" or "(N)O" answer is required. RDCHAR was updated in ORACLSX to use the character variable available in VS FORTRAN. In ORACLSX and TRANFUNC, RDCHAR is used to read the first letter of the user's input. The user may enter "Y" or "YES", or "N" or "NO" as an acceptable responses.

In each of these three subroutines a protection feature is built in. The user may enter one "null" entry without program execution halting. If this happens, a warning message will be sent to the screen and the program will recover. Two "null" entrees in a row will produce an error message and terminate the program sending the user back to the controlling EXEC. This is a handy feature as it allows an escape from the program anywhere the user is prompted for an input. Also in these subroutines is a check for correct data type. If the data input by the user is not of the correct type, an error message is sent to the screen instructing the user to enter the correct type (i.e. real, integer, character).

F. PROGRAM CAPABILITIES

This section explains the analysis capabilities of TRANFUNC. Figure 5.1 shows TRANFUNC's main option menu. Discussions of each of the options listed in the menu will follow. Discussions will cover; the data files output by the different options, the solution algorithms used, and the use of an example problem to demonstrate each option. All analysis options listed in Figure 5.1 allow input from the screen or from an old OPTMATD data file. The OPTMATD file may be from a previous TRANFUNC run or from the ORACLSX program. All options allow the user to create an OPTMATD data file at the end of program analysis. This file will save only the discrete matrices entered into the program. No matrices generated in the program are written to the OPTMATD file. Results to be used in the graphing options of the ORACLS EXEC are output to the OPTGRAPH data files. They will be discussed in the individual option discussions.

1. Open-Loop Eigensystem Analysis, {A} Matrix

a. Program Operation

Option 1 performs eigenvalue analysis on the system matrix, {A}. {A} is a square matrix dimensioned, (NS,NS). "NS" eigenvalues will be found and printed out. Eigenvalues may be real or complex. The open-loop right eigenvector matrix; {T}, and open-loop left eigenvector matrix; $\{T\}^{-1}$, are also printed out.

```
                TRANFUNC OPTIONS:
1 - OPEN-LOOP EIGENSYSTEM ANALYSIS ONLY, {A} MATRIX
2 - OPEN-LOOP TRANSFER FUNCTION & EIGENSYSTEM
3 - NOISE TRANSFER FUNCTION & CLOSED-LOOP EIGENSYSTEM
4 - COMPENSATOR TRANSFER FUNCTION & ESTIMATOR EIGENSYS
5 - MARKOV PARAMETER CHANGE
6 - HELP -- PROGRAM DESCRIPTION
7 - EXIT -- RETURN TO ORACLS EXEC
SELECT OPTION: 1, 2, 3, 4, 5, 6, 7;  (SETS ITFOL FLAG)
  NOTE: MODAL ANALYSIS AVAILABLE IN OPTIONS: 2, 3, 4
```

Figure 5.1 TRANFUNC Option Menu.

b. Output Data Files

This option outputs the system parameters and eigenvalues to the OPTGRAPH file; OPTGROL data.

c. Solution Algorithms

Analysis of the eigensystem is carried out using the following subroutines from OPTSYSX [Ref. 3]: BALANC, ORTHES, ORTRAN, EREXIT, and BALBAK. The OPTSYSX subroutine CNORM, updated to the discrete nomenclature and retitled DCNORM is also used.

d. Example Problem Run

To demonstrate the eigensystem analysis option of TRANFUNC, the Kwakernaak and Sivan discrete control example problem, discussed in ORACLSX, was used again. Appendix E is a recording of the terminal session where the example problem data was used to demonstrate the eigensystem analysis option. Also included there is a copy of the HELP information available in the TRANFUNC program.

2. Open-Loop Transfer Function Analysis

Figure 5.2 shows the Open-Loop Transfer Function option menu. It contains the open-loop transfer function equation and available analysis options. The user is informed here that to use the OPTGRAPH plotting program requires the selection of either option 1 or 2. Also pointed out are the nonzero requirements for the system parameters "NC" and "NO", the number of controls and number of observations/measurements respectively.

```
            OPEN-LOOP TRANSFER FUNCTION OPTIONS:
               Z/U = {H}*{ z{I}-{A} }INV*{B}
      OPTION 1 -- POLES, RESIDUES, AND ZEROS COMPUTED
      OPTION 2 -- ONLY POLES AND ZEROS COMPUTED
      OPTION 3 -- ONLY POLES AND RESIDUES COMPUTED
      OPTION 4 -- EXIT -- RETURN TO TRANFUNC OPTIONS
      SELECT OPTION: 1, 2, 3, OR 4   (SETS ITF1=1,2,OR,3)
        NOTE: POLES AND ZEROS MUST BE SELECTED IF YOU
              WISH TO USE OPTGRAPH.
        NOTE: REQUIRES NC>0, NO>0
```

Figure 5.2 Open-Loop Transfer Function Options.

a. Program Operation

The user selects the desired option from the menu and program execution begins with input of the system parameters. Input of the required matrices follows next. At this point the user is prompted as to whether or not to have the modal distribution and gain matrices determined. Modal matrices can be used to determine the controlability and the observability/reconstructability of the system. Modal matrices are further explained in Section 7 to follow.

b. Output Data Files

The open-loop transfer function option outputs the system parameters, eigenvalues, transfer function gain, and order of the numerator to the OPTGRAPH file; OPTGROL data. This file may now be used in the OPTGRAPH FORTRAN program to obtain Pole-Zero and Root-Locus plots. Figures 5.3 and 5.4 show OPTGRAPH's output for the open-loop transfer function.

c. Solution Algorithms

The eigenvalue analysis for the open-loop transfer function option is carried out using the same subroutines mentioned in the discussion of the eigensystem analysis option. All eigen values are checked for system stability after being computed. If an eigenvalue falls outside the unit circle in the z plane, the system is unstable. In this case a statement of the system's instability is sent to the screen and the transfer function analysis is bypassed.

Transfer function analysis is carried out by OPTSYSX's subroutine TF. Option control flags ITFX and ITF2 indicate to TF the type of transfer function and the analysis desired. Subroutines POLES, ZEROS and RESID are called from TF to perform the analysis indicated by the flags.

d. Example Problem Run

The Kwakernaak and Sivan example problem is used to demonstrate the open-loop transfer function option.

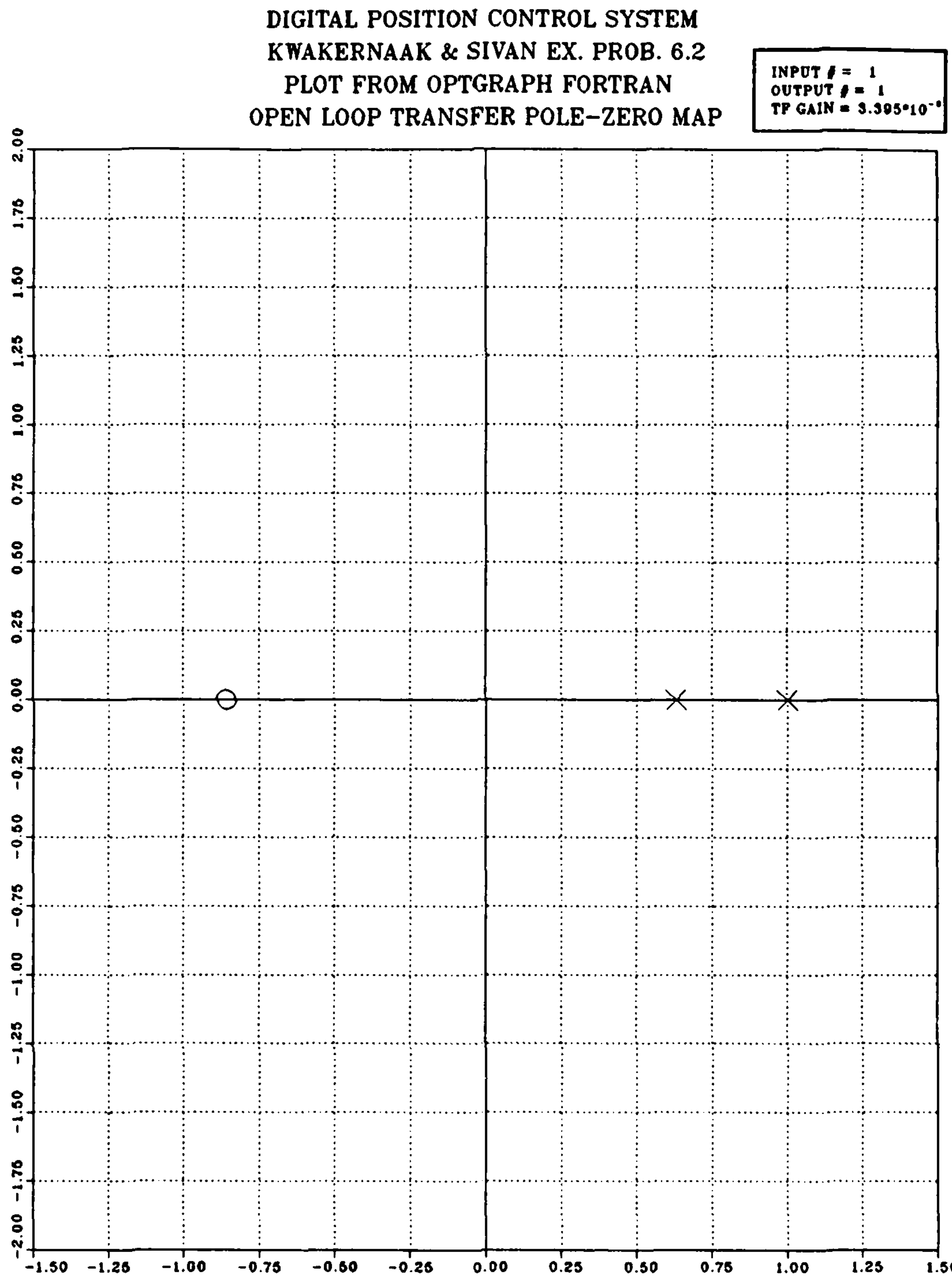


Figure 5.3 TRANFUNC Example Run #2, Plot #1.

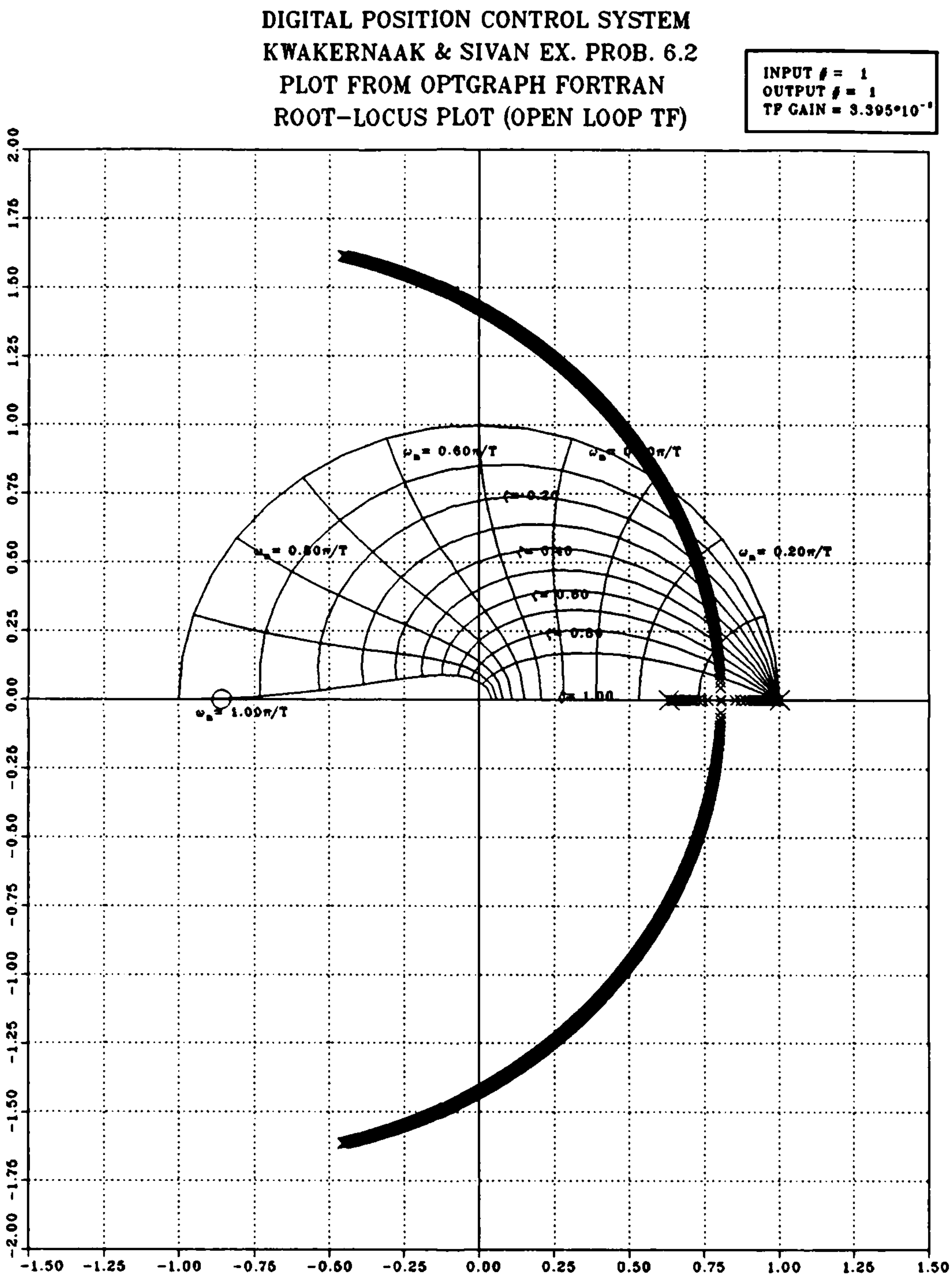


Figure 5.4 TRANFUNC Example Run #2, Plot #2.

Appendix F is a recording of a terminal session demonstrating this option with the example problem data. Figures 5.3 and 5.4 are the pole-zero and root-locus plots from OPTGRAPH for the example problem data.

3. Noise Transfer Function Analysis

a. Program Operation

Figure 5.5 shows the Noise Transfer Function option menu. It includes the noise transfer function equation and analysis options available. "Notes" are present in Figure 5.5 to remind the user of program restrictions and requirements germane to noise transfer function analysis.

Program operation proceeds as in the open-loop case. Open-loop eigenvalues are calculated and the modal matrices are computed if desired. The closed-loop regulator dynamics matrix, {A-BF}, is formed, and eigensystem analysis for the closed-loop follows. The closed-loop right eigenvector matrix, {M} and closed-loop optimal regulator left eigenvector matrix, $\{M\}^{-1}$, are computed. All eigenvalues are compared to the unit circle for system stability. Instability statements are issued if required and the transfer function analysis bypassed. Transfer function analysis is as discussed in the open-loop transfer function discussions.

b. Output Data Files

The noise transfer function option outputs the system parameters, eigenvalues, transfer function gain, and order of the numerator to the OPTGRAPH file; OPTGRNO data. This file may now be used in the OPTGRAPH FORTRAN program to obtain Pole-Zero and Root-Locus plots for the noise transfer function.

```
NOISE TRANSFER FUNCTION OPTIONS:
   Z/U = {H}*{ z{I}-{A}+{B}*{F} }INV*{GAMD}
OPTION 1 -- POLES, RESIDUES, AND ZEROS COMPUTED
OPTION 2 -- ONLY POLES AND ZEROS COMPUTED
OPTION 3 -- ONLY POLES AND RESIDUES COMPUTED
OPTION 4 -- EXIT -- RETURN TO TRANFUNC OPTIONS
SELECT OPTION 1, 2, 3, OR 4    (SETS ITF2 = 1,2,3)
NOTE: NOISE TF FUNCTION THRU CLOSED LOOP SYSTEM;
NOTE:  POLES AND ZEROS MUST BE SELECTED IF YOU
       WISH TO USE OPTGRAPH.
NOTE:  REQUIRES NC>0, NO>0, NG>0
```

Figure 5.5 Noise Transfer Function Options.

c. Solution Algorithms

Analysis of the open-loop and closed-loop eigensystems analyzed in this option is done using the subroutines described in the open-loop transfer function discussion. Transfer function analysis is again carried out using the subroutine TF. This time the flags ITFX and ITF3 are used to indicate the noise transfer function and desired analysis. Subroutines POLES, ZEROS and RESID are called in TF to perform the desired analysis.

d. Example Problem Run

The Kwakernaak and Sivan example problem is used to demonstrate the noise transfer function option. Appendix G is a recording of a terminal session demonstrating this option with the example problem data.

4. Compensator Transfer Function Analysis

a. Program Operation

Figure 5.6 shows the Compensator Transfer Function option menu. It includes the compensator transfer function equation and analysis options available. "Notes" are present in Figure 5.6 to remind the user of program restrictions and requirements germane to compensator transfer function analysis.

Program operation proceeds in a manner similar to the noise transfer function analysis. The open loop eigenvalues are calculated and the modal matrices are computed if desired. Then the closed-loop filter dynamics matrix, {A+KH} is formed. Eigensystem analysis of the estimator follows. The closed-loop right eigenvector matrix, {M}, the measurement eigenvector, {H(BAR)*M}, and the closed-loop optimal filter left eigenvector matrix, $\{M\}^{-1}$, are computed. All eigenvalues are compared to the unit circle for system stability. Instability statements are issued if required and the transfer function analysis bypassed. Transfer function analysis is carried out and the results printed as described in the the open-loop discussion.

b. Output Data Files

The compensator transfer function option outputs the system parameters, eigenvalues, transfer function gain, and order of the numerator to the OPTGRAPH file; OPTGRCM data. This file may now be used in the OPTGRAPH FORTRAN program to obtain Pole-Zero and Root-Locus plots for the compensator transfer function.

```
COMPENSATOR TRANSFER FUNCTION OPTIONS:
U/Z = -{F}*{ z{I}-{A}+{B}*{F}+{K}*{H} }INV*{K}
OPTION 1 -- POLES, RESIDUES, AND ZEROS COMPUTED
OPTION 2 -- ONLY POLES AND ZEROS COMPUTED
OPTION 3 -- ONLY POLES AND  RESIDUES COMPUTED
OPTION 4 -- EXIT -- RETURN TO TRANFUNC OPTIONS
SELECT OPTION 1, 2, 3, OR 4    (SETS ITF3 = 1,2,3)
NOTE: COMPENSATOR TRANSFER FUNCTION ABOVE IS FROM
      MEASUREMENT TO INPUT.
NOTE: A COMPENSATOR TRANSFER FUNCTION MAY BE COMPUTED
      ONLY IF BOTH THE REGULATOR {F} AND FILTER {K}
      GAINS ARE AVAILABLE. THEY MAY BE CALCULATED IN
      THE "OPTREG" AND "KBFIL" PROGRAMS.
NOTE: POLES AND ZEROS MUST BE SELECTED IF YOU WISH TO
      USE OPTGRAPH.
NOTE: REQUIRES NC>0, NO>0
```

Figure 5.6 Compensator Transfer Function Options.

c. Solution Algorithms

Analysis of the open-loop and estimator eigensystems in this option is done using the subroutines described previously discussed. Transfer function analysis is via the subroutine TF. This time the flags ITFX and ITF4 are used to indicate the compensator transfer function and desired analysis. Subroutines POLES, ZEROS and RESID are called in TF to perform the desired analysis.

d. Example Problem Run

The Kwakernaak and Sivan example problem is used to demonstrate the compensator transfer function option. Appendix H is a recording of a terminal session demonstrating this option with the example problem data.

5. <u>The MARKOV Parameter</u>

```
THIS OPTION DETERMINES THE CRITERIA FOR DECIDING WHEN
A MARKOV PARAMETER IS ZERO. THE MARKOV PARAMETER
INDICATES THE ORDER OF THE NUMERATOR POLYNOMIAL OF
EACH TRANSFER FUNCTION.

 ALL "N" ZEROS OF THIS POLYNOMIAL ARE PRINTED OUT AND
 THIS TEST TELLS HOW MANY EXTRA ROOTS EXIST AT Z = 0.
 LESS THAN 10.0**{-IE} IS CONSIDERED ZERO.

   THE DEFAULT VALUE OF THIS PARAMETER {IE} IS 6.
   IN OTHER WORDS, IE = 1.0E-6.

    IF YOU DESIRE A DIFFERENT MARKOV CRITERIA,
           ENTER THE INTEGER VALUE.

    IF YOU DESIRE THE DEFAULT VALUE, TYPE "6"
```

Figure 5.7 MARKOV Parameter Option.

6. <u>HELP</u>

Figure 5.8 shows the HELP feature available in TRANFUNC. The menu gives the user the option of obtaining a hardcopy of the information selected for viewing. Information available in HELP has been included in the terminal session for the eigensystem analysis. See Appendix E.

7. <u>Modal Matrices</u>

In all of the transfer function analysis options of TRANFUNC the user may select to have the modal matrices computed. Modal matrices can be used in determining whether a system is controllable and observable/reconstructable. If the modal control distribution matrix, {TI•B} has no zero elements, the system is completely controllable. If the

```
"HELP" PROVIDES AN OVERVIEW OF THE PROGRAM OPTIONS
 AVAILABLE IN  "TRANFUNC"  AND SOME OF THE EQUATIONS
 USED IN THE CALCULATIONS.

 1 -- TERMINAL VIEWING OF SELECTED INFORMATION

 2 -- TERMINAL VIEWING PLUS HARDCOPY TO YOUR "A" DISK

 3 -- EXIT: RETURN TO THE TRANFUNC OPTIONS

NOTE:  OPTION "2" WILL PLACE THE FILE: "TRANFUNC HELP"
       ON YOUR "A" DISK CONTAINING THE SELECTED
       INFORMATION THAT YOU HAVE VIEWED.

             SELECT OPTION: 1, 2, OR 3
```

Figure 5.8 TRANFUNC HELP Control Menu.

modal measurement scaling matrix, {H(BAR)•T} has no zero elements, the system is completely observable/ reconstructable. With these matrices computed the user can tell at a glance whether the system is controllable and observable with respect to any state/input.

VI. SPECIAL USE CAPABILITIES OF ORACLS

The ORACLSX and TRANFUNC programs were designed with modular programing in mind. They have a main program which calls the selected analysis subroutine after system parameters and input data have been entered. This type of setup allows an interested user the freedom to develop an analysis subroutine suited to a particular problem. This new subroutine could then be added to the main program as an additional option. System parameters and data input/output handling would still be handled by the main program. ORACLS's [Ref. 1] support and analysis subroutines could be used to develop this subroutine. This would minimize development time and any interface problems. Additional subroutines could be added as needed once interface problems were worked out.

This capability is being used by a student working on a Masters Thesis in the area of self healing control systems at the Naval Postgraduate School, Monterey, California. It required a program which would input a large group of continuous matrices, discretize them, and then combine them into matrices appropriate for analysis in ORACLS. The program was easily put together using the matrix handling subroutines of ORACLSX and ORACLS. Flexibility such as this gives ORACLS unlimited potential in the design and analysis of discrete control systems.

VII. CONCLUSIONS

The advent of the digital computer and the microprocessor has moved the study and design of digital control systems to the forefront of control engineering. Control engineers and students are continually in need of computer programs to handle the analysis of discrete systems. The ORACLSX and TRANFUNC programs developed in this thesis give just such a capability to the CONTROLS analysis package. These programs when used in conjunction with the OPTSYSX program [Ref. 3], provide the user with the ability not only to handle analysis of continuous and discrete systems, but to be able to move from one to the other. Results from ORACLSX and TRANFUNC are compatible with the OPTPLOT [Ref. 5] and OPTGRAPH [Ref. 4] programs. This allows a graphical displaying of the program results, a feature highly desirable in the study and design of controls systems.

A few example problems were used to test program operation and the accuracy of generated results. All tests produced favorable and accurate results. The user is cautioned, however that the programs developed in this thesis may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

APPENDIX A

ORCONV EXAMPLE RUN

```
BEGIN RECORDING OF TERMINAL SESSION
R; T=0.01/0.02 20:37:19
-----------------------------------------------------------
controls
-----------------------------------------------------------
DASD 200 LINKED R/O; R/W BY 0637P
C (200) R/O
-----------------------------------------------------------
   PLOTTING IS DONE THRU DISSPLA. UP TO 20% OF YOUR DISK
       SPACE MAY BE NEEDED OTHERWISE ERROR MESSAGES
***********************************************************

     CONTROLS CONSISTS OF THREE INTERACTIVE PROGRAMS

          1  DACSAP       (SISO)
          2  OPTSYS       (MIMO)
          3  ORACLS       (MIMO)

          4  HELP - PROGRAM DESCRIPTIONS
          5  SAMPLE PROBLEMS WITH PROGRAM DIRECTIONS
          6  PROGRAM DOCUMENTATION SOURCES
          7  EXIT

          ENTER  1 ,  2 ,  3 ,  4 ,  5 ,  6,  OR  7
***********************************************************

NORMALLY IN ANY FORTRAN PROGRAM TWO NULL ENTREES TERMINATE
  THE PROGRAM SENDING YOU BACK TO THE CONTROLLING EXEC

3
-----------------------------------------------------------
'251' REPLACES ' F (251) '
F (251) R/O
'251' REPLACES ' F (251) '
F (251) R/O
-----------------------------------------------------------

****** THE ORACLS EXEC ALLOWS THE FOLLOWING OPTIONS: ******

1  ORACLSX FORTRAN: --------DISCRETE SYSTEM ANALYSIS-------
                   (A-D CONVERSION, OPT. REG., KALMAN-BUCY
                    FILTER AND DISCRETE TRANSIENT ANALYSIS)

2  TRANFUNC FORTRAN: -DISCRETE TRANSFER FUNCTION ANALYSIS-
                     (SYSTEM EIGENVALUES, OPEN LOOP, NOISE,
                     AND COMPENSATOR T.F.s, MODAL MATRICES)

3  OPTPLOT FORTRAN:  (PLOTTING OF TRANSIENT RESPONSES FOR
                        STATES AND CONTROLS)

4  OPTGRAPH FORTRAN: ( POLE-ZERO, ROOT-LOCUS )

5  OUTPUT SELECTION -- TERMINAL OR "A" DISK FILE

6  HELP -- PROGRAM AND DATA FILE RELATIONSHIP EXPLANATIONS

7  EXIT -- RETURN TO CMS
```

```
** SELECT AN OPTION, ANY OTHER INPUT RETURNS YOU TO MENU **
1
----------------------------------------------------------
LOADING ORACLS.. DISCRETE SYSTEM ANALYSIS
----------------------------------------------------------
                   GENERAL ORACLS OPTIONS:
   1 -- ORCONV: ANALOG TO DIGITAL MATRIX CONVERSION
   2 -- ORDSAL: DISCRETE SYSTEM ANALYSIS
   3 -- ORTRAL: TRANSIENT ANALYSIS OF A DISCRETE SYSTEM
   4 -- HELP:   PROGRAM & EQUATION DESCRIPTIONS
   5 -- EXIT:   RETURN TO ORACLS EXEC
 NOTE: SELECT OPTION - 5; IF YOU ARE USING THE OUTPUT TO
       DISK OPTION AND WOULD LIKE TO CHANGE FILENAMES
 NOTE: NORMALLY ANY TIME DURING THE PROGRAM TWO SUCCESSIVE
       NULL "ENTERS" TERMINATES THE PROGRAM, SENDING YOU
       BACK TO THE ORACLS EXEC.
            SELECT AN OPTION: 1,2, 3, 4, OR 5.
4
----------------------------------------------------------
     "HELP" PROVIDES AN OVERVIEW OF THE PROGRAM OPTIONS
      AVAILABLE IN  "ORACLS"  AND SOME OF THE EQUATIONS
      USED IN THE CALCULATIONS.
      1 -- TERMINAL VIEWING OF SELECTED INFORMATION
      2 -- TERMINAL VIEWING PLUS HARDCOPY TO YOUR "A" DISK
      3 -- EXIT: RETURN TO THE ORACLS OPTIONS

   NOTE: OPTION "2" WILL PLACE THE FILE; "ORACLS HELP" ON
         YOUR "A" DISK CONTAINING THE SELECTED INFORMATION
         THAT YOU HAVE VIEWED AT THE TERMINAL.
                   SELECT OPTION: 1, 2, OR 3
1
----------------------------------------------------------
                 "HELP" INFORMATION OPTIONS:
1 -- OPTSYSX-ORACLS; EQUATION & MATRICES NOTATION COMPARED
2 -- ORCONV: ANALOG TO DIGITAL MATRIX CONVERSION
3 -- KBFIL:  DISCRETE KALMAN-BUCY FILTER
4 -- OPTREG: DISCRETE OPTIMAL REGULATOR
5 -- ORTRAL: TRANSIENT ANALYSIS OF A DISCRETE SYSTEM
6 -- EXIT:   RETURN TO ORACLS OPTIONS
7 -- EXIT:   RETURN TO ORACLS EXEC
     SELECT AN OPTION: 1,2, 3, 4, 5, 6, OR 7.
1
```

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

   ORACLS IS A COMPLETELY INTERACTIVE DISCRETE SYSTEMS
   CONTROL PROGRAM. IT WILL SOLVE NUMEROUS CONTROL
   PROBLEMS OF THE FOLLOWING TYPES OF CONTROL EQUATIONS:

          CONTINUOUS SYSTEM:  (OPTSYSX NOTATION)

 SYSTEM EQUATION:          XDOT = {F}*X +{G}*U +{GAM}*(W+WO)

 OUTPUT EQUATION:          Y = {H}*X + {D}*U

 MEASUREMENT EQUATION:     Z = {H}*X + {D}*U + V ;  V:N(O,R)

 CONTROL LAW:              U = -{C}*X

 COST EQUATION:     J = 1/2*(INTGRL: {Y*{A}*Y + U*{B}*U} DT)

---------------------------------------------------------------------

          DISCRETE SYSTEM:       (ORACLS NOTATION)

 SYSTEM EQUATION:

      X((I+1)*T) = {A}*X(I*T) + {B}*U(I*T)+ {GAMD}*WD(I*T)

 OUTPUT EQUATION:           Y(I) = {H}*X(I) + {G}*U(I)

 MEASUREMENT EQUATION:      Z(I) = {H}*X(I) + {G}*U(I) +V(I)

 CONTROL LAW:               U = -{F}*X

 COST EQUATION:     J = #(SUM:I=0-N: X¬(I*T)*{V1}*X(I*T) + ...
                 ...X¬(I*T)*{S}*U(I*T) + U¬(I*T)*{V2}*U(I*T)

         WHERE "T" IS THE SAMPLE TIME INTERVAL.
         WHERE "¬" = TRANSPOSE.
         WHERE "#" IS LIMIT AS "N" APPROACHES INFINITY.

---------------------------------------------------------------------

 DO YOU WISH A LIST OF MATRICES USED IN OPTSYSX AND ORACLS?
                 ANSWER (Y)ES OR (N)
y
---------------------------------------------------------------------

MATRIX DESCRIPTION                OPTSYSX NAME   ORACLS NAME
----------------------------      ------------   -----------

SYSTEM MATRIX:                        {F}            {A}
CONTROL MATRIX:                       {G}            {B}
NOISE MATRIX:                        {GAM}          {GAMD}
OBSERVABLES MATRIX:                   {H}            {H}
MEASUREMENT-FEED FWD. DIST. MATRIX:   {D}            {G}
CONTROL GAIN MATRIX:                  {C}            {F}
FILTER GAIN MATRIX:                   {K}            {K}
OUTPUT COST MATRIX:                   {A}            {Q}
CONTROL COST MATRIX:                  {B}            {R}
PROCESS NOISE MATRIX:                 {Q}            {V1}
MEASUREMENT NOISE MATRIX:             {R}            {V2}
CROSS PRODUCT WEIGHTING MATRIX:                      {S}
RICCATI EQUATION SOLUTION MATRIX:                    {P}
NOISE VECTOR:                         {W}            {WD}
CONSTANT NOISE VECTOR:                {WO}           {WO}

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

"HELP" INFORMATION OPTIONS:

```
1 -- OPTSYSX-ORACLS; EQUATION & MATRICES NOTATION COMPARED
2 -- ORCONV: ANALOG TO DIGITAL MATRIX CONVERSION
3 -- KBFIL:  DISCRETE KALMAN-BUCY FILTER
4 -- OPTREG: DISCRETE OPTIMAL REGULATOR
5 -- ORTRAL: TRANSIENT ANALYSIS OF A DISCRETE SYSTEM
6 -- EXIT:   RETURN TO ORACLS OPTIONS
7 -- EXIT:   RETURN TO ORACLS EXEC
     SELECT AN OPTION: 1,2, 3, 4, 5, 6, OR 7.
2
-----------------------------------------------------------

ORCONV IS AN  ANALOG - DIGITAL  MATRIX  CONVERSION PROGRAM
THAT WILL ACCEPT INPUT FROM EITHER THE  SCREEN OR FROM THE
"OPTMAT DATA"  FILE FROM THE OPTSYSX  PROGRAM. THE PROGRAM
WILL CONVERT THE FOLLOWING CONTINUOUS SYSTEM MATRICES:
           {F}, {G}, {GAM},  {A}, {B}, {Q},  {R}
        TO THE  FOLLOWING DISCRETE SYSTEM MATRICES:
           {A}, {B}, {GAMD}, {Q}, {R}, {V1}, {V2}
   AND ALSO COMPUTES THE DISCRETE CROSS PRODUCT WEIGHTING
   MATRIX; {S}
-----------------------------------------------------------
   WISH TO VIEW THE CONVERSION EQUATIONS USED IN ORCONV?
                  ANSWER (Y)ES OR (N)O.
y
-----------------------------------------------------------
THE FOLLOWING ARE THE CONVERSION EQUATIONS USED IN "ORCONV:
{A}  = EXP({F}*T)
{B}  = INTGRL:0-T ( (EXP({F}*TAU))*{G} ) DTAU
{GAMD} = INTGRL:0-T ( EXP({F}*TAU)*{GAM} ) DTAU
{Q}  = INTGRL:0-T ( EXP({F}*TAU)*{A}*(EXP({F}¬)*TAU) ) DTAU
{R}  = INTGRL:0-T ( {B} + {H}¬(TAU,0)*{A}*{H}(TAU,0) ) DTAU
{V1} = INTGRL:0-T ( EXP({F}¬*TAU)*{Q}*(EXP({F})*TAU) ) DTAU
{V2} = INTGRL:0-T ({R} + {H1}¬(TAU,0)*{Q}*{H1}(TAU,0)) DTAU
{S}  = 2*INTGRL:0-T ( (EXP({F}¬*TAU))*{Q}*{H}(TAU,0) ) DTAU
NOTE: { }¬ = { }TRANSPOSE
      {H}(TT,0)  = INTGRL:0-TT ( (EXP({F}*TAU))*{G} )  DTAU
      {H1}(TT,0) = INTGRL:0-TT ( (EXP({F}¬*TAU))*{G} ) DTAU
      "T" IS THE SAMPLE TIME
-----------------------------------------------------------
```

```
                    "HELP" INFORMATION OPTIONS:
1 -- OPTSYSX-ORACLS; EQUATION & MATRICES NOTATION COMPARED
2 -- ORCONV: ANALOG TO DIGITAL MATRIX CONVERSION
3 -- KBFIL:  DISCRETE KALMAN-BUCY FILTER
4 -- OPTREG: DISCRETE OPTIMAL REGULATOR
5 -- ORTRAL: TRANSIENT ANALYSIS OF A DISCRETE SYSTEM
6 -- EXIT:   RETURN TO ORACLS OPTIONS
7 -- EXIT:   RETURN TO ORACLS EXEC
     SELECT AN OPTION: 1,2, 3, 4, 5, 6, OR 7.
6
-----------------------------------------------------------
                     GENERAL ORACLS OPTIONS:
   1 -- ORCONV: ANALOG TO DIGITAL MATRIX CONVERSION
   2 -- ORDSAL: DISCRETE SYSTEM ANALYSIS
   3 -- ORTRAL: TRANSIENT ANALYSIS OF A DISCRETE SYSTEM
   4 -- HELP:   PROGRAM & EQUATION DESCRIPTIONS
   5 -- EXIT:   RETURN TO ORACLS EXEC
 NOTE: SELECT OPTION - 5; IF YOU ARE USING THE OUTPUT TO
       DISK OPTION AND WOULD LIKE TO CHANGE FILENAMES
 NOTE: NORMALLY ANY TIME DURING THE PROGRAM TWO SUCCESSIVE
       NULL "ENTERS" TERMINATES THE PROGRAM, SENDING YOU
       BACK TO THE ORACLS EXEC.
            SELECT AN OPTION: 1,2, 3, 4, OR 5.
1
-----------------------------------------------------------
    ENTER THE # OF STATES {NS} OF THE SYSTEM MATRIX
    {"F"-MATRIX}.
                 THE CONTINUOUS SYSTEM EQUATION:
                            {NS}
                              |
                 XDOT = {F}*X + {G}*U + {GAM}*(W+WO)
                         |       |        |
                     {NS*NS} {NS*NC}  {NS*NG}
NS = ?
2
-----------------------------------------------------------
  ENTER THE # OF CONTROLS {NC} OF THE CONTROL SYSTEM MODEL
    {"G"-MATRIX}.

                   THE CONTINUOUS SYSTEM EQUATION:
                                  {NC}
                                    |
```

```
               XDOT = {F}*X + {G}*U + {GAM}*(W+WO)
                          |         |          |
                       {NS*NS} {NS*NC}  {NS*NG}

NC = ?

1
-----------------------------------------------------------

    ENTER THE # OF PROCESS NOISE SOURCES {NG} OF THE
    {"GAMMA"-MATRIX}.

                THE CONTINUOUS SYSTEM EQUATION:
                                              {NG}
                                                |
               XDOT = {F}*X + {G}*U + {GAM}*(W+WO)
                         |        |        |
                     {NS*NS} {NS*NC}  {NS*NG}

NG = ?

0
-----------------------------------------------------------

  ENTER THE # OF MEASUREMENTS OR OBSERVATIONS {NO} OF THE
    {"H"-MATRIX}.

  THE OUTPUT EQUATION:             THE MEASUREMENT EQUATION:

 {NO}                             {NO}
  |                                 |
  Y = {H}*X + {D}*U                 Z = {H}*X + {D}*U + V
         |       |                         |       |
    {NO*NS} {NO*NC}                  {NO*NS} {NO*NC}

NO = ?

0
-----------------------------------------------------------

          WILL A FEED-FORWARD DISTRIBUTION MATRIX
          {"D" - MATRIX} BE INPUT ?

  THE OUTPUT EQUATION:             THE MEASUREMENT EQUATION:

   Y = {H}*X + {D}*U                Z = {H}*X + {D}*U + V

                 TYPE "YES" OR "NO"'

               NOTE: SETS THE IFDFW FLAG
n
-----------------------------------------------------------

 WHAT IS THE SAMPLE TIME INTERVAL ("DELT") FOR GENERATING
 THE DISCRETE MATRICES?

 DELT = ?          ENTER A DECIMAL ANSWER.
                (I.E. 1.0  OR .5  OR .05  ETC)

 .1
-----------------------------------------------------------

 FLAG/PARAMETER SETTINGS FOR THIS RUN ARE AS FOLLOWS:

 F   G   GAM   A   B   Q   R       -- (CONTINUOUS NAME)
 1   1    0    0   0   0   0   0   -- (MATRICES CONVERTED)
 A   B   GAMD  Q   R   V1  V2  S   -- (DISCRETE NAME)
```

```
SAMPLE TIME = 0.100
ORDER OF SYSTEM =  2
NUMBER OF CONTROLS =  1
NUMBER OF OBSERVATIONS =  0
NUMBER OF PROCESS NOISE SOURCES =  0
-----------------------------------------------------------
   ENTER THE SYSTEM MATRIX {"F"-MATRIX}
        DIMENSION = # STATES {NS} X # STATES {NS}

YOU MAY ENTER THE MATRIX OR HAVE THE PROGRAM GENERATE
A DESIRED MATRIX BY SELECTING ONE OF THE FOLLOWING:
        1 - NULL MATRIX
        2 - IDENTITY MATRIX
        3 - IDENTITY MATRIX SCALED BY A DESIRED VALUE
        4 - ANY OTHER MATRIX
            SELECT ANY OPTION
4
-----------------------------------------------------------
   THE ELEMENT F( 1, 1)=
 0
   THE ELEMENT F( 1, 2)=
 1
   THE ELEMENT F( 2, 1)=
 0
   THE ELEMENT F( 2, 2)=
-4.6
-----------------------------------------------------------
             THE SYSTEM MATRIX {"F"-MATRIX}...

   0.00000      1.00000
   0.00000     -4.60000

   DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
        TYPE "YES" OR "NO".
n
-----------------------------------------------------------
   ENTER THE CONTROL DISTRIBUTION MATRIX {"G"-MATRIX}.
        DIMENSION = # STATES {NS} X # CONTROLS {NC}

 YOU MAY ENTER THE MATRIX OR HAVE THE PROGRAM GENERATE
    A NULL MATRIX BY SELECTING ONE OF THE FOLLOWING:
             1 - NULL MATRIX
             2 - ANY OTHER MATRIX
                 SELECT AN OPTION
```

```
2
------------------------------------------------------------
   THE ELEMENT G( 1, 1)=
 0
   THE ELEMENT G( 2, 1)=
 .787
------------------------------------------------------------
        THE CONTROL DISTRIBUTION MATRIX {"G"-MATRIX}...
   0.00000
   0.78700

  DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
        TYPE "YES" OR "NO".
n
------------------------------------------------------------
DO YOU WISH TO GENERATE AN "OPTMAT" DATA FILE TO SAVE THE:
 {F}  (SYSTEM),         {G} (CONTROL),
 {H}  (OBSERVABLES),    {D} (MEASUREMENT- FEED FWD. DIST.),
{GAM} (NOISE),          {A} (OUTPUT COST),
 {B}  (CONTROL COST),   {Q} (PROCESS NOISE INTENSITY (PSD)),
 {R}  (MEASUREMENT NOISE INTENSITY (PSD))
  MATRICES AS YOU HAVE JUST ENTERED FOR REENTRY TO THE
  OPTSYSX OR ORACLS PROGRAMS?
 NOTE: THIS WILL WRITE OVER THE OLD "OPTMAT" FILE IF YOU
       HAVE USED ONE FOR THIS RUN.
                       (Y OR N)
y
------------------------------------------------------------
OPTMAT DATA FILE INPUT TO ORCONV PROGRAM: ORACLES PROGRAMS

     F     MATRIX        2 ROWS       2 COLUMNS
  0.0000000E+00   1.0000000E+00
  0.0000000E+00  -4.6000000E+00

     G     MATRIX        2 ROWS       1 COLUMNS
  0.0000000E+00
  7.8700000E-01
------------------------------------------------------------
 ORCONV: ANALOG - DIGITAL CONVERSION...DISCRETE MATRICES...
   THE SAMPLE TIME INTERVAL FOR THIS RUN =    0.1000
     A     MATRIX        2 ROWS       2 COLUMNS
  1.0000000E+00   8.0155729E-02
  0.0000000E+00   6.3128365E-01

     B     MATRIX        2 ROWS       1 COLUMNS
  3.3950959E-03
  6.3082559E-02
```

```
--------------------------------------------------------------
 ........MATRICES CONVERTED....ORCONV COMPLETE...........
DO YOU WISH TO GENERATE AN OPTMATD DATA FILE TO SAVE THE:
 {A}  (SYSTEM),         {B}  (CONTROL),
 {H}  (OBSERVABLES),  {G}  (MEASUREMENT- FEED FWD. DIST.),
{GAMD}  (NOISE),        {F}  (CONTROL GAIN),
 {K}  (FILTER GAIN),  {Q}  (OUTPUT COST),
 {R}  (CONTROL COST), {V1} (PROCESS NOISE INTENSITY (PSD)),
 {V2} (MEASUREMENT NOISE INTENSITY (PSD)),
 {S}  (DISCRETE CROSS PRODUCT WEIGHTING)
  MATRICES FOR REENTRY TO THE OPTSYSX OR ORACLS PROGRAMS?
                          (Y OR N)
y
--------------------------------------------------------------
                GENERAL ORACLS OPTIONS:
   1 -- ORCONV: ANALOG TO DIGITAL MATRIX CONVERSION
   2 -- ORDSAL: DISCRETE SYSTEM ANALYSIS
   3 -- ORTRAL: TRANSIENT ANALYSIS OF A DISCRETE SYSTEM
   4 -- HELP:   PROGRAM & EQUATION DESCRIPTIONS
   5 -- EXIT:   RETURN TO ORACLS EXEC
 NOTE: SELECT OPTION - 5; IF YOU ARE USING THE OUTPUT TO
       DISK OPTION AND WOULD LIKE TO CHANGE FILENAMES
 NOTE: NORMALLY ANY TIME DURING THE PROGRAM TWO SUCCESSIVE
       NULL "ENTERS" TERMINATES THE PROGRAM, SENDING YOU
       BACK TO THE ORACLS EXEC.
             SELECT AN OPTION: 1,2, 3, 4, OR 5.
5
--------------------------------------------------------------
 ...ORACLS IS NOW TERMINATED....RETURNING TO ORACLS EXEC...

 MESSAGE SUMMARY: MESSAGE NUMBER - COUNT
                           187      22
--------------------------------------------------------------
****** THE ORACLS EXEC ALLOWS THE FOLLOWING OPTIONS: ******
1  ORACLSX FORTRAN: --------DISCRETE SYSTEM ANALYSIS-------
                   (A-D CONVERSION, OPT. REG., KALMAN-BUCY
                    FILTER AND DISCRETE TRANSIENT ANALYSIS)
2  TRANFUNC FORTRAN: -DISCRETE TRANSFER FUNCTION ANALYSIS-
                     (SYSTEM EIGENVALUES, OPEN LOOP, NOISE,
                     AND COMPENSATOR T.F.s, MODAL MATRICES)
3  OPTPLOT FORTRAN:  (PLOTTING OF TRANSIENT RESPONSES FOR
                        STATES AND CONTROLS)
4  OPTGRAPH FORTRAN: ( POLE-ZERO, ROOT-LOCUS )
```

```
5  OUTPUT SELECTION -- TERMINAL OR "A" DISK FILE

6  HELP -- PROGRAM AND DATA FILE RELATIONSHIP EXPLANATIONS

7  EXIT -- RETURN TO CMS

** SELECT AN OPTION, ANY OTHER INPUT RETURNS YOU TO MENU **
7
-----------------------------------------------------------
DASD 200 DETACHED
R; T=0.29/1.40 20:40:55
-----------------------------------------------------------
record off
END RECORDING OF TERMINAL SESSION
```

APPENDIX B

KBFIL EXAMPLE RUN

```
----------------------------------------------------------
                  "HELP" INFORMATION OPTIONS:
1 -- OPTSYSX-ORACLSX; EQUATION & MATRICES NOTATION COMPARED
2 -- ORCONV: ANALOG TO DIGITAL MATRIX CONVERSION
3 -- KBFIL:  DISCRETE KALMAN-BUCY FILTER
4 -- OPTREG: DISCRETE OPTIMAL REGULATOR
5 -- ORTRAL: TRANSIENT ANALYSIS OF A DISCRETE SYSTEM
6 -- EXIT:   RETURN TO ORACLSX OPTIONS
7 -- EXIT:   RETURN TO ORACLS EXEC
     SELECT AN OPTION: 1,2, 3, 4, 5, 6, OR 7.
3
----------------------------------------------------------
KBFIL WILL SOLVE THE DISCRETE TIME-INVARIANT OPTIMAL
KALMAN-BUCY FILTER PROBLEM. SOLUTION OF THIS PROBLEM
PRODUCES THE OPTIMAL FILTER GAIN, "K" MATRIX WHICH MAY
BE OUTPUT TO THE OPTMATD FILE FOR USE IN THE TRANFUNC
PROGRAM THE OPTIMAL ESTIMATOR PROBLEM IS TO CONSTRUCT
AN ESTIMATE, XHAT(I) OF X(I) FROM KNOWLEDGE OF THE
OUTPUTS, Y(I) SUCH THAT THE COST CONSTRAINT IS MINIMIZED.
IF THE SYSTEM IS OBSERVABLE/RECONSTRUCTIBLE AND
CONTROLLABLE THE ASYMPTOTIC OPTIMAL OBSERVER PROBLEM
EXISTS AND XHAT(I) IS GIVEN BY:

XHAT(I+1)={A}*XHAT(I)+{B}U(I)+{K}*(Y(I)-{H}*XHAT(I)-{G}U(I))

WITH FILTER GAIN

       {K} = {A}*{P}*{H}¬*( {R} + {H}*{P}*{H}¬) INV

AND WITH {P} SATISFYING:

  {P} = {M}*{P}*{M}¬ + {K}*{R}*{F}¬ + {GAMD}*{Q}*{GAMD}¬
```

```
FOR

                    {M} = {A} - {B}*{K}

THE MATRIX "P" REPRESENTS THE RECONSTRUCTION ERROR.

WHERE: { }¬ = MATRIX TRANSPOSE
-----------------------------------------------------------
                "HELP" INFORMATION OPTIONS:
1 -- OPTSYSX-ORACLSX; EQUATION & MATRICES NOTATION COMPARED
2 -- ORCONV: ANALOG TO DIGITAL MATRIX CONVERSION
3 -- KBFIL:  DISCRETE KALMAN-BUCY FILTER
4 -- OPTREG: DISCRETE OPTIMAL REGULATOR
5 -- ORTRAL: TRANSIENT ANALYSIS OF A DISCRETE SYSTEM
6 -- EXIT:   RETURN TO ORACLSX OPTIONS
7 -- EXIT:   RETURN TO ORACLS EXEC
     SELECT AN OPTION: 1,2, 3, 4, 5, 6, OR 7.
6
-----------------------------------------------------------
                  GENERAL ORACLSX OPTIONS:
   1 -- ORCONV: ANALOG TO DIGITAL MATRIX CONVERSION
   2 -- ORDSAL: DISCRETE SYSTEM ANALYSIS
   3 -- ORTRAL: TRANSIENT ANALYSIS OF A DISCRETE SYSTEM
   4 -- HELP:   PROGRAM & EQUATION DESCRIPTIONS
   5 -- EXIT:   RETURN TO ORACLS EXEC
        SELECT AN OPTION: 1,2, 3, 4, OR 5.
 NOTE: SELECT OPTION - 5; IF YOU ARE USING THE OUTPUT TO
       DISK OPTION AND WOULD LIKE TO CHANGE FILENAMES
 NOTE: NORMALLY ANY TIME DURING THE PROGRAM TWO SUCCESSIVE
       NULL "ENTERS" TERMINATES THE PROGRAM, SENDING YOU
       BACK TO THE ORACLS EXEC.
2
-----------------------------------------------------------
                      ORDSAL OPTIONS:
    1 -- KBFIL : DISCRETE KALMAN-BUCY FILTER ANALYSIS
    2 -- OPTREG: DISCRETE OPTIMAL REGULATOR ANALYSIS
    3 -- EXIT:   RETURN TO ORACLSX OPTIONS
    4 -- EXIT:   RETURN TO ORACLS EXEC
         SELECT AN OPTION: 1, 2, 3, OR 4.
```

```
 NOTE: TO PERFORM COMPENSATOR TRANSFER FUNCTION ANALYSIS IN
       TRANFUNC REQUIRES BOTH THE {K} AND {F} MATRICES. DO
       "OPTREG" FIRST AND THEN "KBFIL", AS THIS ENSURES THE
       CORRECT {H} MATRIX WILL BE AVAILABLE IN TRANFUNC.

1
-----------------------------------------------------------

THE "A","B","GAMD","H","G","F","K","Q","R","V1","V2" AND "S"
matrices FROM YOUR PREVIOUS ORACLS RUN WERE SAVED.

         THE FOLLOWING OPTIONS ARE AVAILABLE:

         1. USE ALL OF THE SAME MATRICES AGAIN.
         2. USE SELECTED MATRICES AGAIN.
         3. INPUT ALL NEW MATRICES.

            ENTER 1, 2, OR 3.

   NOTE: EACH SAVED MATRIX WILL BE REDISPLAYED AT
         THE PROPER INPUT SEQUENCE INTERVAL
         AND YOU WILL HAVE THE OPTION OF CHANGING
         INDIVIDUAL MATRIX ELEMENTS.

   NOTE: A CHANGE IN THE ORDER OF THE SYSTEM; -NS-
         REQUIRES SELECTION OF OPTION 3

2
-----------------------------------------------------------

    DO YOU WISH TO SAVE THE "A"-MATRIX FROM THE LAST
    RUN TO BE USED IN THE FOLLOWING RUN?

    NOTE: THE MATRIX WILL BE REDISPLAYED AT
    THE PROPER INPUT SEQUENCE INTERVAL
    AND YOU WILL HAVE THE OPTION OF CHANGING
    INDIVIDUAL MATRIX ELEMENTS.

              TYPE "YES" OR "NO".
y
-----------------------------------------------------------

    ENTER THE # OF PROCESS NOISE SOURCES {NG} OF THE
    {"GAMD"-MATRIX}.

               THE DISCRETE SYSTEM EQUATION:

                                                  {NG}
                                                    |
        X(I+1) = {A}*X(I) + {B}*U(I) + {GAMD}*(WD+WO)
                   |          |           |
               {NS*NS)    {NS*NC}     {NS*NG}

NG = ?

2
-----------------------------------------------------------

  ENTER THE # OF MEASUREMENTS OR OBSERVATIONS {NO} OF THE
  {"H"-MATRIX}.

   THE OUTPUT EQUATION:      THE MEASUREMENT EQUATION:

{NO}                        {NO}
 |                            |
Y(I) = {H}*X(I)+{G}*U(I)  Z(I) = {H}*X(I) + {G}*U(I) + V(I)
         |         |               |          |          |
     {NO*NS}   {NO*NC}         {NO*NS}    {NO*NC}    {NO*1}
```

```
NO = ?
2
------------------------------------------------------------
              THE SYSTEM MATRIX {"A"-MATRIX}...

    1.00000      0.08016
    0.00000      0.63128

   DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
         TYPE "YES" OR "NO".
n
------------------------------------------------------------
ENTER THE PROCESS NOISE DISTRIBUTION MATRIX {"GAMD"-MATRIX}.
 DIMENSION = # STATES {NS} X # PROCESS NOISE SOURCES {NG}.
    YOU MAY ENTER THE MATRIX OR HAVE THE PROGRAM GENERATE
    A DESIRED MATRIX BY SELECTING ONE OF THE FOLLOWING:
       1 - NULL MATRIX
       2 - IDENTITY MATRIX
       3 - IDENTITY MATRIX SCALED BY A DESIRED VALUE
       4 - ANY OTHER MATRIX
           SELECT ANY OPTION
2
------------------------------------------------------------
 THE PROCESS NOISE DISTRIBUTION MATRIX {"GAMD"-MATRIX}...
    1.00000      0.00000
    0.00000      1.00000
 DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
         TYPE "YES" OR "NO".
n
------------------------------------------------------------
    ENTER THE MEASUREMENT SCALING MATRIX {"H"-MATRIX}.
     DIMENSION = # OBSERVATIONS {NO} X # STATES {NS}.
   YOU MAY ENTER THE MATRIX OR HAVE THE PROGRAM GENERATE
    A DESIRED MATRIX BY SELECTING ONE OF THE FOLLOWING:
       1 - NULL MATRIX
       2 - IDENTITY MATRIX
       3 - IDENTITY MATRIX SCALED BY A DESIRED VALUE
       4 - ANY OTHER MATRIX
           SELECT ANY OPTION
2
------------------------------------------------------------
```

```
        THE MEASUREMENT SCALING MATRIX {"H"-MATRIX}...

    1.00000      0.00000
    0.00000      1.00000

  DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
         TYPE "YES" OR "NO".
n
-----------------------------------------------------------
    ENTER THE PROCESS NOISE INTENSITY (PSD) MATRIX
                 ({"V1"}-MATRIX)

 DIMENSION = # PROCESS NOISE SOURCES {NG} X
                              # PROCESS NOISE SOURCES {NG}.

    YOU MAY ENTER THE MATRIX OR HAVE THE PROGRAM GENERATE
    A DESIRED MATRIX BY SELECTING ONE OF THE FOLLOWING:

       1 - NULL MATRIX

       2 - IDENTITY MATRIX

       3 - IDENTITY MATRIX SCALED BY A DESIRED VALUE

       4 - ANY OTHER MATRIX

         SELECT ANY OPTION
2
-----------------------------------------------------------
    THE PROCESS NOISE INTENSITY (PSD) MATRIX......V1

    1.00000      0.00000
    0.00000      1.00000

  DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
         TYPE "YES" OR "NO".
n
-----------------------------------------------------------
    ENTER THE MEASUREMENT NOISE INTENSITY (PSD) MATRIX
                   ({"V2"}-MATRIX)

    DIMENSION = # OBSERVATIONS {NO} X # OBSERVATIONS {NO}

  YOU MAY ENTER THE MATRIX OR HAVE THE PROGRAM GENERATE
  A DESIRED MATRIX BY SELECTING ONE OF THE FOLLOWING:

        1 - NULL MATRIX

        2 - IDENTITY MATRIX

        3 - IDENTITY MATRIX SCALED BY A DESIRED VALUE

        4 - ANY OTHER MATRIX

          SELECT ANY OPTION
2
-----------------------------------------------------------
   THE MEASUREMENT NOISE INTENSITY (PSD) MATRIX....V2....

    1.00000      0.00000
```

```
    0.00000      1.00000
  DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
        TYPE "YES" OR "NO".
n
-----------------------------------------------------------
 FLAG/PARAMETER SETTINGS FOR THIS RUN ARE AS FOLLOWS:

 THE SAMPLE TIME INTERVAL FOR THE SYSTEM IS =    0.10000
 ORDER OF SYSTEM =  2
 NUMBER OF CONTROLS =  1
 NUMBER OF OBSERVATIONS =  2
 NUMBER OF PROCESS NOISE SOURCES =  2
-----------------------------------------------------------
KALMAN-BUCY FILTER ANALYSIS...............ORACLES PROGRAMS
THE SAMPLE TIME INTERVAL (DELT) FOR THIS SYSTEM IS = 0.100

ASYMFI: SUBROUTINE TO SOLVE THE DISCRETE INFINITE-DURATION
        OPTIMAL FILTER PROBLEM.

      A     MATRIX           2 ROWS         2 COLUMNS
  1.0000000E+00   8.0155729E-02
  0.0000000E+00   6.3128365E-01

     GAMD   MATRIX           2 ROWS         2 COLUMNS
  1.0000000E+00   0.0000000E+00
  0.0000000E+00   1.0000000E+00

      H     MATRIX           2 ROWS         2 COLUMNS
  1.0000000E+00   0.0000000E+00
  0.0000000E+00   1.0000000E+00
INTENSITY MATRIX FOR COVARIANCE OF MEASUREMENT NOISE

      V2    MATRIX           2 ROWS         2 COLUMNS
  1.0000000E+00   0.0000000E+00
  0.0000000E+00   1.0000000E+00

      V1    MATRIX           2 ROWS         2 COLUMNS
  1.0000000E+00   0.0000000E+00
  0.0000000E+00   1.0000000E+00
INTENSITY MATRIX FOR COVARIANCE OF PROCESS NOISE;
              {GAMD}*{V1}*{GAMD}

            MATRIX           2 ROWS         2 COLUMNS
  1.0000000E+00   0.0000000E+00
  0.0000000E+00   1.0000000E+00

KALMAN-BUCY FILTER GAIN

      K     MATRIX           2 ROWS         2 COLUMNS
  6.1913667E-01   4.9382360E-02
  3.3817731E-03   3.4673134E-01
```

STEADY-STATE VARIANCE MATRIX OF RECONSTRUCTION ERROR

```
     P     MATRIX          2 ROWS        2 COLUMNS
  1.6230950E+00   3.1174278E-02
  3.1174278E-02   1.2188858E+00
```

EIGENVALUES OF P

```
    EVLP  MATRIX           2 ROWS        1 COLUMNS
  1.2164957E+00
  1.6254851E+00

    A-KH  MATRIX           2 ROWS        2 COLUMNS
  3.8086333E-01   3.0773369E-02
 -3.3817731E-03   2.8455231E-01
```

EIGENVALUES OF A-KH MATRIX

```
  2.8564526E-01   0.0000000E+00
  3.7977038E-01   0.0000000E+00
```

......DISCRETE KALMAN-BUCY FILTER ANALYSIS COMPLETE.......

DO YOU WISH TO GENERATE AN "OPTMATD" DATA FILE TO SAVE THE:

```
{A}     (SYSTEM),          {B}  (CONTROL),
{H}     (OBSERVABLES),     {G}  (MEASUREMENT- FEED FWD. DIST.),
{GAMD}  (NOISE),           {F}  (CONTROL GAIN),
{K}     (FILTER GAIN)      {Q}  (OUTPUT COST),
{R}     (CONTROL COST)     {V1} (PROCESS NOISE INTENSITY (PSD))
{V2}    (MEASUREMENT NOISE INTENSITY (PSD))
{S}   (DISCRETE CROSS PRODUCT WEIGHTING)
```

MATRICES FOR REENTRY TO THE OPTSYSX OR ORACLS PROGRAMS?
(Y OR N)

y

ORDSAL OPTIONS:

1 -- KBFIL : DISCRETE KALMAN-BUCY FILTER ANALYSIS

2 -- OPTREG: DISCRETE OPTIMAL REGULATOR ANALYSIS

3 -- EXIT: RETURN TO ORACLSX OPTIONS

4 -- EXIT: RETURN TO ORACLS EXEC

SELECT AN OPTION: 1, 2, 3, OR 4.

NOTE: TO PERFORM COMPENSATOR TRANSFER FUNCTION ANALYSIS IN TRANFUNC REQUIRES BOTH THE {K} AND {F} MATRICES. DO "OPTREG" FIRST AND THEN "KBFIL", AS THIS ENSURES THE CORRECT {H} MATRIX WILL BE AVAILABLE IN TRANFUNC.

4

..ORACLS IS NOW TERMINATED.....RETURNING TO ORACLS EXEC...

APPENDIX C

OPTREG EXAMPLE RUN

```
------------------------------------------------------------
                "HELP" INFORMATION OPTIONS:
1 -- OPTSYSX-ORACLS; EQUATION & MATRICES NOTATION COMPARED
2 -- ORCONV: ANALOG TO DIGITAL MATRIX CONVERSION
3 -- KBFIL:  DISCRETE KALMAN-BUCY FILTER
4 -- OPTREG: DISCRETE OPTIMAL REGULATOR
5 -- ORTRAL: TRANSIENT ANALYSIS OF A DISCRETE SYSTEM
6 -- EXIT:   RETURN TO ORACLS OPTIONS
7 -- EXIT:   RETURN TO ORACLS EXEC
     SELECT AN OPTION: 1,2, 3, 4, 5, 6, OR 7.
4
------------------------------------------------------------
OPTREG IS A DISCRETE SYSTEM ANALYSIS PROGRAM THAT WILL
ACCEPT INPUT FROM EITHER THE SCREEN OR FROM AN "OPTMATD"
DATA FILE. IT USES THE DISCRETE  MATRICES: {A}, {B}, {H},
{Q}, AND {R} TO COMPUTE THE OPTIMAL FILTER GAINS; {FHAT}
AND {F}. IF THE SYSTEM HAS A CROSS PRODUCT WEIGHTING MATRIX
{S}, THE PROGRAM WILL CALCULATE A NEW GAIN MATRIX; {FE}
WHICH WILL ELIMINATE THE CROSS PRODUCT TERM; {S} IN THE
QUADRATIC SCALAR FUNCTION. NEW MATRICES; {AHAT}, {BHAT},
{QHAT}, AND {RHAT} ARE THEN CALCULATED AND USED AS INPUTS
TO THE PROGRAM.
------------------------------------------------------------
        DO YOU HAVE A CROSS PRODUCT WEIGHTING MATRIX ?
                        ANSWER (Y)ES OR (N)O.
n
------------------------------------------------------------
               "HELP" INFORMATION OPTIONS:
1 -- OPTSYSX-ORACLS; EQUATION & MATRICES NOTATION COMPARED
2 -- ORCONV: ANALOG TO DIGITAL MATRIX CONVERSION
3 -- KBFIL:  DISCRETE KALMAN-BUCY FILTER
```

```
4 -- OPTREG: DISCRETE OPTIMAL REGULATOR
5 -- ORTRAL: TRANSIENT ANALYSIS OF A DISCRETE SYSTEM
6 -- EXIT:   RETURN TO ORACLS OPTIONS
7 -- EXIT:   RETURN TO ORACLS EXEC
     SELECT AN OPTION: 1,2, 3, 4, 5, 6, OR 7.
6
-----------------------------------------------------------
                GENERAL ORACLS OPTIONS:
   1 -- ORCONV: ANALOG TO DIGITAL MATRIX CONVERSION
   2 -- ORDSAL: DISCRETE SYSTEM ANALYSIS
   3 -- ORTRAL: TRANSIENT ANALYSIS OF A DISCRETE SYSTEM
   4 -- HELP:   PROGRAM & EQUATION DESCRIPTIONS
   5 -- EXIT:   RETURN TO ORACLS EXEC
 NOTE: SELECT OPTION - 5; IF YOU ARE USING THE OUTPUT TO
       DISK OPTION AND WOULD LIKE TO CHANGE FILENAMES
 NOTE: NORMALLY ANY TIME DURING THE PROGRAM TWO SUCCESSIVE
       NULL "ENTERS" TERMINATES THE PROGRAM, SENDING YOU
       BACK TO THE ORACLS EXEC.
       SELECT AN OPTION: 1,2, 3, 4, OR 5.
2
-----------------------------------------------------------
                     ORDSAL OPTIONS:
     1 -- KBFIL : DISCRETE KALMAN-BUCY FILTER ANALYSIS
     2 -- OPTREG: DISCRETE OPTIMAL REGULATOR ANALYSIS
     3 -- EXIT:   RETURN TO ORACLS OPTIONS
     4 -- EXIT:   RETURN TO ORACLS EXEC
          SELECT AN OPTION: 1, 2, 3, OR 4.
 NOTE: TO PERFORM COMPENSATOR TRANSFER FUNCTION ANALYSIS IN
       TRANFUNC REQUIRES BOTH THE {K} AND {F} MATRICES. DO
       "OPTREG" FIRST AND THEN "KBFIL", AS THIS ENSURES THE
       CORRECT {H} MATRIX WILL BE AVAILABLE IN TRANFUNC.
2
-----------------------------------------------------------
  THE "A","B","GAMD","H","G","F","K","Q","R","V1","V2" AND
  "S" MATRICES FROM YOUR PREVIOUS ORACLS RUN WERE SAVED.
       THE FOLLOWING OPTIONS ARE AVAILABLE:
           1. USE ALL OF THE SAME MATRICES AGAIN.
           2. USE SELECTED MATRICES AGAIN.
           3. INPUT ALL NEW MATRICES.
         ENTER 1, 2, OR 3.
         NOTE: EACH SAVED MATRIX WILL BE REDISPLAYED AT
               THE PROPER INPUT SEQUENCE INTERVAL
               AND YOU WILL HAVE THE OPTION OF CHANGING
```

INDIVIDUAL MATRIX ELEMENTS.

NOTE: A CHANGE IN THE ORDER OF THE SYSTEM; -NS-
REQUIRES OPTION 3 SELECTION.

2

DO YOU WISH TO SAVE THE "A"-MATRIX FROM THE LAST RUN TO BE USED IN THE FOLLOWING RUN?

NOTE: THE MATRIX WILL BE REDISPLAYED AT THE PROPER INPUT SEQUENCE INTERVAL AND YOU WILL HAVE THE OPTION OF CHANGING INDIVIDUAL MATRIX ELEMENTS.

TYPE "YES" OR "NO".

y

DO YOU WISH TO SAVE THE "B"-MATRIX FROM THE LAST RUN TO BE USED IN THE FOLLOWING RUN?

NOTE: THE MATRIX WILL BE REDISPLAYED AT THE PROPER INPUT SEQUENCE INTERVAL AND YOU WILL HAVE THE OPTION OF CHANGING INDIVIDUAL MATRIX ELEMENTS.

TYPE "YES" OR "NO".

y

ENTER THE # OF PROCESS NOISE SOURCES {NG} OF THE {"GAMD"-MATRIX}.

THE DISCRETE SYSTEM EQUATION:

```
                                              {NG}
                                                |
X(I+1) = {A}*X(I) + {B}*U(I) + {GAMD}*(WD+WO)
           |          |          |
        {NS*NS)    {NS*NC}    {NS*NG}
```

NG = ?

0

ENTER THE # OF MEASUREMENTS OR OBSERVATIONS {NO} OF THE {"H"-MATRIX}.

THE OUTPUT EQUATION:

```
{NO}
 |
Y(I)={H}*X(I) + {G}*U(I)
      |          |
  {NO*NS}    {NO*NC}
```

THE MEASUREMENT EQUATION:

```
{NO}
 |
Z(I)={H}*X(I) + {G}*U(I) + V(I)
      |          |          |
  {NO*NS}    {NO*NC}    {NO*1}
```

NO = ?

2

IS THE SYSTEM YOU WISH TO EVALUATE A STABLE SYSTEM ?

(Y)ES OR (N)O ?

NOTE: ANSWER "NO" IF IT IS UNSTABLE OR YOU ARE NOT SURE.

```
        "OPTREG" WILL TEST THE MATRIX {A-BF} FOR STABILITY
        RELATIVE TO .9. IF A STABILIZING GAIN IS REQUIRED,
        IT WILL BE COMPUTED AND NOTED IN THE RESULTS.
y
-----------------------------------------------------------

             THE SYSTEM MATRIX {"A"-MATRIX}...

    1.00000     0.08016
    0.00000     0.63128

  DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?

         TYPE "YES" OR "NO".
n
-----------------------------------------------------------

      THE CONTROL DISTRIBUTION MATRIX {"B"-MATRIX}...

    0.00340
    0.06308

    DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?

         TYPE "YES" OR "NO".
n
-----------------------------------------------------------

     ENTER THE MEASUREMENT SCALING MATRIX {"H"-MATRIX}.

     DIMENSION = # OBSERVATIONS {NO} X # STATES {NS}.

   YOU MAY ENTER THE MATRIX OR HAVE THE PROGRAM GENERATE
   A DESIRED MATRIX BY SELECTING ONE OF THE FOLLOWING:

         1 - NULL MATRIX

         2 - IDENTITY MATRIX

         3 - IDENTITY MATRIX SCALED BY A DESIRED VALUE

         4 - ANY OTHER MATRIX

             SELECT ANY OPTION
2
-----------------------------------------------------------

      THE MEASUREMENT SCALING MATRIX {"H"-MATRIX}...

    1.00000     0.00000
    0.00000     1.00000

  DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?

         TYPE "YES" OR "NO".
n
-----------------------------------------------------------

    ENTER THE OUTPUT MEASUREMENT COST MATRIX {"Q"-MATRIX}.

    DIMENSION = # OBSERVATIONS {NO} X # OBSERVATIONS {NO},

    YOU MAY ENTER THE MATRIX OR HAVE THE PROGRAM GENERATE
    A DESIRED MATRIX BY SELECTING ONE OF THE FOLLOWING:

         1 - NULL MATRIX
```

```
        2 - IDENTITY MATRIX
        3 - IDENTITY MATRIX SCALED BY A DESIRED VALUE
        4 - ANY OTHER MATRIX
            SELECT ANY OPTION
2
-----------------------------------------------------------
    THE OUTPUT MEASUREMENT COST MATRIX {"Q"-MATRIX}...

    1.00000      0.00000
    0.00000      1.00000

    DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
         TYPE "YES" OR "NO".
y
-----------------------------------------------------------
    ENTER THE ROW NUMBER OF THE ELEMENT TO BE CHANGED.
2
    ENTER THE COLUMN NUMBER OF THE ELEMENT TO BE CHANGED.
2
    THE ELEMENT Q( 2, 2)=
0
-----------------------------------------------------------
    THE OUTPUT MEASUREMENT COST MATRIX {"Q"-MATRIX}...

    1.00000      0.00000
    0.00000      0.00000

    DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
         TYPE "YES" OR "NO".
n
-----------------------------------------------------------
    ENTER THE CONTROL COST WEIGHTING MATRIX {"R"-MATRIX}
       DIMENSION = # CONTROLS {NC} X # CONTROLS {NC}.
    YOU MAY ENTER THE MATRIX OR HAVE THE PROGRAM GENERATE
    A DESIRED MATRIX BY SELECTING ONE OF THE FOLLOWING:
        1 - NULL MATRIX
        2 - IDENTITY MATRIX
        3 - IDENTITY MATRIX SCALED BY A DESIRED VALUE
        4 - ANY OTHER MATRIX
             SELECT ANY OPTION
4
-----------------------------------------------------------
    THE ELEMENT R( 1, 1)=
 .00002
```

```
          THE CONTROL COST MATRIX..........R...
     0.00002
     DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
          TYPE "YES" OR "NO".
n
-----------------------------------------------------------
 FLAG/PARAMETER SETTINGS FOR THIS RUN ARE AS FOLLOWS:


 SYSTEM was input aS STABLE
 THE SAMPLE TIME INTERVAL FOR THE SYSTEM IS =  0.10
 ORDER OF SYSTEM =  2
 NUMBER OF CONTROLS =  1
 NUMBER OF OBSERVATIONS =  2
 NUMBER OF PROCESS NOISE SOURCES =  0
-----------------------------------------------------------
OPTREG: DISCRETE OPTIMAL FILTER ANALYSIS...ORACLES PROGRAMS
 THE SAMPLE TIME INTERVAL FOR THE SYSTEM IS =  0.10
 SYSTEM WAS INPUT AS STABLE
     A    MATRIX        2 ROWS        2 COLUMNS
 1.0000000E+00   8.0155729E-02
 0.0000000E+00   6.3128365E-01
     B    MATRIX        2 ROWS        1 COLUMNS
 3.3950959E-03
 6.3082559E-02
     H    MATRIX        2 ROWS        2 COLUMNS
 1.0000000E+00   0.0000000E+00
 0.0000000E+00   1.0000000E+00
     Q    MATRIX        2 ROWS        2 COLUMNS
 1.0000000E+00   0.0000000E+00
 0.0000000E+00   0.0000000E+00
     R    MATRIX        1 ROWS        1 COLUMNS
 2.0000000E-05

 RICTNW: SUBROUTINE TO SOLVE DISCRETE STEADY-STATE
         RICCATI EQUATION BY THE NEWTON ALGORITHM.
 MATRIX (H TRANSPOSE)QH

    HTQH  MATRIX        2 ROWS        2 COLUMNS
 1.0000000E+00   0.0000000E+00
 0.0000000E+00   0.0000000E+00

 IN SUM, THE SEQUENCE OF PARTIAL SUMS HAS EXCEEDED STAGE
 50 without convergence
 FINAL VALUES OF P AND F AFTER  6 ITERATIONS TO CONVERGE

     P    MATRIX        2 ROWS        2 COLUMNS
 1.6770747E+00   5.3358856E-02
 5.3358856E-02   4.9991775E-03
     F    MATRIX        1 ROWS        2 COLUMNS
```

```
  1.1037719E+02   1.2666098E+01

RESIDUAL ERROR IN RICCATI EQUATION

     EROR  MATRIX          2 ROWS        2 COLUMNS
  7.3822048E-09   8.4713316E-10
  8.4713316E-10   9.7210612E-11

EIGENVALUES OF P

     EVLP  MATRIX          2 ROWS        1 COLUMNS
  3.2981335E-03
  1.6787757E+00

CLOSED-LOOP RESPONSE MATRIX A-BF

     A-BF  MATRIX          2 ROWS        2 COLUMNS
  6.2525884E-01   3.7153110E-02
 -6.9628758E+00  -1.6772625E-01

EIGENVALUES OF A-BF

  2.2876630E-01   3.1856891E-01
  2.2876630E-01  -3.1856891E-01

FOR THE ORIGINAL SAMPLED-DATA PROBLEM:

     FHAT  MATRIX          1 ROWS        2 COLUMNS
  1.1037719E+02   1.2666098E+01
      F    MATRIX          1 ROWS        2 COLUMNS
  1.1037719E+02   1.2666098E+01
-----------------------------------------------------------

 .....CONTROL GAINS CALCULATED.......OPTREG COMPLETED.....
DO YOU WISH TO GENERATE AN "OPTMATD" DATA FILE TO SAVE THE:
  {A}  (SYSTEM),        {B}  (CONTROL),
  {H}  (OBSERVABLES),   {G}  (MEASUREMENT- FEED FWD. DIST.),
{GAMD} (NOISE),         {F}  (CONTROL GAIN),
  {K}  (FILTER GAIN),   {Q}  (OUTPUT COST),
  {R}  (CONTROL COST), {V1} (PROCESS NOISE INTENSITY (PSD)),
  {V2} (MEASUREMENT NOISE INTENSITY (PSD)),
  {S}  (DISCRETE CROSS PRODUCT WEIGHTING)
  MATRICES FOR REENTRY TO THE OPTSYSX OR ORACLS PROGRAMS?
                      (Y OR N)
y
-----------------------------------------------------------

                    ORDSAL OPTIONS:
    1 -- KBFIL : DISCRETE KALMAN-BUCY FILTER ANALYSIS
    2 -- OPTREG: DISCRETE OPTIMAL REGULATOR ANALYSIS
```

```
    3 -- EXIT:   RETURN TO ORACLS OPTIONS

    4 -- EXIT:   RETURN TO ORACLS EXEC

         SELECT AN OPTION: 1, 2, 3, OR 4.

  NOTE: NORMALLY ANY TIME DURING ANY PROGRAM TWO SUCCESSIVE
        NULL "ENTERS" TERMINATES THE PROGRAM, SENDING YOU
        BACK TO THE ORACLS EXEC.

4
-----------------------------------------------------------

IS NOW TERMINATED.....RETURNING TO ORACLS EXEC...

-----------------------------------------------------------

 MESSAGE SUMMARY: MESSAGE NUMBER - COUNT
                         187        4
                         208        1
-----------------------------------------------------------

****** THE ORACLS EXEC ALLOWS THE FOLLOWING OPTIONS: ******

1  ORACLSX FORTRAN: --------DISCRETE SYSTEM ANALYSIS-------
                   (A-D CONVERSION, OPT. REG., KALMAN-BUCY
                    FILTER AND DISCRETE TRANSIENT ANALYSIS)

2  TRANFUNC FORTRAN: -DISCRETE TRANSFER FUNCTION ANALYSIS-
                     (SYSTEM EIGENVALUES, OPEN LOOP, NOISE,
                     AND COMPENSATOR T.F.s, MODAL MATRICES)

3  OPTPLOT FORTRAN:  (PLOTTING OF TRANSIENT RESPONSES FOR
                        STATES AND CONTROLS)

4  OPTGRAPH FORTRAN: ( POLE-ZERO, ROOT-LOCUS )

5  OUTPUT SELECTION -- TERMINAL OR "A" DISK FILE

6  HELP -- PROGRAM AND DATA FILE RELATIONSHIP EXPLANATIONS

7  EXIT -- RETURN TO CMS

** SELECT AN OPTION, ANY OTHER INPUT RETURNS YOU TO MENU **
7
-----------------------------------------------------------
DASD 200 DETACHED
R; T=0.29/1.40 20:40:55
-----------------------------------------------------------
record off
END RECORDING OF TERMINAL SESSION
```

APPENDIX D

ORTRAL EXAMPLE RUN

```
------------------------------------------------------------
              "HELP" INFORMATION OPTIONS:
1 -- OPTSYSX-ORACLS; EQUATION & MATRICES NOTATION COMPARED
2 -- ORCONV: ANALOG TO DIGITAL MATRIX CONVERSION
3 -- KBFIL:  DISCRETE KALMAN-BUCY FILTER
4 -- OPTREG: DISCRETE OPTIMAL REGULATOR
5 -- ORTRAL: TRANSIENT ANALYSIS OF A DISCRETE SYSTEM
6 -- EXIT:   RETURN TO ORACLS OPTIONS
7 -- EXIT:   RETURN TO ORACLS EXEC
     SELECT AN OPTION: 1,2, 3, 4, 5, 6, OR 7.
5
------------------------------------------------------------
ORTRAL IS A DISCRETE  SYSTEM TRANSIENT  ANALYSIS PROGRAM
THAT WILL ACCEPT INPUT FROM  EITHER THE SCREEN OR FROM AN
"OPTMATD DATA"  FILE. IT USES THE DISCRETE  MATRICES: {A},
{B}, {H}, AND  {G}, AND CALCULATES THE TRANSIENT RESPONSE
OF A DISCRETE SYSTEM FOR A DESIRED NUMBER OF STAGES/POINTS.
THE PROGRAM CALCULATES THE TRANSIENT RESPONSE OF A DISCRETE
SYSTEM  FOR A GIVEN SET OF INITIAL CONDITIONS; "X(0)",
BASED ON THE  FOLLOWING  EQUATIONS:

              X(I+1) = {A}*X(I) + {B}*U(I)
                Y(I) = {H}*X(I) + {G}*U(I)
                U(I) = -{F}*X(I) + UC(I)

NOTE: IF THE MATRIX {A-BF}  IS ASYMPTOTICALLY STABLE THE
      STEADY STATE VALUE OF "X", GIVEN BY:

            X = { {I} - {{A}-{B}{F}} }"*{B}*{UC}

      MAY BE COMPUTED AND PRINTED. ("=MATRIX INVERSE)
NOTE: {UC} IS THE CONTROL INPUT (DRIVING FUNCTION) AND MAY
      BE SELECTED AS EITHER A "STEP" OR "RAMP".

ORTRAL OUTPUTS TO THE OPTPLOT DATA FILE THE "TIME", CONTROL
 VECTOR; "U", AND THE STATE VECTOR; "X" FOR PLOTTING VIA
     OPTPLOT FORTRAN AVAILABLE IN THE ORACLS EXEC.
------------------------------------------------------------
              "HELP" INFORMATION OPTIONS:
1 -- OPTSYSX-ORACLS; EQUATION & MATRICES NOTATION COMPARED
```

```
2 -- ORCONV: ANALOG TO DIGITAL MATRIX CONVERSION
3 -- KBFIL:  DISCRETE KALMAN-BUCY FILTER
4 -- OPTREG: DISCRETE OPTIMAL REGULATOR
5 -- ORTRAL: TRANSIENT ANALYSIS OF A DISCRETE SYSTEM
6 -- EXIT:   RETURN TO ORACLS OPTIONS
7 -- EXIT:   RETURN TO ORACLS EXEC
     SELECT AN OPTION: 1,2, 3, 4, 5, 6, OR 7.
6
-----------------------------------------------------------
                  GENERAL ORACLS OPTIONS:
   1 -- ORCONV: ANALOG TO DIGITAL MATRIX CONVERSION
   2 -- ORDSAL: DISCRETE SYSTEM ANALYSIS
   3 -- ORTRAL: TRANSIENT ANALYSIS OF A DISCRETE SYSTEM
   4 -- HELP:   PROGRAM & EQUATION DESCRIPTIONS
   5 -- EXIT:   RETURN TO ORACLS EXEC
        SELECT AN OPTION: 1,2, 3, 4, OR 5.
  NOTE: SELECT OPTION - 5; IF YOU ARE USING THE OUTPUT TO
        DISK OPTION AND WOULD LIKE TO CHANGE FILENAMES
  NOTE: NORMALLY ANY TIME DURING THE PROGRAM TWO SUCCESSIVE
        NULL "ENTERS" TERMINATES THE PROGRAM, SENDING YOU
        BACK TO THE ORACLS EXEC.
3
-----------------------------------------------------------
 THE "A","B","GAMD","H","G","F","K","Q","R","V1","V2" AND
 "S" MATRICES FROM YOUR PREVIOUS ORACLS RUN WERE SAVED.
        THE FOLLOWING OPTIONS ARE AVAILABLE:
            1. USE ALL OF THE SAME MATRICES AGAIN.
            2. USE SELECTED MATRICES AGAIN.
            3. INPUT ALL NEW MATRICES.
        ENTER 1, 2, OR 3.
  NOTE: EACH SAVED MATRIX WILL BE REDISPLAYED AT
        THE PROPER INPUT SEQUENCE INTERVAL
        AND YOU WILL HAVE THE OPTION OF CHANGING
        INDIVIDUAL MATRIX ELEMENTS.
  NOTE: A CHANGE IN THE ORDER OF THE SYSTEM; -NS-
        REQUIRES OPTION 3.
2
-----------------------------------------------------------
    DO YOU WISH TO SAVE THE "A"-MATRIX FROM THE LAST
    RUN TO BE USED IN THE FOLLOWING RUN?
    NOTE: THE MATRIX WILL BE REDISPLAYED AT
    THE PROPER INPUT SEQUENCE INTERVAL
    AND YOU WILL HAVE THE OPTION OF CHANGING
    INDIVIDUAL MATRIX ELEMENTS.
```

TYPE "YES" OR "NO".

y

DO YOU WISH TO SAVE THE "B"-MATRIX FROM THE LAST RUN TO BE USED IN THE FOLLOWING RUN?

NOTE: THE MATRIX WILL BE REDISPLAYED AT THE PROPER INPUT SEQUENCE INTERVAL AND YOU WILL HAVE THE OPTION OF CHANGING INDIVIDUAL MATRIX ELEMENTS.

TYPE "YES" OR "NO".

y

DO YOU WISH TO SAVE THE "F"-MATRIX FROM THE LAST RUN TO BE USED IN THE FOLLOWING RUN?

NOTE: THE MATRIX WILL BE REDISPLAYED AT THE PROPER INPUT SEQUENCE INTERVAL AND YOU WILL HAVE THE OPTION OF CHANGING INDIVIDUAL MATRIX ELEMENTS.

TYPE "YES" OR "NO".

n

ENTER THE # OF PROCESS NOISE SOURCES {NG} OF THE {"GAMD"-MATRIX}.

THE DISCRETE SYSTEM EQUATION:

```
                                                  {NG}
                                                    |
X(I+1) = {A}*X(I) + {B}*U(I) + {GAMD}*(WD+WO)
              |            |            |
         {NS*NS}      {NS*NC}      {NS*NG}
```

NG = ?

0

ENTER THE # OF MEASUREMENTS OR OBSERVATIONS {NO} OF THE {"H"-MATRIX}.

THE OUTPUT EQUATION: THE MEASUREMENT EQUATION:

```
{NO}                         {NO}
 |                             |
Y(I) = {H}*X(I)+{G}*U(I)    Z(I) = {H}*X(I) + {G}*U(I) + V(I)
         |         |                  |          |         |
     {NO*NS}   {NO*NC}            {NO*NS}    {NO*NC}   {NO*1}
```

NO = ?

0

IS THE SYSTEM YOU WISH TO EVALUATE A STABLE SYSTEM ?

(Y)ES OR (N)O ?

NOTE: TO GET THE STEADY STATE VALUE IN "ORTRAL" YOU MUST ANSWER YES!

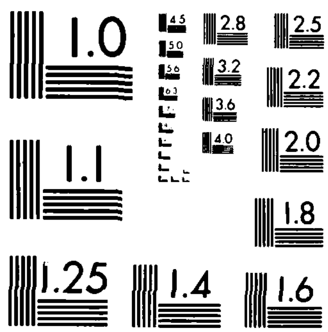
```
y
--------------------------------------------------------------
               THE SYSTEM MATRIX {"A"-MATRIX}...
    1.00000     0.08016
    0.00000     0.63128
   DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
          TYPE "YES" OR "NO".
n
--------------------------------------------------------------
       THE CONTROL DISTRIBUTION MATRIX {"B"-MATRIX}...
    0.00340
    0.06308
    DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
         TYPE "YES" OR "NO".
n
--------------------------------------------------------------
    ENTER THE FEEDBACK GAIN CONTROL MATRIX {"F"-MATRIX}.
         DIMENSION = # CONTROLS {NC} X # STATES {NS}.
    YOU MAY ENTER THE MATRIX OR HAVE THE PROGRAM GENERATE
    A NULL MATRIX BY SELECTING ONE OF THE FOLLOWING:
              1 - NULL MATRIX
              2 - ANY OTHER MATRIX
                  SELECT AN OPTION
2
--------------------------------------------------------------
    THE ELEMENT F( 1, 1)=
158.5
    THE ELEMENT F( 1, 2)=
17.33

--------------------------------------------------------------
         THE FEEDBACK GAIN CONTROL MATRIX {"F"-MATRIX}
  158.50000    17.33000
   DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
         TYPE "YES" OR "NO".
n
--------------------------------------------------------------
ENTER INITIAL CONDITIONS OF THE STATE: STATE VECTOR {"X(0)"}
    DIMENSION = # OF STATES {NS} X 1.
        SELECT THE APPROPRIATE INITIAL CONDITIONS:
              1 - ALL I.C."S ARE ZERO
              2 - NON-ZERO I.C."S
```

AD-A158 754 AN INTERACTIVE DISCRETE CONTROLS ANALYSIS OPTION (ORACLS) FOR THE CONTROLS ANALYSIS PACKAGE ON THE IBM 3033(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA 2/2

UNCLASSIFIED M K BRENNY JUN 85 F/G 9/2 NL

END
FILMED
DTIC



MICROCOPY RESOLUTION TEST CHART

)ARDS-1963-A

```
                 ENTER: 1 OR 2
2
------------------------------------------------------------
    THE ELEMENT X( 1, 1)=
 .1
    THE ELEMENT X( 2, 1)=
0
------------------------------------------------------------
          THE INITIAL CONDITIONS VECTOR {"X(0)"}....
    0.10000
    0.00000
    DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
         TYPE "YES" OR "NO".
n
------------------------------------------------------------
   HOW MANY POINTS DO YOU WANT THE SYSTEM EVALUATED AT?
 NPTS = ?      (ENTER AN INTEGER ANSWER)
3
------------------------------------------------------------
             THE CONTROL LAW FOR ORACLS IS:
                  U(I) = -{F}*X(I) + {UC}
  WHERE {UC} IS THE CONTROL INPUT (I.E. DRIVING FUNCTION)
      THE FOLLOWING DRIVING FUNCTIONS ARE AVAILABLE:
        1 - NO INPUT    (I.E. {UC} IS A NULL VECTOR)
        2 - STEP INPUT
        3 - RAMP INPUT
     ENTER  0, 1, OR 2 FOR THE DESIRED DRIVING FUNCTION.
2
------------------------------------------------------------
   AT WHAT STAGE DO YOU DESIRE THE STEP INPUT TO START?
T(1) = ?
0
   AT WHAT STAGE DO YOU DESIRE THE STEP INPUT TO STOP?
T(2) = ?
NOTE: TO GET THE STEADY STATE VALUE OF X(I) THE STOP STAGE
      MUST BE EQUAL OR GREATER THAN THE FINAL STAGE. (I.E.
      THE NUMBER OF POINTS.)
1
------------------------------------------------------------
       WHAT IS THE MAXIMUM VALUE OF THE STEP INPUT?
```

```
AMP = ?
1
------------------------------------------------------------
              DO YOU WISH TO DRIVE CONTROL # 1 ?
                   ANSWER  (Y)ES OR (N)O
y
------------------------------------------------------------
 FLAG/PARAMETER SETTINGS FOR THIS RUN ARE AS FOLLOWS:
 THE SAMPLE TIME INTERVAL FOR THE SYSTEM IS =    0.10000
 THE DRIVING FUNCTION IS A "STEP" INPUT WITH:
                                START TIME =      0
                                END TIME   =      1
                                MAX. AMP.  =    1.00000
 CONTROLS BEING DRIVEN:
                       CONTROL # 1 -- YES
 ORDER OF SYSTEM =  2
 NUMBER OF CONTROLS =  1
 NUMBER OF OBSERVATIONS =  0
 NUMBER OF PROCESS NOISE SOURCES =  0
------------------------------------------------------------
ORTRAL: TRANSIENT ANALYSIS OF DISCRETE SYSTEMS.............

THE SAMPLE TIME INTERVAL (DELT) FOR THIS SYSTEM IS = 0.1000
THE DRIVING FUNCTION IS A "STEP" INPUT WITH:
                                   START TIME =      0
                                   END TIME   =      1
                                   MAX. AMP.  =    1.00000

CONTROLS BEING DRIVEN:
                        CONTROL # 1 -- YES
------------------------------------------------------------
COMPUTATION OF TRANSIENT RESPONSE FOR THE DIGITAL SYSTEM

      A     MATRIX        2 ROWS       2 COLUMNS
  1.0000000E+00   8.0155729E-02
  0.0000000E+00   6.3128365E-01

      B     MATRIX        2 ROWS       1 COLUMNS
  3.3950959E-03
  6.3082559E-02

H IS A NULL MATRIX

G IS A NULL MATRIX

      F     MATRIX        1 ROWS       2 COLUMNS
  1.5850000E+02   1.7330000E+01
```

```
   X(0)  MATRIX         2 ROWS        1 COLUMNS
 1.0000000E-01
 0.0000000E+00

------------------------------------------------------------

STRUCTURE OF PRINTING TO FOLLOW

   STAGE     TIME (SEC) = STAGE*DELT
 INPUT    - UC(I) TRANSPOSE; FOR APPROPRIATE DRIVING FUNCTION
 STATE    - X(I) TRANSPOSE; FROM X(I+1) = {A}*X(I) + {B}*U(I)
 CONTROL - U(I) TRANSPOSE; FROM U(I) = -{F}*X(I) + UC(I)

    0              0.00000
 UC(I):   0.1000000E+01
  X(I):   0.1000000E+00  0.0000000E+00
  U(I):  -0.1585000E+02
    1              0.10000
 UC(I):   0.1000000E+01
  X(I):   0.4618773E-01 -0.9998586E+00
  U(I):   0.1100679E+02
    2              0.20000
 UC(I):   0.0000000E+00
  X(I):   0.3412459E-02  0.6314235E-01
  U(I):  -0.1635132E+01
    3              0.30000
 UC(I):   0.0000000E+00
  X(I):   0.2922251E-02 -0.6328755E-01
  U(I):   0.6335965E+00
------------------------------------------------------------

 .....OPTPLOT DATE FILE GENERATED.....ORTRAL COMPLETE.......
DO YOU WISH TO GENERATE AN "OPTMATD" DATA FILE TO SAVE THE:
  {A}  (SYSTEM),         {B}  (CONTROL),
  {H}  (OBSERVABLES),  {G}  (MEASUREMENT- FEED FWD. DIST.),
{GAMD} (NOISE),          {F}  (CONTROL GAIN),
  {K}  (FILTER GAIN),  {Q}  (OUTPUT COST),
  {R}  (CONTROL COST), {V1} (PROCESS NOISE INTENSITY (PSD)),
  {V2} (MEASUREMENT NOISE INTENSITY (PSD)),
  {S}  (DISCRETE CROSS PRODUCT WEIGHTING)
  MATRICES FOR REENTRY TO THE OPTSYSX OR ORACLS PROGRAMS?

n
------------------------------------------------------------

                 GENERAL ORACLS OPTIONS:
   1 -- ORCONV: ANALOG TO DIGITAL MATRIX CONVERSION
   2 -- ORDSAL: DISCRETE SYSTEM ANALYSIS
   3 -- ORTRAL: TRANSIENT ANALYSIS OF A DISCRETE SYSTEM
   4 -- HELP:   PROGRAM & EQUATION DESCRIPTIONS
   5 -- EXIT:   RETURN TO ORACLS EXEC
        SELECT AN OPTION: 1,2, 3, 4, OR 5.
```

```
NOTE: SELECT OPTION - 5: IF YOU ARE USING THE OUTPUT TO
      DISK OPTION AND WOULD LIKE TO CHANGE FILENAMES

NOTE: NORMALLY ANY TIME DURING THE PROGRAM TWO SUCCESSIVE
      NULL "ENTERS" TERMINATES THE PROGRAM, SENDING YOU
      BACK TO THE ORACLS EXEC.

5
-----------------------------------------------------------

 ..ORACLS IS NOW TERMINATED.....RETURNING TO ORACLS EXEC...
```

APPENDIX E

TRANFUNC EXAMPLE RUN #1 (EIGENSYSTEM)

```
BEGIN RECORDING OF TERMINAL SESSION
R; T=0.01/0.02 20:37:19
------------------------------------------------------------
controls
------------------------------------------------------------
DASD 200 LINKED R/O; R/W BY 0637P
C (200) R/O
------------------------------------------------------------
   PLOTTING IS DONE THRU DISSPLA. UP TO 20% OF YOUR DISK
       SPACE MAY BE NEEDED OTHERWISE ERROR MESSAGES
************************************************************

     CONTROLS CONSISTS OF THREE INTERACTIVE PROGRAMS

         1  DACSAP      (SISO)
         2  OPTSYS      (MIMO)
         3  ORACLS      (MIMO)

         4  HELP - PROGRAM DESCRIPTIONS
         5  SAMPLE PROBLEMS WITH PROGRAM DIRECTIONS
         6  PROGRAM DOCUMENTATION SOURCES
         7  EXIT

         ENTER  1 ,  2 ,  3 ,  4 ,  5 ,  6,  OR  7
************************************************************

NORMALLY IN ANY FORTRAN PROGRAM TWO NULL ENTREES TERMINATE
  THE PROGRAM SENDING YOU BACK TO THE CONTROLLING EXEC

3
------------------------------------------------------------
'251' REPLACES ' F (251) '
F (251) R/O
'251' REPLACES ' F (251) '
F (251) R/O
------------------------------------------------------------

****** THE ORACLS EXEC ALLOWS THE FOLLOWING OPTIONS: ******

1  ORACLSX FORTRAN: --------DISCRETE SYSTEM ANALYSIS-------
                   (A-D CONVERSION, OPT. REG., KALMAN-BUCY
                    FILTER AND DISCRETE TRANSIENT ANALYSIS)

2  TRANFUNC FORTRAN: -DISCRETE TRANSFER FUNCTION ANALYSIS-
                     (SYSTEM EIGENVALUES, OPEN LOOP, NOISE,
                     AND COMPENSATOR T.F.s, MODAL MATRICES)

3  OPTPLOT FORTRAN:  (PLOTTING OF TRANSIENT RESPONSES FOR
                        STATES AND CONTROLS)

4  OPTGRAPH FORTRAN: ( POLE-ZERO, ROOT-LOCUS )

5  OUTPUT SELECTION -- TERMINAL OR "A" DISK FILE

6  HELP -- PROGRAM AND DATA FILE RELATIONSHIP EXPLANATIONS

7  EXIT -- RETURN TO CMS
```

```
** SELECT AN OPTION, ANY OTHER INPUT RETURNS YOU TO MENU **
2
------------------------------------------------------------
2
LOADING TRANFUNC..... DISCRETE TRANSFER FUNCTION ANALYSIS
------------------------------------------------------------
                    TRANFUNC OPTIONS:
 1 - OPEN-LOOP EIGENSYSTEM ANALYSIS ONLY, {A} MATRIX
 2 - OPEN-LOOP TRANSFER FUNCTION & EIGENSYSTEM
 3 - NOISE TRANSFER FUNCTION & CLOSED-LOOP EIGENSYSTEM
 4 - COMPENSATOR TRANSFER FUNCTION & ESTIMATOR EIGENSYSTEM
 5 - MARKOV PARAMETER CHANGE
 6 - HELP -- PROGRAM DESCRIPTION
 7 - EXIT -- RETURN TO ORACLS EXEC
 SELECT OPTION:  1, 2, 3, 4, 5, 6, OR 7   (SETS ITFOL FLAG)
    NOTE: MODAL ANALYSIS AVAILABLE IN OPTIONS: 2, 3, 4
6
------------------------------------------------------------
    "HELP" PROVIDES AN OVERVIEW OF THE PROGRAM OPTIONS
     AVAILABLE IN "TRANFUNC" AND SOME OF THE EQUATIONS
     USED IN THE CALCULATIONS.
     1 -- TERMINAL VIEWING OF SELECTED INFORMATION
     2 -- TERMINAL VIEWING PLUS HARDCOPY TO YOUR "A" DISK
     3 -- EXIT: RETURN TO THE TRANFUNC OPTIONS

   NOTE: OPTION "2" WILL PLACE THE FILE: "TRANFUNC HELP"
         ON YOUR "A" DISK CONTAINING THE INFORMATION YOU
         SELECTED TO VIEW AT THE TERMINAL.
                   SELECT OPTION: 1, 2, OR 3
1
------------------------------------------------------------
                   "HELP" INFORMATION OPTIONS:
      1 -- TRANFUNC:  EQUATIONS AND MATRICES DEFINED
      2 -- TRANFUNC:  DISCRETE TRANSFER FUNCTION ANALYSIS
      3 -- MODAL:     DISCUSSION OF MODAL MATRICES
      4 -- EXIT:      RETURN TO TRANFUNC OPTIONS
      5 -- EXIT:      RETURN TO ORACLS EXEC

          SELECT AN OPTION: 1, 2, 3, OR 4.
------------------------------------------------------------
   TRANFUNC IS A COMPLETELY INTERACTIVE DISCRETE TRANSFER
   FUNCTION ANALYSIS PROGRAM BASED ON THE FOLLOWING CONTROL
```

```
EQUATIONS:
          DISCRETE SYSTEM:      (ORACLS NOTATION)
                         SYSTEM EQUATION:
X((I+1)*T) = {A}*X(I*T) + {B}*U(I*T) + {GAMD}*WD(I*T)
OUTPUT EQUATION:          Y(I) = {H}*X(I) + {G}*U(I)
MEASUREMENT EQUATION:     Z(I) = {H}*X(I) + {G}*U(I) +V(I)
CONTROL LAW:              U = -{F}*X
COST EQUATION:  J = #(SUM:I=0-N: X¬(I*T)*{V1}*X(I*T) + ..
             ...X¬(I*T)*{S}*U(I*T) + U¬(I*T)*{V2}*U(I*T)

       WHERE "T" IS THE SAMPLE TIME INTERVAL.
       WHERE "¬" = TRANSPOSE.
       WHERE "#" IS LIMIT AS "N" APPROACHES INFINITY.
-----------------------------------------------------------
     DO YOU WISH A LIST OF MATRICES USED IN TRANFUNC?
                   ANSWER (Y)ES OR (N)
y
-----------------------------------------------------------
       MATRIX DESCRIPTION                    ORACLS NAME
   -----------------------------------      -----------

     SYSTEM MATRIX:                              {A}
     CONTROL MATRIX:                             {B}
     NOISE MATRIX:                              {GAMD}
     OBSERVABLES MATRIX:                         {H}
     MEASUREMENT - FEED FWD. DIST. MATRIX:       {G}
     CONTROL GAIN MATRIX:                        {F}
     FILTER GAIN MATRIX:                         {K}
     OUTPUT COST MATRIX:                         {Q}
     CONTROL COST MATRIX:                        {R}
     PROCESS NOISE MATRIX:                       {V1}
     MEASUREMENT NOISE MATRIX:                   {V2}
     CROSS PRODUCT WEIGHTING MATRIX:             {S}
     RICCATI EQUATION SOLUTION MATRIX:           {P}
     NOISE VECTOR:                               {WD}
     CONSTANT NOISE VECTOR:                      {WO}
-----------------------------------------------------------
               "HELP" INFORMATION OPTIONS:
    1 -- TRANFUNC:  EQUATIONS AND MATRICES DEFINED
    2 -- TRANFUNC:  DISCRETE TRANSFER FUNCTION ANALYSIS
    3 -- MODAL:     DISCUSSION OF MODAL MATRICES
    4 -- EXIT:      RETURN TO TRANFUNC OPTIONS
    5 -- EXIT:      RETURN TO ORACLS EXEC

       SELECT AN OPTION: 1, 2, 3, OR 4.
2
-----------------------------------------------------------
      TRANFUNC: DISCRETE TRANSFER FUNCTION ANALYSIS.
```

COMPUTES THE POLES, ZEROS, AND RESIDUES FOR A DESIRED TRANSFER FUNCTION. COMPUTATION OF MODAL MATRICES IS ALSO AVAILABLE DURING TRANSFER FUNCTION ANALYSIS. OUTPUTS RESULTS TO THE CORRESPONDING DATA FILES FOR PLOTTING VIA OPTGRAPH FORTRAN AVAILABLE IN THE ORACLS EXEC. OPTION 1 MAY BE USED TO FIND THE EIGENVALUES OF THE SYSTEM MATRIX.

```
   DO YOU WISH TO VIEW THE TRANSFER FUNCTION EQUATIONS?
                  ANSWER (Y)ES OR (N)O.
y
-----------------------------------------------------------
        TRANSFER FUNCTION EQUATIONS USED IN TRANFUNC
       --- OPEN-LOOP TRANSFER FUNCTION EQUATION: ---
              Z/U = {H}*{ z{I}-{A} }INV*{B}
          --- NOISE TRANSFER FUNCTION EQUATION: ---
          Z/U = {H}*{ z{I}-{A}+{B}*{F} }INV*{GAMD}
       --- COMPENSATOR TRANSFER FUNCTION EQUATION: ---
      U/Z = -{F}*{ z{I}-{A}+{B}*{F}+{K}*{H} }INV*{K}
  NOTE: THE COMPENSATOR TRANSFER FUNCTION IS FROM
        MEASUREMENT TO INPUT.
-----------------------------------------------------------
                 "HELP" INFORMATION OPTIONS:
   1 -- TRANFUNC:  EQUATIONS AND MATRICES DEFINED
   2 -- TRANFUNC:  DISCRETE TRANSFER FUNCTION ANALYSIS
   3 -- MODAL:     DISCUSSION OF MODAL MATRICES
   4 -- EXIT:      RETURN TO TRANFUNC OPTIONS
   5 -- EXIT:      RETURN TO ORACLS EXEC

        SELECT AN OPTION: 1, 2, 3, OR 4.
3
-----------------------------------------------------------
```

MODAL MATRICES MAY BE COMPUTED IN ALL TRANSFER FUNCTION ANALYSIS OPTIONS. MODAL MATRICES CAN BE USED IN DETERMINING WHETHER A SYSTEM IS CONTROLLABLE AND OBSERVABLE. IF THE MODAL DISTRIBUTION MATRIX, {TI*B} HAS NO ZERO ELEMENTS, THE SYSTEM IS COMPLETELY CONTROLLABLE. IF THE MODAL MEASUREMENT SCALING MATRIX, {H(BAR)*T} HAS NO ZERO ELEMENTS, THE

SYSTEM IS COMPLETELY OBSERVABLE/RECONSTRUCTIBLE. WITH THESE MATRICES THE USER CAN SEE AT A GLANCE WHETHER THE SYSTEM IS CONTROLLABLE AND OBSERVABLE WITH RESPECT TO ANY STATE/INPUT.

"HELP" INFORMATION OPTIONS:

```
1 -- TRANFUNC:  EQUATIONS AND MATRICES DEFINED
2 -- TRANFUNC:  DISCRETE TRANSFER FUNCTION ANALYSIS
3 -- MODAL:     DISCUSSION OF MODAL MATRICES
4 -- EXIT:      RETURN TO TRANFUNC OPTIONS
5 -- EXIT:      RETURN TO ORACLS EXEC

     SELECT AN OPTION: 1, 2, 3, OR 4.
4
```

TRANFUNC OPTIONS:

```
 1 - OPEN-LOOP EIGENSYSTEM ANALYSIS ONLY, {A} MATRIX
 2 - OPEN-LOOP TRANSFER FUNCTION & EIGENSYSTEM
 3 - NOISE TRANSFER FUNCTION & CLOSED-LOOP EIGENSYSTEM
 4 - COMPENSATOR TRANSFER FUNCTION & ESTIMATOR EIGENSYSTEM
 5 - MARKOV PARAMETER CHANGE
 6 - HELP -- PROGRAM DESCRIPTION
 7 - EXIT -- RETURN TO ORACLS EXEC
 SELECT OPTION:  1, 2, 3, 4, 5, 6, OR 7   (SETS ITFOL FLAG)
     NOTE: MODAL ANALYSIS AVAILABLE IN OPTIONS: 2, 3, 4
1
```

```
THE "A","B","GAMD","H","G","F","K","Q","R","V1","V2" AND "S"
MATRICES  FROM YOUR PREVIOUS ORACLS RUN WERE SAVED.
         THE FOLLOWING OPTIONS ARE AVAILABLE:

         1. USE ALL OF THE SAME MATRICES AGAIN.
         2. USE SELECTED MATRICES AGAIN.
         3. INPUT ALL NEW MATRICES.

         ENTER 1, 2, OR 3.

   NOTE: EACH SAVED MATRIX WILL BE REDISPLAYED AT
         THE PROPER INPUT SEQUENCE INTERVAL
         AND YOU WILL HAVE THE OPTION OF CHANGING
        INDIVIDUAL MATRIX ELEMENTS.

   NOTE: A CHANGE IN THE ORDER OF THE SYSTEM; -NS-
         REQUIRES OPTION 3.

1
```

THE SYSTEM MATRIX {"A"-MATRIX}...

```
1.00000      0.08016
0.00000      0.63128
```

DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
TYPE "YES" OR "NO".

n

FLAG/PARAMETER SETTINGS FOR THIS RUN ARE AS FOLLOWS:

```
ITFOL  IM  IE  ITF1  ITF2  ITF3  IFGFW
  1     0   6    0     0     0     0
```

THE SAMPLE TIME INTERVAL FOR THE SYSTEM IS =   0.10000

ORDER OF SYSTEM = 2

NUMBER OF CONTROLS = 1

NUMBER OF OBSERVATIONS = 2

NUMBER OF PROCESS NOISE SOURCES = 2

TRANFUNC:.......OPEN LOOP EIGEN VALUE ANALYSIS.............

```
ITFOL  IM  IE  ITF1  ITF2  ITF3  IFGFW
  1     0   6    0     0     0     0
```

THE SAMPLE TIME INTERVAL FOR THE SYSTEM IS =   0.10000

```
     A     MATRIX          2 ROWS        2 COLUMNS
 1.0000000E+00   8.0155729E-02
 0.0000000E+00   6.3128365E-01
```

OPEN LOOP EIGENVALUES..........DET(ZI-A)..

1.00000E+00: 6.31284E-01:

OPEN LOOP RIGHT EIGENVECTOR MATRIX.......T....

```
1.000000D+00 -2.124296D-01
0.000000D+00  9.771764D-01
```

OPEN LOOP LEFT EIGENVECTOR MATRIX......T-INV..

```
1.000000D+00  2.173913D-01
0.000000D+00  1.023357D+00
```

..TRANFUNC COMPLETED........FILES FOR OPTGRAPH GENERATED..

DO YOU WISH TO GENERATE AN "OPTMATD" DATA FILE TO SAVE THE:

{A}   (SYSTEM),   {B} (CONTROL),

```
{H}    (OBSERVABLES),  {G}  (MEASUREMENT- FEED FWD. DIST.),
{GAMD} (NOISE),        {F}  (CONTROL GAIN),
{K}    (FILTER GAIN),  {Q}  (OUTPUT COST),
{R}    (CONTROL COST), {V1} (PROCESS NOISE INTENSITY (PSD))
{V2}   (MEASUREMENT NOISE INTENSITY (PSD)),
{S}   (DISCRETE CROSS PRODUCT WEIGHTING),
  MATRICES FOR REENTRY TO THE OPTSYSX OR ORACLS PROGRAMS?
                       (Y OR N)
n
-----------------------------------------------------------
 ...TRANFUNC IS NOW TERMINATED...RETURNING TO ORACLS EXEC..
-- --------------------------------------------------------
******* THE ORACLS EXEC ALLOWS THE FOLLOWING OPTIONS: *****
1  ORACLSX FORTRAN: --------DISCRETE SYSTEM ANALYSIS-------
                   (A-D CONVERSION, OPT. REG., KALMAN-BUCY
                    FILTER AND DISCRETE TRANSIENT ANALYSIS)
2  TRANFUNC FORTRAN: -DISCRETE TRANSFER FUNCTION ANALYSIS-
                     (SYSTEM EIGENVALUES, OPEN LOOP, NOISE,
                     AND COMPENSATOR T.F.s, MODAL MATRICES)
3  OPTPLOT FORTRAN:  (PLOTTING OF TRANSIENT RESPONSES FOR
                        STATES AND CONTROLS)
4  OPTGRAPH FORTRAN: ( POLE-ZERO, ROOT-LOCUS )
5  OUTPUT SELECTION -- TERMINAL OR "A" DISK FILE
6  HELP -- PROGRAM AND DATA FILE RELATIONSHIP EXPLANATIONS
7  EXIT -- RETURN TO CMS
** SELECT AN OPTION, ANY OTHER INPUT RETURNS YOU TO MENU **
7
-----------------------------------------------------------
DASD 200 DETACHED
R; T=0.27/1.29 16:22:17
-----------------------------------------------------------
record off
END RECORDING OF TERMINAL SESSION
```

APPENDIX F

TRANFUNC EXAMPLE RUN #2 (OPEN-LOOP TF)

```
---------------------------------------------------------
                  TRANFUNC OPTIONS:
 1 - OPEN-LOOP EIGENSYSTEM ANALYSIS ONLY, {A} MATRIX
 2 - OPEN-LOOP TRANSFER FUNCTION & EIGENSYSTEM
 3 - NOISE TRANSFER FUNCTION & CLOSED-LOOP EIGENSYSTEM
 4 - COMPENSATOR TRANSFER FUNCTION & ESTIMATOR EIGENSYSTEM
 5 - MARKOV PARAMETER CHANGE
 6 - HELP -- PROGRAM DESCRIPTION
 7 - EXIT -- RETURN TO ORACLS EXEC
 SELECT OPTION:  1, 2, 3, 4, 5, 6, OR 7   (SETS ITFOL FLAG)
    NOTE: MODAL ANALYSIS AVAILABLE IN OPTIONS: 2, 3, 4
2
---------------------------------------------------------
          OPEN-LOOP TRANSFER FUNCTION OPTIONS:
            Z/U = {H}*{ z{I}-{A} }INV*{B}
      OPTION 1 -- POLES, RESIDUES, AND ZEROS COMPUTED
      OPTION 2 -- ONLY POLES AND ZEROS COMPUTED
      OPTION 3 -- ONLY POLES AND RESIDUES COMPUTED
      OPTION 4 -- EXIT -- RETURN TO TRANFUNC OPTIONS
  SELECT OPTION: 1, 2, 3, OR 4   (SETS ITF1=1,2,OR,3)
     NOTE: POLES AND ZEROS MUST BE SELECTED IF YOU
           WISH TO USE OPTGRAPH
     NOTE: REQUIRES NC>0, NO>0
1
---------------------------------------------------------
THE "A","B","GAMD","H","G","F","K","Q","R","V1","V2" AND "S"
MATRICES  FROM YOUR PREVIOUS ORACLS RUN WERE SAVED.
         THE FOLLOWING OPTIONS ARE AVAILABLE:
         1. USE ALL OF THE SAME MATRICES AGAIN.
         2. USE SELECTED MATRICES AGAIN.
         3. INPUT ALL NEW MATRICES.
         ENTER 1, 2, OR 3.
   NOTE: EACH SAVED MATRIX WILL BE REDISPLAYED AT
         THE PROPER INPUT SEQUENCE INTERVAL
```

AND YOU WILL HAVE THE OPTION OF CHANGING INDIVIDUAL MATRIX ELEMENTS.

NOTE: A CHANGE IN THE ORDER OF THE SYSTEM; -NS- REQUIRES OPTION 3.

```
1
-----------------------------------------------------------
            THE SYSTEM MATRIX {"A"-MATRIX}...

    1.00000      0.08016
    0.00000      0.63128

  DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
        TYPE "YES" OR "NO".
n
-----------------------------------------------------------
        THE CONTROL DISTRIBUTION MATRIX {"B"-MATRIX}...

    0.00340
    0.06308

  DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
        TYPE "YES" OR "NO".
n
-----------------------------------------------------------
        THE MEASUREMENT SCALING MATRIX {"H"-MATRIX}...

    1.00000      0.00000
    0.00000      1.00000

  DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
        TYPE "YES" OR "NO".
n
-----------------------------------------------------------
     DO YOU WISH TO DETERMINE THE MODAL DISTRIBUTION
     AND GAIN MATRICES?
                   TYPE (Y)ES OR (N)O
y
-----------------------------------------------------------
    FLAG/PARAMETER SETTINGS FOR THIS RUN ARE AS FOLLOWS:

 ITFOL  IM  IE  ITF1  ITF2  ITF3  IFGFW
   2     1   6    1     0     0     0

 THE SAMPLE TIME INTERVAL FOR THE SYSTEM IS =    0.10000
 ORDER OF SYSTEM =  2
 NUMBER OF CONTROLS =  1
 NUMBER OF OBSERVATIONS =  2
 NUMBER OF PROCESS NOISE SOURCES =  2
-----------------------------------------------------------
TRANFUNC:.......OPEN LOOP TRANSFER FUNCTION ANALYSIS.......
```

```
ITFOL   IM   IE   ITF1   ITF2   ITF3   IFGFW
  2      1    6     1      0      0      0

THE SAMPLE TIME INTERVAL FOR THE SYSTEM IS =  0.100

     A     MATRIX          2 ROWS          2 COLUMNS
 1.0000000E+00   8.0155729E-02
 0.0000000E+00   6.3128365E-01

     B     MATRIX          2 ROWS          1 COLUMNS
 3.3950959E-03
 6.3082559E-02

     H     MATRIX          2 ROWS          2 COLUMNS
 1.0000000E+00   0.0000000E+00
 0.0000000E+00   1.0000000E+00

   OPEN LOOP EIGENVALUES..........DET(ZI-A)..

1.00000E+00: 6.31284E-01:

   OPEN LOOP RIGHT EIGENVECTOR MATRIX.......T....

1.000000D+00 -2.124296D-01
0.000000D+00  9.771764D-01

   OPEN LOOP LEFT EIGENVECTOR MATRIX......T-INV..

1.000000D+00  2.173913D-01
0.000000D+00  1.023357D+00

   ...............MODAL MATRICES...............

   MODAL CONTROL DISTRIBUTION MATRIX......TI*B..

   1.710870D-02
   6.455596D-02

   MODAL MEASUREMENT SCALING MATRIX...H(BAR)*T..

   1.000000D+00 -2.124296D-01
   0.000000D+00  9.771764D-01

   ........OPEN LOOP TRANSFER FUNCTIONS........
TF FOR INPUT NO.  1 AND OUTPUT NO.  1:
  ORDER OF NUMERATOR =  1          TF GAIN =  0.3395E-02
  NUMERATOR EIGENVALUES (INCLUDING EXTRANEOUS ZERO VALUES):
   ( 0.000000)+J( 0.000000)
   (-0.858049)+J( 0.000000)

  RESIDUES AT THE POLES:
```

```
           P O L E S                 R E S I D U E S
        REAL(A)     IMAG(B)
    ( 1.000000)+J( 0.000000)    ( 0.017109)*EXP(A*T)
    ( 0.631284)+J( 0.000000)    (-0.013714)*EXP(A*T)

TF FOR INPUT NO.  1 AND OUTPUT NO.  2:
  ORDER OF NUMERATOR =  1         TF GAIN =  0.6308E-01
  NUMERATOR EIGENVALUES (INCLUDING EXTRANEOUS ZERO VALUES):
    ( 1.000000)+J( 0.000000)
    ( 0.000000)+J( 0.000000)

  RESIDUES AT THE POLES:
              P O L E S             R E S I D U E S
        REAL(A)     IMAG(B)
    ( 1.000000)+J( 0.000000)    ( 0.000000)*EXP(A*T)
    ( 0.631284)+J( 0.000000)    ( 0.063083)*EXP(A*T)
----------------------------------------------------------
 ..TRANFUNC COMPLETED........FILES FOR OPTGRAPH GENERATED..
DO YOU WISH TO GENERATE AN "OPTMATD" DATA FILE TO SAVE THE:
{A}     (SYSTEM),        {B}  (CONTROL),
{H}     (OBSERVABLES),   {G}  (MEASUREMENT- FEED FWD. DIST.),
{GAMD}  (NOISE),         {F}  (CONTROL GAIN),
{K}     (FILTER GAIN),   {Q}  (OUTPUT COST),
{R}     (CONTROL COST),  {V1} (PROCESS NOISE INTENSITY (PSD))
{V2}    (MEASUREMENT NOISE INTENSITY (PSD)),
{S}   (DISCRETE CROSS PRODUCT WEIGHTING),
  MATRICES FOR REENTRY TO THE OPTSYSX OR ORACLS PROGRAMS?
                         (Y OR N)
n
c---------------------------------------------------------
 ...TRANFUNC IS NOW TERMINATED...RETURNING TO ORACLS EXEC..
c---------------------------------------------------------
```

APPENDIX G

TRANFUNC EXAMPLE RUN #3 (NOISE TF)

```
-----------------------------------------------------------
                 TRANFUNC OPTIONS:
 1 - OPEN-LOOP EIGENSYSTEM ANALYSIS ONLY, {A} MATRIX
 2 - OPEN-LOOP TRANSFER FUNCTION & EIGENSYSTEM
 3 - NOISE TRANSFER FUNCTION & CLOSED-LOOP EIGENSYSTEM
 4 - COMPENSATOR TRANSFER FUNCTION & ESTIMATOR EIGENSYSTEM
 5 - MARKOV PARAMETER CHANGE
 6 - HELP -- PROGRAM DESCRIPTION
 7 - EXIT -- RETURN TO ORACLS EXEC
 SELECT OPTION:  1, 2, 3, 4, 5, 6, OR 7   (SETS ITFOL FLAG)
    NOTE: MODAL ANALYSIS AVAILABLE IN OPTIONS: 2, 3, 4
3
-----------------------------------------------------------
             NOISE TRANSFER FUNCTION OPTIONS:
           Z/U = {H}*( z{I}-{A}+{B}*{F} )INV*{GAMD}
       OPTION 1 -- POLES, RESIDUES, AND ZEROS COMPUTED
       OPTION 2 -- ONLY POLES AND ZEROS COMPUTED
       OPTION 3 -- ONLY POLES AND RESIDUES COMPUTED
       OPTION 4 -- EXIT -- RETURN TO TRANFUNC OPTIONS
       SELECT OPTION 1, 2, 3, OR 4    (SETS ITF2 = 1,2,3)
     NOTE: NOISE TF FUNCTION THRU CLOSED LOOP SYSTEM;
     NOTE: POLES AND ZEROS MUST BE SELECTED IF YOU
           Wish to use OPTGRAPH.
     NOTE: REQUIRES NC>0, NO>0, NG>0
1
-----------------------------------------------------------
THE "A","B","GAMD","H","G","F","K","Q","R","V1","V2" AND "S"
MATRICES  FROM YOUR PREVIOUS ORACLS RUN WERE SAVED.
         THE FOLLOWING OPTIONS ARE AVAILABLE:
         1. USE ALL OF THE SAME MATRICES AGAIN.
         2. USE SELECTED MATRICES AGAIN.
         3. INPUT ALL NEW MATRICES.
         ENTER 1, 2, OR 3.
```

```
NOTE: EACH SAVED MATRIX WILL BE REDISPLAYED AT
      THE PROPER INPUT SEQUENCE INTERVAL
      AND YOU WILL HAVE THE OPTION OF CHANGING
     INDIVIDUAL MATRIX ELEMENTS.

NOTE: A CHANGE IN THE ORDER OF THE SYSTEM; -NS-
      REQUIRES OPTION 3.

1
-----------------------------------------------------------

             THE SYSTEM MATRIX {"A"-MATRIX}...

   1.00000      0.08016
   0.00000      0.63128

  DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
         TYPE "YES" OR "NO".
n
-----------------------------------------------------------

        THE CONTROL DISTRIBUTION MATRIX {"B"-MATRIX}...

   0.00340
   0.06308

   DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
         TYPE "YES" OR "NO".
n

-----------------------------------------------------------

 THE PROCESS NOISE DISTRIBUTION MATRIX {"GAMD"-MATRIX}...

   1.00000      0.00000
   0.00000      1.00000

    DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
         TYPE "YES" OR "NO".
n

-----------------------------------------------------------

     THE MEASUREMENT SCALING MATRIX {"H"-MATRIX}...

   1.00000      0.00000
   0.00000      1.00000

  DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
         TYPE "YES" OR "NO".
n
-----------------------------------------------------------

      THE FEEDBACK GAIN CONTROL MATRIX {"F"-MATRIX}

 110.40000    12.66000

  DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?
         TYPE "YES" OR "NO".
n
-----------------------------------------------------------
```

```
     DO YOU WISH TO DETERMINE THE MODAL DISTRIBUTION
     AND GAIN MATRICES?
                        TYPE (Y)ES OR (N)O
y
------------------------------------------------------------
   FLAG/PARAMETER SETTINGS FOR THIS RUN ARE AS FOLLOWS:
 ITFOL  IM  IE  ITF1  ITF2  ITF3  IFGFW
   3     1   6    0     1     0     0
 THE SAMPLE TIME INTERVAL FOR THE SYSTEM IS =   0.10000
 ORDER OF SYSTEM =  2
 NUMBER OF CONTROLS =  1
 NUMBER OF OBSERVATIONS =  2
 NUMBER OF PROCESS NOISE SOURCES =  2
------------------------------------------------------------
TRANFUNC:............NOISE TRANSFER FUNCTION ANALYSIS......
 ITFOL  IM  IE  ITF1  ITF2  ITF3  IFGFW
   3     1   6    0     1     0     0
 THE SAMPLE TIME INTERVAL FOR THE SYSTEM IS =   0.10000

      A      MATRIX        2 ROWS        2 COLUMNS
  1.0000000E+00   8.0155729E-02
  0.0000000E+00   6.3128365E-01

      B      MATRIX        2 ROWS        1 COLUMNS
  3.3950959E-03
  6.3082559E-02

     GAMD    MATRIX        2 ROWS        2 COLUMNS
  1.0000000E+00   0.0000000E+00
  0.0000000E+00   1.0000000E+00

      H      MATRIX        2 ROWS        2 COLUMNS
  1.0000000E+00   0.0000000E+00
  0.0000000E+00   1.0000000E+00

      F      MATRIX        1 ROWS        2 COLUMNS
  1.1040000E+02   1.2660000E+01

    OPEN LOOP EIGENVALUES..........DET(ZI-A)..

 1.00000E+00: 6.31284E-01:

    OPEN LOOP RIGHT EIGENVECTOR MATRIX.......T....

 1.000000D+00 -2.124296D-01
 0.000000D+00  9.771764D-01


    OPEN LOOP LEFT EIGENVECTOR MATRIX......T-INV..
```

```
 1.000000D+00  2.173913D-01
 0.000000D+00  1.023357D+00
```

...............MODAL MATRICES...............

MODAL CONTROL DISTRIBUTION MATRIX......TI*B..

```
 1.710870D-02
 6.455596D-02
```

MODAL PROCESS NOISE DISTRIBUTION MATRIX...TI*GAMD..

```
 1.000000D+00  2.173913D-01
 0.000000D+00  1.023357D+00
```

MODAL MEASUREMENT SCALING MATRIX...H(BAR)*T..

```
 1.000000D+00 -2.124296D-01
 0.000000D+00  9.771764D-01
```

THE MODAL CONTROL GAINS.................F*T..

```
 1.104000D+02 -1.108118D+01
```

...THE CLOSED LOOP DYNAMICS MATRIX ....{A-B*F}..

```
 6.251814D-01  3.717381D-02
-6.964315D+00 -1.673415D-01
```

CLOSED LOOP REGULATOR E-VALUES..DET(ZI-A+B*F)..

2.28920E-01, 3.19166E-01:

C-LOOP RIGHT EIGENVECTOR MATRIX..........M....

```
-5.689885D-02 -4.582878D-02
 1.000000D+00  0.000000D+00
```

CONTROL EIGENVECTOR MATRIX..............F*M..

C-LOOP OPT. REG. LEFT E-VECTOR MATRIX..M-INV

```
 0.000000D+00  1.000000D+00
-2.182035D+01 -1.241553D+00
```

..NOISE TRANSFER FUNCTIONS THROUGH THE CLOSED-LOOP SYSTEM..

TF FOR INPUT NO. 1 AND OUTPUT NO. 1:

ORDER OF NUMERATOR = 1   TF GAIN = 0.1000E+01

NUMERATOR EIGENVALUES (INCLUDING EXTRANEOUS ZERO VALUES):

(-0.167342)+J(0.000000)

```
( 0.000000)+J( 0.000000)

RESIDUES AT THE POLES:
          P O L E S                    R E S I D U E S
  REAL(A)        IMAG(B)
( 0.228920)+J( 0.319166)  ( 1.000000) EXP(A*T)*COS(B*T)
( 0.228920)+J(-0.319166)  ( 1.241553) EXP(A*T)*SIn(B*T)

TF FOR INPUT NO.  1 AND OUTPUT NO.  2:

  NO FINITE ZEROS.  TF GAIN = -0.6964E+01

RESIDUES AT THE POLES:
            P O L E S                   R E S I D U E S
    REAL(A)      IMAG(B)
( 0.228920)+J( 0.319166)  ( 0.000000) EXP(A*T)*COS(B*T)
( 0.228920)+J(-0.319166)  (-21.820348) EXP(A*T)*SIN(B*T)

TF FOR INPUT NO.  2 AND OUTPUT NO.  1:

  NO FINITE ZEROS.  TF GAIN =  0.3717E-01

RESIDUES AT THE POLES:
              P O L E S                 R E S I D U E S
    REAL(A)            IMAG(B)
( 0.228920)+J( 0.319166)    ( 0.000000) EXP(A*T)*COS(B*T)
( 0.228920)+J(-0.319166)    ( 0.116472) EXP(A*T)*SIN*B*T)

TF FOR INPUT NO.  2 AND OUTPUT NO.  2:
ORDER OF NUMERATOR =  1         TF GAIN =  0.1000E+01
NUMERATOR EIGENVALUES (INCLUDING EXTRANEOUS ZERO VALUES):
( 0.625181)+J( 0.000000)
( 0.000000)+J( 0.000000)

RESIDUES AT THE POLES:
          P O L E S                    R E S I D U E S
  REAL(A)        IMAG(B)
( 0.228920)+J( 0.319166)    ( 1.000000) EXP(A*T)*COS(B*T)
( 0.228920)+J(-0.319166)    (-1.241553) EXP(A*T)*SIN(B*T)
----------------------------------------------------------
```

```
 ..TRANFUNC COMPLETED........FILES FOR OPTGRAPH GENERATED..
DO YOU WISH TO GENERATE AN "OPTMATD" DATA FILE TO SAVE THE:
{A}     (SYSTEM),         {B}  (CONTROL),
{H}     (OBSERVABLES),    {G}  (MEASUREMENT- FEED FWD. DIST.),
{GAMD} (NOISE),           {F}  (CONTROL GAIN),
{K}     (FILTER GAIN),    {Q}  (OUTPUT COST),
{R}     (CONTROL COST),   {V1} (PROCESS NOISE INTENSITY (PSD))
{V2}    (MEASUREMENT NOISE INTENSITY (PSD)),
{S}    (DISCRETE CROSS PRODUCT WEIGHTING),
  MATRICES FOR REENTRY TO THE OPTSYSX OR ORACLS PROGRAMS?
                        (Y OR N)
n
-----------------------------------------------------------
 ...TRANFUNC IS NOW TERMINATED...RETURNING TO ORACLS EXEC..
-----------------------------------------------------------
```

APPENDIX H

TRANFUNC EXAMPLE RUN #4 (COMPENSATOR TF)

```
-----------------------------------------------------------
                  TRANFUNC OPTIONS:
 1 - OPEN-LOOP EIGENSYSTEM ANALYSIS ONLY, {A} MATRIX
 2 - OPEN-LOOP TRANSFER FUNCTION & EIGENSYSTEM
 3 - NOISE TRANSFER FUNCTION & CLOSED-LOOP EIGENSYSTEM
 4 - COMPENSATOR TRANSFER FUNCTION & ESTIMATOR EIGENSYSTEM
 5 - MARKOV PARAMETER CHANGE
 6 - HELP -- PROGRAM DESCRIPTION
 7 - EXIT -- RETURN TO ORACLS EXEC
 SELECT OPTION:  1, 2, 3, 4, 5, 6, OR 7   (SETS ITFOL FLAG)
    NOTE: MODAL ANALYSIS AVAILABLE IN OPTIONS: 2, 3, 4
4
-----------------------------------------------------------
         COMPENSATOR TRANSFER FUNCTION OPTIONS:
      U/Z = -{F}*{ z{I}-{A}+{B}*{F}+{K}*{H} }INV*{K}
     OPTION 1 -- POLES, RESIDUES, AND ZEROS COMPUTED
     OPTION 2 -- ONLY POLES AND ZEROS COMPUTED
     OPTION 3 -- ONLY POLES AND  RESIDUES COMPUTED
     OPTION 4 -- EXIT -- RETURN TO TRANFUNC OPTIONS
     SELECT OPTION 1, 2, 3, OR 4    (SETS ITF3 = 1,2,3)
    NOTE: COMPENSATOR T.F. IS FROM MEASUREMENT TO INPUT
    NOTE: A COMPENSATOR TRANSFER FUNCTION MAY BE COMPUTED
          ONLY IF BOTH THE REGULATOR {F} AND FILTER {K}
          GAINS ARE AVAILABLE. THEY MAY BE CALCULATED IN
          THE "OPTREG" AND "KBFIL" OPTIONS OF ORACLSX.
    NOTE: POLES AND ZEROS MUST BE SELECTED IF YOU WISH
          TO USE OPTGRAPH.
    NOTE: REQUIRES NC>0, NO>0
1
-----------------------------------------------------------

-----------------------------------------------------------
THE "A","B","GAMD","H","G","F","K","Q","R","V1","V2" AND "S"
MATRICES  FROM YOUR PREVIOUS ORACLS RUN WERE SAVED.
         THE FOLLOWING OPTIONS ARE AVAILABLE:
```

```
        1. USE ALL OF THE SAME MATRICES AGAIN.
        2. USE SELECTED MATRICES AGAIN.
        3. INPUT ALL NEW MATRICES.

        ENTER 1, 2, OR 3.

  NOTE: EACH SAVED MATRIX WILL BE REDISPLAYED AT
        THE PROPER INPUT SEQUENCE INTERVAL
        AND YOU WILL HAVE THE OPTION OF CHANGING
       INDIVIDUAL MATRIX ELEMENTS.

  NOTE: A CHANGE IN THE ORDER OF THE SYSTEM; -NS-
        REQUIRES OPTION 3.
1
-----------------------------------------------------------

              THE SYSTEM MATRIX {"A"-MATRIX}...

   1.00000      0.08016
   0.00000      0.63128

  DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?

        TYPE "YES" OR "NO".
n
-----------------------------------------------------------

        THE CONTROL DISTRIBUTION MATRIX {"B"-MATRIX}...

   0.00340
   0.06308

   DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?

        TYPE "YES" OR "NO".
n
-----------------------------------------------------------

        THE MEASUREMENT SCALING MATRIX {"H"-MATRIX}...

   1.00000      0.00000
   0.00000      1.00000

   DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?

        TYPE "YES" OR "NO".
n
-----------------------------------------------------------

        THE FEEDBACK GAIN CONTROL MATRIX {"F"-MATRIX}

 110.40000    12.66000

   DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?

        TYPE "YES" OR "NO".
n
-----------------------------------------------------------

    THE FEEDBACK GAIN ESTIMATOR MATRIX {"K"-MATRIX}

   0.61914      0.04938
   0.00338      0.34673

 DO YOU WISH TO CHANGE THE VALUE OF ANY MATRIX ELEMENT?

        TYPE "YES" OR "NO".
n
```

```
-----------------------------------------------------------
    DO YOU WISH TO DETERMINE THE MODAL DISTRIBUTION
    AND GAIN MATRICES?
                        TYPE (Y)ES OR (N)O
y
-----------------------------------------------------------
   FLAG/PARAMETER SETTINGS FOR THIS RUN ARE AS FOLLOWS:

 ITFOL   IM   IE   ITF1   ITF2   ITF3   IFGFW
   4      1    6    0      0      1      0

 THE SAMPLE TIME INTERVAL FOR THE SYSTEM IS =    0.10000

 ORDER OF SYSTEM =  2

 NUMBER OF CONTROLS =  1

 NUMBER OF OBSERVATIONS =  2

 NUMBER OF PROCESS NOISE SOURCES =  2
-----------------------------------------------------------
TRANFUNC:......COMPENSATOR TRANSFER FUNCTION ANALYSIS......
 ITFOL   IM   IE   ITF1   ITF2   ITF3   IFGFW
   4      1    6    0      0      1      0
 THE SAMPLE TIME INTERVAL FOR THE SYSTEM IS =    0.10000

      A     MATRIX          2 ROWS        2 COLUMNS
  1.0000000E+00   8.0155729E-02
  0.0000000E+00   6.3128365E-01

      B     MATRIX          2 ROWS        1 COLUMNS
  3.3950959E-03
  6.3082559E-02

      H     MATRIX          2 ROWS        2 COLUMNS
  1.0000000E+00   0.0000000E+00
  0.0000000E+00   1.0000000E+00

      F     MATRIX          1 ROWS        2 COLUMNS
  1.1040000E+02   1.2660000E+01

      K     MATRIX          2 ROWS        2 COLUMNS
  6.1913667E-01   4.9382360E-02
  3.3817731E-03   3.4673134E-01

   OPEN LOOP EIGENVALUES..........DET(ZI-A)..

 1.00000E+00: 6.31284E-01:

   OPEN LOOP RIGHT EIGENVECTOR MATRIX.......T....

 1.000000D+00 -2.124296D-01
 0.000000D+00  9.771764D-01

   OPEN LOOP LEFT EIGENVECTOR MATRIX......T-INV..

 1.000000D+00  2.173913D-01
```

```
0.000000D+00  1.023357D+00


   ...............MODAL MATRICES...............

   MODAL CONTROL DISTRIBUTION MATRIX......TI*B..

   1.710870D-02
   6.455596D-02

   MODAL MEASUREMENT SCALING MATRIX...H(BAR)*T..

   1.000000D+00  2.124296D-01
   0.000000D+00  9.771764D-01

   THE MODAL CONTROL GAINS.................F*T..

   1.1 [illegible]00D+02 -1.108118D+01

   MODAL FILTER STEADY STATE GAINS........TI*K..

   6.198718D-01  1.247587D-01
   3.460760D-03  3.548298D-01

   ... THE CLOSED LOOP FILTER DYNAMICS MATRIX ...{A-KH}..

1.619137D+00  1.295381D-01
3.381773D-03  9.780150D-01


   ..........EIGENSYSTEM OF ESTIMATOR..........

   CLOSED LOOP ESTIMATOR E-VALUES..DET(ZI-A+K*H)..

1.61982E+00: 9.77332E-01:

   C-LOOP RIGHT EIGENVECTOR MATRIX..........M....

9.999861D-01 -1.978447D-01
5.269093D-03  9.802334D-01

   MEASUREMENT EIGENVECTOR MATRIX.....H(BAR)*M..

   9.999861D-01 -1.978447D-01
   5.269093D-03  9.802334D-01

   C-LOOP OPT. FILTER LEFT E-VECTOR MATRIX..M-INV.

 9.989515D-01  2.016226D-01
-5.369709D-03  1.019081D+00

... COMPENSATOR TRANSFER FUNCTIONS FROM MEAS. TO INPUT ...
               U/Z = -F*(zI-A+B*F+K*H)INV*K
```

```
TF DENOMINATOR EIGENVALUES:
  ( 0.711854)+J( 0.564795)
  ( 0.711854)+J(-0.564795)

TF FOR INPUT NO.  1 AND OUTPUT NO.  1:
  ORDER OF NUMERATOR =  1          TF GAIN =  0.6840E+02
  NUMERATOR EIGENVALUES (INCLUDING EXTRANEOUS ZERO VALUES):
  ( 0.977322)+J( 0.000000)
  ( 0.000000)+J( 0.000000)

  RESIDUES AT THE POLES:
                POLES                      RESIDUES
    REAL(A)        IMAG(B)
  ( 0.711854)+J( 0.564795)   ( 68.395501) EXP(A*T)*COS(B*T)
  ( 0.711854)+J(-0.564795)   (-32.147575) EXP(A*T)*SIN(B*T)

TF FOR INPUT NO.  2 AND OUTPUT NO.  1:
  ORDER OF NUMERATOR =  1          TF GAIN =  0.9841E+01
  NUMERATOR EIGENVALUES (INCLUDING EXTRANEOUS ZERO VALUES):
  ( 0.759912)+J( 0.000000)
  ( 0.000000)+J( 0.000000)

  RESIDUES AT THE POLES:
            POLES                     RESIDUES
    REAL(A)       IMAG(B)
  ( 0.711854)+J( 0.564795)   ( 9.841431) EXP(A*T)*COS(B*T)
  ( 0.711854)+J(-0.564795)   (-0.837409) EXP(A*T)*SIN(B*T)
-----------------------------------------------------------
 ..TRANFUNC COMPLETED........FILES FOR OPTGRAPH GENERATED..
DO YOU WISH TO GENERATE AN "OPTMATD" DATA FILE TO SAVE THE:
{A}    (SYSTEM),        {B}  (CONTROL),
{H}    (OBSERVABLES),   {G}  (MEASUREMENT- FEED FWD. DIST.),
{GAMD} (NOISE),         {F}  (CONTROL GAIN),
{K}    (FILTER GAIN),   {Q}  (OUTPUT COST),
{R}    (CONTROL COST),  {V1} (PROCESS NOISE INTENSITY (PSD))
{V2}    (MEASUREMENT NOISE INTENSITY (PSD)),
{S}   (DISCRETE CROSS PRODUCT WEIGHTING),
```

```
        MATRICES FOR REENTRY TO THE OPTSYSX OR ORACLS PROGRAMS?
                              (Y OR N)
n
-----------------------------------------------------------
 ...TRANFUNC IS NOW TERMINATED...RETURNING TO ORACLS EXEC..
-----------------------------------------------------------
```

LIST OF REFERENCES

1. NASA Langley Research Center (NASA-TP-1106), ORACLS - A System for Linear-Quadratic-Gaussian Control Law Design, by E.S. Armstrong, Hampton Va., April 1978.

2. Kwakernaak, H. and Sivan, R., Linear Optimal Control Systems, Wiley-Interscience, 1972.

3. Hoden, J.G., Interactive Implementation of the Optimal Systems Control Design Program (OPTSYSX) on the IBM 3033, MS Thesis , Naval Postgraduate School, Monterey, Ca., Mar. 1984.

4. Laptas, M.H., Development of Graphical Pole-Zero, Root-Locus, Bode, Nyquist, and Nichols Responses Using the OPTSYSX Program, MS Thesis , Naval Postgraduate School, Monterey, Ca., Sept. 1984.

5. Diel, H.A., Development of Graphical Time Response Using the OPTSYSX Program, MS Thesis , Naval Postgraduate School, Monterey, Ca., Sept. 1984.

6. Cooksey, M.C., An Interactive Computer Aid for the Design and Analysis of Linear, Single Input/Single Output Digital And Continuous Control Systems, MS Thesis , Naval Postgraduate School, Monterey, Ca., Dec. 1984.

7. Franklin, G.F. and Powell, J.D., Digital Control of Dynamic Systems, Addison-Wesley, 1980 (2nd Printing, 1981).

8. W.R. Church Computer Center, Using EXEC Files under CMS, Technical Note: TM-VM-04, Naval Postgraduate School, Feb. 1984.

9. Lipschutz, S. and Poe, A., Schaum's Outline of Theory and Problems of Programing with FORTRAN, McGraw-Hill, 1978

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