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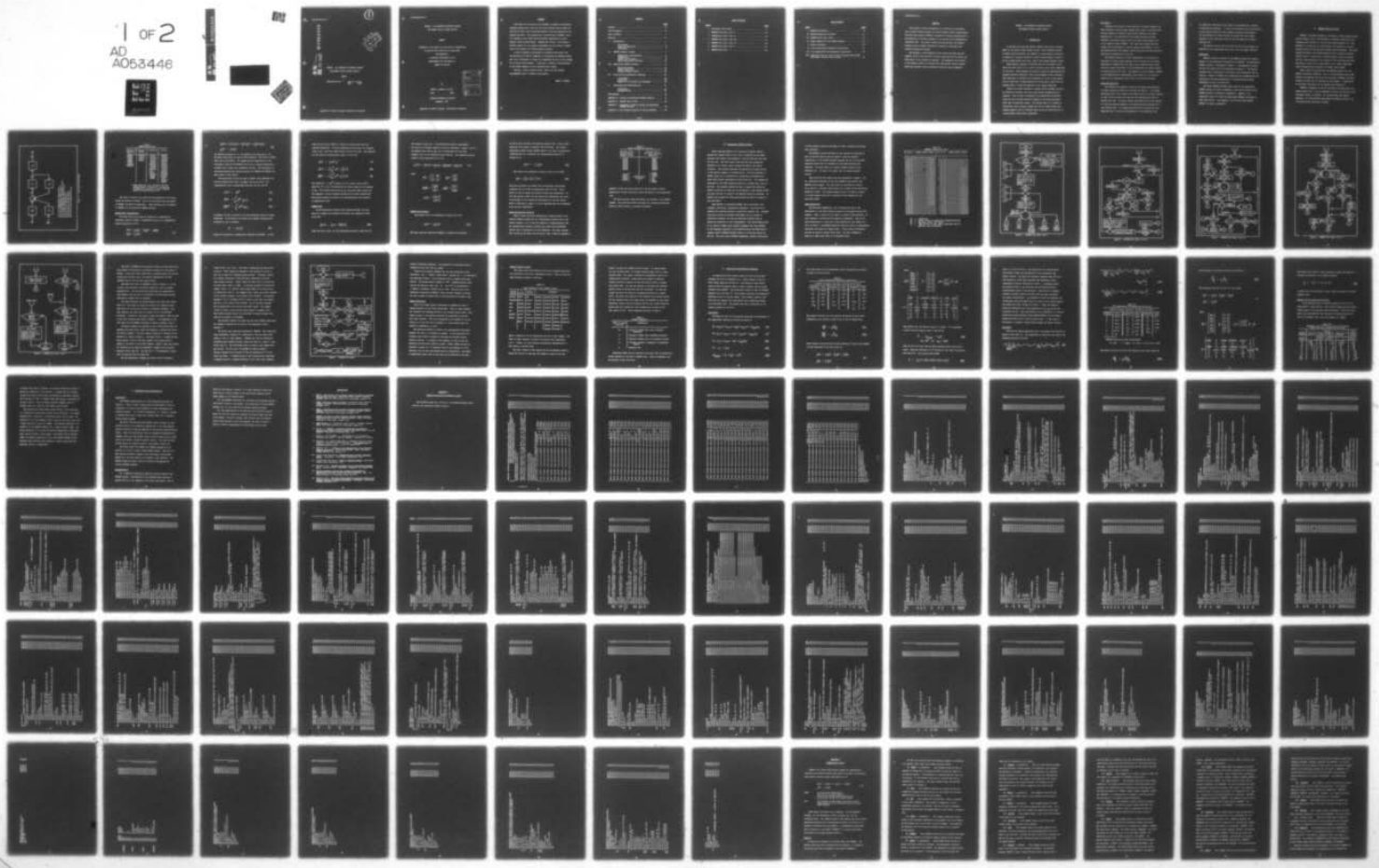

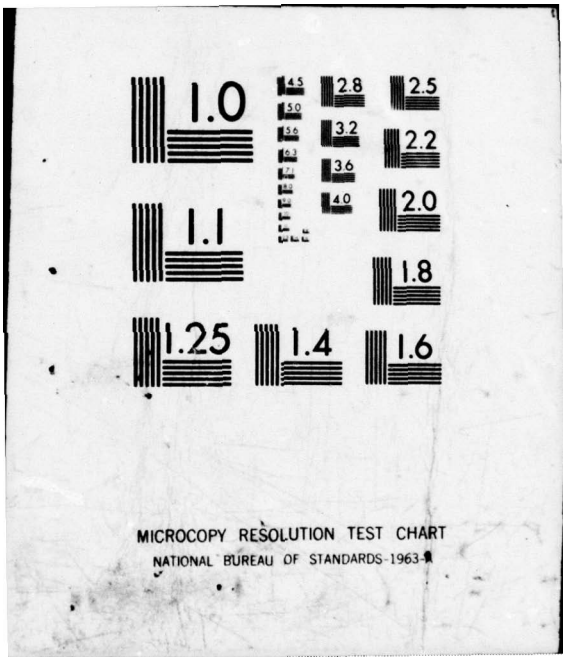
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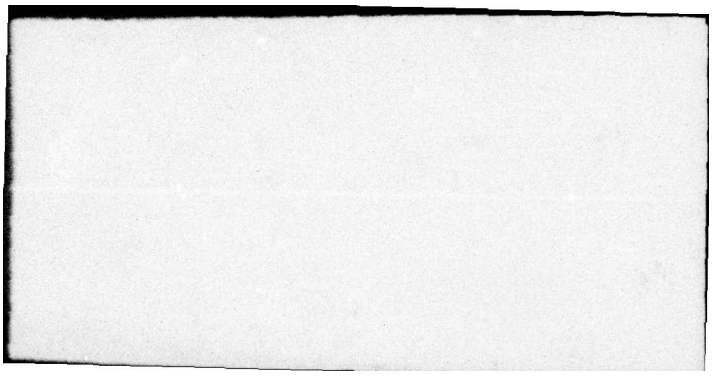

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INTERAC - AN INTERACTIVE SOFTWARE PACKAGE FOR DIRECT DIGITAL CONTROL DESIGN

THESIS

AFIT/GGC/EE/77D-1 James A. Colgate
Capt USAF

Approved for public release; distribution unlimited

AFIT/GGC/EE/77D-1

INTERAC - AN INTERACTIVE SOFTWARE PACKAGE FOR DIRECT DIGITAL CONTROL DESIGN

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

ACCESSION for
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by

James A. Colgate, B.S.E.E.

Capt USAF

Graduate Guidance and Control

December 1977

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Preface

This report is the result of my attempt to develop an interactive computer program that a user can use to get exactly what he needs (no more and no less) with the minimum amount of work and expertise in the program operation. The program that I started with is FORTRAC, which is a package of the latest state-of-the-art algorithms for direct digital control system design. Through this effort, I have gained a healthy respect for the computer programmers who can produce a simple easy to use program for solving complex problems.

I wish to express my gratitude to Professor Brian Porter from the University of Salford, England, for developing the FORTRAC package and to Dr. Constantine H. Houpis for suggesting the use of this package for a control system design. I also wish to thank Mr. Duane Robertus of the Flight Dynamics Lab for sponsoring this thesis.

Finally, I wish to thank my wife, Julie, for her constant encouragement while I worked on this project.

James A. Colgate

Contents

	Page
Preface	ii
List of Figures	iv
List of Tables	v
Abstract	vi
I. Introduction	1
The Problem	2
Scope and Objectives	2
Development	3
II. FORTRAC Computer Package	4
Sampled Data Transformation	6
Augmentation	8
Control Law Synthesis	9
Matrix Manipulation Routines	10
III. Specialized INTERAC Software	12
Input Subroutines	13
Output Subroutines	23
Program Sequence Control	24
IV. C-141 and F-4E Mathematical Modeling	26
C-141 Model	26
F-4E Model	29
Results of F-4E Control Law Synthesis	32
V. Conclusions and Recommendations	34
Conclusions	34
Recommendations	34
Bibliography	36
Appendix A: Listing of Specialized INTERAC Software	37
Appendix B: INTERAC User's Guide	83
Appendix C: Programmer's Guide for Using the Specialized INTERAC Software	98
Appendix D: Card Sequence Required to Utilize FORTRAC	110

List of Figures

Figure		Page
1	Continuous Time System	5
2	READNUM Flow Chart, Part I	15
3	READNUM Flow Chart, Part II	16
4	READNUM Flow Chart, Part III	17
5	READNUM Flow Chart, Part IV	18
6	READNUM Flow Chart, Part V	19
7	READCOM Flow Chart	22

List of Tables

Table		Page
I	FORTRAC Subroutines	6
II	Matrix Manipulation Routines	11
III	READNUM Legal Entry Table	14
IV	Legal Commands For The INTERAC Package	24
V	Option Catagories	25
VI	C-141 Longitudinal Dimensional Derivatives	27
VII	F-4E Longitudinal Non-dimensional Derivatives	30
VIII	Simulation Data for the F-4E with a Discrete-Time Flight Path Angle Tracking Control System	32

Abstract

The purpose of this investigation is to develop an interactive, user oriented software package for direct digital control system design. The batch mode program, FORTRAC, developed by Professor Brian Porter of the University of Salford, England, is the source of the computational algorithms used. This report details the input,output, and program sequence control software developed to produce an efficient, user oriented interactive package.

The package is very forgiving of user errors and gives the user complete control over what data to input, what data will be output, and which parts of the program are executed. The package is quite useful in the design process for discrete-time time-optimal control systems, where many possible control parameter variations must be examined.

INTERAC - AN INTERACTIVE SOFTWARE PACKAGE FOR DIRECT DIGITAL CONTROL DESIGN

I. Introduction

In the past few years the digital computer has become a valuable asset in the control system design process. With increased interest in modern control theories, the computer is fast becoming a necessity. A portion of a computer program for control system design is going to be the coding dealing with input, output, and program sequence control.

Many computer programs in classical and a few in modern control theory now exist (Ref 1,2,3,4, and 5), but most can be quite cumbersome for the user. These programs are written in terms of computational and computer resource efficiency, often at the expense of user efficiency. User efficiency is defined as the capability of a user to get exactly what he needs from a program execution (no more and no less) with the minimum amount of work and expertise in the program operation.

There is no unique solution to a given control problem, and thus an iterative procedure with one or more design parameters may be required. This can best be achieved in an interactive environment where the user can make selective changes in the design parameters based upon intermediate outputs. The problem then is to develop an interactive, user oriented, program for the I-O (input-output) and program sequence control functions which can be put around any set of control system design theory algorithms.

The Problem

Professor Brian Porter of the University of Salford, England, has been developing a control system design theory based on discrete state variable feedback to achieve a time optimal response at any given sampling rate. The algorithms for this design process have been furnished by Professor Porter and the Air Force Flight Dynamics Lab in the computer program FORTRAC. This batch mode program which was written for the University of Salford computer and adapted to run on the Wright-Patterson AFB computer system along with the SCOPE operating system can be cumbersome for the user.

The problem focused on in this investigation is to develop the interactive I-O and program sequence control software for the design algorithms of FORTRAC which will give a user oriented design package that will operate efficiently on the CDC-6600/Cyber-74 computer system at Wright-Patterson AFB, Ohio. The capability of this package, INTERAC, is then demonstrated by synthesizing control laws for a fly-by-wire system for the longitudinal axis of the C-141 and F-4E aircraft.

Scope and Objectives

The software was designed to meet the following characteristics: (1) Input timing and format will be under user control. (2) Program termination will not be caused by any format errors in an input sequence. In case of such an error, the user will be notified and be asked to reenter that item. (3) Output content and format will be user defined. (4) Only user desired elements of the program need be executed and in user defined order. (5) Program directions will be printed for the beginning user or they can be suppressed for the experienced user.

(6) Additional algorithms can be added to the package with a minimum of additional programming. (7) The I-O subroutines can be used directly in any program requiring a user oriented, interactive environment. (8) The package will operate within the 60,000 word field length available to the interactive users on the CDC computers at Wright-Patterson AFB.

The control laws for the C-141 and F-4E fly-by-wire systems are obtained for the longitudinal axis and at only one flight condition.

Development

Chapter 2 gives an overview of the FORTRAC package with specific emphasis on the algorithms incorporated into INTERAC. The specialized INTERAC software is discussed in chapter 3. The mathematical models for the C-141 and the F-4E are developed in Chapter 4. The chapter concludes with a discussion of the control laws obtained for the two aircraft. Chapter 5 presents the conclusions and recommendations for inproving the software package and for continued control system development for the C-141 and F-4E.

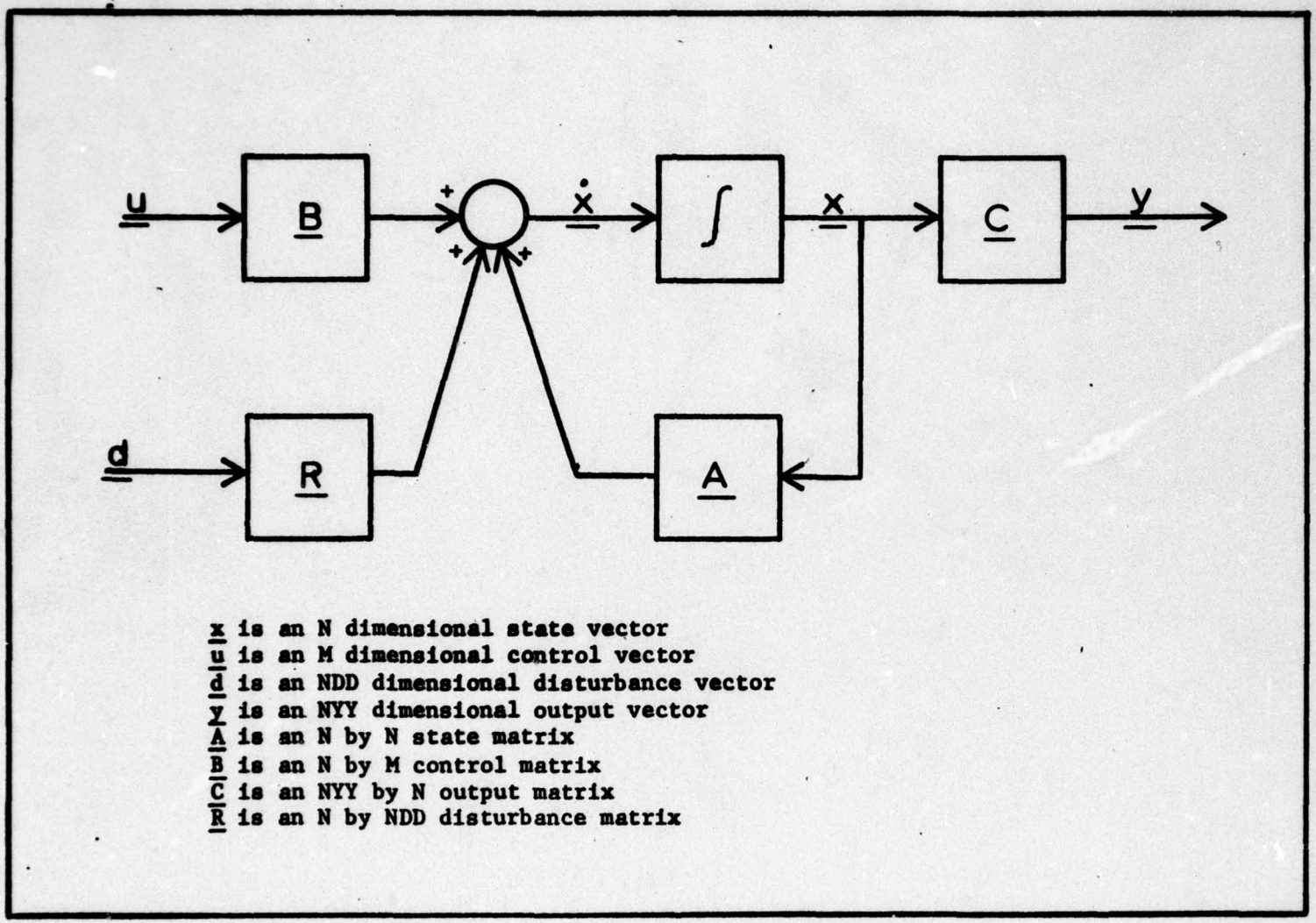
The actual FORTRAN Extended source code for the specialized INTERAC software is given in Appendix A, and a user's guide for the INTERAC package is contained in Appendix B. Appendix C is a programmer's guide for using the specialized INTERAC subroutines in other applications. Card sequence for the batch mode program, FORTRAC, is shown in Appendix D.

II. FORTRAC Computer Package

FORTRAC, a software package for the design of multivariable digital control systems, (Ref 6) was developed by Professor Brian Porter and furnished under contract to the Air Force Flight Dynamics Lab. This package is a collection of 42 subroutines tied together by a master program written for the particular design problem attempted. The master program furnished to the Flight Dynamics Lab will design a discrete control law for a sixth order or smaller system, design an observer, and run a time simulation of the system for the resulting controller. The theory is good for any order system, but a larger dimensioned master program would be required for higher order systems.

Table I shows the subroutines from FORTRAC grouped into four general functional categories. Most of the subroutines listed under control law synthesis and utility are included in INTERAC, and their specific function will be discussed in this chapter. A description of the other subroutines can be obtained from Reference 6.

FORTRAC is designed to take the continuous time description of a linear system (Fig 1), and to synthesize a control law for any of the following classes of problems: (1) discrete-time time-optimal regulator, (2) discrete-time time-optimal disturbance rejector, and (3) discrete-time time-optimal tracker.



$\underline{x}$ is an N dimensional state vector
$\underline{u}$ is an M dimensional control vector
$\underline{d}$ is an NDD dimensional disturbance vector
$\underline{y}$ is an NYY dimensional output vector
$\underline{A}$ is an N by N state matrix
$\underline{B}$ is an N by M control matrix
$\underline{C}$ is an NYY by N output matrix
$\underline{R}$ is an N by NDD disturbance matrix

Figure 1. Continuous Time System

Table I
FORTRAC Subroutines

Control Law Synthesis	Observer Design	Simulation	Utility
RPDATA	TRANFAC	DISCLS	ZEROELE
EIGSTR	FULLOB1	*EIGNVAL	DF01CKF
EIGVAV	REDOB1	DISSIMU	MATRE10
SAMPLE	REDOB2	GENCOM	MATPR10
AUGMAT		GENDIST	SETQUP
TRANFAB		*STSTATE	UREFORM
*CONGAIN		STIMEST	*ACHOROW
		SAMSIMU	SUB1000
		*KUTAMER	SUB2000
		DIF	SUB3000
		*STCONT	*APLFORM
		STIMECO	*BRNFORM
		PRIRES	*STQDOWN
		SAMRES	CINDS
			CALCBAR
			CONLAW

* These names had to be shortened from the original names in Reference 6 in adapting the package to operate on the CDC computer system at Wright-Patterson AFB.

The type of problem to be solved and the dimensions of the input system are handled by RPDATA. The I-O of the matrix data are handled by MATRE10 and MATPR10 respectively. These functions will be handled in INTERAC by the specialized INTERAC software.

Sampled Data Transformation

The first step in any class of problem is to transform the continuous system of Figure 1, described by Eq (1), to a sampled-data system description, Eq (2).

$$\dot{\underline{x}}(t) = \underline{A}\,\underline{x}(t) + \underline{B}\,\underline{u}(t) + \underline{R}\,\underline{d}(t)$$
$$\underline{y}(t) = \underline{C}\,\underline{x}(t) \qquad (1)$$

$$\underline{x}(k+1) = \underline{F}(T)\underline{x}(k) + \underline{G}(T)\underline{u}(k) + \underline{DR}(T)\underline{d}(k)$$
$$\underline{y}(k) = \underline{C}\underline{x}(k) \qquad (2)$$

All discrete functions of k are implied to be functions of kT. Two major subroutines are used in this operation. The first is EIGSTR, which also calls EIGVAV. The eigenvalues and eigenvectors of the continuous system are determined with the aid of matrix manipulation routines from a common user mathematics library. The description of the matrix manipulation routines required for FORTRAC and INTERAC are given later in this chapter.

The second major subroutine used is SAMPLE, which generates the discrete matrices $\underline{F}(T)$, $\underline{G}(T)$, and $\underline{DR}(T)$ from $\underline{A}$, $\underline{B}$, and $\underline{R}$. The transformation can be accomplished using Eqs (3),(4), and (5).

$$\underline{F}(T) = e^{\underline{A}T} \qquad (3)$$

$$\underline{G}(T) = \int_0^T e^{\underline{A}t}\,\underline{B}\,dt \qquad (4)$$

$$\underline{DR}(T) = \int_0^T e^{\underline{A}t}\,\underline{R}\,dt \qquad (5)$$

In general, an exact solution to the above equations cannot be easily determined. To facilitate the solution the diagonal matrix $\underline{\Lambda}$ which satisfies Eq (6) is produced,

$$\underline{A} = \underline{U}\underline{\Lambda}\underline{U}^{-1} \qquad (6)$$

where $\underline{U}$ is the matrix of eigenvectors obtained from EIGSTR. At this

point the subroutine SAMPLE is limited to systems which have non-repeated eigenvalues. Multiple eigenvalues would produce off diagonal terms in $\underline{\Lambda}$, thus this simplification could not be used. The equations for the discrete transformation reduce to (Ref 6:27)

$$\underline{F}(T) = \underline{U} e^{\underline{\Lambda} T} \underline{U}^{-1} \tag{7}$$

$$\underline{G}(T) = \underline{U}\left[\int_0^T e^{\underline{\Lambda} t}\, dt\right]\underline{U}^{-1}\underline{B} \tag{8}$$

$$\underline{DR}(T) = \underline{U}\left[\int_0^T e^{\underline{\Lambda} t}\, dt\right]\underline{U}^{-1}\underline{R} \tag{9}$$

The computation of $e^{\underline{\Lambda} T}$ becomes a set of scalar problems $e^{\lambda_i T}$, where the λ_i's are the eigenvalues of $\underline{A}$ which appear on the diagonal of $\underline{\Lambda}$. The constant matrices $\underline{U}$, $\underline{U}^{-1}$, $\underline{B}$, and $\underline{R}$ are taken outside the the integrals, and the integrals become sets of scalar integrations. The $\underline{C}$ matrix remains the same in the transformation from continuous to sampled-data form.

Augmentation

In the disturbance rejection and tracking problems, the next step is to augment the system with discrete-time integrators shown in Eq (10).

$$\underline{z}(k+1) = \underline{z}(k) + T[\underline{e}'(k)] \tag{10}$$

where the error, $\underline{e}'(k)$, for the disturbance rejector is $\underline{y}(k)$ and for

the tracker is $\underline{y}(k)-\underline{v}(k)$. The rationale and specific requirements for the use of integral feedback is given in Reference 7 (papers 7 and 9). The command input matrix, $\underline{DE} = \underline{IT}$, is established for the input command, v(k), in the augmented system equation. The augmented discrete system is then represented by Eq (11).

$$\underline{x}'(k+1) = \underline{AF}\,\underline{x}'(k) + \underline{AG}\,\underline{u}(k) + \underline{ADR}\,\underline{d}(k) + \underline{ADE}\,\underline{v}(k) \qquad (11)$$

where

$$\underline{AF} = \begin{bmatrix} \underline{F} & \underline{\emptyset} \\ \underline{CT} & \underline{I} \end{bmatrix} \qquad \underline{AG} = \begin{bmatrix} \underline{G} \\ \underline{\emptyset} \end{bmatrix}$$

$$\underline{ADR} = \begin{bmatrix} \underline{DR} \\ \underline{\emptyset} \end{bmatrix} \qquad \underline{ADE} = \begin{bmatrix} \underline{\emptyset} \\ -\underline{DE} \end{bmatrix}$$

$$\underline{x}'(k) = \begin{bmatrix} \underline{x}(k) \\ \underline{z}(k) \end{bmatrix} \qquad (12)$$

Control Law Synthesis

The control law to be synthesized is given by Eq (13).

$$\underline{u}(k) = \underline{K}\,\underline{x}'(k) \qquad (13)$$

The first step uses subroutine TRANFAB to transform the matrices

AF and AG into Brunovsky controllable canonical form. This is done using the first method of Aplevich (Ref 8:124-126). The utility subroutines SETQUP through STQDOWN (Table I) are used to achieve the transformation and to generate the transformation matrix $\underline{T}^{-1}$ to satisfy Eq 14.

$$\underline{x}''(k) = \underline{T}^{-1}\underline{x}'(k) \tag{14}$$

The control law synthesized to meet Eq (13) is as follows.

$$\underline{u}(k) = \underline{L}^{-1}[\underline{H} + \underline{E}]\,\underline{T}^{-1}\underline{x}'(k) \tag{15}$$

The $\underline{H}$ and $\underline{L}$ matrices are formed from the Brunovsky controllable canonical form of AF and AG respectively (Ref 6:44-46). The $\underline{E}$ matrix is used to specify the desired closed-loop eigenvalues. For the time-optimal control law the closed-loop eigenvalues are placed at the origin in the z-plane and the $\underline{E}$ matrix is the zero matrix. Refer to Reference 6, page 45, for the algorithm used for calculating $\underline{E}$ for non-zero eigenvalues.

Matrix Manipulation Routines

Table II shows the matrix manipulation routines called in the original FORTRAC package and the corresponding routines used in the version adapted to run on the CDC computers at Wright-Patterson AFB. The eigenstructure analysis routines were taken from the EISPACK Library (Ref 9) available on the CDC computers. The other routines were written by the author and the source code is shown in Appendix A.

Table II
Matrix Manipulation Routines

Routines Called In The Original FORTRAC Package		Routines Used In The Wright-Patterson Adaptation
F01CAF		PRESET
F01CBF		IDENT
F01CCF		COPYAB
F01CDF		ADDMAT
F01CEF		SUBMAT
F01CJF		TRANPOS
F04AEF		INVERT
F01ATF, F01AKF, F02AGF, F02APF	Eigenstructure Routines	BALANC, ELMHES, ELTRAN, HQR, HQR2, BALBAK

Appendix C gives the syntax required to use the author's matrix manipulation routines and gives a brief description of the algorithms used.

The above routines along with DISCLS are included in the INTERAC package. The subroutine DISCLS calculates the closed-loop equations which can then be used in a discrete simulation.

III. Specialized INTERAC Software

Before adapting FORTRAC to an interactive program, several interactive programs (Ref 1,2,3,4, and 5) available on the Wright-Patterson AFB computer were examined to see how efficient they were for the user. The first item of note was that each program had different input format, output content and format, and control structure. This greatly increases the workload on the user who has to use several programs in a design effort. With the exception of OPTCON, there are no provisions for correcting an erroneous data point entry without reentering the entire data set. All programs are terminated by the SCOPE operating system for a simple input error by the user. All programs allowed the user to select the options he wished to execute, but there are no provisions to stop between options and allow the user to decide if the sequence should be continued. In general each program has some good and many bad points in regard to user efficiency.

Three methods of developing FORTRAC into an efficient, user oriented, interactive, package were considered. The first was to redefine the operating system for interactive computer use. Although this would provide the greatest improvement for all classes of interactive programs, the time and resources required would be beyond the capability of this investigation. The second method would be to utilize a higher order computer language other than FORTRAN. Of the languages available on the Wright-Patterson CDC-6600/Cyber-74 computer system, FORTRAN Extended seemed to be the best suited for the job. This left direct FORTRAN programming, possibly sacrificing

a little computer resource efficiency in order to achieve the desired user efficiency.

The INTERAC software described in this chapter was developed to meet the specifications given in Chapter 1 using the maximum capabilities of the FORTRAN Extended language (Ref 10) and the SCOPE operating system (Ref 11) available on the Wright-Patterson AFB computers. The three areas in a typical program operation cycle addressed are: (1) input, (2) output, and (3) program sequence control.

Input includes both numeric data and alphanumeric commands. The two subroutines developed for this are READNUM (read numeric) and READCOM (read command). The data output is controlled in content by an entry in a variable output table and in format by the subroutines PRINTR and LISTER. The program sequence control is based on entries in a valid command table and is achieved in this program with the subroutine COMND.

Input Subroutines

The subroutine READNUM was first conceptualized due to the deficiencies in the SCOPE operating system on the Wright-Patterson AFB computer. When a format error is made in a numeric input operation, an error message is printed and the program is terminated. This can be quite frustrating to a user who is just entering the last number of a 10 by 10 matrix. The READNUM subroutine reads all inputs as alphanumeric characters and checks for format errors. If any errors are detected the user is asked to reenter those items. The error checking is based on a legal entry table to be discussed later.

Table III
READNUM, Legal Entry Table

♦A	♦B	♦C	LEGAL ENTRY TABLE	♦A	♦B	♦C	LEGAL ENTRY TABLE
♦♦	♦♦	01	6666666666666666666				
:	00	02	11111111111153555555	5	40	34	11111111111113111112
A	01	03	11111111111131555553	6	41	35	11111111111113111112
B	02	04	11111111111151555555	7	42	36	11111111111113111112
C	03	05	11111111111131555553	8	43	37	11111111111113111112
D	04	06	11111111111151555555	9	44	38	11111111111113111112
E	05	07	11111111111151555225	+	45	39	11111111111113551552
F	06	08	11111111111151555555	-	46	40	11111111111113551552
G	07	09	11111111111151555555	♦	47	41	11111111111113555552
H	10	10	11111111111151555555	/	50	42	11111111111142455554
I	11	11	11111111111151555555	(	51	43	11111111111153555555
J	12	12	11111111111151555555	)	52	44	11111111111153555555
K	13	13	11111111111151555555	$	53	45	11111111111135777773
L	14	14	11111111111131555553	=	54	46	11111111111153555555
M	15	15	11111111111151555555		55	47	11111111111112244441
N	16	16	11111111111151555555	,	56	48	11111111111112344441
O	17	17	11111111111151555555	.	57	49	11111111111113555532
P	20	18	11111111111151555555	#	60	50	11111111111153555555
Q	21	19	11111111111151555555	[	61	51	11111111111153555555
R	22	20	11111111111151555553	]	62	52	11111111111153555555
S	23	21	11111111111151555555	%	63	53	11111111111153555555
T	24	22	11111111111151555555	"	64	54	11111111111153555555
U	25	23	11111111111151555555	_	65	55	11111111111153555555
V	26	24	11111111111151555555	!	66	56	11111111111153555555
W	27	25	11111111111151555555	&	67	57	11111111111153555555
X	30	26	11111111111151555555	'	70	58	11111111111153555555
Y	31	27	11111111111151555555	?	71	59	11111111111153555555
Z	32	28	11111111111131555553	<	72	60	11111111111153555555
0	33	29	11111111111113111112	>	73	61	11111111111153555555
1	34	30	11111111111113111112	@	74	62	11111111111153555555
2	35	31	11111111111113111112	\	75	63	11111111111153555555
3	36	32	11111111111113111112	^	76	64	11111111111153555555
4	37	33	11111111111113111112	;	77	65	11111111111153555555

♦A -- CHARACTER
♦B -- OCTAL VALUE OF CHARACTER REPRESENTATION
♦C -- DECIMAL INDEX FOR TABLE
♦♦ -- THIS ENTRY IN THE TABLE PROVIDES FOR AN END OF LINE INDICATOR.

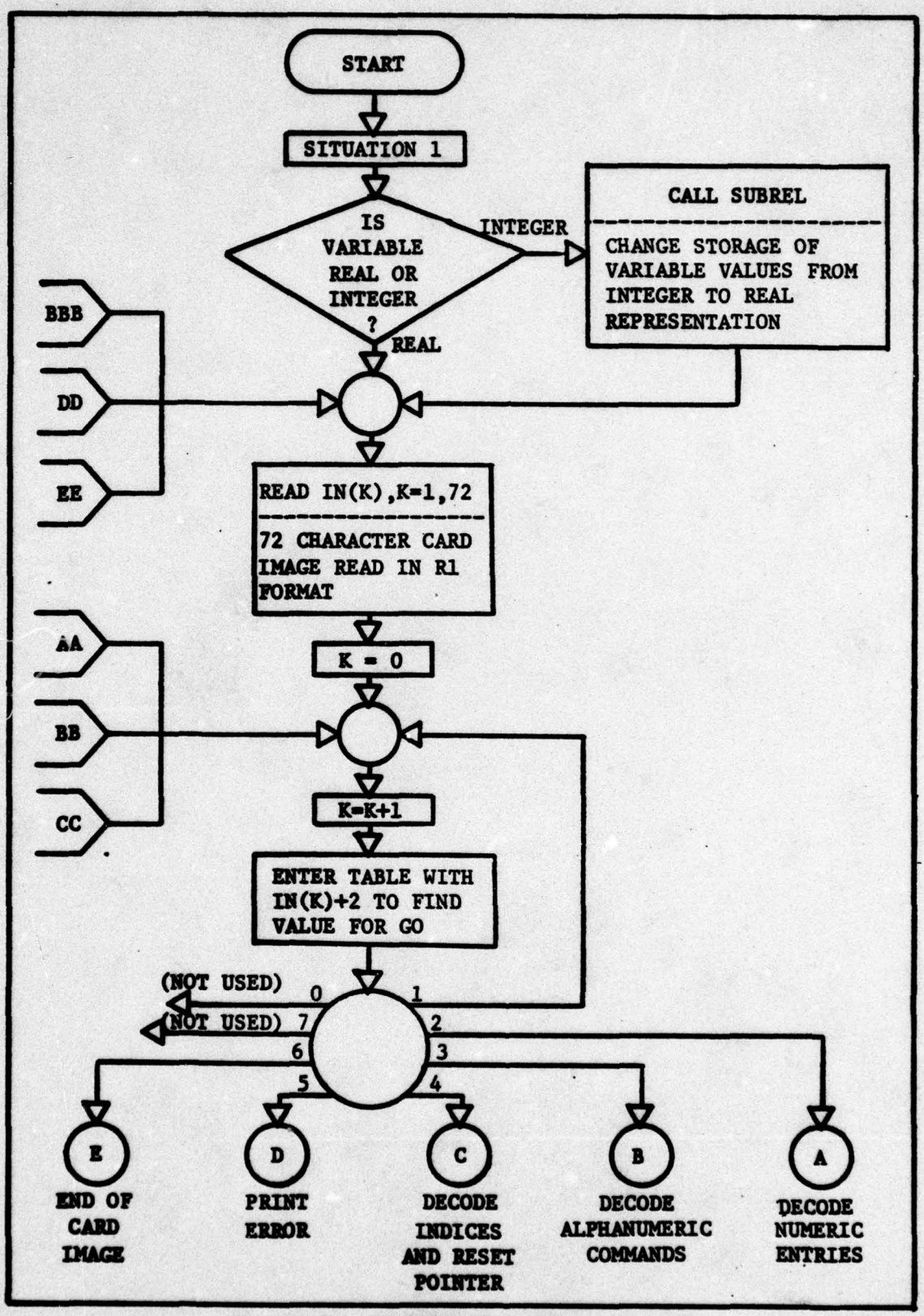


Figure 2. READNUM Flow Chart, Part I

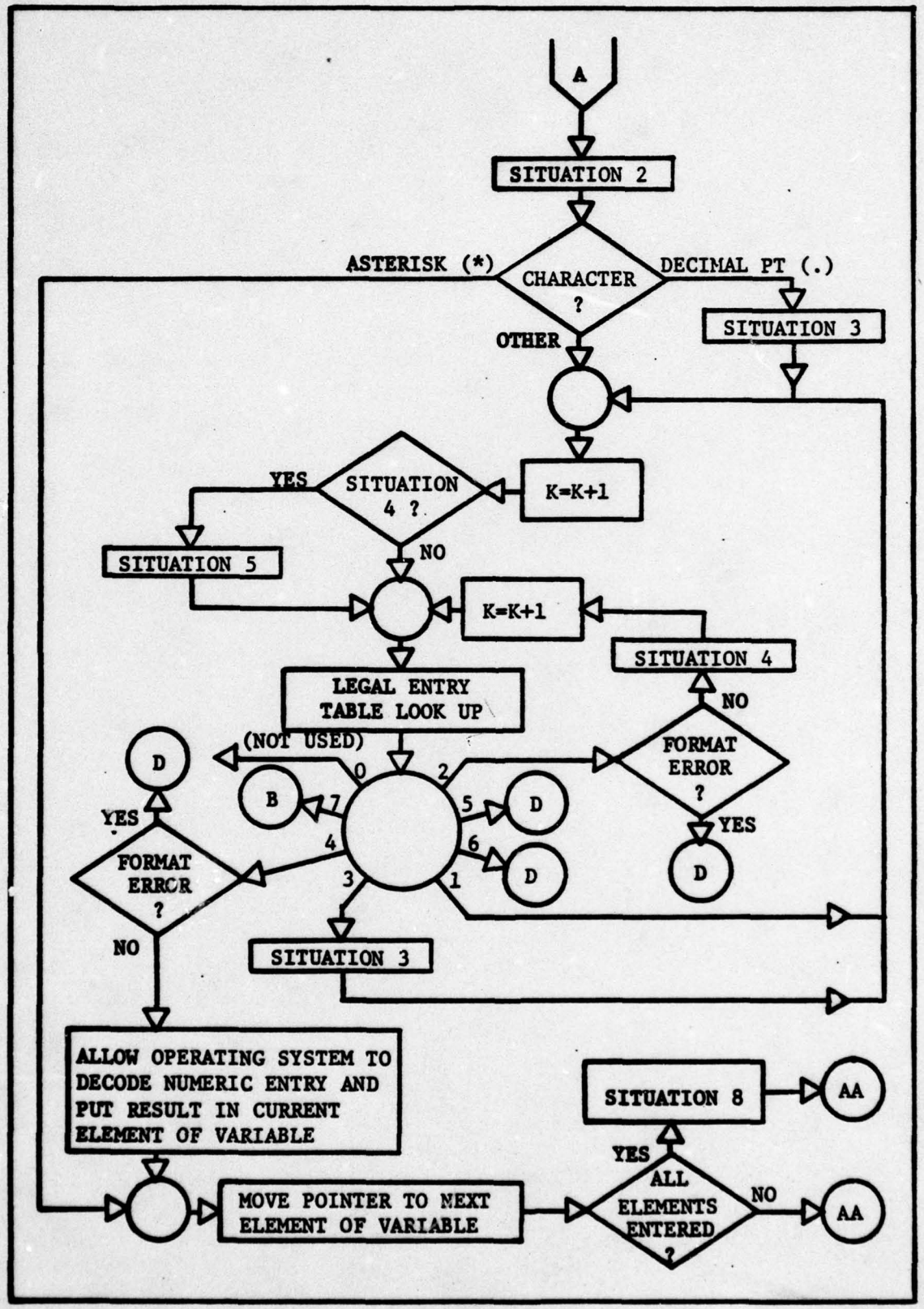


Figure 3. READNUM Flow Chart, Part II

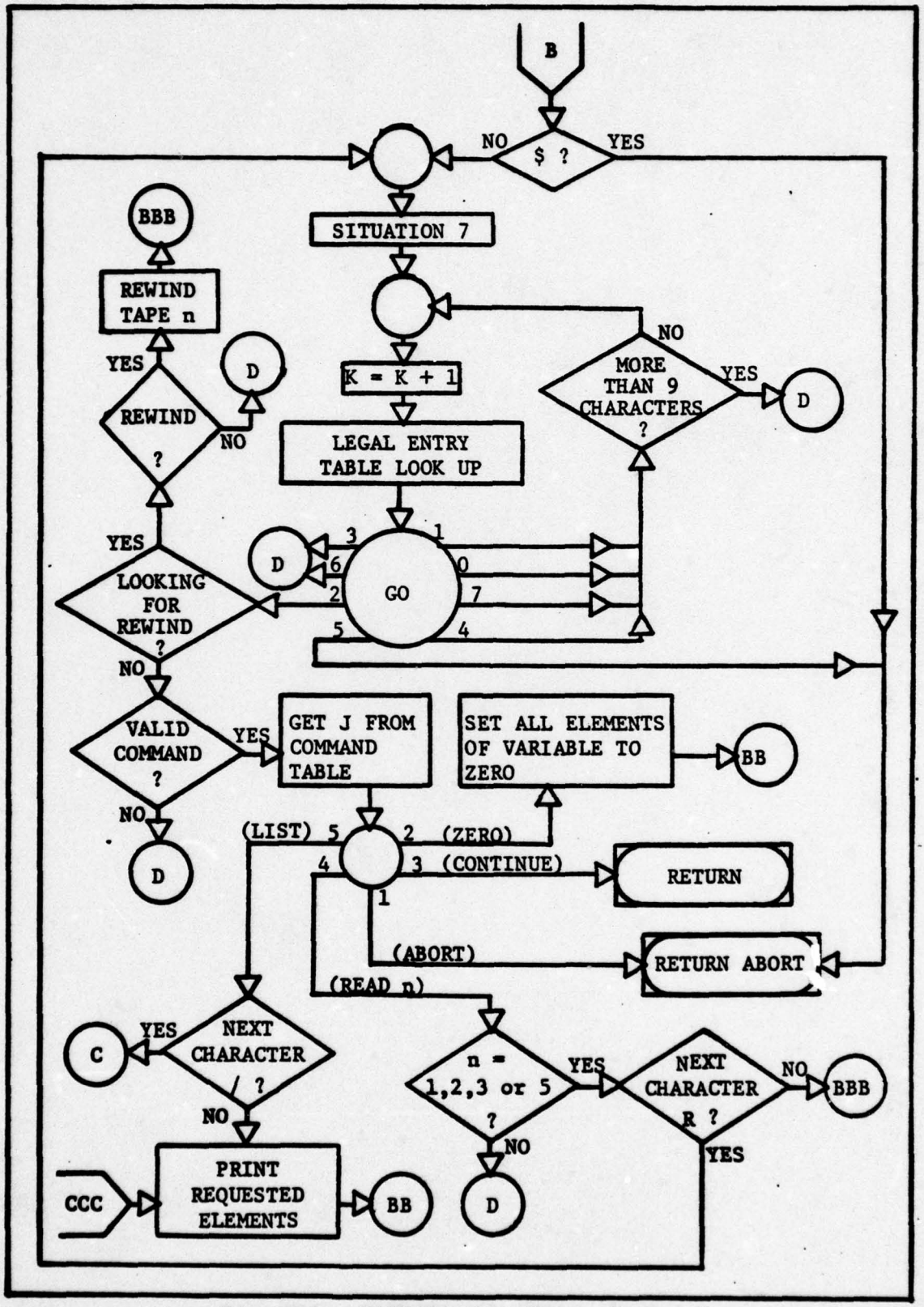


Figure 4. READNUM Flow Chart, Part III

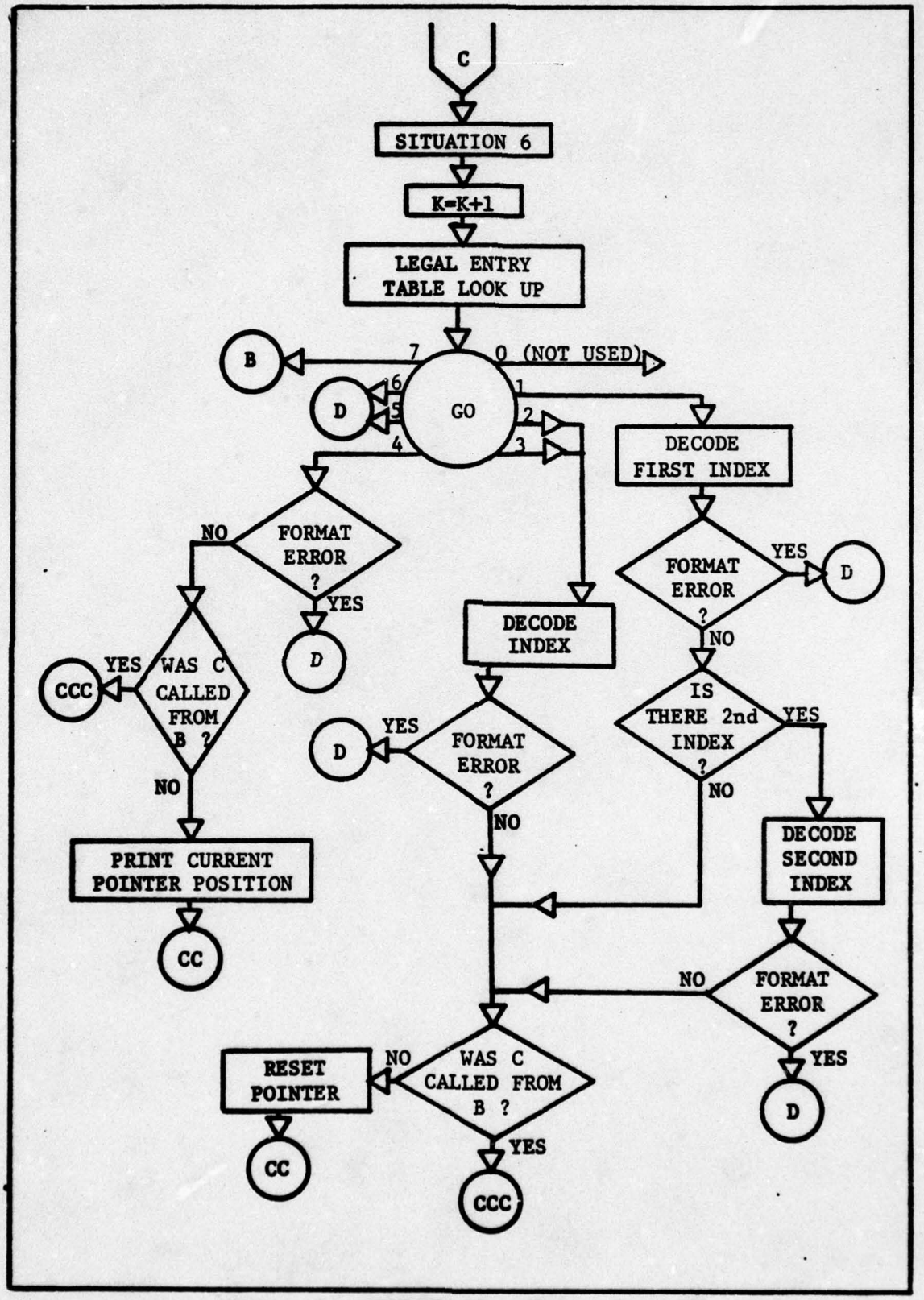


Figure 5. READNUM Flow Chart, Part IV

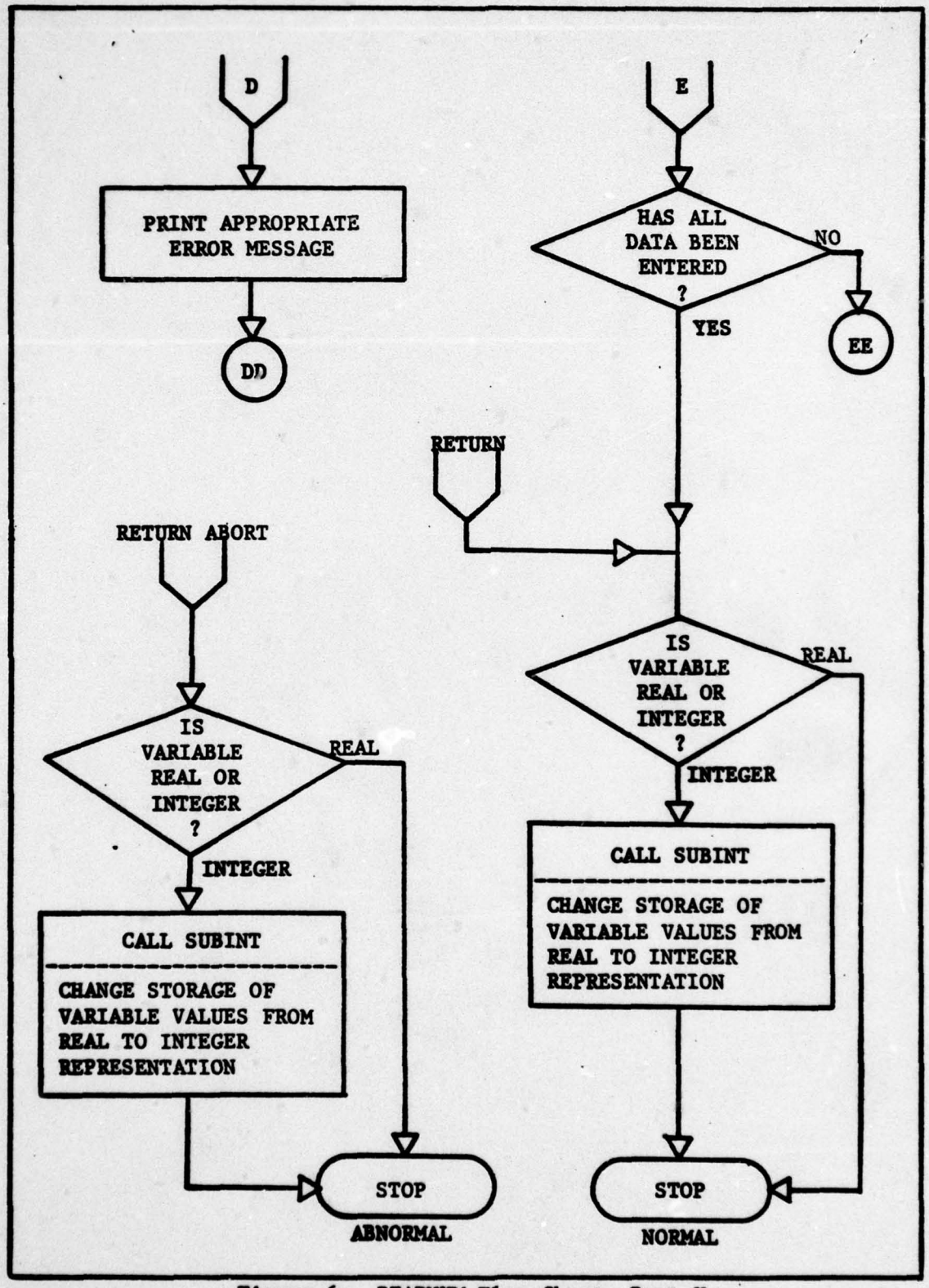


Figure 6. READNUM Flow Chart, Part V

The power in READNUM is particularly evident in matrix data entry. Each element of the matrix is constantly available for data entry or change. A data entry error noted after a carriage return can still be corrected on the next line. Six special commands give the user complete control over the data input process.

The basic flow chart for READNUM is shown in Figure 2. As can be seen, this subroutine can handle variables in real or integer representation. All data within the subroutine are represented as real numbers, and just prior to termination the subroutine converts them back to integer form if necessary.

All input characters are checked against the legal entry table, Table III. This table is stored as an array of 65 computer words. Each octal bit of the word is used in a different situation. Thus each character can cause one of 8 actions in up to 20 different situations. Situation 1 (the table is read from right to left) is used at the first decision point shown in Figure 2. The remainder of the flow chart for the READNUM subroutine is shown in Figures 3 thru 6.

All matrix elements are entered by rows in free format until all elements have been filled, unless the sequence is altered with one of the special commands. The first special character of interest is the asterisk (*), shown in Figure 3. The entry of the * causes the data entry pointer to move to the next element of the matrix with no change to the value of the current element. Figure 4 shows the section for decoding the six special alphanumeric commands and the special character dollar sign ($). Any time the $ is encountered a return abort is executed from the subroutine.

The six alphanumeric commands are "abort","zero","continue",

"read","list", and "/n,m/". The "abort" command has the same result as the $. "Zero" causes all elements of the variable to be set to zero and is useful for entering sparse matrices. "Continue" results in a normal termination of the subroutine regardless of the data entry pointer position. "Read" allows the input data to be read from the file TAPE1, TAPE2, or TAPE3. An optional parameter following the command "read n" is "rewind", which causes TAPEn to be rewound prior to reading data from it. The command "list" causes the current contents of the variable elements to be printed at the terminal. The optional parameter "/n,m/" following "list" is used to print only one element, one row, or one column of the variable. All of the above commands may be abbreviated to as little as the first letter. The command "/n,m/" is used to reset the data entry pointer to element (n,m). This allows previous errors to be corrected or several elements that need not be entered to be skipped.

The technical aspects for using this and other INTERAC subroutines for different programs can be found in the Programmer's Guide, Appendix C.

The second input subroutine developed is READCOM. This subroutine reads alphanumeric commands of 9 characters or less and checks them against a list of valid commands. Commands may have any characters, including single embedded blanks, except the slash (/), comma (,), and dollar sign ($). Any abbreviation that is unique in the command list may be used. The flow chart for READCOM is shown in Figure 7. Multiple commands may be entered if they are separated by "/" or at least two blanks. A command string is also recognized and identified. A command string is a command followed by one or more other commands

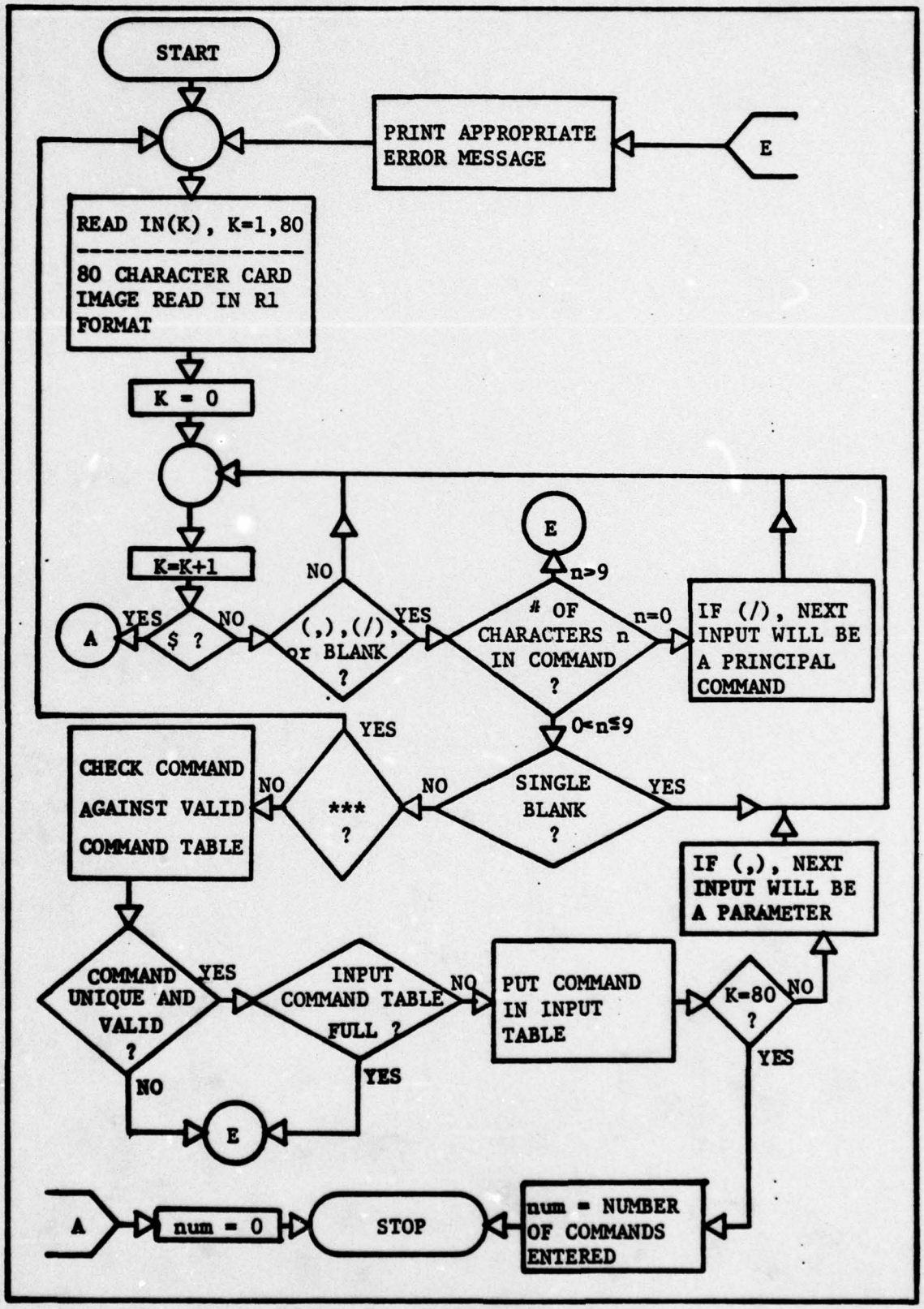


Figure 7. READCOM Flow Chart

acting as modifing parameters. The parameters are separated from the command and from each other by commas.

There are two special commands that are used internally in the subroutine. The $ causes a return abort. Anytime the $ is encountered the subroutine returns with an indication that no commands have been entered. The second special command is "***". READCOM normally reads only one 80 character input line. But when "***" is encountered as a command or parameter, another line is read. There are four error conditions recognized by READCOM. After the error message is printed the user is asked to reenter and is allowed another 80 character line.

Output Subroutines

Five of the legal commands interpreted by READCOM are used to change parameters in the output subroutines. Three of these commands are concerned with changing entries in the variable output table. Data output is sent to two possible locations as prescribed by the user with these commands. Data can be displayed at the terminal or can be written on a local file (to be disposed to a line printer after the program is terminated), or both.

The subroutine PRINTR is called by the computational subroutines whenever the value of a variable is changed. In this subroutine the variable output table is checked to see where the variable values should be printed. If display at the terminal or write to file are indicated the subroutine LISTER is called. Within LISTER the data is formated to appear on a 72 character line for the terminal or a 132 character line for the line printer output as appropriate. The number of significant digits used in each case can be specified by the user.

Program Sequence Control

The output format and content as well as all program operations are controlled by the user's alphanumeric inputs. Table IV lists all legal commands available to the user.

Table IV

Legal Commands For The INTERAC Package

Utility Options	I-O Options	Design Options	Variables			
OPTIONS	ENTER	RUN	AMATRIX	AFMATRIX	CEIGEN	INTEGRATE
VARIABLES	CHANGE	FORTRAC	BMATRIX	AGMATRIX	DEIGEN	MODAL
SAVE	DFORMAT	SAMPLE	RMATRIX	AEMATRIX	DESIGEN	INVMODAL
STOP	OFORMAT	AUGMAT	CMATRIX	ARMATRIX	CLEIGEN	UREFORM
END	DISPLAY	TRANSFORM	FMATRIX	ACMATRIX	TSAMPLE	APLFORM
RESTART	OUTPUT	CONLAW	GMATRIX	BFMATRIX	DIMENSION	BRNFORM
REWIND	DELETE	CLOSELOOP	DEMATRIX	BGMATRIX	STATES	CINDICES
	PRINT	SETDIMEN	DRMATRIX	TINVERSE	CONTROLS	COFMATRIX
				KMATRIX	COMMANDS	
				CLMATRIX	DISTURBS	

Refer to Appendix B for the description and use of each command. The table of legal commands is stored in the array LIST, dimensioned n by 7. Column 1 of LIST contains the Hollerith representation of each option or variable name.

The other columns of LIST contain all the information needed to decide what action to take when the command is input by the user.

Column 2 divides the commands into four types: (1) option names, (2) real variable names, (3) integer variable names, and (4) output variable names. The output variables are intermediate results in a computational algorithm. These results are stored in temporary scratch locations in memory, and the user may not enter or change data within them. The user may indicate if and where the variable results should be printed when they are calculated. All real and integer variables are stored in contiguous locations in a common block. The other five columns of LIST indicate the starting location for the variable within the common block, the maximum row and column dimensions allowed, and the currently used row and column dimensions. Option names are divided into five catagories by an entry in the last column of LIST. These catagories are shown in Table V.

Table V
Option Catagories

Entry In Column 7 Of LIST	Description
+n	Principal command only, with n required parameters
0	Principal command only, parameters optional
-1	Principal command only, no parameters allowed
-2	Principal command or parameter, no parameters allowed
-3	Parameter only

Subroutine COMND uses the entries in the array LIST to initiate the action requested by the user's command input. Refer to Appendix A for the listing of this subroutine.

IV. C-141 and F-4E Mathematical Modeling

An analog fly-by-wire control system for the C-141 has been designed and built by Honeywell, Inc. under contract to the Air Force Flight Dynamics Lab (Ref 12). The results of this project could provide data against which to check a digital control system designed using INTERAC. The second plant chosen to test the INTERAC package is an F-4E (Ref 13). This chapter describes the mathematical modeling process for the two plants. After several computer runs, the C-141 was dropped from consideration due to modeling problems to be discussed later. The chapter ends with a discussion of the results obtained for the F-4E.

C-141 Model

The model for the C-141 was derived using data from Reference 12. The longitudinal equations of motion are given as

$$\ddot{\theta} = M_{\dot{w}}\dot{w} + M_w w + M_q\dot{\theta} + M_{\delta e}\delta e + M_{\delta sp}\delta sp \qquad (16)$$

$$\dot{w} = Z_u u + Z_w w + U_o\dot{\theta} + Z_{\delta e}\delta e + Z_{\delta sp}\delta sp \qquad (17)$$

$$\dot{u} = X_u u + X_w w - g\theta + X_{\delta sp}\delta sp \qquad (18)$$

$$\dot{h} = -w + U_o\theta \qquad (19)$$

$$a_{z_{pilot}} = \dot{w} + U_o\dot{\theta} - lx\,\ddot{\theta} \qquad (20)$$

The coefficients for the heavyweight landing configuration are given in Table VI (Ref 12:28,31).

Table VI
C-141 Longitudinal Dimensional Derivatives

257,000 lb Weight, Gear Down, 119 KCAS at Sea Level

Parameter	Value	Parameter	Value	Parameter	Value
M_w	-.00102	Z_u	-.321	X_u	-.044
M_w	-.0051	Z_w	-.558	X_w	.083
M_q	-.645	U_o	201	g	32.2
$M_{\delta e}$	-.743	$Z_{\delta e}$	-5.36	$X_{\delta sp}$	-4.25
$M_{\delta sp}$	.240	$Z_{\delta sp}$	33.0	1x	47
				U_{co}	350

The transfer functions for the elevator and spoiler actuator-servo combinations were modeled as given in Eq 21 and 22 respectively.

$$\frac{\delta e}{e_i} = \frac{10}{s + 10} \tag{21}$$

$$\frac{\delta sp}{sp_i} = \frac{5}{s + 5} \tag{22}$$

These transfer functions and the above equations of motion were modeled as state equations in the form of Eq (1).

$$\begin{aligned} \underline{\dot{x}}(t) &= \underline{A}\,\underline{x}(t) + \underline{B}\,\underline{u}(t) + \underline{R}\,\underline{d}(t) \\ \underline{y}(t) &= \underline{C}\,\underline{x}(t) \end{aligned} \tag{1}$$

where

$$\underline{x}(t) = \begin{bmatrix} \dot{\theta}(t) \\ \theta(t) \\ w(t) \\ u(t) \\ h(t) \\ \delta e(t) \\ \delta sp(t) \end{bmatrix} \quad \underline{B} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 10 & 0 \\ 0 & 5 \end{bmatrix} \quad \underline{u}(t) = \begin{bmatrix} e_i \\ sp_i \end{bmatrix} \quad \underline{R} = \underline{\emptyset}$$

$$A = \begin{bmatrix} -.85 & 0 & -.00453 & .00033 & 0 & -.736 & .206 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 201 & 0 & -.558 & -.321 & 0 & -5.36 & 33 \\ 0 & -32.2 & .083 & -.044 & 0 & 0 & -4.25 \\ 0 & 201 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -10 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -5 \end{bmatrix} \qquad (23)$$

The $\underline{C}$ matrix was then chosen to give a C^* output. C^* is described in Ref 14 and the equation used is (Ref 12:55)

$$C^* = a_{z_{pilot}} + K_q \dot{\theta} \qquad (24)$$

$$K_q = .217 \quad \text{for} \quad U_{co} = 350$$

This was the first hint that the data provided by Ref 12 may not be valid. Using the definition of C^* from Ref 14, the value of K_q should have been 10.8. The $\underline{C}$ matrix then became.

$$C = [\ 0 \ -.345 \ -.336 \ 0 \ 29.3 \ 23.3] \qquad (25)$$

where β is 442.2 or 452.8. The control law for a discrete-time time-optimal tracker was synthesized for both $\underline{C}$ matrices with similar results. The gains were excessive (greater than 10^4) and a time simulation showed huge overshoots and impossible control requirements (elevator deflections of 400°). A modeling problem was suspected when it was noted that the calculated Brunovsky transformation matrix $\underline{T}^{-1}$ was incorrect. This was due to computer numerical problems caused by the fact that the plant as modeled was almost uncontrollable. In an attempt to verify the modeling, the coefficients taken from Page 28 and 31 of Ref 12 were checked against the analog flow chart on Page 33 of Ref 12. There were numerous numerical differences and a sign difference in the δ_{sp} term in the $\dot{u}$ equation (Eq 18). Thus the validity of any comparison of a discrete fly-by-wire system developed using INTERAC/FORTRAC with the analog system described in Ref 12 was in serious doubt. At this time it was decided to attempt a control system design for another aircraft.

F-4E Model

The F-4E was modeled using data from a lab project from the EE 6.41 course at AFIT (Ref 13). The coefficients of Table VII were used in the following equations of motion:

$$\ddot{\theta} = \frac{1}{\left(\frac{I_y}{Sqc}\right)}\left[\frac{c}{2U_o} C_{m_{\dot{\alpha}}} \dot{\alpha}' + C_{m_\alpha} \alpha' + \frac{c}{2U_o} C_{m_q} \dot{\theta}' + C_{m_{\delta e}} \delta e\right] \quad (26)$$

$$\dot{\alpha}' = \frac{1}{\left(\frac{mU_o}{Sq} - \frac{c}{2U_o} C_{Z_{\dot{\alpha}}}\right)}\left[C_{Z_u} u' + C_{Z_\alpha} \alpha' + \left(\frac{mU_o}{Sq} + \frac{c}{2U_o} C_{Z_q}\right)\dot{\theta}' + C_{Z_{\delta_e}} \delta e\right] \quad (27)$$

$$\dot{u}' = \frac{1}{\left(\frac{mU_o}{Sq}\right)}\left[C_{X_u} u' + C_{X_\alpha} \alpha' + C_W \theta' + C_{X_{\delta_T}} \delta_T\right] \quad (28)$$

Table VII
F-4E Longitudinal Non-dimensional Derivatives

33,439 lb Weight, Gear Down, 138 KCAS at Sea Level

Parameter	Value	Parameter	Value	Parameter	Value
I_y	137,710	$C_{m_{\dot{\alpha}}}$	-.9801	C_{Z_u}	-2.0
U_o	230.5	C_{m_α}	-.07634	C_{Z_α}	-2.967
q	63.14	C_{m_q}	-2.066	C_{Z_q}	-2.276
c	16.04	$C_{m_{\delta_e}}$	-.5776	$C_{Z_{\delta_e}}$	-.3887
g	32.174	C_{X_u}	-.339	$C_{X_{\delta_T}}$	.2
S	530	C_{X_α}	.630		

Dimensionalizing and other relationships

$m = w/g \quad C = -mg/Sq \quad u' = u/U_o \quad \alpha = 57.3\alpha' \quad \theta = 57.3\theta'$

The elevator actuator and servo were modeled as the first order lag

$$\frac{\delta e}{e_i} = \frac{20}{s + 20} \quad (29)$$

and the engine and throttle actuator were modeled as

$$\frac{\delta_T}{T_i} = \frac{2}{s+2} \tag{30}$$

The statespace equation for the F-4E then became

$$\begin{aligned} \dot{\underline{x}}(t) &= \underline{A}\,\underline{x}(t) + \underline{B}\,\underline{u}(t) + \underline{R}\,\underline{d}(t) \\ \underline{y}(t) &= \underline{C}\,\underline{x}(t) \end{aligned} \tag{1}$$

where

$$\underline{x}(t) = \begin{bmatrix} \dot{\theta}(t) \\ \theta(t) \\ \alpha(t) \\ u(t) \\ e(t) \\ T(t) \end{bmatrix} \quad \underline{B} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 20 & 0 \\ 0 & 2 \end{bmatrix} \quad \underline{u}(t) = \begin{bmatrix} e(t) \\ T(t) \end{bmatrix} \quad \underline{R} = \underline{\emptyset}$$

$$\underline{A} = \begin{bmatrix} -.4115 & 0 & -.2424 & .009231 & -2.244 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ .989 & 0 & -.4146 & -.06946 & -.05431 & 0 \\ 0 & -.5717 & .3541 & -.04737 & 0 & 6.442 \\ 0 & 0 & 0 & 0 & 20 & 0 \\ 0 & 0 & 0 & 0 & 0 & -2 \end{bmatrix} \tag{31}$$

The $\underline{C}$ matrix was chosen to allow tracking of flight path angle, $\theta - \alpha$, as would be desirable in an automatic approach.

$$\underline{C} = [0\ 1\ -1\ 0\ 0\ 0] \tag{32}$$

A control law was synthesized to track flight path angle for various sampling times.

Results of F-4E Control Law Synthesis

At all sampling times a simulation showed the F-4E to be on track within 4 sample periods. This requires higher gains and higher control power as the sampling interval decreases. Table VIII shows some of the representative data obtained for sampling intervals of .05 to 5.0 seconds, with a unit step command of 1 degree.

Table VIII
Simulation Data for the F-4E with a Discrete-Time Flight Path Angle Tracking Control System

Sampling Interval Seconds	Maximum: Elevator Deflection	Maximum: Change in Forward Velocity ft/sec	Maximum: Negative Peak in Commanded Output	Maximum: Magnitude of Feedback Gain Required	Final Change in Forward Velocity ft/sec
.05	-8010 °	-255	-15.6°	2.5×10^5	-255
.1	-1245 °	-154	- 4.9°	1.4×10^4	-154
.25	- 87.6°	- 62	- .7°	353	- 62
.5	- 12 °	- 29	- .1°	24	- 29
.6	- 7.3°	- 24	- .01°	15	- 24
.7	.4°	16	0.0	17.5	3.6
.8	.4°	14	0.0	12.5	3.2
.9	.3°	13	0.0	9.3	3.1
1.0	.3°	11	0.0	7.2	2.9
2.0	.2°	5	0.0	1.2	.08
5.0	.3°	13	0.0	.7	13.4

At sample times below .5 seconds, the elevator deflection required is beyond the capability of the aircraft. A sample time of 2 seconds requires the least control power and produces the smoothest response. But 8 seconds to track a 1 degree flight path change is excessive for aircraft control. Even the lowest practical sampling time of .5 seconds, may be too high for this fighter type aircraft.

The discrete-time time-optimal control seems to work quite well, if a relatively long sampling interval can be tolerated. If a higher sampling time is required, a sub-optimal control must be used. One possibility is to use deadbeat control, which in this case would allow 7 sample periods to track the command. The deadbeat algorithm is not presently in the INTERAC package, but it could be easily added. The second possibility is to place the desired eigenvalues at some place other than the origin in the z-plane. Since there are an infinite number of possible eigenvalues to use, the INTERAC package is more desirable than the batch mode program for quickly trying the most promising choices of eigenvalues.

V. Conclusions and Recommendations

Conclusions

The INTERAC package meets all of the specifications given in Chapter 1. There is still a little room for improvement in the I-O versatility, but what is now presented is a vast improvement over existing programs. In a current investigation, Lt. Stanley J. Larimer is incorporating many of these user oriented ideas into a classical control design package.

The use of discrete-time time-optimal control systems for total aircraft control is not generally possible due to the long sampling interval required to keep the magnitude of the control within practical limits. There are applications, with low frequency disturbances and commands, where the time-optimal control could be used, such as cruise control and possibly automatic approach control. The total aircraft control system will probably require a sub-optimal control law.

The theory behind the FORTRAC and INTERAC packages does not provide a cut and dry control system design process. There are too many possible parameter changes in the multi-input, multi-output system for a one best answer to be achieved in one iteration. The INTERAC package provides a basis for quickly investigating the various parameter changes.

Recommendations

(1) A graphical simulation capability should be added to the INTERAC package. The magnitude of the feedback gains does give a general idea as to the responce of the closed loop system. But, as

shown for the sampling interval of .6 and.7 seconds in Table VIII, there can be a drastic change in the total system response without large changes in the feedback gains.

(2) The DEADBEAT subroutine for achieving the sub-optimal control law should be added to the package. This subroutine is in the FORTRAC package, but it is not called by the master program furnished.

(3) The investigation of the discrete-time fly-by-wire control system for the C-141 should be continued with basic flight test data from Lockheed. The heavy transport type aircraft does not normally require high frequency control and response, and thus it would be ideal for further investigating the time-optimal control laws.

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Appendix A

Listing of Specialized INTERAC Software

The following pages are a listion of the FORTRAN Extended source code for the specialized INTERAC software.

```
      PROGRAM INTERAC(INPUT=1008/80,OUTPUT=1008,TAPE5=INPUT,                INTERAC    2
     1                TAPE6=OUTPUT,TAPE8=1008,TAPE7=1008,ANSWER=1008,       INTERAC    3
     2                TAPE1=1008,TAPE2=1009,TAPE3=1008,DATA=5008,           INTERAC    4
     3                TAPE99=ANSWER,TAPE55=DATA,TAPE65=5008)                INTERAC    5
      COMMON/LISTING/NL,LIST(75,7)                                          INTERAC    6
      COMMON/LISTOUT/N,LISTO(75)                                            INTERAC    7
C                                                                           INTERAC    8
C     WHEN CHANGING DIMENSIONS OF THE ARRAY LIST THE ROW DIMENSION OF       INTERAC    9
C     LISTO AND THE DIMENSION STATEMENTS FOR LIST IN SUBROUTINES            INTERAC   10
C     FORTRAC,COMND, OPEN, AND STRING MUST ALSO BE CHANGED ACCORDINGLY.     INTERAC   11
C                                                                           INTERAC   12
      COMMON/RVAR/NTOT,TOT(3500)                                            INTERAC   13
      COMMON/IVAR/NITOT,ITOT(25)                                            INTERAC   14
      COMMON/CONTROL/DSP,BATCH                                              INTERAC   15
      COMMON/TITLE/ITITLE(5)                                                INTERAC   16
      COMMON/FORMS/NDREP,NDFW,NDNSD,NOREP,NOFW,NONSD                        INTERAC   17
      DATA (LIST(  1,I),I=1,7),LISTO(  1)/10HENTER     E,3HCMD,             INTERAC   18
     1                                    1, 0, 0, 0, 0,1/                 INTERAC   19
      DATA (LIST(  2,I),I=1,7),LISTO(  2)/10HSTOP      D,3HCMD,             INTERAC   20
     1                                    2, 0, 0, 0,-1,1/                 INTERAC   21
      DATA (LIST(  3,I),I=1,7),LISTO(  3)/10HAMATRIX   G,3HREL,             INTERAC   22
     1                                    1, 1, 1,20,20,4/                 INTERAC   23
      DATA (LIST(  4,I),I=1,7),LISTO(  4)/10HBMATRIX   G,3HREL,             INTERAC   24
     1                                  401, 1, 1,20,10,4/                 INTERAC   25
      DATA (LIST(  5,I),I=1,7),LISTO(  5)/10HEND       C,3HCMD,             INTERAC   26
     1                                    3, 0, 0, 0,-1,1/                 INTERAC   27
      DATA (LIST(  6,I),I=1,7),LISTO(  6)/10HPRINT     E,3HCMD,             INTERAC   28
     1                                    4, 0, 0, 0, 0,1/                 INTERAC   29
      DATA (LIST(  7,I),I=1,7),LISTO(  7)/10HDFORMAT   G,3HCMD,             INTERAC   30
     1                                    5, 0, 0, 0,-1,1/                 INTERAC   31
      DATA (LIST(  8,I),I=1,7),LISTO(  8)/10HCHANGE    F,3HCMD,             INTERAC   32
     1                                    6, 0, 0, 0, 0,1/                 INTERAC   33
      DATA (LIST(  9,I),I=1,7),LISTO(  9)/10HDISPLAY   G,3HCMD,             INTERAC   34
     1                                    7, 0, 0, 0, 0,1/                 INTERAC   35
      DATA (LIST( 10,I),I=1,7),LISTO( 10)/10HOUTPUT    F,3HCMD,             INTERAC   36
```

```
     1                                        8, 0, 0, 0, 0,1/                INTERAC    37
      DATA (LIST( 11,I),I=1,7),LISTO( 11)/10HDELETE    F,3HCMD,               INTERAC    38
     1                                        9, 0, 0, 0, 0,1/                INTERAC    39
      DATA (LIST( 12,I),I=1,7),LISTO( 12)/10HOPTIONS   G,3HCMD,               INTERAC    40
     1                                       10, 0, 0, 0,-1,1/                INTERAC    41
      DATA (LIST( 13,I),I=1,7),LISTO( 13)/10HVARIABLESI,3HCMD,                INTERAC    42
     1                                       11, 0, 0, 0,-1,1/                INTERAC    43
      DATA (LIST( 14,I),I=1,7),LISTO( 14)/10HSAVE      D,3HCMD,               INTERAC    44
     1                                       12, 0, 0, 0,-1,1/                INTERAC    45
      DATA (LIST( 15,I),I=1,7),LISTO( 15)/10HRESTART   G,3HCMD,               INTERAC    46
     1                                       13, 0, 0, 0, 0,1/                INTERAC    47
      DATA (LIST( 16,I),I=1,7),LISTO( 16)/10HREWIND    F,3HCMD,               INTERAC    48
     1                                       14, 0, 0, 0,-2,1/                INTERAC    49
      DATA (LIST( 17,I),I=1,7),LISTO( 17)/10HRUN       C,3HCMD,               INTERAC    50
     1                                       15, 0, 0, 0, 1,1/                INTERAC    51
      DATA (LIST( 18,I),I=1,7),LISTO( 18)/10HDEIGEN    F,3HREL,               INTERAC    52
     1                                    1741, 1, 1,20, 2,2/                 INTERAC    53
      DATA (LIST( 19,I),I=1,7),LISTO( 19)/10HDIMENSIONI,3HINT,                INTERAC    54
     1                                       1, 1, 4, 1, 1,4/                 INTERAC    55
      DATA (LIST( 20,I),I=1,7),LISTO( 20)/10HFORTRAC   G,3HCMD,               INTERAC    56
     1                                       16, 0, 0, 1,-2,1/                INTERAC    57
      DATA (LIST( 21,I),I=1,7),LISTO( 21)/10HSAMPLE    F,3HCMD,               INTERAC    58
     1                                       17, 0, 0, 2,-2,1/                INTERAC    59
      DATA (LIST( 22,I),I=1,7),LISTO( 22)/10HAUGMAT    F,3HCMD,               INTERAC    60
     1                                       18, 0, 0, 3,-2,1/                INTERAC    61
      DATA (LIST( 23,I),I=1,7),LISTO( 23)/10HTRANSFORMI,3HCMD,                INTERAC    62
     1                                       19, 0, 0, 4,-2,1/                INTERAC    63
      DATA (LIST( 24,I),I=1,7),LISTO( 24)/10HCONLAW    F,3HCMD,               INTERAC    64
     1                                       20, 0, 0, 5,-2,1/                INTERAC    65
      DATA (LIST( 25,I),I=1,7),LISTO( 25)/10HCLOSELOOPI,3HCMD,                INTERAC    66
     1                                       21, 0, 0, 6,-2,1/                INTERAC    67
      DATA (LIST( 26,I),I=1,7),LISTO( 26)/10HCOFMATRIXI,3HOUT,                INTERAC    68
     1                                        0, 0, 0, 0, 0,1/                INTERAC    69
      DATA (LIST( 27,I),I=1,7),LISTO( 27)/10HINTEGRATEI,3HINT,                INTERAC    70
     1                                        5, 1, 1, 1,10,1/                INTERAC    71
```

```
      DATA (LIST( 28,I),I=1,7),LISTO( 28)/10HOFORMAT  G,3HCMD,          INTERAC    72
     1                                     22, 0, 0, 0,-1,1/            INTERAC    73
      DATA (LIST( 29,I),I=1,7),LISTO( 29)/10HSETDIMEN H,3HCMD,          INTERAC    74
     1                                     23, 0, 0, 0,-1,1/            INTERAC    75
      DATA (LIST( 30,I),I=1,7),LISTO( 30)/10HRMATRIX  G,3HREL,          INTERAC    76
     1                                    601, 1, 1,20, 5,4/            INTERAC    77
      DATA (LIST( 31,I),I=1,7),LISTO( 31)/10HCMATRIX  G,3HREL,          INTERAC    78
     1                                    701, 1, 1,10,20,4/            INTERAC    79
      DATA (LIST( 32,I),I=1,7),LISTO( 32)/10HFMATRIX  G,3HREL,          INTERAC    80
     1                                    901, 1, 1,20,20,3/            INTERAC    81
      DATA (LIST( 33,I),I=1,7),LISTO( 33)/10HGMATRIX  G,3HREL,          INTERAC    82
     1                                   1301, 1, 1,20,10,3/            INTERAC    83
      DATA (LIST( 34,I),I=1,7),LISTO( 34)/10HDEMATRIX H,3HREL,          INTERAC    84
     1                                   1501, 1, 1,20, 5,1/            INTERAC    85
      DATA (LIST( 35,I),I=1,7),LISTO( 35)/10HDRMATRIX H,3HREL,          INTERAC    86
     1                                   1601, 1, 1,20, 5,1/            INTERAC    87
      DATA (LIST( 36,I),I=1,7),LISTO( 36)/10HAFMATRIX H,3HREL,          INTERAC    88
     1                                    901, 1, 1,20,20,4/            INTERAC    89
      DATA (LIST( 37,I),I=1,7),LISTO( 37)/10HAGMATRIX H,3HREL,          INTERAC    90
     1                                   1301, 1, 1,20,10,4/            INTERAC    91
      DATA (LIST( 38,I),I=1,7),LISTO( 38)/10HAEMATRIX H,3HREL,          INTERAC    92
     1                                   1501, 1, 1,20, 5,4/            INTERAC    93
      DATA (LIST( 39,I),I=1,7),LISTO( 39)/10HARMATRIX H,3HREL,          INTERAC    94
     1                                   1601, 1, 1,20, 5,4/            INTERAC    95
      DATA (LIST( 40,I),I=1,7),LISTO( 40)/10HACMATRIX H,3HREL,          INTERAC    96
     1                                    701, 1, 1,10,20,4/            INTERAC    97
      DATA (LIST( 41,I),I=1,7),LISTO( 41)/10HCEIGEN   F,3HREL,          INTERAC    98
     1                                   1701, 1, 1,20, 2,1/            INTERAC    99
      DATA (LIST( 42,I),I=1,7),LISTO( 42)/10HCLEIGEN  G,3HREL,          INTERAC   100
     1                                   1781, 1, 1,20, 2,3/            INTERAC   101
      DATA (LIST( 43,I),I=1,7),LISTO( 43)/10HBFMATRIX H,3HREL,          INTERAC   102
     1                                   1821, 1, 1,20,20,1/            INTERAC   103
      DATA (LIST( 44,I),I=1,7),LISTO( 44)/10HBGMATRIX H,3HREL,          INTERAC   104
     1                                   2221, 1, 1,20,10,1/            INTERAC   105
      DATA (LIST( 45,I),I=1,7),LISTO( 45)/10HTINVERSE H,3HREL,          INTERAC   106
```

```
1                                          2421, 1, 1,20,20,1/
 DATA (LIST( 46,I),I=1,7),LISTO( 46)/10HKMATRIX  G,3HREL,
1                                          2921, 1, 1,10,20,3/
 DATA (LIST( 47,I),I=1,7),LISTO( 47)/10HDESEIGEN H,3HREL,
1                                          3422, 1, 1,20, 2,4/
 DATA (LIST( 48,I),I=1,7),LISTO( 48)/10HCLMATRIX H,3HREL,
1                                          3021, 1, 1,20,20,1/
 DATA (LIST( 49,I),I=1,7),LISTO( 49)/10HTSAMPLE  G,3HREL,
1                                          3421, 1, 1, 1, 1,3/
 DATA (LIST( 50,I),I=1,7),LISTO( 50)/10HSTATES   F,3HINT,
1                                            1, 1, 1, 1, 1,1/
 DATA (LIST( 51,I),I=1,7),LISTO( 51)/10HCONTROLS H,3HINT,
1                                            2, 1, 1, 1, 1,1/
 DATA (LIST( 52,I),I=1,7),LISTO( 52)/10HCOMMANDS H,3HINT,
1                                            3, 1, 1, 1, 1,1/
 DATA (LIST( 53,I),I=1,7),LISTO( 53)/10HDISTURBS H,3HINT,
1                                            4, 1, 1, 1, 1,1/
 DATA (LIST( 54,I),I=1,7),LISTO( 54)/10HMODAL    E,3HOUT,
1                                            0, 0, 0, 0, 0,4/
 DATA (LIST( 55,I),I=1,7),LISTO( 55)/10HINVMODAL H,3HOUT,
1                                            0, 0, 0, 0, 0,1/
 DATA (LIST( 56,I),I=1,7),LISTO( 56)/10HCINDICES H,3HOUT,
1                                            0, 0, 0, 0, 0,2/
 DATA (LIST( 57,I),I=1,7),LISTO( 57)/10HUREFORM  G,3HOUT,
1                                            0, 0, 0, 0, 0,1/
 DATA (LIST( 58,I),I=1,7),LISTO( 58)/10HAPLFORM  G,3HOUT,
1                                            0, 0, 0, 0, 0,1/
 DATA (LIST( 59,I),I=1,7),LISTO( 59)/10HBRNFORM  G,3HOUT,
1                                            0, 0, 0, 0, 0,2/
 DATA NL,N,NTOT,NITOT/59,59,3500,25/
 DATA NOREP,NOFW,NONSO/5,13,5/
 DATA NOREP,NOFW,NONSO/10,12,4/
 DATA ITITLE/5*1H /
 CALL COMND
 END
```

```
INTERAC   107
INTERAC   108
INTERAC   109
INTERAC   110
INTERAC   111
INTERAC   112
INTERAC   113
INTERAC   114
INTERAC   115
INTERAC   116
INTERAC   117
INTERAC   118
INTERAC   119
INTERAC   120
INTERAC   121
INTERAC   122
INTERAC   123
INTERAC   124
INTERAC   125
INTERAC   126
INTERAC   127
INTERAC   128
INTERAC   129
INTERAC   130
INTERAC   131
INTERAC   132
INTERAC   133
INTERAC   134
INTERAC   135
INTERAC   136
INTERAC   137
INTERAC   138
INTERAC   139
INTERAC   140
INTERAC   141
```

```
      SUBROUTINE COMND                                                  COMND     2
      COMMON/LISTING/NL,LIST(75,7)                                      COMND     3
      COMMON/LISTOUT/NO,LISTO(1)                                        COMND     4
      COMMON/RVAR/NTOT,TOT(1)                                           COMND     5
      COMMON/IVAR/NITOT,ITOT(1)                                         COMND     6
      COMMON/CONTROL/DSP,BATCH                                          COMND     7
      COMMON/FORMS/NDREP,NDFW,NDNSD,NOREP,NOFW,NONSD                    COMND     8
      LOGICAL BATCH                                                     COMND     9
      INTEGER DSP,CMD(12),CMST,CMED                                     COMND    10
      CALL CONNEC(5LINPUT)                                              COMND    11
      CALL CONNEC(5LTAPE8)                                              COMND    12
      CALL DATE(TODAY)                                                  COMND    13
      CALL TIME(CLOCK)                                                  COMND    14
      PRINT(6,*)"  IF YOU ARE AT A TERMINAL TYPE TTY  >"                COMND    15
      READ 5,JCN,KCN                                                    COMND    16
    5 FORMAT(R3,1X,R1)                                                  COMND    17
      IF(JCN.EQ.3RTTY) GO TO 10                                         COMND    18
      DSP=6                                                             COMND    19
      BATCH=.TRUE.                                                      COMND    20
      GO TO 12                                                          COMND    21
   10 DSP=8                                                             COMND    22
      BATCH=.FALSE.                                                     COMND    23
      CALL DISCON(6LOUTPUT)                                             COMND    24
      REWIND 6                                                          COMND    25
   12 PRINT(6,15)TODAY,CLOCK                                            COMND    26
   15 FORMAT("1",10X,"START     DATE ",A10,5X,"TIME ",A10,////)         COMND    27
      IF(KCN.NE.1RS) GO TO 5000                                         COMND    28
   20 PRINT(6,*)                                                        COMND    29
      PRINT(6,*)                                                        COMND    30
      PRINT(6,*)"  COMMAND >>"                                          COMND    31
      NUM=12                                                            COMND    32
      CALL READCOM(CMD,NUM)                                             COMND    33
      IF(CMD(1).EQ.0) GO TO 90                                          COMND    34
      CMED=0                                                            COMND    35
   25 CMST=CMED+2                                                       COMND    36
```

```
      K=0                                                                    COMND    37
      DO 30 I=CMST,NUM                                                       COMND    38
      IF(CMD(I).GE.0) GO TO 35                                               COMND    39
      K=K+1                                                                  COMND    40
   30 CONTINUE                                                               COMND    41
   35 CMST=CMST-1                                                            COMND    42
      IF(K.EQ.0) GO TO 50                                                    COMND    43
      IF(LIST(CMD(CMST),2).NE.3HCMD) GO TO 45                                COMND    44
      IF(LIST(CMD(CMST),7).LT.0 .OR. LIST(CMD(CMST),7).GT.K) GO TO 45        COMND    45
      CALL STRING(LIST(CMD(CMST),3),CMD(CMST+1),K),RETURNS(20)               COMND    46
      GO TO 40                                                               COMND    47
   40 CMED=CMST+K                                                            COMND    48
      IF(CMED.EQ.NUM) GO TO 20                                               COMND    49
      GO TO 25                                                               COMND    50
   45 PRINT(6,46)AND(LIST(CMD(CMST),1),778),LIST(CMD(CMST),1),               COMND    51
     1 AND(LIST(-CMD(CMST+K),1),778),LIST(-CMD(CMST+K),1)                    COMND    52
      IF(BATCH) STOP                                                         COMND    53
      GO TO 40                                                               COMND    54
   46 FORMAT(/,5X,"COMMAND STRING",3X,A=,".......",A=,3X,                    COMND    55
     1   "ILLEGAL AND IGNORED.",/)                                           COMND    56
   50 JCN=CMD(CMST)                                                          COMND    57
      IF(LIST(JCN,2).EQ.3HOUT) GO TO 60                                      COMND    58
      IF(LIST(JCN,2).EQ.3HREL .OR. LIST(JCN,2).EQ.3HINT) GO TO 75            COMND    59
      IF(LIST(JCN,7).EQ.-3 .OR. LIST(JCN,7).GT.0) GO TO 60                   COMND    60
      GO TO ( 100, 200, 300, 400, 500, 600, 700, 800, 900,1000,              COMND    61
     1       1100,1200,1300,1400,3000,1600,1700,1800,1900,2000,              COMND    62
                                                                            COMND    63
     2       2100,2200,2300,3000,3000,3000,3000,3000,3000,3000)              COMND    64
     3 LIST(JCN,3)                                                          COMND    65
   60 PRINT(6,65)AND(LIST(JCN,1),778),LIST(JCN,1)                           COMND    66
      GO TO 40                                                               COMND    67
   65 FORMAT(/10X,A=,3X,"ILLEGAL AND IGNORED",/)                            COMND    68
   75 CALL OPEN(JCN),RETURNS(20)                                            COMND    69
      GO TO 40                                                               COMND    70
   90 IF(BATCH) STOP                                                        COMND    71
```

```
      GO TO 20                                                                  COMND      72
C*****ENTER**                                                                   COMND      73
  100 PRINT(8,150)                                                              COMND      74
      NC=1                                                                      COMND      75
      CALL READCOM(ICOM,NC)                                                     COMND      76
      IF(ICOM.EQ.0) GO TO 90                                                    COMND      77
      IF(LIST(ICOM,1).EQ.10HEND      C) GO TO 40                                COMND      78
      IF(LIST(ICOM,2).EQ.3HCMD .OR. LIST(ICOM,2).EQ.3HOUT) GO TO 120            COMND      79
      CALL OPEN(ICOM),RETURNS(20)                                               COMND      80
      GO TO 100                                                                 COMND      81
  120 PRINT(8,65)AND(LIST(ICOM,1),778),LIST(ICOM,1)                             COMND      82
      GO TO 100                                                                 COMND      83
  150 FORMAT(/10X,"ENTER VARIABLE NAME OR END  >>")                             COMND      84
C*****STOP**     **END**                                                        COMND      85
  200 PRINT(8,250)                                                              COMND      86
  250 FORMAT(/,5X,"INTERAC TERMINATED, ANSWER IS DISCONNECTED AND CONTAI        COMND      87
     1NS",/," YOUR PRINTED DATA.  FILE DATA HAS THE CURRENT CONTENTS",          COMND      88
     2/," OF ALL VARIABLES;  THEY CAN BE RELOADED AT SOME FUTURE TIME BY        COMND      89
     3",/," THE COMMAND RESTART.")                                              COMND      90
  300 CALL DATE(TODAY)                                                          COMND      91
      CALL TIME(CLOCK)                                                          COMND      92
      PRINT(55,340)TODAY,CLOCK                                                  COMND      93
      PRINT(8,345)TODAY,CLOCK                                                   COMND      94
  340 FORMAT(2A10)                                                              COMND      95
  345 FORMAT(5X,"DATA SAVED AT ",2A10)                                          COMND      96
      PRINT(55,*)(TOT(I),I=1,NTOT)                                              COMND      97
      PRINT(55,*)(ITOT(I),I=1,NITOT)                                            COMND      98
      PRINT(55,*)((LIST(I,4),LIST(I,5)),I=1,NL)                                 COMND      99
      PRINT(55,*)(LISTO(I),I=1,NO)                                              COMND     100
      CALL RETURN(5LTAPE7)                                                      COMND     101
      CALL RETURN(5LTAPE8)                                                      COMND     102
      CALL RETURN(5LTAPE65)                                                     COMND     103
      PRINT(8,350)TODAY,CLOCK                                                   COMND     104
  350 FORMAT("2",19X,"STOP      DATE ",A10,5X,"TIME ",A10)                      COMND     105
      CALL FORMOUT                                                              COMND     106
```

```
C*****PRINT**                                                          COMND   107
  400 PRINT(8,150)                                                     COMND   108
      NC=1                                                             COMND   109
      CALL RFADCOM(ICOM,NC)                                            COMND   110
      IF(ICOM.EQ.0) GO TO 90                                           COMND   111
      IF(LIST(ICOM,1).EQ.10HEND      C) GO TO 40                       COMND   112
      IF(LIST(ICOM,2).EQ.3HCMD .OR. LIST(ICOM,2).EQ.3HOUT) GO TO 420   COMND   113
      NP=LIST(ICOM,4)                                                  COMND   114
      MP=LIST(ICOM,5)                                                  COMND   115
      NDP=LIST(ICOM,6)                                                 COMND   116
      IF(LIST(ICOM,2).EQ.3HINT) GO TO 410                              COMND   117
      CALL PPINTR(0,LIST(ICOM,1),TOT(LIST(ICOM,3)),NP,MP,NDP)          COMND   118
      GO TO 400                                                        COMND   119
  410 CALL PPINTI(0,LIST(ICOM,1),ITOT(LIST(ICOM,3)),NP,MP,NDP)         COMND   120
      GO TO 400                                                        COMND   121
  420 PRINT(8,65)AND(LIST(ICOM,1),778),LIST(ICOM,1)                    COMND   122
      GO TO 400                                                        COMND   123
C*****DFORMAT**                                                        COMND   124
  500 PRINT(8,550)                                                     COMND   125
      CALL RFADNUM(10H          A,NC,1,1,1,.FALSE.),RETURNS(20)        COMND   126
      IF(NC.LT.1 .OR. NC.GT.14) GO TO 500                              COMND   127
      NDREP=66/(NC+7)                                                  COMND   128
      NDFW=NC+7                                                        COMND   129
      NDNSD=NC-1                                                       COMND   130
      GO TO 40                                                         COMND   131
  550 FORMAT(5X,"ENTER NUMBER OF SIGNIFICANT DIGITS  0 < N < 15."/)    COMND   132
C*****CHANGE**                                                         COMND   133
  600 PRINT(8,150)                                                     COMND   134
      NC=1                                                             COMND   135
      CALL READCOM(ICOM,NC)                                            COMND   136
      IF(ICOM.EQ.0) GO TO 90                                           COMND   137
      IF(LIST(ICOM,1).EQ.10HEND      C) GO TO 40                       COMND   138
      IF(LIST(ICOM,2).EQ.3HCMD) GO TO 620                              COMND   139
      CALL RFOPEN(ICOM),RETURNS(20)                                    COMND   140
      GO TO 600                                                        COMND   141
```

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  620 PRINT(8,65)AND(LIST(ICOM,1),77B),LIST(ICOM,1)                    COMND   142
      GO TO 600                                                        COMND   143
C*****DISPLAY**                                                        COMND   144
  700 PRINT(8,*)"  VARIABLES TO BE DISPLAYED AT TERMINAL"              COMND   145
      DO 720 J=1,NL                                                    COMND   146
      IF(LISTO(J).NE.2 .AND. LISTO(J).NE.3) GO TO 720                  COMND   147
      PRINT(8,750)AND(LIST(J,1),77B),LIST(J,1)                         COMND   148
  720 CONTINUE                                                         COMND   149
      GO TO 40                                                         COMND   150
  750 FORMAT(5X,A=)                                                    COMND   151
C*****OUTPUT**                                                         COMND   152
  800 PRINT(8,*)"  VARIABLES TO BE PRINTED TO ANSWER"                  COMND   153
      DO 820 J=1,NL                                                    COMND   154
      IF(LISTO(J).NE.3 .AND. LISTO(J).NE.4) GO TO 820                  COMND   155
      PRINT(8,850)AND(LIST(J,1),77B),LIST(J,1)                         COMND   156
  820 CONTINUE                                                         COMND   157
      GO TO 40                                                         COMND   158
  850 FORMAT(5X,A=)                                                    COMND   159
C*****DELETE**                                                         COMND   160
  900 PRINT(8,*)"  ALL VARIABLES HAVE BEEN REMOVED FROM THE DISPLAY AND COMND   161
     1OUTPUT LISTS."                                                   COMND   162
      DO 920 J=1,NL                                                    COMND   163
      LISTO(J)=1                                                       COMND   164
  920 CONTINUE                                                         COMND   165
      GO TO 40                                                         COMND   166
C*****OPTIONS**                                                        COMND   167
 1000 PRINT(8,*)"  VALID COMMANDS"                                     COMND   168
      DO 1020 J=1,NL                                                   COMND   169
      IF(LIST(J,2).NE.3HCMD) GO TO 1020                                COMND   170
      IF(LIST(J,7)) 1005,1010,1015                                     COMND   171
 1005 PRINT(8,1050)AND(LIST(J,1),77B),LIST(J,1)                        COMND   172
      GO TO 1020                                                       COMND   173
 1010 PRINT(8,1060)AND(LIST(J,1),77B),LIST(J,1)                        COMND   174
      GO TO 1020                                                       COMND   175
 1015 PRINT(8,1070)AND(LIST(J,1),77B),LIST(J,1)                        COMND   176
```

```
 1020 CONTINUE                                                          COMND    177
      GO TO 40                                                          COMND    178
 1050 FORMAT(5X,A=)                                                     COMND    179
 1060 FORMAT(5X,A=,T18,"{,PARAMETER LIST}")                             COMND    180
 1070 FORMAT(5X,A=,T18,",PARAMETER(S)")                                 COMND    181
C*****VARIABLES**                                                       COMND    182
 1100 PRINT(8,*)"  VALID VARIABLES          MAX DIMENSION ALLOWED"      COMND    183
      DO 1120 J=1,NL                                                    COMND    184
      IF(LIST(J,2).EQ.3HCMD) GO TO 1120                                 COMND    185
      ISIM=1H                                                           COMND    186
      IF(LIST(J,2).EQ.3HOUT) ISIM=1H*                                   COMND    187
      PRINT(8,1150)ISIM,AND(LIST(J,1),77B),LIST(J,1),LIST(J,6),LIST(J,7) COMND    188
 1120 CONTINUE                                                          COMND    189
      PRINT(8,*)                                                        COMND    190
      PRINT(8,*)"  * -- TEMPORARY VARIABLE PRINTED ONLY DURING PROGRAM E COMND    191
     ^XECUTION."                                                        COMND    192
      GO TO 40                                                          COMND    193
 1150 FORMAT(5X,A2,A=,T33,"(",I3,",",I3,")")                            COMND    194
C*****SAVE**                                                            COMND    195
 1200 CALL DATE(TODAY)                                                  COMND    196
      CALL TIME(CLOCK)                                                  COMND    197
      PRINT(55,340)TODAY,CLOCK                                          COMND    198
      PRINT(8,345)TODAY,CLOCK                                           COMND    199
      PRINT(55,*)(TOT(I),I=1,NTOT)                                      COMND    200
      PRINT(55,*)(ITOT(I),I=1,NITOT)                                    COMND    201
      PRINT(55,*)((LIST(I,4),LIST(I,5)),I=1,NL)                         COMND    202
      PRINT(55,*)(LISTO(I),I=1,NO)                                      COMND    203
      GO TO 40                                                          COMND    204
C*****RESTART**                                                         COMND    205
 1300 REWIND 65                                                         COMND    206
      PRINT(65,*)(TOT(I),I=1,NTOT)                                      COMND    207
      PRINT(65,*)(ITOT(I),I=1,NITOT)                                    COMND    208
      PRINT(65,*)((LIST(I,4),LIST(I,5)),I=1,NL)                         COMND    209
      PRINT(65,*)(LISTO(I),I=1,NO)                                      COMND    210
      READ(55,340)TODAY,CLOCK                                           COMND    211
```

```
      IF(EOF(6LTAPE55).NE.0.0) GO TO 1350                                COMND   212
      READ(55,*)(TOT(I),I=1,NTOT)                                        COMND   213
      IF(EOF(6LTAPE55).NE.0.0) GO TO 1350                                COMND   214
      READ(55,*)(ITOT(I),I=1,NITOT)                                      COMND   215
      IF(EOF(6LTAPE55).NE.0.0) GO TO 1350                                COMND   216
      READ(55,*)((LIST(I,4),LIST(I,5)),I=1,NL)                           COMND   217
      IF(EOF(6LTAPE55).NE.0.0) GO TO 1350                                COMND   218
      READ(55,*)(LISTO(I),I=1,NO)                                        COMND   219
      IF(EOF(6LTAPE55).NE.0.0) GO TO 1350                                COMND   220
      PRINT(8,1340)TODAY,CLOCK                                           COMND   221
 1340 FORMAT(/,5X,"DATA SAVED AT ",2A10," RELOADED.")                    COMND   222
      GO TO 40                                                           COMND   223
 1350 PRINT(8,*)"  EOF ENCOUNTERED ON RESTART - REWIND IS PROBABLY NECES COMND   224
     1SARY"                                                              COMND   225
      REWIND 65                                                          COMND   226
      READ(65,*)(TOT(I),I=1,NTOT)                                        COMND   227
      READ(65,*)(ITOT(I),I=1,NITOT)                                      COMND   228
      READ(65,*)((LIST(I,4),LIST(I,5)),I=1,NL)                           COMND   229
      READ(65,*)(LISTO(I),I=1,NO)                                        COMND   230
      GO TO 40                                                           COMND   231
C*****REWIND**                                                           COMND   232
 1400 REWIND 55                                                          COMND   233
      GO TO 40                                                           COMND   234
C*****FORTRAC**                                                          COMND   235
 1500 CALL FORTRAC(1)                                                    COMND   236
      GO TO 40                                                           COMND   237
C*****SAMPLE**                                                           COMND   238
 1700 CALL FORTRAC(2)                                                    COMND   239
      GO TO 40                                                           COMND   240
C*****AUGMAT**                                                           COMND   241
 1800 CALL FORTRAC(3)                                                    COMND   242
      GO TO 40                                                           COMND   243
C*****TRANSFORM**                                                        COMND   244
 1900 CALL FORTRAC(4)                                                    COMND   245
      GO TO 40                                                           COMND   246
```

```
C*****CONTROL**                                                          COMND   247
 2000 CALL FORTRAC(5)                                                    COMND   248
      GO TO 40                                                           COMND   249
C*****CLOSELCOF**                                                        COMND   250
 2100 CALL FORTRAC(6)                                                    COMND   251
      GO TO 40                                                           COMND   252
C*****OFORMAT**                                                          COMND   253
 2200 PRINT(8,550)                                                       COMND   254
      CALL READNUM(10H          A,NC,1,1,1,.FALSE.),RETURNS(20)          COMND   255
      IF(NC.LT.1 .OR. NC.GT.14) GO TO 2200                               COMND   256
      NOREP=126/(NC+7)                                                   COMND   257
      NOFW=NC+7                                                          COMND   258
      NONSD=NC-1                                                         COMND   259
      GO TO 40                                                           COMND   260
C*****SETDIMEN**                                                         COMND   261
 2300 CALL FORTRAC(100)                                                  COMND   262
      GO TO 40                                                           COMND   263
C    **NOT USED YET**                                                    COMND   264
 3000 PRINT(8,*)"  COMMAND NOT AVAILABLE"                                COMND   265
      GO TO 40                                                           COMND   266
C*****INTRODUCTION**                                                     COMND   267
 5000 PRINT(8,5001)                                                      COMND   268
 5001 FORMAT(/,10X,"WELCOME TO INTERAC:  A SOFTWARE PACKAGE FOR",/,      COMND   269
     1  5X,"DIRECT DIGITAL CONTROL SYSTEM DESIGN FOR",/,                 COMND   270
     2  5X,"LINEAR MULTI-INPUT, MULTI-OUTPUT PLANTS.  FOR A",/,          COMND   271
     3  5X,"STEP BY STEP PROCEEDURE IN USING THIS PACKAGE",/,            COMND   272
     4  5X,"TYPE  FORTRAC.")                                             COMND   273
      GO TO 20                                                           COMND   274
      END                                                                COMND   275
```

```
      SUBROUTINE STRING(N,CMD,K),RETURNS(ABORT)                          STRING     2
      COMMON/LISTING/NL,LIST(75,7)                                       STRING     3
      COMMON/LISTOUT/NO,LISTO(1)                                         STRING     4
      COMMON/RVAR/NTOT,TOT(1)                                            STRING     5
      COMMON/IVAR/NITOT,ITOT(1)                                          STRING     6
      COMMON/TITLE/ITITLE(5)                                             STRING     7
      INTEGER CMD(K)                                                     STRING     8
      DO 2 I=1,K                                                         STRING     9
    2 CMD(I)=-CMD(I)                                                     STRING    10
      GO TO ( 10,500,500, 40,500, 60, 70 ,80, 90,500,                    STRING    11
     1 *      500,500,130,500,150,500,500,500,500,500,                   STRING    12
     2        500,500,500,500,500,500,500,500,500,500) N                 STRING    13
    5 RETURN ABORT                                                       STRING    14
C*****ENTER**                                                            STRING    15
   10 DO 18 I=1,K                                                        STRING    16
      IF(LIST(CMD(I),2).EQ.3HCMD .OR. LIST(CMD(I),2).EQ.3HOUT) GO TO 15  STRING    17
      CALL OPEN(CMD(I)),RETURNS(5)                                       STRING    18
      GO TO 18                                                           STRING    19
   15 PRINT(6,16)AND(LIST(CMD(I),1),778),LIST(CMD(I),1)                  STRING    20
   16 FORMAT(/,5X,"ENTER,",A=," ILLEGAL AND IGNORED")                    STRING    21
   18 CONTINUE                                                           STRING    22
      RETURN                                                             STRING    23
C*****PRINT**                                                            STRING    24
   40 DO 48 I=1,K                                                        STRING    25
      IF(LIST(CMD(I),2).EQ.3HCMD .OR. LIST(CMD(I),2).EQ.3HOUT) GO TO 45  STRING    26
      NP=LIST(CMD(I),4)                                                  STRING    27
      MP=LIST(CMD(I),5)                                                  STRING    28
      NDP=LIST(CMD(I),6)                                                 STRING    29
      IF(LIST(CMD(I),2).EQ.3HINT) GO TO 44                               STRING    30
      CALL PRINTR(0,LIST(CMD(I),1),TOT(LIST(CMD(I),3)),NP,MP,NDP)        STRING    31
      GO TO 48                                                           STRING    32
   44 CALL PRINTI(0,LIST(CMD(I),1),ITOT(LIST(CMD(I),3)),NP,MP,NDP)       STRING    33
      GO TO 48                                                           STRING    34
   45 PRINT(6,46)AND(LIST(CMD(I),1),778),LIST(CMD(I),1)                  STRING    35
   46 FORMAT(/,5X,"PRINT,",A=," ILLEGAL AND IGNORED")                    STRING    36
```

```
   48 CONTINUE                                                                    STRING     37
      RETURN                                                                      STRING     38
C*****CHANGE**                                                                    STRING     39
   60 DO 68 I=1,K                                                                 STRING
      IF(LIST(CMD(I),2).EQ.3HCMD .OR. LIST(CMD(I),2).EQ.3HOUT) GO TO 65           STRING     41
      CALL REOPEN(CMD(I)),RETURNS(5)                                              STRING     42
      GO TO 68                                                                    STRING     43
   65 PRINT(6,66)AND(LIST(CMD(I),1),77B),LIST(CMD(I),1)                           STRING     44
   66 FORMAT(/,5X,"CHANGE,",A=,"  ILLEGAL AND IGNORED")                          STRING     45
   68 CONTINUE                                                                    STRING     46
      RETURN                                                                      STRING     47
C*****DISPLAY**                                                                   STRING     48
   70 DO 78 I=1,K                                                                 STRING     49
      IF(LIST(CMD(I),2).EQ.3HCMD) GO TO 75                                        STRING     50
      ITEMP=LISTO(CMD(I))                                                         STRING     51
      LISTO(CMD(I))=2                                                             STRING     52
      IF(ITEMP.EQ.4) LISTO(CMD(I))=3                                              STRING     53
      GO TO 78                                                                    STRING     54
   75 PRINT(6,76)AND(LIST(CMD(I),1),77B),LIST(CMD(I),1)                           STRING     55
   76 FORMAT(/,5X,"DISPLAY,",A=,"  ILLEGAL AND IGNORED")                         STRING     56
   78 CONTINUE                                                                    STRING     57
      RETURN                                                                      STRING     58
C*****OUTPUT**                                                                    STRING     59
   80 DO 88 I=1,K                                                                 STRING     60
      IF(LIST(CMD(I),2).EQ.3HCMD) GO TO 85                                        STRING     61
      ITEMP=LISTO(CMD(I))                                                         STRING     62
      LISTO(CMD(I))=4                                                             STRING     63
      IF(ITEMP.EQ.2) LISTO(CMD(I))=3                                              STRING     64
      GO TO 88                                                                    STRING     65
   85 PRINT(6,86)AND(LIST(CMD(I),1),77B),LIST(CMD(I),1)                           STRING     66
   86 FORMAT(/,5X,"OUTPUT,",A=,"  ILLEGAL AND IGNORED")                          STRING     67
   88 CONTINUE                                                                    STRING     68
      RETURN                                                                      STRING     69
C*****DELETE**                                                                    STRING     70
   90 DO 96 I=1,K                                                                 STRING     71
```

```
      IF(LIST(CMD(I),2).EQ.3HCMD) GO TO 95                              STRING     72
      LISTO(CMD(I))=1                                                   STRING     73
      GO TO 98                                                          STRING     74
   95 PRINT(8,96)AND(LIST(CMD(I),1),77B),LIST(CMD(I),1)                 STRING     75
   96 FORMAT(/,5X,"DELETE,",A=," ILLEGAL AND IGNORED")                  STRING     76
   98 CONTINUE                                                          STRING     77
      RETURN                                                            STRING     78
C*****RESTART**                                                         STRING     79
  130 IF(K.GT.1) GO TO 135                                              STRING     80
      IF(LIST(CMD(1),1).NE.10HREWIND   F) GO TO 137                     STRING     81
      REWIND 65                                                         STRING     82
      PRINT(65,*)(TOT(I),I=1,NTOT)                                      STRING     83
      PRINT(65,*)(ITOT(I),I=1,NITOT)                                    STRING     84
      PRINT(65,*)((LIST(I,4),LIST(I,5)),I=1,NL)                         STRING     85
      PRINT(65,*)(LISTO(I),I=1,NO)                                      STRING     86
      REWIND 55                                                         STRING     87
      READ(55,131)TODAY,CLOCK                                           STRING     88
      IF(EOF(6LTAPE55).NE.0.0) GO TO 133                                STRING     89
      READ(55,*)(TOT(I),I=1,NTOT)                                       STRING     90
      IF(EOF(6LTAPE55).NE.0.0) GO TO 133                                STRING     91
      READ(55,*)(ITOT(I),I=1,NITOT)                                     STRING     92
      IF(EOF(6LTAPE55).NE.0.0) GO TO 133                                STRING     93
      READ(55,*)((LIST(I,4),LIST(I,5)),I=1,NL)                          STRING     94
      IF(EOF(6LTAPE55).NE.0.0) GO TO 133                                STRING     95
      READ(55,*)(LISTO(I),I=1,NO)                                       STRING     96
      IF(EOF(6LTAPE55).NE.0.0) GO TO 133                                STRING     97
      PRINT(8,132)TODAY,CLOCK                                           STRING     98
      RETURN                                                            STRING     99
  131 FORMAT(2A10)                                                      STRING    100
  132 FORMAT(/,5X,"DATA SAVED AT ",2A10," RELOADED.")                   STRING    101
  133 PRINT(8,*)"  TAPE55 DOES NOT CONTAIN ANY DATA"                    STRING    102
      REWIND 65                                                         STRING    103
      READ(65,*)(TOT(I),I=1,NTOT)                                       STRING    104
      READ(65,*)(ITOT(I),I=1,NITOT)                                     STRING    105
      READ(65,*)((LIST(I,4),LIST(I,5)),I=1,NL)                          STRING    106
```

```
      READ(65,*)(LISTO(I),I=1,NO)                                          STRING    107
      RETURN                                                               STRING    108
  135 PRINT(8,136)AND(LIST(CMD(K),1),778),LIST(CMD(K),1)                   STRING    109
  136 FORMAT(/,5X,"COMMAND STRING  RESTART,...,",A=," ILLEGAL AND IGNORE   STRING    110
     1D")                                                                  STRING    111
      RETURN                                                               STRING    112
  137 PRINT(8,138)AND(LIST(CMD,1),778),LIST(CMD,1)                         STRING    113
  138 FORMAT(/,5X,"RESTART,",A=,"  ILLEGAL AND IGNORED")                   STRING    114
      RETURN                                                               STRING    115
C*****RUN**                                                                STRING    116
  150 IF(K.GT.1) GO TO 155                                                 STRING    117
      IF(LIST(CMD(1),6).EQ.0 .OR. LIST(CMD(1),7).NE.-2) GO TO 157          STRING    118
      CALL FORTRAC(LIST(CMD(1),6)+10)                                      STRING    119
      RETURN                                                               STRING    120
  155 PRINT(8,156)AND(LIST(CMD(K),1),778),LIST(CMD(K),1)                   STRING    121
  156 FORMAT(/,5X,"COMMAND STRING  RUN,...,",A=,"  ILLEGAL AND IGNORED")   STRING    122
      RETURN                                                               STRING    123
  157 PRINT(8,158)AND(LIST(CMD(1),1),778),LIST(CMD(1),1)                   STRING    124
  158 FORMAT(/,5X,"RUN,",A=,"  ILLEGAL AND IGNORED")                       STRING    125
      RETURN                                                               STRING    126
  500 PRINT(8,*)" COMMAND STRING NOT AVAILABLE"                            STRING    127
      RETURN                                                               STRING    128
      END                                                                  STRING    129
```

```
      SUBROUTINE READNUM(NAME,MATRIX,N,M,ND,REAL),RETURNS(ABORT)          READNUM      2
      COMMON/CONTROL/DSP,BATCH                                           READNUM     98
      LOGICAL REAL,BATCH,LIST,END                                        READNUM     99
      REAL MATRIX(ND,M)                                                  READNUM    100
      INTEGER A(65),IN(73),COMMAND(6),AM(10),SLASH(2),                   READNUM    101
     ^AM1,GO,COMMA,REW,RET,WORD,POINTER,WORDST,DSP                       READNUM    102
      DATA A/6666666666666666666B,1111111111111535555B,                  READNUM    103
     ^1111111111113155555B,1111111111115155555B,1111111111113155555B,   READNUM    104
     ^1111111111115155555B,1111111111115155522B,1111111111115155555B,   READNUM    105
     ^1111111111115155555B,1111111111115135555B,1111111111115155555B,   READNUM    106
     ^1111111111115155555B,1111111111115155555B,1111111111113155553B,   READNUM    107
     ^1111111111115155555B,1111111111115155555B,1111111111115155555B,   READNUM    108
     ^1111111111115155555B,1111111111115155555B,1111111111115155553B,   READNUM    109
     ^1111111111115155555B,1111111111115155555B,1111111111115155555B,   READNUM    110
     ^1111111111115155555B,1111111111115155555B,1111111111115155555B,   READNUM    111
     ^1111111111115155555B,1111111111113155553B,                        READNUM    112
     ^10*1111111111113111112B,                                          READNUM    113
     ^1111111111113551552B,1111111111113551552B,1111111111113555552B,   READNUM    114
     ^1111111111114245555B,1111111111115355555B,1111111111115355555B,   READNUM    115
     ^1111111111113577773B,1111111111115355555B,1111111111112244441B,   READNUM    116
     ^1111111111112344441B,1111111111113555332B,1111111111115355555B,   READNUM    117
     ^1111111111115355555B,1111111111115355555B,1111111111115355555B,   READNUM    118
     ^1111111111115355555B,1111111111115355555B,1111111111115355555B,   READNUM    119
     ^1111111111115355555B,1111111111115355555B,1111111111115355555B,   READNUM    120
     ^1111111111115355555B,1111111111115355555B,1111111111115355555B,   READNUM    121
     ^1111111111115355555B,1111111111115355555B,1111111111115355555B/   READNUM    122
      DATA AM/0000030000000000770,0000000000000077770,                   READNUM    123
     ^0000000000007777777B,0000000000777777777B,                        READNUM    124
     ^0000000007777777777B,0000000777777777777B,                        READNUM    125
     ^0000077777777777777B,0007777777777777777B,                        READNUM    126
     ^0077777777777777777B,7777777777777777777B/                        READNUM    127
      COMMAND(1)=5HABORT                                                 READNUM    128
      COMMAND(2)=4HZERO                                                  READNUM    129
      COMMAND(3)=8HCONTINUE                                              READNUM    130
      COMMAND(4)=4HREAD                                                  READNUM    131
```

```
      COMMAND(5)=4HLIST                                                  READNUM   132
      COMMAND(6)=6HREWIND                                                READNUM   133
      AM1=SHIFT(MASK(3),3)                                               READNUM   134
      IROW=ICOL=POINTER=II=1                                             READNUM   135
      IN(73)=-1                                                          READNUM   136
      INUNIT=5                                                           READNUM   137
      END=LIST=.FALSE.                                                   READNUM   138
      NN=N*M                                                             READNUM   139
      COMMA=1R,                                                          READNUM   140
      IF(NAME.EQ.10HDIMENSIONI .OR. NAME.EQ.10H          A) GO TO 1      READNUM   141
      PRINT(OSP,97)AND(NAME,77B),NAME,N,M                                READNUM   142
    1 IF(REAL) GO TO 2                                                   READNUM   143
      CALL SUBREL(MATRIX,MATRIX,N,M,ND)                                  READNUM   144
    2 CALL HAZEL(4HBELL)                                                 READNUM   145
      READ(INUNIT,99)(IN(K),K=1,72)                                      READNUM   146
      GO TO (3,5,7,700,9)  INUNIT                                        READNUM   147
    3 IF(EOF(5LTAPE1).EQ.0) GO TO 9                                      READNUM   148
      GO TO 8                                                            READNUM   149
    5 IF(EOF(5LTAPE2).EQ.0) GO TO 9                                      READNUM   150
      GO TO 8                                                            READNUM   151
    7 IF(EOF(5LTAPE3).EQ.0) GO TO 9                                      READNUM   152
    8 INUNIT=5                                                           READNUM   153
      PRINT(OSP,98)                                                      READNUM   154
      GO TO 2                                                            READNUM   155
    9 KK=1                                                               READNUM   156
      K=0                                                                READNUM   157
   10 K=K+1                                                              READNUM   158
      GO=AND(SHIFT(A(IN(K)+2),-3*(II-1)),AM1)                            READNUM   159
      GO TO (10,200,300,400,520,600,700) GO                              READNUM   160
   97 FORMAT(/,5X,A=,"   DIMENSIONED (",I3,",",I3,") IS OR",/)           READNUM   161
   98 FORMAT(/30X,"EOF ENCOUNTERED ON TAPE, ENTER REMAININ",/,           READNUM   162
     ^30X,"DATA FROM KEYBOARD",/)                                        READNUM   163
   99 FORMAT(72R1)                                                       READNUM   164
C**********                                                             READNUM   165
C          DECODING NUMERICAL ENTRIES                                    READNUM   166
```

```
C**********                                                          READNUM   167
  200 IF(IN(K).EQ.1R*) GO TO 247                                     READNUM   168
      IF(POINTER.GT.NN .AND. END) GO TO 249                          READNUM   169
      NE=0                                                           READNUM   170
      NUMST=K                                                        READNUM   171
      I=1                                                            READNUM   172
      IF(IN(K).EQ.1R.) I=2                                           READNUM   173
  210 K=K+1                                                          READNUM   174
      IF(I.EQ.3) I=4                                                 READNUM   175
  215 GO=AND(SHIFT(A(IN(K)+2),-3*I),AM1)                             READNUM   176
      GO TO (210,220,230,240,250,260,270) GO                         READNUM   177
  220 IF(IN(K-1).LE.36) GO TO 225                                    READNUM   178
      IF(K-2.EQ.0) GO TO 500                                         READNUM   179
      IF(IN(K-2).LE.36) GO TO 225                                    READNUM   180
      GO TO 500                                                      READNUM   181
  225 I=3                                                            READNUM   182
      K=K+1                                                          READNUM   183
      NE=K                                                           READNUM   184
      GO TO 215                                                      READNUM   185
  230 I=2                                                            READNUM   186
      GO TO 210                                                      READNUM   187
  240 IF(I.EQ.3) GO TO 500                                           READNUM   188
      IF(I.EQ.4) GO TO 241                                           READNUM   189
      IF(IN(K-1).LE.36) GO TO 245                                    READNUM   190
      IF(K-2.EQ.0) GO TO 500                                         READNUM   191
      IF(IN(K-2).LE.36) GO TO 245                                    READNUM   192
      GO TO 500                                                      READNUM   193
  241 L=0                                                            READNUM   194
      IF(IN(NE).EQ.1R+ .OR. IN(NE).EQ.1R-) L=1                       READNUM   195
      IF(K-NE-3-L)245,242,500                                        READNUM   196
  242 IF(IN(NE+L)-29)245,243,500                                     READNUM   197
  243 IF(IN(NE+L+1)-36)245,244,500                                   READNUM   198
  244 IF(IN(NE+L+2).GT.1R3) GO TO 500                                READNUM   199
  245 REWIND 7                                                       READNUM   200
      L=K-1                                                          READNUM   201
```

```
      WRITE(7,99)(IN(J),J=NUMST,L)                                    READNUM   202
      REWIND 7                                                        READNUM   203
      READ(7,*)MATRIX(IROW,ICOL)                                      READNUM   204
  247 POINTER=POINTER+1                                               READNUM   205
      IROW=(POINTER-1)/M+1                                            READNUM   206
      ICOL=POINTER-(IROW-1)*M                                         READNUM   207
      IF(POINTER.GE.NN+1) GO TO 249                                   READNUM   208
  248 KK=K                                                            READNUM   209
      IF(IN(K).EQ.1R*) KK=K+1                                         READNUM   210
      GO TO 10                                                        READNUM   211
  249 END=.TRUE.                                                      READNUM   212
      II=8                                                            READNUM   213
      GO TO 248                                                       READNUM   214
  250 GO TO 520                                                       READNUM   215
  260 GO TO 560                                                       READNUM   216
  270 GO TO 300                                                       READNUM   217
C**********                                                           READNUM   218
C           DECODES COMMANDS                                          READNUM   219
C**********                                                           READNUM   220
  300 REW=1                                                           READNUM   221
      IF(IN(K).EQ.1R$) GO TO 330                                      READNUM   222
  305 WORDST=K                                                        READNUM   223
      I=6                                                             READNUM   224
      L=-1                                                            READNUM   225
  310 K=K+1                                                           READNUM   226
      L=L+1                                                           READNUM   227
      GO=AND(SHIFT(A(IN(K)+2),-3*I),AM1)                              READNUM   228
      IF(GO.EQ.5) GO TO 330                                           READNUM   229
      IF(GO.EQ.2) GO TO 320                                           READNUM   230
      IF(GO.EQ.3) GO TO 520                                           READNUM   231
      IF(L.GT.9) GO TO 530                                            READNUM   232
      IF(GO.EQ.6) GO TO 560                                           READNUM   233
      GO TO 310                                                       READNUM   234
  320 WORD=IN(WORDST)                                                 READNUM   235
      IF(L.EQ.0) GO TO (324,366) REW                                  READNUM   236
```

```
      DO 322 J=1,L                                                    READNUM   237
  322 WORD=OR(SHIFT(WORD,6),IN(WORDST+J))                             READNUM   238
      IF(REW.EQ.2) GO TO 366                                          READNUM   239
  324 DO 325 J=1,5                                                    READNUM   240
      IF(AND(SHIFT(COMMAND(J),6*(L+1)),AM(L+1)).EQ.WORD) GO TO 327    READNUM   241
  325 CONTINUE                                                        READNUM   242
      GO TO 530                                                       READNUM   243
  327 IF(IN(K).EQ.1RR .AND. J.NE.5) GO TO 540                         READNUM   244
      GO TO (330,340,350,360,370) J                                   READNUM   245
  330 IF(REAL) RETURN ABORT                                           READNUM   246
      DO 335 J=1,N                                                    READNUM   247
      DO 335 JJ=1,M                                                   READNUM   248
  335 IF(ABS(MATRIX(J,JJ)).GT.1E14) MATRIX(J,JJ)=0.0                  READNUM   249
      CALL SUBINT(MATRIX,MATRIX,N,M,ND)                               READNUM   250
      RETURN ABORT                                                    READNUM   251
  340 DO 345 J=1,N                                                    READNUM   252
      DO 345 JJ=1,M                                                   READNUM   253
  345 MATRIX(J,JJ)=0.0                                                READNUM   254
      END=.FALSE.                                                     READNUM   255
      IROW=ICOL=POINTER=1                                             READNUM   256
      PRINT(OSP,399)AND(NAME,AM(1)),NAME                              READNUM   257
      KK=K                                                            READNUM   258
      GO TO 10                                                        READNUM   259
  350 END=.TRUE.                                                      READNUM   260
      GO TO 600                                                       READNUM   261
  360 K=K+2                                                           READNUM   262
      NUM=0                                                           READNUM   263
      IF(IN(K-1).EQ.28) NUM=1                                         READNUM   264
      IF(IN(K-1).EQ.29) NUM=2                                         READNUM   265
      IF(IN(K-1).EQ.30) NUM=3                                         READNUM   266
      IF(IN(K-1).EQ.32) NUM=5                                         READNUM   267
      IF(NUM.EQ.0) GO TO 540                                          READNUM   268
      IF(IN(K).NE.45 .AND. IN(K).NE.46) GO TO 540                     READNUM   269
      IF(IN(K+1).EQ.1RR) GO TO 365                                    READNUM   270
  364 INUNIT=NUM                                                      READNUM   271
```

```
      GO TO 2                                                                  READNUM   272
  365 REW=2                                                                    READNUM   273
      K=K+1                                                                    READNUM   274
      GO TO 385                                                                READNUM   275
  366 IF(AND(SHIFT(COMMAND(6),6*(L+1)),AM(L+1)).NE.WORD) GO TO 530             READNUM   276
      REWIND NUM                                                               READNUM   277
      GO TO 364                                                                READNUM   278
  370 IF(IN(K).NE.1R/ .AND. IN(K+1).NE.1R/) GO TO 372                          READNUM   279
      IF(IN(K).NE.1R/) K=K+1                                                   READNUM   280
      LIST=.TRUE.                                                              READNUM   281
      GO TO 400                                                                READNUM   282
  372 SLASH(1)=SLASH(2)=0                                                      READNUM   283
  375 LIST=.FALSE.                                                             READNUM   284
      IF(SLASH(2).GT.M .OR. SLASH(1).GT.NN) GO TO 550                          READNUM   285
      IF(SLASH(2).NE.0 .AND. SLASH(1).GT.N) GO TO 550                          READNUM   286
      IF(M.EQ.1 .AND.N.EQ.1) GO TO 380                                         READNUM   287
      IF(M.EQ.1) GO TO 381                                                     READNUM   288
      IF(N.EQ.1) GO TO 383                                                     READNUM   289
      IF(SLASH(1).EQ.0 .AND. SLASH(2).EQ.0) GO TO 388                          READNUM   290
      IF(SLASH(1).EQ.0) GO TO 386                                              READNUM   291
      IF(SLASH(2).EQ.0) GO TO 387                                              READNUM   292
      PRINT(OSP,390)AND(NAME,AM(1)),NAME,SLASH(1),SLASH(2),MATRIX(SLASH(       READNUM   293
     ^1),SLASH(2))                                                             READNUM   294
  377 KK=K+1                                                                   READNUM   295
      END=.FALSE.                                                              READNUM   296
      GO TO 10                                                                 READNUM   297
  380 PRINT(OSP,398)AND(NAME,AM(1)),NAME,MATRIX(1,1)                           READNUM   298
      GO TO 377                                                                READNUM   299
  381 IF(SLASH(1).EQ.0) GO TO 382                                              READNUM   300
      PRINT(OSP,397)AND(NAME,AM(1)),NAME,SLASH(1),MATRIX(SLASH(1),1)           READNUM   301
      GO TO 377                                                                READNUM   302
  382 J=1                                                                      READNUM   303
      PRINT(OSP,396)AND(NAME,AM(1)),NAME,J                                     READNUM   304
      PRINT(OSP,395)(MATRIX(JJ,J),JJ=1,N)                                      READNUM   305
      PRINT(OSP,*)                                                             READNUM   306
```

```
      GO TO 377                                                          READNUM   307
  383 IF(SLASH(2).EQ.0 .AND. SLASH(1).GT.1) GO TO 384                    READNUM   308
      IF(SLASH(2).EQ.0) GO TO 385                                        READNUM   309
      PRINT(DSP,397)AND(NAME,AM(1)),NAME,SLASH(2),MATRIX(1,SLASH(2))     READNUM   310
      GO TO 377                                                          READNUM   311
  384 PRINT(DSP,397)AND(NAME,AM(1)),NAME,SLASH(1),MATRIX(1,SLASH(1))     READNUM   312
      GO TO 377                                                          READNUM   313
  385 J=1                                                                READNUM   314
      PRINT(DSP,394)AND(NAME,AM(1)),NAME,J                               READNUM   315
      PRINT(DSP,393)(MATRIX(J,JJ),JJ=1,M)                                READNUM   316
      PRINT(DSP,*)                                                       READNUM   317
      GO TO 377                                                          READNUM   318
  386 PRINT(DSP,396)AND(NAME,AM(1)),NAME,SLASH(2)                        READNUM   319
      PRINT(DSP,395)(MATRIX(J,SLASH(2)),J=1,N)                           READNUM   320
      PRINT(DSP,*)                                                       READNUM   321
      GO TO 377                                                          READNUM   322
  387 PRINT(DSP,394)AND(NAME,AM(1)),NAME,SLASH(1)                        READNUM   323
      PRINT(DSP,393)(MATRIX(SLASH(1),J),J=1,M)                           READNUM   324
      PRINT(DSP,*)                                                       READNUM   325
      GO TO 377                                                          READNUM   326
  388 PRINT(DSP,392)AND(NAME,AM(1)),NAME                                 READNUM   327
      DO 389 J=1,N                                                       READNUM   328
  389 PRINT(DSP,391)J,(MATRIX(J,JJ),JJ=1,M)                              READNUM   329
      PRINT(DSP,*)                                                       READNUM   330
      GO TO 377                                                          READNUM   331
  390 FORMAT(5X,A=,"(",I3,",",I3,") = ",G20.14,/)                        READNUM   332
  391 FORMAT(/1X,I3,"}",G15.8,3(2X,G15.8),/,4(2X,G15.8))                 READNUM   333
  392 FORMAT(25X,A=)                                                     READNUM   334
  393 FORMAT(2X,4(3X,G15.8))                                             READNUM   335
  394 FORMAT(5X,A=,", ROW ",I3,/)                                        READNUM   336
  395 FORMAT(5X,G15.8)                                                   READNUM   337
  396 FORMAT(5X,A=,", COLUMN ",I3,/)                                     READNUM   338
  397 FORMAT(5X,A=,"(",I3,") = ",G20.14,/)                               READNUM   339
  398 FORMAT(5X,A=," = ",G20.14,/)                                       READNUM   340
  399 FORMAT(/,30X,A=," SET TO ZERO",//)                                 READNUM   341
```

```
C**********                                                          READNUM   342
C          DECODES INDECIES WITHIN SLASHES                           READNUM   343
C**********                                                          READNUM   344
  400 SLASH(1)=SLASH(2)=0                                           READNUM   345
      I=5                                                           READNUM   346
      K=K+1                                                         READNUM   347
      GO=AND(SHIFT(A(IN(K)+2),-3*I),AM1)                            READNUM   348
      GO TO (410,420,430,440,520,560,300) GO                        READNUM   349
  410 RET=1                                                         READNUM   350
      GO TO 480                                                     READNUM   351
  411 SLASH(1)=NUM                                                  READNUM   352
      IF(IN(K).EQ.1R/) GO TO 440                                    READNUM   353
      K=K+1                                                         READNUM   354
      IF(IN(K).EQ.1R/) GO TO 440                                    READNUM   355
      IF(IN(K).EQ.45 .AND. IN(K-1).NE.46) GO TO 540                 READNUM   356
      IF(IN(K).EQ.45) GO TO 415                                     READNUM   357
      IF(IN(K).EQ.1R$) GO TO 300                                    READNUM   358
      IF(AND(SHIFT(A(IN(K)+2),-3*I),AM1).NE.1) GO TO 540            READNUM   359
      RET=2                                                         READNUM   360
      GO TO 480                                                     READNUM   361
  412 SLASH(2)=NUM                                                  READNUM   362
      K=K-1                                                         READNUM   363
  415 K=K+1                                                         READNUM   364
      IF(IN(K).EQ.1R/) GO TO 440                                    READNUM   365
      IF(IN(K).EQ.1R$) GO TO 300                                    READNUM   366
      GO TO 540                                                     READNUM   367
  420 K=K+1                                                         READNUM   368
      IF(IN(K).EQ.1R/) GO TO 440                                    READNUM   369
      IF(IN(K).NE.46) GO TO 435                                     READNUM   370
  430 K=K+1                                                         READNUM   371
  435 IF(IN(K).EQ.1R$) GO TO 300                                    READNUM   372
      IF(IN(K).EQ.-1) GO TO 560                                     READNUM   373
      IF(AND(SHIFT(A(IN(K)+2),-3*I),AM1).NE.1) GO TO 540            READNUM   374
      RET=2                                                         READNUM   375
      GO TO 480                                                     READNUM   376
```

```
440 IF(LIST) GO TO 375                                                  READNUM  377
    IF(SLASH(1).EQ.0 .AND. SLASH(2).EQ.0) GO TO 460                     READNUM  378
    IF(SLASH(1).EQ.0) GO TO 540                                         READNUM  379
    IF(SLASH(2).EQ.0) GO TO 450                                         READNUM  380
    IF(SLASH(1).GT.N .OR. SLASH(2).GT.M) GO TO 550                      READNUM  381
    IROW=SLASH(1)                                                       READNUM  382
    ICOL=SLASH(2)                                                       READNUM  383
    POINTER=(IROW-1)*M+ICOL                                             READNUM  384
    END=.FALSE.                                                         READNUM  385
445 KK=K+1                                                              READNUM  386
    II=1                                                                READNUM  387
    GO TO 10                                                            READNUM  388
450 IF(SLASH(1).GT.NN) GO TO 550                                        READNUM  389
    POINTER=SLASH(1)                                                    READNUM  390
    IROW=(POINTER-1)/M+1                                                READNUM  391
    ICOL=POINTER-(IROW-1)*M                                             READNUM  392
    END=.FALSE.                                                         READNUM  393
    GO TO 445                                                           READNUM  394
460 IF(N.EQ.1 .AND. M.EQ.1) GO TO 464                                   READNUM  395
    IF(N.EQ.1) GO TO 465                                                READNUM  396
    IF(M.EQ.1) GO TO 467                                                READNUM  397
    PRINT(DSP,499)AND(NAME,AM(1)),NAME,IROW,ICOL                        READNUM  398
462 KK=K+1                                                              READNUM  399
    GO TO 10                                                            READNUM  400
464 PRINT(DSP,497)AND(NAME,AM(1)),NAME                                  READNUM  401
    GO TO 462                                                           READNUM  402
465 PRINT(DSP,498)AND(NAME,AM(1)),NAME,ICOL                             READNUM  403
    GO TO 462                                                           READNUM  404
467 PRINT(DSP,498)AND(NAME,AM(1)),NAME,IROW                             READNUM  405
    GO TO 462                                                           READNUM  406
480 NUMST=K                                                             READNUM  407
485 K=K+1                                                               READNUM  408
    IF(AND(SHIFT(A(IN(K)+2),-3*I),AM1).EQ.1) GO TO 485                  READNUM  409
    IF(IN(K).EQ.1RS) GO TO 300                                          READNUM  410
    IF(IN(K).EQ.-1) GO TO 560                                           READNUM  411
```

```
      IF(IN(K).NE.45 .AND. IN(K).NE.46 .AND. IN(K).NE. 1R/) GO TO 520     READNUM   412
      L=K-1.                                                              READNUM   413
      REWIND 7                                                            READNUM   414
      WRITE(7,99)(IN(J),J=NUMST,L)                                        READNUM   415
      REWIND 7                                                            READNUM   416
      READ(7,*)TEMP                                                       READNUM   417
      IF(TEMP.LT.0.0) GO TO 550                                           READNUM   418
      NUM=IFIX(TEMP)                                                      READNUM   419
      GO TO (411,412) RET                                                 READNUM   420
  497 FORMAT(/,30X,A=," IS A NONDIMENSIONED VARIABLE",/)                  READNUM   421
  498 FORMAT(/,30X,"NEXT ENTRY GOES INTO",/,30X,A=,"(",I3,")"/)           READNUM   422
  499 FORMAT(/,30X,"NEXT ENTRY GOES INTO",/,30X,A=,"(",I3,",",I3,")"/)    READNUM   423
C**********                                                               READNUM   424
C          ERROR PRINTING SECTION                                         READNUM   425
C**********                                                               READNUM   426
  500 LL=KK-1                                                             READNUM   427
      L1=K-KK                                                             READNUM   428
      PRINT(OSP,599)(IN(J),J=1,72)                                        READNUM   429
      PRINT(OSP,596)LL,L1                                                 READNUM   430
      PRINT(OSP,590)                                                      READNUM   431
  505 IF(LL.EQ.0) GO TO 510                                               READNUM   432
      PRINT(OSP,599)(IN(J),J=1,LL),COMMA                                  READNUM   433
      GO TO 515                                                           READNUM   434
  510 PRINT(OSP,*)                                                        READNUM   435
  515 PRINT(OSP,598)KK                                                    READNUM   436
      GO TO 575                                                           READNUM   437
  520 LL=KK-1                                                             READNUM   438
      L=K-1                                                               READNUM   439
      PRINT(OSP,599)(IN(J),J=1,72)                                        READNUM   440
      PRINT(OSP,597)L                                                     READNUM   441
      PRINT(OSP,591)                                                      READNUM   442
      GO TO 505                                                           READNUM   443
  530 LL=KK-1                                                             READNUM   444
      L1=K-KK                                                             READNUM   445
      PRINT(OSP,599)(IN(J),J=1,72)                                        READNUM   446
```

```
      PRINT(OSP,596)LL,L1                                                    READNUM   447
      PRINT(OSP,592)                                                         READNUM   448
      GO TO 505                                                              READNUM   449
  540 LL=KK-1                                                                READNUM   450
      L1=K-KK                                                                READNUM   451
      PRINT(OSP,599)(IN(J),J=1,72)                                           READNUM   452
      PRINT(OSP,596)LL,L1                                                    READNUM   453
      PRINT(OSP,593)                                                         READNUM   454
      GO TO 505                                                              READNUM   455
  550 LL=KK-1                                                                READNUM   456
      L1=K-KK                                                                READNUM   457
      PRINT(OSP,599)(IN(J),J=1,72)                                           READNUM   458
      PRINT(OSP,596)LL,L1                                                    READNUM   459
      PRINT(OSP,594)                                                         READNUM   460
      GO TO 505                                                              READNUM   461
  560 LL=KK-1                                                                READNUM   462
      L1=K-KK                                                                READNUM   463
      PRINT(OSP,599)(IN(J),J=1,72)                                           READNUM   464
      PRINT(OSP,596)LL,L1                                                    READNUM   465
      PRINT(OSP,595)                                                         READNUM   466
      PRINT(OSP,599)(IN(J),J=1,LL),COMMA                                     READNUM   467
      PRINT(OSP,*)                                                           READNUM   468
  575 INUNIT=5                                                               READNUM   469
      IF(BATCH) RETURN ABORT                                                 READNUM   470
      LIST=.FALSE.                                                           READNUM   471
      II=1                                                                   READNUM   472
      GO TO 2                                                                READNUM   473
  590 FORMAT(/,30X,"ILL FORMATED NUMBER--PLEASE RETYPE FROM:",//)            READNUM   474
  591 FORMAT(/,30X,"ILLEGAL CHARACTER--PLEASE RETYPE FROM:",//)              READNUM   475
  592 FORMAT(/,30X,"COMMAND UNRECOGNIZED--PLEASE RETYPE FROM:",//)           READNUM   476
  593 FORMAT(/,30X,"FORMAT ERROR--PLEASE RETYPE FROM:",//)                   READNUM   477
  594 FORMAT(/,30X,"INDICE OUT OF RANGE--PLEASE RETYPE FROM:",//)            READNUM   478
  595 FORMAT(/,30X,"MORE THAN 72 CHARACTERS--RETYPE ALL AFTER:",//)          READNUM   479
  596 FORMAT(1X,=X,=("^"))                                                   READNUM   480
  597 FORMAT(1X,=X,"^")                                                      READNUM   481
```

```
  598 FORMAT("+",=X)                                                    READONUM   482
  599 FORMAT(1X,72R1)                                                   READONUM   483
C**********                                                             READONUM   484
C          TERMINATION OF READNUM OPERATION                             READONUM   485
C**********                                                             READONUM   486
  600 IF(END) GO TO 650                                                 READONUM   487
      GO TO 2                                                           READONUM   488
  650 IF(REAL) RETURN                                                   READONUM   489
      DO 660 J=1,N                                                      READONUM   490
      DO 660 JJ=1,M                                                     READONUM   491
      IF(ABS(MATRIX(J,JJ)).GT.1E14) GO TO 670                           READONUM   492
  660 CONTINUE                                                          READONUM   493
      CALL SUBINT(MATRIX,MATRIX,N,M,ND)                                 READONUM   494
      RETURN                                                            READONUM   495
  670 PRINT(DSP,699)AND(NAME,AM(1)),NAME,J,JJ,MATRIX(J,JJ)              READONUM   496
      IROW=J                                                            READONUM   497
      ICOL=JJ                                                           READONUM   498
      POINTER=(IROW-1)*M+ICOL                                           READONUM   499
      GO TO 575                                                         READONUM   500
  699 FORMAT(30X,A=," IS INTEGER MODE:",/,30X,"ELEMENT(",I3,",",I3,     READONUM   501
     ^") = ",G16.10,/,30X,"IS TOO LARGE--PLEASE REENTER",/)             READONUM   502
C**********                                                             READONUM   503
C          GLITCH IN PROGRAM                                            READONUM   504
C**********                                                             READONUM   505
  700 PRINT(DSP,799)                                                    READONUM   506
      RETURN ABORT                                                      READONUM   507
  799 FORMAT(72("*"),/,3X,"PROGRAM IMPROPERLY LOADED--TERMINATE AND RELO READONUM   508
     ^AD",/,72("*"))                                                    READONUM   509
      END                                                               READONUM   510
```

```
      SUBROUTINE SUBINT(DAT,IDAT,N,M,ND)                    READNUM   511
      DIMENSION DAT(ND,M),IDAT(ND,M)                        READNUM   512
      DO 10 J=1,N                                           READNUM   513
      DO 10 JJ=1,M                                          READNUM   514
      IDAT(J,JJ)=IFIX(DAT(J,JJ))                            READNUM   515
   10 CONTINUE                                              READNUM   516
      RETURN                                                READNUM   517
      ENTRY SUBREL                                          READNUM   518
      DO 20 J=1,N                                           READNUM   519
      DO 20 JJ=1,M                                          READNUM   520
   20 DAT(J,JJ)=FLOAT(IDAT(J,JJ))                           READNUM   521
      RETURN                                                READNUM   522
      END                                                   READNUM   523
```

```
      SUBROUTINE READCOM(COM,NUM)                                    READCOM     2
      INTEGER COM(NUM),IN(80),GO,ANS,DSP,AM(10),DUP                  READCOM    67
      COMMON/CONTROL/DSP,BATCH                                       READCOM    68
      COMMON/LISTING/NL,LIST(1)                                      READCOM    69
      LOGICAL COMMA,BATCH                                            READCOM    70
      DATA AM/77B,7777B,777777B,77777777B,7777777777B,               READCOM    71
     ^777777777777B,777777777777777B,77777777777777777B,            READCOM    72
     ^7777777777777777777B,77777777777777777777B/                    READCOM    73
    5 DO 10 I=1,NUM                                                  READCOM    74
   10 COM(I)=0                                                       READCOM    75
      J=0                                                            READCOM    76
      COMMA=.FALSE.                                                  READCOM    77
   20 READ 90,(IN(K),K=1,80)                                         READCOM    78
      KK=1                                                           READCOM    79
      GO=0                                                           READCOM    80
      DO 40 K=1,80                                                   READCOM    81
      IF(IN(K).EQ.1R$) GO TO 88                                      READCOM    82
      IF(IN(K).EQ.1R,) GO=1                                          READCOM    83
      IF(IN(K).EQ.1R ) GO=2                                          READCOM    84
      IF(IN(K).EQ.1R/) GO=3                                          READCOM    85
      IF(GO.EQ.0) GO TO 40                                           READCOM    86
      LL=K-KK                                                        READCOM    87
      IF(LL.GT.9) GO TO 50                                           READCOM    88
      IF(LL.EQ.0.AND.GO.EQ.3) COMMA=.FALSE.                          READCOM    89
      IF(LL.EQ.0) GO TO 35                                           READCOM    90
      IF(GO.NE.2) GO TO 25                                           READCOM    91
      IF(IN(K+1).NE.1R ) GO TO 36                                    READCOM    92
   25 J=J+1                                                          READCOM    93
      IF(J.GT.NUM) GO TO 55                                          READCOM    94
      COM(J)=0                                                       READCOM    95
      DO 30 L=1,LL                                                   READCOM    96
   30 COM(J)=OR(SHIFT(COM(J),6),IN(KK+L-1))                          READCOM    97
      IF(COM(J).NE.3R***) GO TO 31                                   READCOM    98
      J=J-1                                                          READCOM    99
      GO TO 20                                                       READCOM   100
```

```
   31 CONTINUE                                                          READCOM   101
      DUP=0                                                             READCOM   102
      DO 32 I=1,NL                                                      READCOM   103
      IF(COM(J).NE.AND(SHIFT(LIST(I),LL*6),AM(LL))) GO TO 32            READCOM   104
      DUP=DUP+1                                                         READCOM   105
      IF(DUP.GT.1) GO TO 60                                             READCOM   106
      ICOM=I                                                            READCOM   107
   32 CONTINUE                                                          READCOM   108
      IF(DUP.EQ.0) GO TO 65                                             READCOM   109
      COM(J)=ICOM                                                       READCOM   110
      IF(COMMA) COM(J)=-ICOM                                            READCOM   111
      COMMA=.FALSE.                                                     READCOM   112
      IF(GO.EQ.1) COMMA=.TRUE.                                          READCOM   113
   35 KK=K+1                                                            READCOM   114
   36 GO=0                                                              READCOM   115
   40 CONTINUE                                                          READCOM   116
      IF(KK.NE.81) GO TO 70                                             READCOM   117
      NUM=J                                                             READCOM   118
      RETURN                                                            READCOM   119
C*****ERROR  MORE THAN 9 CHARACTERS IN COMMAND NAME***                  READCOM   120
   50 K=KK+9                                                            READCOM   121
      PRINT(DSP,98)(IN(L),L=KK,K)                                       READCOM   122
      GO TO 75                                                          READCOM   123
C*****ERROR  TOO MANY COMMAND NAMES ENTERED**                           READCOM   124
   55 K=K-1                                                             READCOM   125
      PRINT(DSP,97)NUM,LL,(IN(L),L=KK,K)                                READCOM   126
   56 PRINT(DSP,96)                                                     READCOM   127
      IF(BATCH) GO TO 88                                                READCOM   128
      READ(5,99)ANS                                                     READCOM   129
      IF(ANS.EQ.1RY) RETURN                                             READCOM   130
      IF(ANS.EQ.1R$) GO TO 88                                           READCOM   131
      IF(ANS.NE.1RN) GO TO 56                                           READCOM   132
      PRINT(DSP,95)                                                     READCOM   133
      GO TO 5                                                           READCOM   134
C*****ERROR  NON UNIQUE ABBREVIATION USED**                             READCOM   135
```

```
   60 J=J-1                                                                  READCOM   136
      K=K-1                                                                  READCOM   137
      PRINT(DSP,94)LL,(IN(L),L=KK,K),AND(LIST(ICOM),AM(1)),LIST(ICOM),       READCOM   138
     1  AND(LIST(I),AM(1)),LIST(I)                                           READCOM   139
      GO TO 75                                                               READCOM   140
C*****ERPOR  COMMAND NAME UNRECOGNIZED**                                     READCOM   141
   65 J=J-1                                                                  READCOM   142
      K=K-1                                                                  READCOM   143
      PRINT(DSP,93)LL,(IN(L),L=KK,K)                                         READCOM   144
      GO TO 75                                                               READCOM   145
C*****ERPOR  INCOMPLETE COMMAND DUE INPUT CHARACTER COUNT LIMITATION**       READCOM   146
   70 PRINT(DSP,92)                                                          READCOM   147
   75 IF(J.EQ.0) GO TO 80                                                    READCOM   148
      ICOM=IABS(COM(J))                                                      READCOM   149
      PRINT(DSP,91)AND(LIST(ICOM),AM(1)),LIST(ICOM)                          READCOM   150
      GO TO 85                                                               READCOM   151
   80 PRINT(DSP,95)                                                          READCOM   152
   85 IF(BATCH) GO TO 88                                                     READCOM   153
      GO TO 20                                                               READCOM   154
C*****ABORT DUE TO $ OR ERROR IN BATCH MODE**                                READCOM   155
   88 NUM=COM(1)=0                                                           READCOM   156
      RETURN                                                                 READCOM   157
   91 FORMAT(/5X,"PLEASE RETYPE ALL AFTER -  ",A=,/)                         READCOM   158
   92 FORMAT(/10X,"COMMAND TRUNCATED DUE TO CHARACTER COUNT.")               READCOM   159
   93 FORMAT(/1X,=R1,"  - IS AN INVALID COMMAND.")                           READCOM   160
   94 FORMAT(/1X,=R1,"  IS A NON UNIQUE ABBREVIATION (",A=,                  READCOM   161
     1  " OR ",A=,"???).")                                                   READCOM   162
   95 FORMAT(/5X,"PLEASE REENTER COMMAND >>")                                READCOM   163
   96 FORMAT(20X,"TYPE   YES -- TO PROCESS CURRENT COMMANDS",/,              READCOM   164
     1  27X,"NO -- TO REENTER ALL COMMANDS     >>")                          READCOM   165
   97 FORMAT(/10X,"MORE THAN ",I2," COMMANDS ENTERED;  ",=R1,                READCOM   166
     1  " AND ALL AFTER",/,10X,"WILL BE IGNORED.")                           READCOM   167
   98 FORMAT(/1X,10R1,"...  IS ILLEGAL (MORE THAN 9 CHARACTERS).")           READCOM   168
   99 FORMAT(80R1)                                                           READCOM   169
      END                                                                    READCOM   170
```

```
      SUBROUTINE PRINTR(NA,NAM,VAR,N,M,ND)                              PRINT      2
      COMMON/LISTOUT/NL,LISTO(1)                                        PRINT      3
      COMMON/TITLE/ITITLE(5)                                            PRINT      4
      COMMON/CONTROL/DSP                                                PRINT      5
      INTEGER DSP                                                       PRINT      6
      NI=1RE                                                            PRINT      7
      GO TO 10                                                          PRINT      8
      ENTRY PRINTI                                                      PRINT      9
      NI=1RI                                                            PRINT     10
   10 IND=3                                                             PRINT     11
      IF(NA.LE.0 .OR. NA.GT.NL) GO TO 15                                PRINT     12
      IND=LISTO(NA)                                                     PRINT     13
      IF(IND.EQ.1) GO TO 38                                             PRINT     14
   15 NAME=NAM                                                          PRINT     15
      DO 20 I=1,5                                                       PRINT     16
      IF(ITITLE(I).NE.1H ) GO TO 25                                     PRINT     17
   20 CONTINUE                                                          PRINT     18
      GO TO 30                                                          PRINT     19
   25 NAME=10H          A                                               PRINT     20
   30 NR=1                                                              PRINT     21
      NDST=6                                                            PRINT     22
      IF(IND.EQ.2) NDST=DSP                                             PRINT     23
      IF(IND.EQ.3) NR=2                                                 PRINT     24
      DO 35 J=1,NR                                                      PRINT     25
      PRINT(NDST,50)ITITLE                                              PRINT     26
      CALL LISTER(NAME,VAR,N,M,ND,NI,NDST)                              PRINT     27
   35 NDST=DSP                                                          PRINT     28
   38 DO 40 I=1,5                                                       PRINT     29
   40 ITITLE(I)=1H                                                      PRINT     30
      RETURN                                                            PRINT     31
   50 FORMAT("N",5X,5A10)                                               PRINT     32
      END                                                               PRINT     33
```

```
      SUBROUTINE LISTER(NAME,VAR,N,M,ND,FOR,DST)                        LISTER     2
      COMMON/FORMS/NDREP,NDFW,NDNSD,NOREP,NOFW,NONSD                    LISTER     3
      COMMON/CONTROL/DSP                                                LISTER     4
      INTEGER DST,DSP                                                   LISTER     5
      DIMENSION VAR(ND,M)                                               LISTER     6
      NUM=NOREP                                                         LISTER     7
      IFW1=NOFW                                                         LISTER     8
      NSD1=NONSD                                                        LISTER     9
      IF(DST.NE.DSP) GO TO 10                                           LISTER    10
      NUM=NDREP                                                         LISTER    11
      IFW1=NDFW                                                         LISTER    12
      NSD1=NDNSD                                                        LISTER    13
   10 CONTINUE                                                          LISTER    14
      IF(M.EQ.1 .AND. N.EQ.1) GO TO 100                                 LISTER    15
      IF(M.EQ.1) GO TO 200                                              LISTER    16
      IF(N.EQ.1) GO TO 300                                              LISTER    17
      GO TO 400                                                         LISTER    18
  100 PRINT(DST,110)AND(NAME,778),NAME,FOR,IFW1,NSD1,VAR(N,M)           LISTER    19
      GO TO 500                                                         LISTER    20
  110 FORMAT(1P,/,10X,A=," = ",V=.=,/)                                  LISTER    21
  200 PRINT(DST,210)AND(NAME,778),NAME                                  LISTER    22
      PRINT(DST,211)((FOR,IFW1,NSD1,VAR(J,1)),J=1,N)                    LISTER    23
      GO TO 500                                                         LISTER    24
  210 FORMAT(1P,/,10X,A=,/)                                             LISTER    25
  211 FORMAT(1P,6X,V=.=)                                                LISTER    26
  300 PRINT(DST,310)AND(NAME,778),NAME                                  LISTER    27
      MM=M                                                              LISTER    28
      IF(M.GT.NUM) MM=NUM                                               LISTER    29
      PRINT(DST,311)NUM,((FOR,IFW1,NSD1,VAR(1,J)),J=1,MM)               LISTER    30
      IF(M.GT.NUM) GO TO 406                                            LISTER    31
      GO TO 500                                                         LISTER    32
  310 FORMAT(1P,/,10X,A=,/)                                             LISTER    33
  311 FORMAT(1P,4X,=(1X,V=.=))                                          LISTER    34
  400 PRINT(DST,410)AND(NAME,778),NAME                                  LISTER    35
      MM=M                                                              LISTER    36
```

```
      IF(M.GT.NUM) MM=NUM                                                LISTER    37
      DO 405 J=1,N                                                       LISTER    38
  405 PRINT(DST,411)J,FOR,IFW1,NSD1,VAR(J,1),NUM-1,                      LISTER    39
     1   ((FOR,IFW1,NSD1,VAR(J,K)),K=2,MM)                               LISTER    40
      IF(M.LE.NUM) GO TO 500                                             LISTER    41
  406 MST=NUM+1                                                          LISTER    42
  407 MM=M-MST+1                                                         LISTER    43
      IF(MM.GT.NUM) MM=NUM                                               LISTER    44
      MEND=MST+MM-1                                                      LISTER    45
      PRINT(DST,*)                                                       LISTER    46
      PRINT(DST,*)                                                       LISTER    47
      DO 408 J=1,N                                                       LISTER    48
  408 PRINT(DST,412)NUM,((FOR,IFW1,NSD1,VAR(J,K)),K=MST,MEND)            LISTER    49
      IF(MEND.EQ.M) GO TO 500                                            LISTER    50
      MST=MEND+1                                                         LISTER    51
      GO TO 407                                                          LISTER    52
  410 FORMAT(1P,/,10X,A=,/)                                              LISTER    53
  411 FORMAT(1F,1X,I3,"}   ",V=.=,=(1X,V=.=))                            LISTER    54
  412 FORMAT(1P,3X,=(1X,V=.=))                                           LISTER    55
  500 PRINT(DST,510)                                                     LISTER    56
  510 FORMAT(//)                                                         LISTER    57
      RETURN                                                             LISTER    58
      END                                                                LISTER    59
```

```
      SUBROUTINE OPEN(NS),RETURNS(ABORT)                                OPEN      2
      COMMON/LISTING/NL,LIST(75,7)                                      OPEN      3
      COMMON/LISTOUT/NO,LISTO(1)                                        OPEN      4
      COMMON/RVAR/NTOT,TOT(1)                                           OPEN      5
      COMMON/IVAR/NITOT,ITOT(1)                                         OPEN      6
      INTEGER DIM(2)                                                    OPEN      7
      IF(LIST(NS,1).EQ.10HDIMENSIONI) PRINT(8,10)                       OPEN      8
   10 FORMAT(/,5X,"PLANT DIMENSIONS (N,M,NCC,NDD) IS OPEN",/)           OPEN      9
      IF(LIST(NS,6).NE.1 .OR. LIST(NS,7).NE.1) GO TO 25                 OPEN     10
      ENTRY FEOPEN                                                      OPEN     11
      IF(LIST(NS,2).EQ.3HREL) GO TO 50                                  OPEN     12
      GO TO 75                                                          OPEN     13
   25 PRINT(8,199)AND(LIST(NS,1),77B),LIST(NS,1),LIST(NS,6),LIST(NS,7)  OPEN     14
      DIM(1)=LIST(NS,4)                                                 OPEN     15
      DIM(2)=LIST(NS,5)                                                 OPEN     16
      CALL READNUM(10HDIMENSIONI,DIM,1,2,1,.FALSE.),RETURNS(40)         OPEN     17
      LIST(NS,4)=DIM(1)                                                 OPEN     18
      LIST(NS,5)=DIM(2)                                                 OPEN     19
      IF(LIST(NS,4).GT.LIST(NS,6) .OR. LIST(NS,5).GT.LIST(NS,7)         OPEN     20
     1   .OR. LIST(NS,4).LT.1 .OR. LIST(NS,5).LT.1) GO TO 25            OPEN     21
      IF(LIST(NS,2).EQ.3HREL) GO TO 50                                  OPEN     22
      GO TO 75                                                          OPEN     23
   40 RETURN ABORT                                                      OPEN     24
   50 CALL READNUM(LIST(NS,1),TOT(LIST(NS,3)),LIST(NS,4),LIST(NS,5),    OPEN     25
     1   LIST(NS,6),.TRUE.),RETURNS(40)                                 OPEN     26
      RETURN                                                            OPEN     27
   75 CALL READNUM(LIST(NS,1),ITOT(LIST(NS,3)),LIST(NS,4),LIST(NS,5),   OPEN     28
     1   LIST(NS,6),.FALSE.),RETURNS(40)                                OPEN     29
      RETURN                                                            OPEN     30
  199 FORMAT(/,5X,"ENTER DESIRED DIMENSIONS OF ",A=,", MAX ALLOWED IS ("OPEN     31
     1,I3,",",I3,").",/)                                              OPEN     32
      END                                                               OPEN     33
```

```
      SUBROUTINE FORMOUT                                                FORMOUT    2
      COMMON/CONTROL/DSP,BATCH                                          FORMOUT    3
      LOGICAL BATCH,STP                                                 FORMOUT    4
      INTEGER A(61,15)                                                  FORMOUT    5
      REWIND 6                                                          FORMOUT    6
      STP=.FALSE.                                                       FORMOUT    7
      ICOUNT=0                                                          FORMOUT    8
      K=1                                                               FORMOUT    9
      READ(6,10)(A(K,I),I=1,15)                                         FORMOUT   10
      K=K+1                                                             FORMOUT   11
    5 READ(6,10)(A(K,I),I=1,15)                                         FORMOUT   12
   10 FORMAT(1R1,13A10,1R1)                                             FORMOUT   13
      IF(EOF(6).NE.0.0) GO TO 50                                        FORMOUT   14
      IF(A(K,1).EQ.1RN .OR. A(K,1).EQ.1R1) GO TO 20                     FORMOUT   15
      IF(K.EQ.61) GO TO 20                                              FORMOUT   16
      K=K+1                                                             FORMOUT   17
      GO TO 5                                                           FORMOUT   18
   20 K=K-1                                                             FORMOUT   19
      IF(ICOUNT+K.GT.59) A(1,1)=1R1                                     FORMOUT   20
      IF(A(1,1).EQ.1R1)ICOUNT=0                                         FORMOUT   21
      DO 30 I=1,K                                                       FORMOUT   22
   30 PRINT(99,10)(A(I,J),J=1,15)                                       FORMOUT   23
      DO 40 I=1,15                                                      FORMOUT   24
   40 A(1,I)=A(K+1,I)                                                   FORMOUT   25
      ICOUNT=ICOUNT+K                                                   FORMOUT   26
      K=2                                                               FORMOUT   27
      IF(STP) GO TO 55                                                  FORMOUT   28
      GO TO 5                                                           FORMOUT   29
   50 STP=.TRUE.                                                        FORMOUT   30
      GO TO 20                                                          FORMOUT   31
   55 CALL CONNEC(6LOUTPUT)                                             FORMOUT   32
      IF(.NOT.BATCH) STOP                                               FORMOUT   33
      REWIND 99                                                         FORMOUT   34
      REWIND 6                                                          FORMOUT   35
  100 READ(99,10)(A(1,I),I=1,15)                                        FORMOUT   36
```

```
      PRINT (6,18)(A(1,I),I=1,15)                                       FORMOUT    37
      IF(EOF(99).NE.0.0) STOP                                           FORMOUT    38
      GO TO 100                                                         FORMOUT    39
      END                                                               FORMOUT    40
```

```
          IDENT   RETURN                                          RETURN      2
          ENTRY   RETURN                                          RETURN      3
          EXT     SYS=                                            RETURN      4
RETURN    BSS?    1                                               RETURN      5
          SB1     1                                               RETURN      6
          MX4     42                                              RETURN      7
          SA?     X1                                              RETURN      8
          SA?     2                                               RETURN      9
LOOP2     ZR      X3,RETURN                                       RETURN     10
          BX5     X3*X4                                           RETURN     11
          BX5     X2-X5                                           RETURN     12
          ZR      X5,GOTIT                                        RETURN     13
          SA?     A3+B1                                           RETURN     14
          EQ      LOOP2                                           RETURN     15
GOTIT     BX3     -X4*X3                                          RETURN     16
          SA3     X3+2                                            RETURN     17
          SA4     UNLOAD                                          RETURN     18
          BX6     X3+X4                                           RETURN     19
          SA6     A3                                              RETURN     20
          EQ      RETURN                                          RETURN     21
UNLOAD    VFD     28/0,2/3,30/0                                   RETURN     22
          END                                                     RETURN     23
```

```
      SUBROUTINE ADDMAT(A,NAD,N,M,B,NBD,C,NCD)                    MATRIX     2
      DIMENSION A(NAD,M),B(NBD,M),C(NCD,M)                        MATRIX     3
      LOGICAL SUB                                                 MATRIX     4
      SUB=.FALSE.                                                 MATRIX     5
    5 DO 10 J=1,M                                                 MATRIX     6
      DO 10 I=1,N                                                 MATRIX     7
      A(I,J)=B(I,J)+C(I,J)                                        MATRIX     8
      IF(SUB) A(I,J)=B(I,J)-C(I,J)                                MATRIX     9
   10 CONTINUE                                                    MATRIX    10
      RETURN                                                      MATRIX    11
      ENTRY SUBMAT                                                MATRIX    12
      SUB=.TRUE.                                                  MATRIX    13
      GO TO 5                                                     MATRIX    14
      END                                                         MATRIX    15
```

```
      SUBROUTINE TRANPOS(A,NAD,N,M,B,NBD)                    MATRIX     16
      DIMENSION A(NAD,M),B(NBD,N)                            MATRIX     17
      LOGICAL KEY                                            MATRIX     18
      KEY=.FALSE.                                            MATRIX     19
    5 DO 10 J=1,M                                            MATRIX     20
      DO 10 I=1,N                                            MATRIX     21
      A(I,J)=B(J,I)                                          MATRIX     22
      IF(KEY) A(I,J)=B(I,J)                                  MATRIX     23
   10 CONTINUE                                               MATRIX     24
      RETURN                                                 MATRIX     25
      ENTRY COPYAB                                           MATRIX     26
      KEY=.TRUE.                                             MATRIX     27
      GO TO 5                                                MATRIX     28
      END                                                    MATRIX     29
```

```
      SUBROUTINE PRESET(A,NAD,N,M,PRE)                          MATRIX     30
      DIMENSION A(NAD,M)                                        MATRIX     31
      LOGICAL IDT                                               MATRIX     32
      IDT=.FALSE.                                               MATRIX     33
    5 DO 10 J=1,M                                               MATRIX     34
      DO 10 I=1,N                                               MATRIX     35
      A(I,J)=PRE                                                MATRIX     36
      IF(IDT) A(J,J)=1.0                                        MATRIX     37
   10 CONTINUE                                                  MATRIX     38
      RETURN                                                    MATRIX     39
      ENTRY IDENT                                               MATRIX     40
      IDT=.TRUE.                                                MATRIX     41
      IF(M.EQ.0) M=N                                            MATRIX     42
      PRE=0.0                                                   MATRIX     43
      GO TO 5                                                   MATRIX     44
      END                                                       MATRIX     45
```

```
      SUBROUTINE MATRIX1(A,NAD,N,M,B,NBD,N1,C,NCD,N2,D,NDD)          MATRIX     46
      DIMENSION A(NAD,M),B(NBD,N1),C(NCD,N2),D(NDD,M)                MATRIX     47
      LOGICAL KEY                                                    MATRIX     48
      ENTRY MAT3MPY                                                  MATRIX     49
      KEY=.FALSE.                                                    MATRIX     50
      DO 5 J=1,M                                                     MATRIX     51
      DO 5 I=1,N                                                     MATRIX     52
    5 A(I,J)=0.0                                                     MATRIX     53
    6 DO 20 I=1,N                                                    MATRIX     54
      DO 20 K=1,N2                                                   MATRIX     55
      TEMP=0.0                                                       MATRIX     56
      DO 10 J=1,N1                                                   MATRIX     57
   10 TEMP=TEMP+B(I,J)*C(J,K)                                        MATRIX     58
      IF(KEY) A(I,K)=TEMP                                            MATRIX     59
      IF(KEY) GO TO 19                                               MATRIX     60
      DO 15 L=1,M                                                    MATRIX     61
   15 A(I,L)=A(I,L)+TEMP*D(K,L)                                      MATRIX     62
   19 CONTINUE                                                       MATRIX     63
   20 CONTINUE                                                       MATRIX     64
      RETURN                                                         MATRIX     65
      ENTRY MAT2MPY                                                  MATRIX     66
      KEY=.TRUE.                                                     MATRIX     67
      IF(N2.EQ.0) N2=M                                               MATRIX     68
      GO TO 6                                                        MATRIX     69
      END                                                            MATRIX     70
```

```
      SUBROUTINE INVERT(A,NAD,B,NBD,N,IFAIL)                    MATRIX     71
      DIMENSION A(NAD,N),B(NBD,N)                               MATRIX     72
      COMMON/CONTROL/DSP                                        MATRIX     73
      LOGICAL IFAIL                                             MATRIX     74
      INTEGER DSP                                               MATRIX     75
      CALL IDENT(A,NAD,N)                                       MATRIX     76
   35 K=0                                                       MATRIX     77
      TEMP=0.0                                                  MATRIX     78
      DO 40 I=J,N                                               MATRIX     79
      IF(TEMP.GT.ABS(B(I,J))) GO TO 40                          MATRIX     80
      TEMP=ABS(B(I,J))                                          MATRIX     81
      K=I                                                       MATRIX     82
   40 CONTINUE                                                  MATRIX     83
      IF(TEMP.EQ.0.0) GO TO 90                                  MATRIX     84
      IF(K.EQ.J) GO TO 50                                       MATRIX     85
      DO 45 I=1,N                                               MATRIX     86
      TEMP=B(K,I)                                               MATRIX     87
      B(K,I)=B(J,I)                                             MATRIX     88
      B(J,I)=TEMP                                               MATRIX     89
      TEMP=A(K,I)                                               MATRIX     90
      A(K,I)=A(J,I)                                             MATRIX     91
   45 A(J,I)=TEMP                                               MATRIX     92
   50 IF(B(J,J).EQ.1.0) GO TO 60                                MATRIX     93
      TEMP=B(J,J)                                               MATRIX     94
      DO 55 I=1,N                                               MATRIX     95
      B(J,I)=B(J,I)/TEMP                                        MATRIX     96
   55 A(J,I)=A(J,I)/TEMP                                        MATRIX     97
   60 DO 70 I=1,N                                               MATRIX     98
      IF(I.EQ.J) GO TO 70                                       MATRIX     99
      IF(B(I,J).EQ.0.0) GO TO 70                                MATRIX    100
      TEMP=B(I,J)                                               MATRIX    101
      DO 65 K=1,N                                               MATRIX    102
      B(I,K)=B(I,K)-TEMP*B(J,K)                                 MATRIX    103
   65 A(I,K)=A(I,K)-TEMP*A(J,K)                                 MATRIX    104
   70 CONTINUE                                                  MATRIX    105
```

```
      J=J+1                                                          MATRIX    106
      IF(J.LE.N) GO TO 35                                            MATRIX    107
      IFAIL=.FALSE.                                                  MATRIX    108
      RETURN                                                         MATRIX    109
   90 IFAIL=.TRUE.                                                   MATRIX    110
      PRINT(ISP,*)"  SUBROUTINE INVERT -- MATRIX IS SINGULAR"        MATRIX    111
      RETURN                                                         MATRIX    112
      END                                                            MATRIX    113
```

Appendix B

INTERAC User's Guide

INTERAC is an interactive software package for synthesizing a discrete state-variable feedback gain matrix to control a multi-input, multi-output continuous plant described by Eq (1).

$$\dot{\underline{x}}(t) = \underline{A}\,\underline{x}(t) + \underline{B}\,\underline{u}(t) + \underline{R}\,\underline{d}(t)$$
$$\underline{y}(t) = \underline{C}\,\underline{x}(t) \qquad (1)$$

where $\underline{A}$ is an N by N state matrix,
$\underline{B}$ is an N by M control matrix,
$\underline{R}$ is an N by NDD disturbance matrix, and
$\underline{C}$ is an (NCC or NDD) by N output matrix.

and $y(t)$ defines the NDD outputs that are to reject disturbances or the NCC outputs that are to track input commands.

Three types of problems can be examined: (1) the regulator problem, (2) the disturbance rejector problem, and (3) the tracking problem. The computer input of the problem type and the plant description matrices can be accomplished directly by the user or in response to requests from the computer. 23 alphanumeric options are used in response to the prompt "COMMAND >>" to control data input, data output, and program sequence control.

Commands

To execute the program for the first time, type FORTRAC. All further input data will be requested by the computer. To terminate the program type STOP in response to the prompt "COMMAND >>".

For the do-it-yourself user the following commands are available for complete input,output, and program sequence control.

(1) ENTER [, parameters] This command allows the user to specify the dimensions of a matrix and then to enter the values for the matrix elements. The parameters are variable names and their use is optional. If the variable names are not included they will be requested by the computer. The legal variable names are described under options 16 through 21.

(2) STOP This command terminates the program and prints a termination message informing the user of the contents of the files ANSWER and DATA that are left by the program.

(3) END This command has two functions. First in response to the prompt "COMMAND >>", the program is terminated, but the termination message is not printed. END is also used to terminate sub-options such as when the command ENTER is given without a parameter list.

(4) PRINT [, parameters] This command causes the current values of the variables identified in the parameter list to be printed at the terminal and to be written to the file ANSWER. The parameters are optional, and if not used the variable names will be requested by the computer.

(5) DFORMAT This command allows the user to specify the number of significant digits to be used for numbers printed at the terminal.

(6) CHANGE [, parameters] This command allows the user to change the values stored in a variable. The dimensions of matrices cannot be changed with this command. The parameters are variable names and their use is optional. If the parameters are not included the

names will be requested by the computer.

(7) DISPLAY [, parameters] This is a dual function command. With the parameters (variable names), the variables to be printed at the terminal are specified. Without the parameters, the variables already designated to be printed at the terminal are identified and the names are printed. The values of the variables on the display list are printed at the terminal whenever the variable is first encountered or when its value is changed in the control design algorithms.

(8) OUTPUT [, parameters] This command is used the same as DISPLAY, except OUTPUT refers to the variables to be written to the file ANSWER.

(9) DELETE [, parameters] This command deletes the named variables (parameters) from both the display and output lists. If no parameters are given, then all variables are removed from both lists.

(10) OPTIONS This command causes a list of the valid options to be printed at the terminal.

(11) VARIABLES This command causes a list of the legal variable names to be printed at the terminal.

(12) SAVE This command causes the current contents of all variables, all matrix dimensions, and the display/output list to be saved on the file DATA. The date and time of the save is printed, and they can be used to identify the data set when it is reloaded with the command RESTART.

(13) RESTART [, REWIND] This command causes the values saved on the file DATA to be reloaded into memory. The optional parameter REWIND is used to rewind the file before reading from it.

The file DATA is a sequential file, and thus RESTART may have to be used several times to get the desired data set if SAVE was used more than once. The date and time that the data set was saved is printed to identify the set that is reloaded.

(14) REWIND This command can be used by itself to rewind the file DATA or as a parameter for RESTART as shown above.

(15) RUN ,parameter This command causes the control design algorithms to be executed starting with the subroutine named in the parameter and terminating after calculating the closed-loop matrix. The valid parameters are FORTRAC, SAMPLE , AUGMAT, TRANSFORM, CONLAW , and CLOSELOOP. All necessary data is assumed to have been entered and all matrices are assumed properly dimensioned.

(16) FORTRAC This command by itself causes all necessary data to be requested and then all control design algorithms to be executed. When this command is used as a parameter for RUN, all control design algorithms are executed with the data currently in memory.

(17) SAMPLE This command causes the sampled-data system description to be computed from the continuous system description. The variables must be entered prior to issuing this command: AMATRIX - the state matrix, BMATRIX - the control matrix, DIMENSION - the array containing the plant dimensions (N, M, NCC, NDD), RMATRIX - the disturbance matrix only if NDD is non-zero , and TSAMPLE - the desired sampling time interval. Values for the following variables are calculated: CEIGEN - the continuous eigenvalues; MODAL - the modal matrix; INVMODAL - the inverse modal matrix; and the discrete system matrices FMATRIX - the state matrix, GMATRIX - the control

matrix, DRMATRIX - the disturbance matrix if NDD is non-zero, and DEIGN - the z-plane eigenvalues.

(18) AUGMAT This command causes the sampled-data system description to be augmented with discrete integrators for disturbance rejection or tracking problems. These variables must be available in memory prior to issuing this command: FMATRIX, GMATRIX, DRMATRIX - if NDD is non-zero, CMATRIX - the output matrix if NDD or NCC is non-zero, DIMENSION, and INTEGRATE - an array containing the number of integrators desired for each NDD or NCC output. One integrator is used to track or reject a step input, two integrators for a ramp, etc. Values for the following variables are calculated: AFMATRIX- the augmented state matrix, AGMATRIX - the augmented control matrix, AFMATRIX - the augmented input command matrix, ARMATRIX - the augmented disturbance matrix, and ACMATRIX - the augmented output matrix.

(19) TRANSFORM This command causes the AF and AG matrices from the augmented system description to be transformed into the Brunovsky controllable canonical form. AFMATRIX, AGMATRIX, and DIMENSION must be available in memory prior to issuing this command. Values for the following variables are calculated: UREFORM - the upper row echelon form of the matrix [AG AF], APLFORM - the Aplevich form of the matrix [AG AF], BRNFORM - the Brunovsky form of the matrix [AG AF], BFMATRIX and BGMATRIX - the Brunovsky controllable canonical form of AFMATRIX and AGMATRIX respectively, TINVERSE - the inverse transformation matrix, and CINDICES - the controllability indices.

(20) CONLAW This command causes the state-variable feedback

gain matrix K to be calculated for the desired closed-loop eigenvalues. BFMATRIX, BGMATRIX, TINVERSE, DIMENSION, and DESEIGEN - the desired eigenvalues, must be available in memory prior to issuing this command. Values for the following variables are calculated: COFMATRIX - the coefficient matrix which will be the zero matrix unless non-zero desired eigenvalues are entered, and KMATRIX - the feedback gain matrix.

(21) CLOSELOOP This command is used to calculate the closed-loop state matrix and the closed-loop eigenvalues. The variables required in memory prior to issuing this command are: AFMATRIX, AGMATRIX, DIMENSION, and KMATRIX. CLMATRIX - the closed-loop matrix and CLEIGEN - the closed-loop eigenvalues are calculated.

(22) OFORMAT This command allows the user to specify the number of significant digits to be used for numbers written to the file ANSWER.

(23) SETDIMEN This command properly dimensions all matrices after the plant dimensions, in the array DIMENSION, have been entered.

(24) "variable name" When the variable name is typed for a command, the user is allowed to set the dimensions of the variable and to enter or change the values of the elements of the variable.

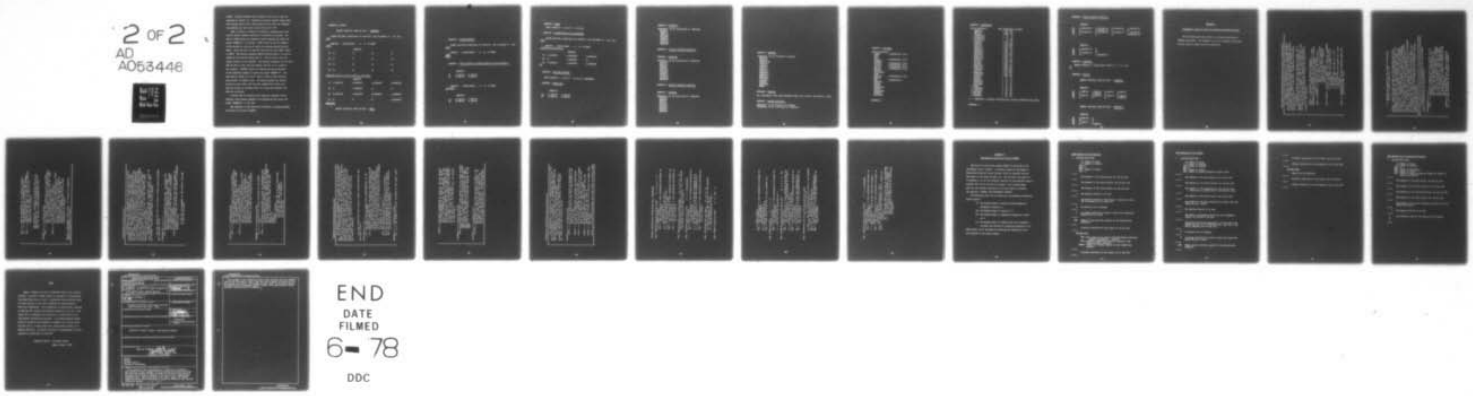
(25) DIMENSION This command opens the array DIMENSION and allows the user to enter N - the number of states, M - the number of controls, and NCC - the number of commands or NDD - the number of disturbances. The elements of DIMENSION are individually addressable by the variable names STATES, CONTROLS, COMMANDS, and DISTURBS.

The above commands are used in response to the prompt "COMMAND >>". If the command has parameters, the parameters must be separated by

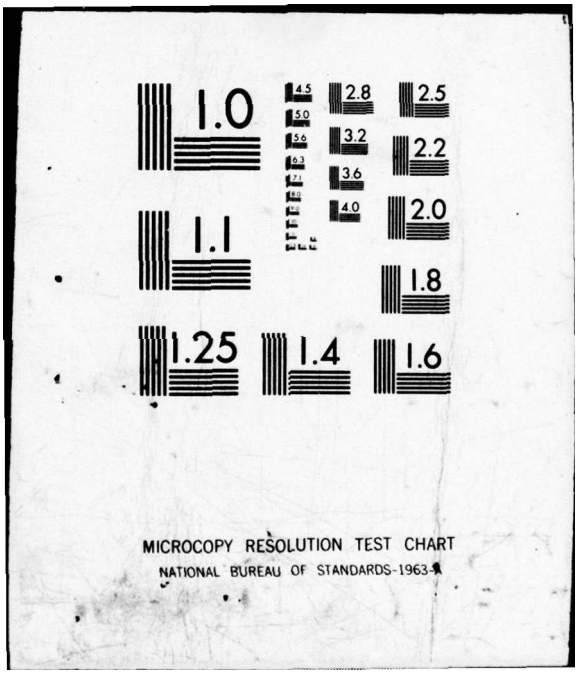
AD-A053 446 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCH--ETC F/G 12/1
INTERAC - AN INTERACTIVE SOFTWARE PACKAGE FOR DIRECT DIGITAL CO--ETC(U)
DEC 77 J A COLGATE

UNCLASSIFIED AFIT/GGC/EE/77D-1 NL

2 OF 2
AD
A053446



END
DATE
FILMED
6-78
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

commas. Multiple commands may be entered on one line if they are separated by slashes (/). Execution of entered commands begins after the carriage return, but to delay execution and enter more commands or parameters,the last entry on the line must be "***".

When a variable is opened for entering or changing data, there are six special commands available to facilitate the process. The first is ABORT which will terminate current commands and return the prompt "COMMAND>>" to the user. ZERO is used to set all elements of the variable to zero and is useful for entering sparse matrices. READ n allows the user to input the data from the file TAPE1, TAPE2, or TAPE3. The optional parameter REWIND following READ n, is used to rewind the file before reading from it. LIST is used to list the current contents of the variable. The optional parameter "/n,m/" after LIST is used to print only one element, one row, or one column of the variable. CONTINUE closes the variable and starts execution of any remaining commands or issues the prompt "COMMAND>>". The last special command is "/n,m/", which is used to reset the data entry pointer to element (n,m). All matrix elements are entered by rows in free format, and this last command can be used to go back and correct an erroneous entry or to skip over elements that need not be entered.

A dollar sign ($) entered at any time will terminate current activity, cause pending commands to be ignored, and will return the prompt "COMMAND>>" to the user.

The remainder of this guide will be devoted to showing examples of the use of the above commands.

```
COMMAND >>ENTER

        ENTER VARIABLE NAME OR END  >>AMATRIX

    ENTER DESIRED DIMENSIONS OF AMATRIX, MAX ALLOWED IS ( 20, 20).
4,4

    AMATRIX   DIMENSIONED (  4,  4) IS OPEN
LIST

                          AMATRIX

  1]  0.              0.              0.              0.

  2]  0.              0.              0.              0.

  3]  0.              0.              0.              0.

  4]  0.              0.              0.              0.

1,2,3,4,/2,2/,1,/3,1/,4,3,2,1,/4,4/,5,L

                          AMATRIX

  1]  1.0000000       2.0000000       3.0000000       4.0000000

  2]  0.              1.0000000       0.              0.

  3]  4.0000000       3.0000000       2.0000000       1.0000000

  4]  0.              0.              0.              5.0000000
CONTINUE

        ENTER VARIABLE NAME OR END  >>END
```

```
COMMAND >>ENTER,AMATRIX

   ENTER DESIRED DIMENSIONS OF AMATRIX, MAX ALLOWED IS ( 20,
2,2

   AMATRIX   DIMENSIONED (  2,  2) IS OPEN
1,2
2,3

COMMAND >>PRINT,AMATRIX/CHANGE,AMATRIX/PRINT,AMATRIX

         AMATRIX

 1]    1.00E+00   2.00E+00
 2]    2.00E+00   3.00E+00

   AMATRIX   DIMENSIONED (  2,  2) IS OPEN
6,7,8,9

         AMATRIX

 1]    6.00E+00   7.00E+00
 2]    8.00E+00   9.00E+00
```

```
COMMAND >>SAVE

  DATA SAVED AT  12/13/77  17.15.37.

COMMAND >>ENTER,AMATRIX/RUN,FORTRAC

  ENTER DESIRED DIMENSIONS OF AMATRIX, MAX ALLOWED IS ( 20, 20).
3,3

  AMATRIX   DIMENSIONED (  3,  3) IS OPEN
1,2,3,0,1,/3,2/,2,L

                        AMATRIX

 1]  1.0000000        2.0000000        3.0000000

 2]  0.               1.0000000        0.

 3]  4.0000000        2.0000000        2.0000000
$

COMMAND >>RESTART,REWIND

  DATA SAVED AT  12/13/77  17.15.37. RELOADED.

COMMAND >>PRINT,AM

        AMATRIX

 1]     6.00E+00   7.00E+00
 2]     8.00E+00   9.00E+00
```

```
COMMAND >>DISPLAY

VARIABLES TO BE DISPLAYED AT TERMINAL
  DEIGEN
  FMATRIX
  GMATRIX
  CLEIGEN
  KMATRIX
  TSAMPLE
  CINDICES
  BRNFORM


COMMAND >>DISPLAY,AMATRIX,BMATRIX


COMMAND >>DISPLAY

VARIABLES TO BE DISPLAYED AT TERMINAL
  AMATRIX
  BMATRIX
  DEIGEN
  FMATRIX
  GMATRIX
  CLEIGEN
  KMATRIX
  TSAMPLE
  CINDICES
  BRNFORM


COMMAND >>DELETE,TSAMPLE,CINDICES


COMMAND >>DISPLAY

VARIABLES TO BE DISPLAYED AT TERMINAL
  AMATRIX
  BMATRIX
  DEIGEN
  FMATRIX
  GMATRIX
  CLEIGEN
  KMATRIX
  BRNFORM
```

```
COMMAND >>OUTPUT

VARIABLES TO BE PRINTED TO ANSWER
  AMATRIX
  BMATRIX
  DIMENSION
  RMATRIX
  CMATRIX
  FMATRIX
  GMATRIX
  AFMATRIX
  AGMATRIX
  AEMATRIX
  ARMATRIX
  ACMATRIX
  CLEIGEN
  KMATRIX
  DESEIGEN
  MODAL


COMMAND >>DELETE

ALL VARIABLES HAVE BEEN REMOVED FROM THE DISPLAY AND OUTPUT LISTS.


COMMAND >>OUTPUT/DISPLAY

VARIABLES TO BE PRINTED TO ANSWER
VARIABLES TO BE DISPLAYED AT TERMINAL
```

```
COMMAND >>OPTIONS

VALID COMMANDS
  ENTER          [,PARAMETER LIST]
  STOP
  END
  PRINT          [,PARAMETER LIST]
  DFORMAT
  CHANGE         [,PARAMETER LIST]
  DISPLAY        [,PARAMETER LIST]
  OUTPUT         [,PARAMETER LIST]
  DELETE         [,PARAMETER LIST]
  OPTIONS
  VARIABLES
  SAVE
  RESTART        [,PARAMETER LIST]
  REWIND
  RUN            ,PARAMETER(S)
  FORTRAC
  SAMPLE
  AUGMAT
  TRANSFORM
  CONLAW
  CLOSELOOP
  DFORMAT
  SETDIMEN

COMMAND >>
```

```
COMMAND >>VARIABLES

VALID VARIABLES          MAX DIMENSION ALLOWED
    AMATRIX                    ( 20, 20)
    BMATRIX                    ( 20, 10)
    DEIGEN                     ( 20,  2)
    DIMENSION                  (  1,  1)
  ◆ COFMATRIX                  (  0,  0)
    INTEGRATE                  (  1, 10)
    RMATRIX                    ( 20,  5)
    CMATRIX                    ( 10, 20)
    FMATRIX                    ( 20, 20)
    GMATRIX                    ( 20, 10)
    DEMATRIX                   ( 20,  5)
    DRMATRIX                   ( 20,  5)
    AFMATRIX                   ( 20, 20)
    AGMATRIX                   ( 20, 10)
    AEMATRIX                   ( 20,  5)
    ARMATRIX                   ( 20,  5)
    ACMATRIX                   ( 10, 20)
    CEIGEN                     ( 20,  2)
    CLEIGEN                    ( 20,  2)
    BFMATRIX                   ( 20, 20)
    BGMATRIX                   ( 20, 10)
    TINVERSE                   ( 20, 20)
    KMATRIX                    ( 10, 20)
    DESEIGEN                   ( 20,  2)
    CLMATRIX                   ( 20, 20)
    TSAMPLE                    (  1,  1)
    STATES                     (  1,  1)
    CONTROLS                   (  1,  1)
    COMMANDS                   (  1,  1)
    DISTURBS                   (  1,  1)
  ◆ MODAL                      (  0,  0)
  ◆ INVMODAL                   (  0,  0)
  ◆ CINDICES                   (  0,  0)
  ◆ UREFORM                    (  0,  0)
  ◆ APLFORM                    (  0,  0)
  ◆ BRNFORM                    (  0,  0)

◆ -- TEMPORARY VARIABLE PRINTED ONLY DURING PROGRAM EXECUTION.

COMMAND >>
```

```
COMMAND >>PRINT,AMATRIX,BMATRIX

        AMATRIX

1]      1.00000E+00    2.00000E+00    3.00000E+00    4.00000E+00
2]      0.             1.00000E+00    0.             0.
3]      4.00000E+00    3.00000E+00    2.00000E+00    1.00000E+00
4]      0.             0.             0.             5.00000E+00


        BMATRIX

1]      3.00000E+00    0.
2]      0.             0.
3]      1.00000E+00    0.
4]      0.             1.00000E+00

COMMAND >>DFORMAT
  ENTER NUMBER OF SIGNIFICANT DIGITS  0 < N < 15.
3

COMMAND >>PRINT

        ENTER VARIABLE NAME OR END  >>AMATRIX

        AMATRIX

1]      1.00E+00    2.00E+00    3.00E+00    4.00E+00
2]      0.          1.00E+00    0.          0.
3]      4.00E+00    3.00E+00    2.00E+00    1.00E+00
4]      0.          0.          0.          5.00E+00

        ENTER VARIABLE NAME OR END  >>BMATRIX

        BMATRIX

1]      3.00E+00    0.
2]      0.          0.
3]      1.00E+00    0.
4]      0.          1.00E+00
```

Appendix C

Programmer's Guide for Using the Specialized INTERAC Software

The following pages give syntax for calling the specialized INTERAC subroutines. All elements in the call statement are defined and any required common blocks are identified.

```
      SUBROUTINE READNUM(NAME,MATRIX,N,M,ND,REAL),RETURNS(ABORT)
C*************************************************************************
C         THE PURPOSE OF THIS SUBROUTINE IS TO ALLOW (NON,SINGLE,
C    OR DOUBLE DIMENSIONED AND REAL OR INTEGER) VARIABLES TO BE
C    FILLED WITH DATA,EXAMINED, AND/OR SELECTIVE ELEMENTS CHANGED.
C    ALL ENTRIES ARE CHECKED FOR VALID FORMAT AND REENTRY IS
C    REQUESTED IF VALIDITY IS NOT MET.  NUMBERS MAY BE ENTERED
C    IN FREE FORMAT.
C         DIMENSIONED VARIABLE DATA ARE ENTERED BY ROWS, IN 72
C    COLUMN CARD IMAGES ON AS MANY LINES AS ARE REQUIRED OR
C    DESIRED TO FILL ALL ELEMENTS.  THE BELL WILL RING EACH TIME
C    THE ROUTINE IS WAITING FOR A 72 COLUMN CARD IMAGE INPUT.
C         THE FOLLOWING ALPHANUMERIC COMMANDS ARE AVAILABLE TO
C    ASSIST IN THE PROCESS.
C
C         ABORT.....TERMINATE THE ROUTINE ABNORMALLY
C         ZERO......SET ALL ELEMENTS OF THE VARIABLE TO ZERO
C         CONTINUE..ALL DATA DESIRED HAS BEEN ENTERED, EXECUTE
C                   A NORMAL RETURN FROM THE ROUTINE
C         READ N (REWIND).....READ THE DATA FOR INPUT FROM
C                             TAPE(N), WHERE N = 1, 2, 3, OR 5.
C                             REWIND IS AN OPTIONAL PARAMETER
C                             CAUSING THE TAPE TO BE REWOUND
C                             PRIOR TO READING
C         LIST (/N,M/)...'LIST' BY ITSELF WILL PRINT ALL ELEMENTS
C                        OF THE VARIABLE.  N & M CAN BE USED
C                        1) TO PRINT ONLY ONE ELEMENT (N & M
C                          SPECIFIED),
C                        2) TO PRINT ONLY ONE ROW (M = 0 OR
C                          MISSING), OR
C                        3) TO PRINT ONLY ONE COLUMN (N = 0 OR
C                          MISSING)
C         /N,M/.....SPECIFIES THAT THE NEXT NUMERIC ENTRY WILL
C                   GO INTO ELEMENT (N,M)
```

```
C         //...PRINTS THE INDICES OF THE ELEMENT INTO WHICH
C              THE NEXT NUMERIC ENTRY WIL. GO
C
C    NOTES:  AFTER THE LAST ELEMENT OF THE VARIABLE HAS BEEN
C    ENTERED, THE REMAINDER OF THE 72 CHARACTER INPUT LINE WILL
C    BE SCANNED FOR ANY OF THE ABOVE COMMANDS EXCEPT READ.
C    ONLY ZERO OR /N,M/ WILL PREVENT A RETURN FROM THE ROUTINE
C    IN THIS CASE.  ABBREVIATIONS OF ANY OF THE ABOVE COMMANDS
C    ARE VALID.  AN * CAUSES THE CURRENT ELEMENT TO BE UNCHANGED
C    AND THE NEXT NUMERIC INPUT TO GO INTO THE SUCCEEDING ELEMENT.
C    A $ AT ANY TIME WILL CAUSE AN ABORT TERMINATION OF THE
C    ROUTINE.  AN ELEMENT OF A ROW OR COLUMN VECTOR CAN BE REFERENCED
C    WITH /N,M/ ( WITH THE APPROPRIATE INDICE 1) OR BY /N/.
C    ALL PRINTOUTS WILL SHOW THE ENTERED DATA IN REAL FORMAT, BUT
C    IF THE VARIABLE IS INTEGER MODE THE STORED NUMBERS WILL BE
C    CHANGED TO INTEGER FORMAT (BY TRUNCATION IF NECESSARY) BEFORE
C    THIS SUBROUTINE RETURNS.
C*************************************************************************
C*************************************************************************
C         A DEFINITION OF THE CALL PARAMENTERS AND THE REQUIRED
C    LABELED COMMON ELEMENTS IS GIVEN BELOW.
C
C    PARAMETERS----------
C         NAME.....HOLLERITH CONSTANT WITH THE 'TITLE' OF THE
C                  VARIABLE IN THE FIRST 9 CHARACTERS, LEFT
C                  JUSTIFIED, AND THE NUMBER OF LETTERS IN
C                  THE 'TITLE' IN THE LAST CHARACTER.  EXAMPLE,
C                  THE TITLE OF THE VARIABLE FOR THE 'A MATRIX'
C                  MIGHT BE 10HA MATRIX H.  (THE DISPLAY CODE
C                  FOR H IS 10 WHICH IS THE OCTAL EQUIVALENT OF
C                  THE INTEGER 8 - THE NUMBER OF LETTERS IN THE
C                  TITLE 'A MATRIX')
C         MATRIX....THE VARIABLE FOR WHICH INPUT IS DESIRED.
C         N.........ROW DIMENSION OF THE VARIABLE DESIRED.
```

```
C         M.........COLUMN DIMENSION OF THE VARIABLE DESIRED.
C         ND........ROW DIMENSION OF THE VARIABLE FROM THE
C                   DIMENSION STATEMENT IN THE CALLING PROGRAM.
C         REAL......LOGICAL CONSTANT EQUAL TO TRUE IF THE VARIABLE
C                   MODE IS REAL AND EQUAL TO FALSE IF THE
C                   VARIABLE MODE IS INTEGER.
C
C              NON DIMENSIONED VARIABLES ARE ENTERED WITH N, M,
C              AND ND EQUAL TO 1.  SINGLE DIMENSIONED VARIABLES
C              HAVE THE NORMALLY UNUSED DIMENSION SET TO 1.
C
C
C    COMMON----------LABELED CONTROL
C         OSP.......THE INTEGER TAPE NUMBER OR A LEFT JUSTIFIED,
C                   ZERO FILLED HOLLERITH CONSTANT INDICATING WHICH
C                   FILE THE SUBROUTINE IS TO WRITE OUT ON.  THIS
C                   FILE SHOULD BE A CONNECTED FILE.
C         BATCH.....A LOGICAL CONSTANT WITH A VALUE OF
C                   TRUE IF THIS ROUTINE IS BEING USED IN A BATCH
C                   JOB AND A VALUE OF FALSE IF USED FOR AN
C                   INTERACTIVE JOB.  (IF ANY FORMAT ERROR IS
C                   DETECTED WHEN RUNNING A BATCH JOB THE
C                   DIAGONISTIC IS PRINTED AND THEN AN ABORT
C                   TERMINATION IS EXECUTED)
C
C    TAPE5 IS THE NORMAL INPUT FILE.  IT SHOULD BE CONNECTED
C    AND/OR EQUIVALENCED TO INPUT.
C*************************************************************************
```

```
      SUBROUTINE READCOM(COM,NUM)
C*****************************************************************
C         THE PURPOSE OF THIS SUBROUTINE IS TO READ IN AND VALIDATE
C    ALPHANUMERIC AND SYMBOLIC COMMANDS OF 9 CHARACTERS OR LESS.
C    COMMANDS MAY HAVE SINGLE IMBEDED BLANKS, AND LEADING BLANKS
C    ARE IGNORED.  COMMANDS ARE SEPARATED BY COMMAS,SLASHES, OR TWO
C    OR MORE BLANKS.  COMMANDS PRECEEDED BY A COMMA ARE CONSIDERED
C    TO BE PARAMETERS OF THE LAST PREVIOUS COMMAND NOT PRECEEDED BY
C    A COMMA.  THIS ROUTINE IS MENT FOR SINGLE COMMAND STRING ENTRIES,
C    BUT MULTIPLE COMMANDS CAN BE ENTERED (SEPARATED BY SLASHES OR
C    2 OR MORE BLANKS) AS LONG AS THE TOTAL CHARACTER COUNT DOES
C    NOT EXCEED 80.  A $ ENTERED AT ANY TIME WILL CAUSE AN ABORT
C    CONDITION AS EXPLAINED BELOW.
C         COMMANDS ARE VALIDATED AGAINST A HOLLERITH ARRAY (LIST) OF
C    LEGAL COMMANDS.  ABBREVIATIONS ARE ALLOWED AS LONG AS THEY
C    ARE UNIQUE.  COMMAND STRING FORMAT IS NOT CHECKED.
C
C
C         THE CALL PARAMETERS AND THE LABELED COMMON BLOCKS REQUIRED
C    ARE EXPLAINED BELOW.
C
C    PARAMENTERS----------
C         COM..AN ARRAY DIMENSIONED AT LEAST NUM.  ON RETURN THIS
C              ARRAY WILL CONTAIN INDICES FOR THE LIST ARRAY
C              CORRESPONDING TO THE COMMANDS ENTERED.  A NEGATIVE
C              VALUE INDICATES THAT THIS COMMAND IS A PARAMENTER
C              IN A COMMAND STRING.
C         NUM..AN INTEGER INDICATING ON INPUT THE MAXIMUM NUMBER OF
C              COMMANDS TO BE READ, AND ON OUTPUT THE NUMBER OF COMMANDS
C              ACTUALLY READ.
C
C                   A ZERO WILL BE RETURNED IN BOTH COM(1) AND NUM
C                   IN CASE OF AN ABORT.
C
```

```
C
C    COMMON----------LABELED CONTROL
C         OSP.......THE INTEGER TAPE NUMBER OR A LEFT JUSTIFIED,
C                   ZERO FILLED HOLLERITH CONSTANT INDICATING WHICH
C                   FILE THE SUBROUTINE IS TO WRITE OUT ON.  THIS
C                   FILE SHOULD BE A CONNECTED FILE.
C         BATCH.....A LOGICAL CONSTANT WITH A VALUE OF
C                   TRUE IF THIS ROUTINE IS BEING USED IN A BATCH
C                   JOB AND A VALUE OF FALSE IF USED FOR AN
C                   INTERACTIVE JOB.  (IF ANY VALIDITY ERROR IS
C                   DETECTED WHEN RUNNING A BATCH JOB THE
C                   DIAGONISTIC IS PRINTED AND THEN COM(1) AND
C                   NUM ARE SET TO ZERO AND A RETURN IS EXECUTED.
C
C
C    COMMON----------LABELED LISTING
C         NL........THE NUMBER OF ACTIVE ELEMENTS IN THE ARRAY
C                   LIST.
C         LIST......AN ARRAY DIMENSIONED AT LEAST NL CONTAINING THE
C                   COMMAND NAMES TO BE CHECKED.  EACH LIST(K) IS A
C                   HOLLERITH CONSTANT WITH THE 'NAME' OF THE COMMAND IN
C                   THE FIRST 9 CHARACTERS, LEFT JUSTIFIED, AND THE
C                   NUMBER OF LETTERS IN THE 'NAME' IN THE LAST
C                   CHARACTER.
C                   EXAMPLE....
C                   A COMMAND  10HTIME     D
C                        THE DISPLAY CODE FOR D IS 04, WHICH WHEN
C                        THE REST OF THE WORD IS MASKED
C                        IS THE INTEGER 4 - THE NUMBER OF
C                        LETTERS IN TIME.
C*****************************************************************
```

```
      SUBROUTINE PRINTR(NA,NAM,VAR,N,M,ND)
C*****************************************************************
C     \   THE PURPOSE OF THIS SUBROUTINE IS TO PRINT THE VALUES OF A NON,
C    ONE, OR TWO DIMENSIONAL VARIABLE.  THE VARIABLE MAY BE PRINTED TO
C    TAPE 6 OR TO A FILE DESIGNATED BY THE USER OR TO BOTH OR TO NEITHER.
C    THE DECISION ON WHERE TO PRINT IS BASED ON A CODE PASSED IN THE
C    COMMON BLOCK LISTOUT FOR EACH VARIABLE. ONCE THE DECISION IS MADE
C    AS TO WHERE TO PRINT, THE SUBROUTINE LISTER IS CALLED TO DO THE
C    ACTUAL PRINTING.  THIS SUBROUTINE IS CALLED WITH THE ENTRY
C    POINT PRINTR FOR REAL VARIABLES AND THE ENTRY POINT PRINTI
C    FOR INTEGER VARIABLES
C
C
C         THE CALL PARAMETERS AND LABELED COMMON BLOCKS REQUIRED ARE
C    EXPLAINED BELOW.
C
C    PARAMETERS----------
C         NA...THE INDEX FOR THE ARRAY LISTO CORRESPONDING TO THE
C              VARIABLE TO BE PRINTED.
C         NAM..HOLLERITH CONSTANT WITH THE NAME OF THE VARIABLE IN THE
C              FIRST 9 CHARACTERS, LEFT JUSTIFIED, AND THE NUMBER OF
C              LETTERS IN THE NAME IN THE LAST CHARACTER; THIS LAST
C              CHARACTER WILL BE AN INTEGER VALUE FOR THE NUMBER OF
C              LETTERS IN THE NAME WHEN THE PRECEEDING NINE CHARACTERS
C              ARE MASKED.  IF NO NAME IS TO BE PRINTED WITH THE VARIABLE
C              THIS SHOULD BE 10H         A.
C         VAR..THE VARIABLE TO BE PRINTED
C         N....THE ROW DIMENSION OF THE VARIABLE TO BE PRINTED
C         M....THE COLUMN DIMENSION OF THE VARIABLE TO BE PRINTED
C         ND...THE ROW DIMENSION OF THE VARIABLE FROM THE DIMENSION
C              STATEMENT IN THE CALLING PROGRAM.
C
C    COMMON----------LABELED LISTOUT
C         NL.........THE NUMBER OF ACTIVE ELEMENTS IN THE ARRAY LISTO
```

```
C        LISTO.....AN ARRAY DIMENSIONED AT LEAST NL WITH AN ELEMENT
C                  FOR EACH VARIABLE TO BE PRINTED.  IF THE VALUE
C                  IS A 1 THE VARIABLE WILL NOT BE PRINTED.  IF THE
C                  VALUE IS A 2 THE VARIABLE WILL BE PRINTED TO THE
C                  FILE SPECIFIED BY OSP IN LABELED COMMON -CONTROL-.
C                  IF THE VALUE IS A 3 THE VARIABLE WILL BE PRINTED
C                  TO BOTH TAPE 6 AND THE FILE OSP.
C                  IF THE VALUE IS A 4 THE VARIABLE WILL BE PRINTED
C                  TO TAPE 6 ONLY.
C
C    COMMON----------LABELED CONTROL
C         OSP..AN INTEGER SPECIFING A TAPE NUMBER FOR THE USERS DESIRED
C              PRINT FILE OR A LEFT JUSTIFIED, ZERO FILLED NAME OF THE
C              USERS FILE. (USUALLY TAPE 5 IS DISCONNECTED FOR HARD
C              COPY STORAGE OF THE PRINTED VALUES AND THE FILE DSP IS
C              CONNECTED TO THE TERMINAL FOR IMMEDIATE DISPLAY TO THE
C              USER)
C
C    COMMON----------LABELED TITLE
C         ITTTLE...DIMENSIONED 5, THIS PROVIDES SPACE TO PRINT A 50
C                  CHARACTER TITLE ABOVE THE VARIABLE PRINTOUT.  IF
C                  THE ARRAY ITITLE IS NON BLANK THE NAME OF THE
C                  VARIABLE WILL NOT BE PRINTED.  THE ARRAY IS SET
C                  TO ALL BLANKS AFTER EACH CALL TO THIS SUBROUTINE.
C*****************************************************************
```

```
      SUBROUTINE LISTER(NAME,VAR,N,M,ND,FOR,DST)
C*****************************************************************
C         THIS SUBROUTINE IS CALLED BY THE SUBROUTINE PRINTR TO TO THE
C     ACTUAL PRINTING OF THE VARIABLES.  THE PARAMETERS USED IN THE
C     CALL ARE GENERATED BY PRINTR AND WILL NOT BE EXPLAINED HERE, AS
C     THE TWO SUBROUTINES ARE MENT TO BE USED TOGETHER.
C         THIS SUBROUTINE USES ONE OTHER LABELED COMMON BLOCK TO
C     DETERMINE THE DESIRED FORMAT FOR THE VARIABLE TO BE PRINTED
C     IN. THESE TERMS ARE EXPLAINED BELOW.
C
C
C     COMMON----------LABELED FORMS
C          NOREP.....AN INTEGER INDICATING THE NUMBER OF COLUMNS TO BE
C                    PRINTED ON ONE LINE ON THE FILE DESIGNATED BY THE
C                    USER WITH DSP.
C          NONSD.....AN INTEGER INDICATING THE NUMBER OF SIGNIFICANT
C                    DIGITS TO BE PRINTED TO THE FILE DSP.
C          NOFW......AN INTEGER INDICATING THE FIELD WITH OF THE FORMAT
C                    USED FOR PRINTING THE VARIABLE TO THE FILE DSP.
C                    THIS NUMBER MUST BE 7 MORE THAN NONSD.
C          NOREP.....AN INTEGER SIMILAR TO NOREP, EXCEPT THIS ONE
C                    CORRESPONDS TO THE FILE TAPE 6.
C          NONSD.....AN INTEGER SERVING THE SAME FUNCTION AS NONSD, ONLY
C                    FOR TAPE 6
C          NOFW......AN INTEGER SPECIFING THE FILED WIDTH FOR TAPE 6 PRINT
C*****************************************************************
```

MATRIX MANIPULATION SUBROUTINE CALL PARAMETERS

```
CALL ADDMAT(A,NAD,N,M,B,NBD,C,NCD)      **  A = B + C  **
        A -- OUTPUT MATRIX
        NAD -- ROW DIMENSION OF A FROM DIMENSION STATEMENT IN
               CALLING PROGRAM
        N -- ROW DIMENSION OF A,B, AND C
        M -- COLUMNS DIMENSION OF A,B, AND C
        B & C -- MATRICES TO BE ADDED
        NBD -- ROW DIMENSION OF B FROM DIMENSION STATEMENT IN
               CALLING PROGRAM
        NCD -- ROW DIMENSION OF C FROM DIMENSION STATEMENT IN
               CALLING PROGRAM

CALL SUBMAT(A,NAD,N,M,NB,NBD,C,NCD)     **  A = B - C  **
        SAME PARAMETERS AS FOR ADDMAT EXCEPT THAT NOW MATRIX
        C IS BEING SUBTRACTED FROM MATRIX B

CALL TRANPOS(A,NAD,N,M,B,NBD)      **  A = B(TRANSPOSE)
        A -- OUTPUT MATRIX
        NAD -- ROW DIMENSION OF A FROM DIMENSION STATEMENT IN
               CALLING PROGRAM
        N -- ROW DIMENSION OF A AND COLUMN DIMENSION OF B
        M -- COLUMN DIMENSION OF A AND ROW DIMENSION OF B
        B -- INPUT MATRIX
        NBD -- ROW DIMENSION OF B FROM DIMENSION STATEMENT IN
               CALLING PROGRAM

CALL COPYAB(A,NAD,N,M,B,NBD)      **  A = B  **
        A, NAD, B, AND NBD ARE THE SAME AS FOR TRANPOS
        N -- ROW DIMENSION OF A AND B
        M -- COLUMN DIMENSION OF A AND B

CALL PRESET(A,NAD,N,M,PRE)      **  A = PRE  **
```

```
        A -- OUTPUT MATRIX
        NAD -- ROW DIMENSION OF A FROM DIMENSION STATEMENT IN
               CALLING PROGRAM
        N -- ROW DIMENSION OF A
        M -- COLUMN DIMENSION OF A
        PRE -- REAL VALUE TO BE SET IN EACH ELEMENT OF A

CALL IDENT(A,NAD,N)      **  A = I  **
        A -- OUTPUT MATRIX
        NAD -- ROW DIMENSION OF A FROM DIMENSION STATEMENT IN
               CALLING PROGRAM
        N -- ROW AND COLUMN DIMENSION OF A

CALL MAT2MPY(A,NAD,N,M,B,NBD,N1,C,NCD)      $$  A = B * C  $$
        A -- OUTPUT MATRIX
        NAD -- ROW DIMENSION OF A FROM DIMENSION STATEMENT IN
               CALLING PROGRAM;;N -- ROW DIMENSION OF A AND B
        M -- COLUMN DIMENSION OF A AND C
        B & C -- MATRICES TO BE MULTIPLIED
        NBD -- ROW DIMENSION OF B FROM DIMENSION STATEMENT IN
               CALLING PROGRAM
        N1 -- COLUMN DIMENSION OF B AND ROW DIMENSION OF C
        NCD -- ROW DIMENSION OF C FROM DIMENSION STATEMENT IN
               CALLING PROGRAM

CALL MAT3MPY(A,NAD,N,M,B,NBD,N1,C,NCD,N2,D,NDD)
                        $$  A = B * C * D  $
        A, NAD, N, NBD, N1, AND NCD ARE THE SAME AS FOR MAT2MPY
        M -- COLUMN DIMENSION OF A AND D
        B,C, & D -- MATRICES TO BE MULTIPLIED
        N2 -- COLUMN DIMENSION OF C AND ROW DIMENSION OF D
        NDD -- ROW DIMENSION OF D FROM DIMENSION STATEMENT IN
               CALLING PROGRAM
```

```
CALL INVERT(A,NAD,B,NBD,N,IFAIL)      **  A = B(INVERSE)
        A -- OUTPUT MATRIX
        NAD -- ROW DIMENSION OF A FROM DIMENSION STATEMENT IN
               CALLING PROGRAM
        B -- INPUT MATRIX  (THIS MATRIX DESTROYED DURING
             EXECUTION)
        NBD -- ROW DIMENSION OF B FROM DIMENSION STATEMENT IN
               CALLING PROGRAM
        N -- ROW AND COLUMN DIMENSIONS OF A AND B
        IFAIL -- LOGICAL VARIABLE RETURNED TRUE IF MATRIX IS
                 SINGULAR
                 (1)  SUBROUTINE IDENT IS CALLED BY THIS ROUTINE
                 (2)  ONE ELEMENT OF LABELED COMMON -CONTROL- IS
                      USED TO INDICATE WHICH FILE THE ERROR
                      MESSAGE SHOULD BE WRITTEN TO IF THE MATRIX
                      IS SINGULAR
```

Appendix D

Card Sequence Required To Utilize FORTRAC

The use of the batch mode program FORTRAC is described in the preliminary report "FORTRAC: A Software Package for the Design of Multivariable Digital Control Systems" which is available from the FGL branch of the Flight Dynamics Lab. The one point that needs to be expanded on is the card sequence required for the different types of problems that can be run with the program. The following pages give the card sequence required for the three types of problems; the regulator, tracker, and disturbance rejector.

The following limits are in effect with the presently dimensioned master program.

(1) The maximum number of states including augmenting integrators allowed is 7.

(2) The maximum number of controls is 4.

(3) The maximum number of augmenting integrators allowed is 3.

(4) The maximum number of samples that can be displayed in either the discrete or continuous simulation is 33.

These limits can be increased by increasing the dimensions on the 133 variables in the master program.

Card Sequence for the Regulator

1 N,M,NCC,NDD,NYY,NPP

N = number of states
M = number of controls
NCC = 0
NDD = 0
NYY = number of outputs
NPP = 0

The elements of the state matrix, one row per card

The elements of the control matrix, one row per card

The elements of the output matrix, one row per card

T The sampling interval to be used

The desired closed-loop eigenvalues, N cards with a real and an imaginary part on each card

---

0 No observer will be designed

K An integer indicating the power to which the closed-loop matrix should be raised

---

NDS Number of time intervals required in the discrete-time simulation

---

N initial conditions for the states, all on one card

EPS,NDS,NSIDS

EPS = the accuracy to be used in the Kutta-Merson subroutine
(suggest approximately .0000001)
NDS = number of sample-time intervals required in the continuous-time simulation
NSIDS = number of divisions required in each sample-time interval

---

N initial conditions for the states, all on one card

Card Sequence for the Tracker

1 N,M,NCC,NDD,NYY,NPP

N = number of states
M = number of controls
NCC = number of commands
NDD = 0
NYY = number of outputs
NPP = number of outputs integrated (equal to NCC)

The elements of the state matrix, one row per card

The elements of the control matrix, one row per card

The elements of the command matrix, one row per card
(this must be entered even if the matrix is null)

The elements of the output matrix, one row per card

The elements of the matrix defining the outputs that will track the input command

---

T The sampling interval to be used

The number of integrators desired for each integrated output, all entered on one card

---

The desired closed-loop eigenvalues, (N + the sum of the numbers entered on the preceeding card) cards with a real and an imaginary part on each card

---

0 No observer will be desinged

K An integer indicating the power to which the closed-loop matrix should be raised

---

NDS Number of time intervals required in the discrete-time simulation

---

N initial conditions for the states, all on one card

Initial conditions for the integrators, all on one card

EPS,NDS,NSIDS

Same as for the regulator

N initial conditions for the states, all on one card

Initial conditions for the integrators, all on one card

Card Sequence for the Disturbance Rejector

1 N,M,NCC,NDD,NYY,NPP

N = number of states
M = number of controls
NCC = 0
NDD = number of disturbances
NYY = number of outputs
NPP = number of outputs integrated (number of outputs to reject disturbances)

The elements of the state matrix, one row per card

The elements of the control matrix, one row per card

The elements of the disturbance matrix, one row per card

The elements of the output matrix, one row per card

The elements of the matrix defining the outputs that will reject disturbances

---

T The sampling interval to be used

.. All remaining cards are the same as for the tracker

Vita

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The purpose of this investigation is to develop an interactive user oriented software package for direct digital control system design. The batch mode program, FORTRAC, developed by Professor Brian Porter of the University of Salford, England, is the source of the computational algorithms used. This report details the input, output, and program sequence control software developed to produce an efficient, user oriented interactive package. over

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The package is very forgiving of user errors and gives the user complete control over what data to input, what data will be output, and which parts of the program are executed. The package is quite useful in the design process for discrete-time time-optimal control systems, where many possible control parameter variations must be examined.