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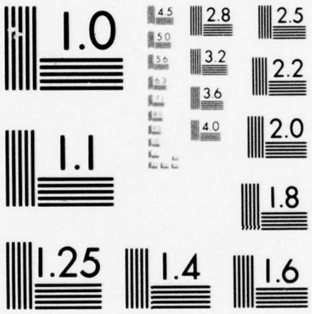

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Volume II

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PILOT MODELING FOR MANNED SIMULATION

Volume II
PROGRAM USER'S MANUAL

AEROSPACE SYSTEMS, INC.
BURLINGTON, MASSACHUSETTS 01803

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A digital computer program (PIREP) has been developed to implement the extended optimal control pilot model discussed in Volume I. The user manual describes the program organization, presents the input formats and program options, provides general comments to assist the user, and presents results for a sample run. The program is written entirely in FORTRAN IV, for operation on the Wright-Patterson computer facility.

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FOREWORD

This report was prepared by Aerospace Systems, Inc. (ASI), Burlington, Massachusetts, for the Air Force Systems Command under Contract No. F33615-75-C-3069. Volume I of the report documents the results of research performed during the period April 1975 to February 1976. This manual is Volume II of the final report, and has been separately bound for the program user's convenience.

The study was sponsored by the Air Force Flight Dynamics Laboratory (AFFDL), Flight Control Division, Systems Dynamics Branch. Mr. John Stone and Mr. Daniel L. Kugel served as Technical Monitors on the contract.

The effort was directed by Mr. John Zvara, President and Technical Director of ASI. Mr. William C. Hoffman served as Project Engineer. Dr. Renwick E. Curry of the MIT Department of Aeronautics and Astronautics and the MIT Man-Vehicle Laboratory, and Dr. Laurence R. Young, Director of the MIT Man-Vehicle Laboratory, contributed to the study as principal consultants. Miss Kristine Doyle and other members of the ASI technical staff assisted in the development, validation and documentation of the computer model.

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SECTION I

INTRODUCTION

In Volume I of this report (Reference 1), an extended pilot model is formulated to predict closed loop pilot behavior in a multi-variable, multi-loop aircraft control task with multiple inputs and outputs. The optimal control model of the human operator was selected as the foundation for the extended model. The conventional optimal control pilot model was extended to incorporate effects of scanning and attention allocation, motion cues sensed by the vestibular system, and VMC/IMC (Visual Meteorological Conditions/Instrument Meteorological Conditions) cues.

A digital computer program (Program PIREP) has been developed to implement the extended optimal control model of the pilot. Volume II, the user's guide for Program PIREP, has been written as a separate volume for the convenience of the user. Program PIREP can be a useful tool to improve simulation analysis and planning, increase simulation efficiency, and lower simulator operating costs. Also, aircraft display and control system design, which depends heavily on pilot models, can benefit from this program.

This document describes the structure and utilization of the program. The analytical formulation of the optimal control model of the pilot and guidelines for specifying the important model parameters to represent a particular simulation situation are contained in Volume I of the report.

PIREP is written entirely in FORTRAN-IV for operation on the CDC-6600 digital computer at Wright-Patterson Air Force Base. Slightly modified versions have been run on the PDP-11 computer. The program was developed with a highly modular structure for ease of program checkout, to simplify the user's understanding of the program, and to facilitate any modifications which might be required for future applications.

Sections 2 and 3 of this manual illustrate programming details of the simulation: functions of the various subroutines, external references, and common storage. The usage of the program is presented in Sections 4 and 5, which describe hardware requirements, inputs, and program operation. Finally, a sample run is included to illustrate the application of PIREP to a typical simulation situation (the low visibility approach scenario described in Section 5.2 of Volume I).

SECTION II

PROGRAM DESCRIPTION

The following discussion provides the user with an understanding of the organization and general operation of Program PIREP. Brief abstracts of each program are presented in Table 1. Table 2 summarizes all external references in PIREP, excluding system library routines.

The program incorporates a package of numerical analysis routines developed by Kleinman for linear multivariable systems studies (Reference 2). Those routines indicated by an asterisk in Table 1 are part of this package but are not required for the present version of PIREP.

Table 1. PIREP Program Abstracts.

PIREP	Main Program. Reads input data; initializes and controls analyses in accordance with selected options; performs iterations on observation and motor noise variances and attention allocation; governs RMS and cost outputs.
SYSMAT	Used (optionally) to input system matrices and cost functional weightings in formatted data field structure.
FDREP	Performs frequency domain analyses and governs associated printout; requires additional input data.
PRTHDG	Prints page heading.
GLINEQ	Solves generalized linear matrix equation $XA_1 + A_2X + C = 0$; an error diagnosis is given if convergence does not occur in 30 iterations.
DINTEG*	Computes symmetric sum $S = \sum_{i=0}^{NT-1} A^i C A^{i'}$.
DSCRT*	Computes matrices $EA = e^{A\delta}$, $EAINT = \int_0^{\delta} e^{A\sigma} d\sigma$ for "small" δ; used in discretizing a continuous linear system.
MAT2	Forms matrix product $Z = XY'$ in cases where product Z is symmetric.
MAT2A	Forms matrix product $Z = X'Y$ in cases where product Z is symmetric.
MAT 3	Forms symmetric matrix product $Z = XYX'$ where Y is symmetric.
MAT3A	Forms symmetric matrix product $Z = X'YX$ where Y is symmetric.
MADD1	Adds two matrices $Z = X + C1 * Y$, where C1 is a scalar.
TRANS1	Takes transpose of a square matrix A, $AT = A'$; both A and AT can share the same storage location.
TRANS2*	Takes transpose of matrix A, $AT = A'$; A and AT cannot share the same storage locations.
EQUATE	Sets matrix A equal to a matrix B, $A = B$; can be used for matrix partitions.
IDNT	Sets up a diagonal matrix A, $A = \text{diag}(C1)$.
DIAG	Sets up matrix A where $A = C1 * B + C2 * I$, where I is the identity matrix.

Table 1. PIREP Program Abstracts (Continued).

FACTOR	Computes a symmetric factorization of a positive semi-definite matrix, A = U'U; also outputs rank of input matrix A.
VMAT1	Multiplies a given vector by a matrix, Y = AX, where X is a vector.
VMAT2*	Computes the vector-matrix product sum, Y = Z + AX, where X is a vector.
VMAT3*	Computes the vector-matrix product sum, Z = AX + BY, where X and Y are vectors.
VADD	Increments a given vector A by a second vector, A = A + C1 * B.
XNORM	Computes and returns an approximation (but not a bound) to the spectral radius of a square matrix A.
TRACE	Computes the trace of a square matrix.
CCMUL	Forms complex product of two complex matrices.
RCMUL	Forms the complex product of a real and a complex matrix, Z = XY, X real.
CRMUL	Forms the complex product of a complex and real matrix, Z = XY, X complex.
VECTIO	Used to read in and/or print and punch a floating point one-dimensional array.
EIGEN	Used to find the eigenvalues of a real matrix.
REDCT	Performs a Householder Reduction via an orthogonal transformation.
DOT	Computes inner product between two linear arrays.
DOT2	Computes a modified dot product between two linear arrays; useful for computing the dot product between two rows of a matrix.
DOT3	Computes the dot product between array A stored as a row vector and array B stored as a column vector.
MATIO	Used to read in and/or print and punch (one row at a time) a floating point two dimensional array.
MRIC	Solves the matrix quadratic equation A'X + XA + Q - XSX = 0; Q and S are positive semi-definite symmetric matrices. Three possible error diagnostic message outputs: nonconvergence, instability, and non-positive definiteness.

Table 1. PIREP Program Abstracts (Continued).

NEXP*	Computes the matrix exponential, $EA = e^{A\tau}$, using a Chebyshev polynomial approximation.
INTEG	Performs the integration $S = \int_0^T e^{A\tau} C e^{A'\tau} d\tau$ where C is a symmetric matrix.
GMINV	Computes inverse of matrix A; if A is singular or not square, GMINV computes the Penrose generalized inverse.
CMINV	Computes inverse of a square complex matrix.
MLINEQ	Solves the linear matrix equation $0 = A'X + XA + C$, where A is a square matrix having eigenvalues with negative real parts, and C is a symmetric matrix.
MAT1A*	Forms the matrix product $Z = XY$, where arrays Z and Y can start at equivalent core locations.
MAT5	Forms the matrix product $Z = XY'$; a sparseness test is done on Y.
MAT5A	Forms the matrix product $Z = X'Y$; a sparseness test is done on Y.
SCALE	Sets a matrix A equal to a matrix B and scales, $A = C1 * B$.
MAT4*	Forms the matrix product $Z = XY'$.
MAT4A*	Forms the matrix product $Z = X'Y$.
MMUL	Forms the matrix product $Z = XY$; a sparseness test is performed on X.
VSCALE	Equates a vector A to a vector B and scales, $A = C1 * B$.
MAT1*	Forms the straightforward matrix product $Z = XY$; generally more accurate than MMUL through its use of DOT3.
MAT6*	Forms the matrix product $Z = XY'$ in cases where the result Z is symmetric; a sparseness test is performed on V.
VADD1	Increments a given row vector A by a second row vector B; useful for adding a scaled row of a matrix to a second row.
XGAIN	Computes the steady-state feedback control gain matrix for the optimal human operator.

Table 1. PIREP Program Abstracts (Concluded).

REGAIN	Computes the describing function gain for the observation thresholds.
CHARCO*	Obtains the coefficients of the characteristic polynomial of a square matrix, A, i.e., $\sum_{i=1}^{N+1} C_i A^{i-1} = 0$
GRAD	Calculates the gradient vector of the performance cost with respect to the observation attention allocations.
NEWPT	Determines the projected cost gradient and selects a revised attention allocation (for attention optimization option).
MONITR*	Determines monitoring attention and performance.
CDIV*	Divides the complex scalar AR + iAI by BR + iBI.
EGVEC*	Computes eigenvectors of a matrix A reduced to upper Block Triangular (Schur) form.
DRIC*	Solves the matrix equation $X = A'X(I + SX)^{-1} A + Q$ that arises in the study of **optimal** discrete systems. A is a square transition matrix, Q and S are positive semi-definite symmetric matrices.
KFILTR*	Solves the matrix equation $X = A[X - XH'(R + HXH')^{-1} HX] A' + Q$ that arises when designing a Kalman filter for a linear discrete system with observations $y = HX$, measurement noise covariance matrix R, and system driving noise covariance matrix Q. A is the system transition matrix; this subroutine is similar to DRIC with the equivalences $A \rightarrow A'$, $S \rightarrow H'R^{-1}H$, $Q \rightarrow Q$.
XMAG	Computes squared magnitude of complex variable.
BLOG	Converts a variable to decibels.
GATIO*	Reads in selected non-zero elements of a matrix in an i, j, a_{ij} format; also prints out matrix and punches deck compatible for subsequent read.
AXPTA*	Solves linear matrix equation $A'X + XA + C = 0$, where A is a matrix having eigenvalues with negative real parts, C is a symmetric matrix; a modified Bartel and Stewart algorithm is used.
DOOLIT*	Computes an LU decomposition of matrix A using partial pivoting; solves the vector equation, $Ax = b$.
SWAP	Swaps either two rows or two columns of a matrix.

Table 2. PIREP External References.

	AXPTA*	BLOG	CCMUL	CDIV*	CHARCO*	CMINV	CRMUL	DIAG	DINTEG*	DOOLIT*	DOT	DOT2	DOT3	DRIC*	DSCRT*	EGVEC*	EIGEN
PIREP												×					×
SYSMAT																	
FDREP		×	×			×	×										
GLINEQ								×					×				
DINTEG*																	
DSCRT*								×									
MAT2												×					
MAT2A											×						
MAT3																	
MAT3A																	
FACTOR												×					
VMAT1													×				
VMAT2*													×				
VECTIO																	
EIGEN																	
REDCT											×		×				
MATIO																	
MRIC																	
MEXP*								×									
INTEG								×									
GMINV											×						
CMINV																	
MLINEQ											×						
MAT1A													×				
MAT5																	
MAT5A																	
MAT4*												×					
MAT4A*											×						
MMUL																	
MAT1*													×				
MAT6*																	
REGAIN																	
CHARCO*																	
GRAD											×						
NEWPT																	
MONITR*																	
EGVEC*				×									×				
DRIC*																	
KFILTR*																	
AXPTA*										×	×						×
DOOLIT*												×					

	EQUATE	FACTOR	FDREP	GATIO*	GLINEQ	GMINV	GRAD	GRANF*	IDNT	INTEG	KFILTR*	MADD1	MAT1*	MAT1A	MAT2	MAT2A	MAT3
PIREP	×		×			×	×		×	×					×	×	×
SYSMAT																	
FDREP																	
GLINEQ	×																
DINTEG*	×											×					×
DSCRT*																	
MAT2																	
MAT2A																	
MAT3															×		
MAT3A																×	
FACTOR																	
VMAT1																	
VMAT2*																	
VECTIO																	
EIGEN																	
REDCT																	
MATIO																	
MRIC	×	×				×				×		×			×	×	
MEXP*	×								×								
INTEG									×								×
GMINV																	
CMINV																	
MLINEQ	×					×											
MAT1A																	
MAT5																	
MAT5A																	
MAT4*																	
MAT4A*																	
MMUL																	
MAT1*																	
MAT6*																	
REGAIN					×							×				×	
CHARCO*	×													×			
GRAD						×										×	×
NEWPT																	
MONITR*	×											×			×	×	×
EGVEC*																	
DRIC*	×	×				×						×			×		×
KFILTR*	×	×				×						×			×	×	
AXPTA*	×								×						×	×	
DOOLIT*																	

	MAT3A	MAT4*	MAT4A*	MAT5	MAT5A	MAT6*	MATIO	MEXP*	MLINEQ	MMUL	MONITR*	MRIC	NEWPT	PRTHDG	RANF*	RCMUL	REDCT
PIREP				×	×		×		×	×	×	×	×	×			
SYSMAT							×										
FDREP										×						×	
GLINEQ										×				×			
DINTEG*																	
DSCRT*										×							
MAT2																	
MAT2A																	
MAT3										×							
MAT3A										×							
FACTOR														×			
VMAT1																	
VMAT2*																	
VECTIO														×			
EIGEN														×			×
REDCT																	
MATIO														×			
MRIC					×				×	×				×			
MEXP*										×							
INTEG										×							
GMINV														×			
CMINV														×			
MLINEQ										×				×			
MAT1A																	
MAT5																	
MAT5A																	
MAT4*																	
MAT4A*																	
MMUL																	
MAT1*																	
MAT6*																	
REGAIN										×		×					
CHARCO*														×			
GRAD	×				×				×	×				×			
NEWPT														×			
MONITR*	×			×					×	×		×	×	×			
EGVEC*																	
DRIC*	×				×				×	×							
KFILTR*	×			×					×	×							
AXPTA*										×							
DOOLIT*																	

	REGAIN	SCALE	SWAP	SYSMAT	TRACE	TRANS1	TRANS2*	VADD	VADD1	VECTIO	VMAT1	VMAT2*	VMAT3*	VSCALE	XGAIN	XMAG	XNORM
PIREP	×	×		×		×				×				×	×		
SYSMAT										×							
FDREP																×	
GLINEQ		×															×
DINTEG*																	
DSCRT*																	
MAT2																	
MAT2A																	
MAT3																	
MAT3A																	
FACTOR			×			×											
VMAT1																	
VMAT2*																	
VECTIO																	
EIGEN																	
REDCT								×									
MATIO																	
MRIC																	×
MEXP*																	×
INTEG		×															×
GMINV								×									
CMINV																	
MLINEQ																	
MAT1A														×			
MAT5								×						×			
MAT5A									×								
MAT4*																	
MAT4A*																	
MMUL									×								
MAT1*																	
MAT6*								×									
REGAIN						×											
CHARCO*					×												×
GRAD					×	×				×	×						
NEWPT										×							
MONITR*						×				×				×	×		
EGVEC*																	
DRIC*																	
KFILTR*						×											
AXPTA*																	
DOOLIT*																	

SECTION III

COMMON STORAGE

In keeping with the modularity goal of PIREP, most related FORTRAN variables used by more than one subroutine are organized into a number of common blocks. Table 3 illustrates this organization, and Table 4 gives the contents and lengths (in decimal) of each common block.

Table 3. PIREP Common Block Organization.

	BDUM	FDREP1	FDREP3	FDREP5	INOU	INPTX	INPTW	INPTY	KPLOT	MAIN1	MAIN2	NOISE	PHEAD	RATIOS	RMS	TIMES	WEIGHT
PIREP	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
SYSMAT					x	x	x	x		x	x						x
FDREP		x	x	x	x	x	x		x	x	x	x				x	x
PRTHDG					x								x				
GLINEQ					x					x	x						
DINTEG*										x							
DSCRT*										x							
MAT2										x							
MAT2A										x							
MADD1										x							
TRANS1										x							
TRANS2*										x							
EQUATE										x							
IDNT										x							
DIAG										x							
FACTOR					x					x							
VMAT3*										x							
XNORM										x							
TRACE										x							
CCMUL										x							
RCMUL										x							
CRMUL										x							
VECTIO					x												
EIGEN					x					x							
REDCT										x							
DOT2										x							
DOT3										x							
MATIO					x					x							
MRIC					x					x	x						
MEXP*										x							
INTEG										x							
GMINV					x					x							
CMINV					x					x							
MLINEQ					x					x							
MAT1A*										x							
MAT5										x							
MAT5A										x							
SCALE										x							
MAT4*										x							
MAT4A*										x							
MMUL										x							
MAT1*										x							
MAT6*										x							
VADD1										x							
REGAIN						x		x		x							x
GRAD					x	x		x		x	x	x		x	x	x	x
NEWPT					x					x		x					
MONITR*		x		x	x	x	x	x		x	x	x		x	x	x	
CDIV*					x												
EGVEC*										x							
DRIC*					x					x	x						
KFILTR*					x					x							
GATIO*					x					x							
AXPTA*					x					x							
DOOLIT*					x					x							

Table 4. Common Block Contents and Lengths.

BDUM (9)	LA	LB	LC	LD	LE
	LQX	LQY	LQU	LQR	
FDREP1 (800)	U (400)	V (400)			
FDREP3 (800)	W (400)	X (400)			
FDREP5 (800)	Y (400)	Z (400)			
INOU (3)	KIN	KOUT	KPUNCH		
INPTX (404)	N	NX	NXI	NU	A (400)
INPTW (201)	NW	E (200)			
INPTY (401)	NY	C (400)			
KPLOT (19)	NV	NH	NCPW	LW	XL
	XH	YL	XH	NXES	NDIR
	IST	NGLV	NGLH	BSYM	GSYM
	PSYM	NDIN1	NDIN2	NUPLTO	
MAIN1 (402)	NDIM	NDIM1	COM1 (400)		
MAIN2 (400)	COM2 (400)				
NOISE (490)	VU0 (30)	V40 (30)	W0 (30)	EG (400)	
PHEAD (11)	TITLE (8)	DAY	NPAGE	LINE	
RATIOS (1182)	IDENTU	IDENTY	PU (30)	VU (30)	PY (30)
	VY (30)	TH (30)	GTH (30)	EE (1000)	
RMS (520)	XRMS (30)	YRMS (30)	URMS (30)	UDRMS (30)	PC (400)
TIMES (404)	T	T1	T2	TIT1	EA (400)
WEIGHT (490)	QX (30)	QY (30)	QR (30)	CG (400)	

SECTION IV

HARDWARE REQUIREMENTS

The complete version of Program PIREP requires approximately $107{,}000_8$ ($36{,}400_{10}$) words of core to load and execute on the CDC 6600 computer. By deleting those routines not used by the AFFDL version of PIREP (i.e., those routines which were indicated by an asterisk in Table 1), this requirement can be reduced to about $75{,}000_8$ ($31{,}300_{10}$) words. Table 5 summarizes the core requirements for the individual elements of PIREP, using the OPT = 1 option with the CDC 6600 Fortran Extended Compiler. Also shown is the approximate space needed for the library routines and system overhead.

The logical unit assignments for Program PIREP input/output operations are shown in Table 6.

Table 5. PIREP Core Requirements.

ROUTINE	LENGTH		ROUTINE	LENGTH	
	OCTAL	DECIMAL		OCTAL	DECIMAL
PIREP	4622	2450	MEXP*	270	184
SYSMAT	161	113	INTEG	347	231
FDREP	2214	1164	GMINV	637	415
PRTHDG	33	27	CMINV	530	344
GLINEQ	605	389	MLINEQ	473	315
DINTEG*	103	67	MATIA*	220	144
DSCRT*	206	134	MAT5	137	95
MAT2	103	67	MAT5A	125	85
MAT2A	104	68	SCALE	57	47
MAT3	43	35	MAT4*	65	53
MAT3A	43	35	MAT4A*	71	57
MADD1	125	85	MMUL	124	84
TRANS1	53	43	VSCALE	36	30
TRANS2*	56	46	MAT1*	66	54
EQUATE	54	44	MAT6*	146	102
IDNT	52	42	VADD1	21	17
DIAG	113	75	XGAIN	150	104
FACTOR	443	291	REGAIN	250	168
VMAT1	46	38	CHARCO*	155	109
VMAT2*	51	41	GRAD	536	350
VMAT3*	62	50	NEWPT	606	390
VADD	21	17	MONITR*	1,263	691
XNORM	112	74	CDIV*	63	51
TRACE	30	24	EGVEC*	664	436
CCMUL	104	68	DRIC*	1,051	553
RCMUL	100	64	KFILTR*	1,215	653
CRMUL	100	64	XMAG	13	11
VECTIO	104	68	BLOG	26	22
EIGEN	654	428	GRANF*	27	23
REDCT	402	25	RANF*	21	17
DOT	32	26	GATIO*	303	195
DOT2	33	27	AXPTA*	1,231	665
DOT3	37	31	DOOLIT*	514	332
MATIO	203	131	SWAP*	25	21
MRIC	771	505		33,120	13,904
BLOCK COMMON				16,250	7,336
SYSTEM/LIBRARY OVERHEAD				~35,400	~15,200
TOTAL				~107,000	~36,400

Table 6. Logical Unit Assignments.

Logical Unit	Corresponding FORTRAN Variable or Logical Unit Number	Remarks
Card Reader	KIN (5)	Combination of namelist and formatted data field input; Logical Unit Number assigned in PIREP and passed through Common Block INOU.
Printer	KOUT (6)	Standard printout. Logical Unit Number assigned in PIREP and passed through INOU.
Punch	KPUNCH	Standard card punch; passed through INOU.
Magnetic Tape	7	Read/write tape used if printout of optimum gains option is designed.

SECTION V

PIREP INPUTS AND OPERATION

There are two different ways that PIREP can be exercised:

Option 1: Control Gain Computations only. This involves computing optimal feedback gains for various choices of cost functional weightings. It is used to get a "feel" for closed-loop system dynamics, pole locations, etc., and to select a nominal set of weightings for subsequent analysis.

Option 2: Full Steady-State Analysis. This is the major use of PIREP and involves computing closed-loop RMS responses via the feedback system consisting of Kalman filter, predictor and feedback gains. Frequency domain measures are also available as outputs.

The input cards/data required by each of these options are described subsequently. In general, the input consists of a title card (alphanumeric), followed by standard Fortran Namelist input cards. The Namelist data is a free-format input, using all but column 1 of the data card, and can be continued from card to card with data elements separated by a comma. The Namelist begins with $PIRDAT and concludes with the next subsequent $. The program is organized so that multiple runs are possible. On any run one can change any or all of the basic input parameters.

5.1 TITLE CARD

80 columns of alphanumeric data which will be printed as a header for each page of output.

5.2 OPTION 1: GAIN COMPUTATIONS ONLY

Three classes of input data are required as follows:

5.2.1 CLASS 1: INITIALIZATION

- Control Switch

  KTRG = ±1

  If KTRG = +1, PIREP reads all input data in Namelist form. If KTRG = -1, PIREP will call a user-furnished subroutine SYSMAT to generate the Class 2, System Dynamics input data. SYSMAT reads formatted input data which appears after the Namelist input data.

- Dimension Information:

NX = total number of states > 0

NX1 = number of noise-shaping states > 0
(These must be the first states in the A matrix.)

NU = number of controls > 0

NW = number of input driving noises ≥ 0

NY = number of displayed outputs ≥ 0

- Constraints:

$NX + NU \leq 20$

$NW \leq 4$

$NY + NU \leq 20$

5.2.2 CLASS 2: SYSTEM DYNAMICS

There are 4 possible sets of class 2 input data corresponding to the 4 parameter matrices A, B, C, D. It is necessary to input only those matrices that are to be changed. Otherwise, the most recent values are retained. Thus, the first time a problem is run, all matrices should be input for initialization. If KTRG = -1, these inputs are obtained from a user-provided subroutine entitled SYSMAT.

Matrix	Dimensions
A	(NX, NX)
B	(NX, NU)
C	(NY, NX)
D	(NY, NU)

5.2.3 CLASS 3: COST FUNCTIONAL WEIGHTINGS

There are 4 possible sets of Class 3 inputs corresponding to the 4 sets of cost weightings QX, QY, QU, and QR. It is necessary to input only those sets of weightings that one wishes to change. Unchanged items retain their most recent values. The first time a problem is run, all weightings should be input. Also no element of QR may be zero.

Vector	Dimensions
QX	NX
QY	NY
QU	NU
QR	NU

5.2.4 EXAMPLE DATA DECK FOR PIREP - OPTION 1

```
TEST CASE  FOR K/S DYNAMICS - OPTION 1      QR = 1
$PIRDAT   KTRG = 1,   NX = 2,   NX1 = 1,   NU = 1,   NW = 1,
NY = 1,   A(1,1) = -2.0,   1.0,   A(1,2) = 2* 0.0,
B(1,1) = 0.,   1.,   C(2,1) = 1.0,   C(1,2) = 1.0,
D(2,1) = 1.0,   E(1,1) = 1.0,
QX(1) = 2*0.,   QY(1) = 1.0,   0.0,
QU(1) = 0.,   QR(1) = 1.0   $

TEST CASE FOR K/S DYNAMICS - OPTION 1      QR = .04
$NAM1   QR(1) = 0.04   $

TEST CASE FOR K/S DYNAMICS - OPTION 1      QR = .0004
$NAM1   QR(1) = 0.0004   $
(End of File Card)
```

5.3 OPTION 2: STEADY-STATE ANALYSIS

There are ten classes of input data associated with Option 2. The first nine are necessary; the remaining one is optional and is called using only break point features as explained below.

5.3.1 CLASS 1: INITIALIZATION

- Control Switches:

  KTRG = ±2

  If KTRG = -2, the System Dynamics matrices (Class 2) will be generated by the user-provided subroutine SYSMAT. Otherwise the matrix entries are read in Namelist form.

  ICODE = 1,...10 (except first run)

  ICODE can be used on second and subsequent runs to cause program transfer to any input class 1 - 10. This allows intermediate data and calculations to be bypassed.

5.3.2 CLASS 2: SYSTEM DYNAMICS

These cards are nearly identical in form to those described in Section 5.2.2, with addition of the Matrix E which has dimensions NX by NW. However, for subsequent analysis, the C and D matrices should have the outputs grouped in position velocity pairs (e.g., $y_1 = h$, $y_2 = \dot{h}$, $y_3 = \theta$, $y_4 = \dot{\theta}$, etc). If KTRG = -2 in Class 1, the 5 matrices A, B, C, D, E are assumed to be generated by the user-provided subroutine SYSMAT.

5.3.3 CLASS 3: COST FUNCTIONAL WEIGHTINGS

These inputs are identical to those described in Section 2.3 for reading in the cost weightings QX, QY, QU, QR. However, in Option 2, the user has the choice of indicating whether the control gains are to be computed optimally according to the supplied set of weightings, or to be read as input.

IDENTW: Indicates whether gains are to be computed or read-in
= 0 (for gains computation), or

= 1 (for external read-in of gains)

If the gains are being computed by the program (IDENTW = 0) no further input need be supplied for Class 3. The resulting gains LOPT will be printed along with the time-constant matrix TN.

The gain matrix LOPT and the time constant matrix TN may be read as input if IDENTW = 1. This is a useful feature if the gains have been computed previously, since the solution of a Riccati Equation is bypassed. In this case, the NU by NX gain matrix LOPT and the NU by NU time constant matrix TN are entered via Namelist PIRDAT. No further input is required for Class 3 once LOPT and TN have been read.

5.3.4 CLASS 4: CONTROLLER TIME DELAY

T = controller time delay in seconds

5.3.5 CLASS 5: PROCESS OR DRIVING NOISE (NW VALUES)

W0 = variances of process or driving noise sources

5.3.6 CLASS 6: ADDITIVE MOTOR NOISE (NU VALUES)

VU = variances of additive motor noises

5.3.7 CLASS 7: OBSERVATIONAL THRESHOLDS (NY VALUES)

TH = indifference thresholds for observations

5.3.8 CLASS 8 OBSERVATION NOISE

$$\text{IDENTY} = \begin{cases} 1 - \text{indicates observation noise is additive} \\ 2 - \text{indicates observation noise is multiplicative} \end{cases}$$

The remaining Class 8 data depends on the selected value of IDENTY. if

IDENTY = 1:

VY = covariance of additive observation noises (NY values)

If IDENTY = 2 (the more common case), additional inputs are possible:

VY = multiplicative observation noise ratios in dB (NY values)

IDENTP =
- 0 - initial values of noise covariances are zero
- 1 - initial values of noise covariances are input as PY0

PY0 = initial conditions on the multiplicative observation noise covariances for the iteration on variance adjustments (NY values). These can be zero, but reasonable initial guesses (e.g. the square of the respective threshold levels) will reduce computation time.

5.3.9 CLASS 9: ATTENTION ALLOCATION FOR CONTROL (NY VALUES)

IDENTA =
- 0 - indicates fractional attentions are to be those actually input, with no further optimization.
- 1 - to optimize attention allocations treating each output as independent, while constraining the total attention to be constant.
- 2 - to optimize attention allocations treating the outputs in dependent position-velocity pairs. The total attention is held constant.

ATTN = initial attention allocation among display outputs (NY values)

GAMC = 0 or 1 (NY values) to indicate whether the corresponding observation is to be considered in the attention allocation optimization. Not applicable if IDENTA = 0.

If one of the optimization triggers (IDENTA = 1 or 2) are selected, the input attention allocations are used as initial conditions for the optimization algorithms. All subsequent iterations generated by the program maintain constant total attentional allocation as determined by the input data. If IDENTA = 2, outputs will be paired to have the same attentional allocation, since both position and velocity are being obtained simultaneously from a single display indicator.

All of the above nine classes of input data are required by PIREP for operation. Upon reading the data of Class 9, the steady-state closed-loop RMS measures are computed along with cost gradients and optimal attentional allocation (if specified). After completing the various computations initiated by Class 9, PIREP returns to read in another title card and the Namelist PIRDAT. An end-of-file will terminate the job, or the Class 1 input switch ICODE can be read in to cause program transfer to any input Class 1-10. Besides transferring back to any of the above points 1-9 for purposes of changing input parameter values, a tenth class of input is available as described below. The optional class is triggered only by user request, and only on the second or subsequent occurrences of Namelist PIRDAT.

5.3.10 CLASS 10: FREQUENCY DOMAIN REPRESENTATION

If ICODE = 10 in Namelist PIRDAT, the program will perform a frequency domain analysis using subroutine FDREP. In this case an additional Namelist FRQDAT must be provided with the following data.

A. Describing function parameters.

Various frequency domain representations can be computed for a man-machine system. Each of these characterizes some aspect of the overall modeling problem, and FDREP produces outputs for the different options according to the value assigned to JX.

JX = 1 - Internal describing function, I_{ij}:

The component I_{ij} is the human transfer function between the displayed quantity y_i and vehicle input (i.e., human output) u_j. This transfer function treats each output independently, i.e., at an information level, and does not consider the simultaneous perception of indicator position and rate.

JX = 2 - Multiple describing function, M_{ijk}:

These are transfers between a given output y_j plus its derivative $y_k = \dot{y}_j$ and the human's control input u_i. These quantities are appropriate when one wants the transfer between a given physically displayed quantity and the control. For outputs ordered in position/velocity pairs, $k = j + 1$.

JX = 3 - Equivalent describing function, E_{ijk}:

These transfer functions are defined, relative to a given input disturbance, w_k, as the ratio of the transfer function between input u_i and noise w_k to the transfer function between output y_j and noise w_k.

JX = 4 - Vehicle describing function, V_{ij}:

This is the transfer function between input u_i and output y_j for the vehicle being controlled. Outputs are treated independently, ignoring any position-velocity pair relationships, as this is not appropriate to the vehicle dynamics.

JX = 5 - Composite describing function, C_{jk}:

For single indicator/display systems this describing function is equal to the single-axis Y_pY_c found in the early man-machine literature. For multi-loop systems it is equivalent to an "outer-loop" describing function. In the closed-loop system we open the loop on a given indicator containing position information y_j and rate information $y_k = \dot{y}_j$. The main use of C_{jk} is to determine the phase and gain margin of the given loop closure.

JX = 0 - Bypass describing function computations.

MU = control index in describing function (set to zero if JX = 5)

MY1 = first output index in describing function

MY2 = second output index in describing function. Set to zero if JX = 1, 3 or 4 or if the derivative of output MY1 is not an output.

MW = driving noise index for use in equivalent describing function. Assumed to be 1 if not supplied.

B. Spectrum Parameters

$$JS = \begin{cases} 1 - \text{State spectrum} \\ 2 - \text{Output spectrum} \\ 3 - \text{Control spectrum} \\ 0 - \text{Bypass spectrum computations} \end{cases}$$

MS = index for spectrum

Spectra outputs, if requested, present the total power (in dB) correlated parts for each of the NW driving noises, and the uncorrelated part or remnant.

C. Specification of Discrete Frequencies

F = Discrete Frequencies for computations in Hertz (16 values)

This is used only to <u>change</u> the existing set of frequencies. F(1) and F(16) must be the smallest and largest frequencies, respectively. If less than 16 frequencies are desired, leave some of the <u>middle</u> fields blank. The default frequencies are: .06, .13, .25, .5, 1, 1.5, 2, 2.8, 4, 5.7, 8, 11, 16, 22, 32, 40 Hz.

Note that a single "call" to Subroutine FDREP can generate at most one describing function and one spectrum. If one wishes several describing functions and/or several spectra, several successive Class 10 transfers are necessary. After performing the Class 10 request, the program expects a new title card and Namelist PIRDAT, and the cycle repeats. To terminate the job read an end-of-file card.

5.3.11 EXAMPLE DATA DECK FOR PIREP - OPTION 2

```
TEST CASE FOR K/S DYNAMICS - OPTION 2. RMS PERFORMANCE.
$PIRDAT KTRG = 2, NX = 2, NX1 = 1, NU = 1, NW = 1, NY = 1,
        A(1,1)   =   -2.0, 1.0,   A(1,2)   =   2*0.0,
        B(1,1)   =   0., 1.,      C(2,1)   =   1.0,     C(1,2)   =   1.0,
        D(2,1)   =   1.0,         E(1,1)   =   1.0,
        QY(1)    =   1.0, 0.0,    QX(1)    =   2*0.,
        QU(1)    =   0.,          QR(1)    =   .0004,
        IDENTW   =   0,           T        =   0.2,
        W0(1)    =   4.0,         VU(1)    =   0.02,
        TH(1)    =   2*0.0,
        VY(1)    =   2*-20.,      VYA(1)   =   2*0.,
        IDENTA   =   0,
        ATTN(1)  =   2*1.0,       PYO(1)   =   2*1.0    $
```

```
TEST CASE FOR K/S DYNAMICS - OPTION 2.  EQUIV. D.F. & OUTPUT SPECTRUM.
$PIRDAT   ICODE = 10    $
$FRQDAT   JX  = 3,   MU = 1,   MY1 = 1,   MY2 = 0,   MW = 1,
          JS  = 2,   MS = 1  $
TEST CASE FOR K/S DYNAMICS - OPTION 2.  COMPOSITE D.F. & CONTROL SPECTRUM.
$PIRDAT   ICODE = 10   $
$FRQDAT  JX  = 5,   MU = 0,   MY1 = 1,   MY2 = 2,   MW = 1,
         JS  = 3,   MS = 1  $
(End-of-File)
```

SECTION VI

SUGGESTIONS AND COMMENTS

This section contains several suggestions and comments to assist the user in running the program and in understanding and interpreting the results. Guidelines for specifying the model parameters to represent a given simulation situation are described in Volume I and will not be repeated here.

The execution time required for the program can vary greatly depending upon the complexity of the system and the desired outputs. The number of states, controls, and display outputs should be kept as small as possible to reasonably represent the situation under evaluation. For this reason it is often desirable to decouple the longitudinal and lateral motions of the aircraft. Requesting the program to optimize the attention allocation will also increase the running time by a substantial margin if the initial attention guesses are far from the optimum values. Likewise, requesting frequency response outputs will also increase the execution time, although this is a relatively modest increase. The user can often reduce the execution time by specifying initial conditions on the multiplicative observation noise covariances as mentioned in Section 5.3.8. Usually, reasonable initial values are the squares of the respective observational noise thresholds. To illustrate the order of magnitude of the execution time the sample run presented in Section 7 required 127 seconds of central processor time.

One use for the program will be to show the differences in pilot performance with and without motion. This can be most readily accomplished by proper ordering of the system states and the observations. The motion system dynamics and vestibular dynamics should be made the last states in the system equations and the vestibular inputs should similarly be placed at the end of the observation vector. Then by merely changing the dimension indices NX and NY (Section 5.2.1), the motion effects and corresponding vestibular inputs can be neglected. Changing the motion system dynamics will require adjustments to the appropriate elements of the matrices A and B. If a large number of variations is desired, this can best be accomplished by setting KTRG = -1, and providing a user-written subroutine SYSMAT to define the system matrices. (See Section 5.2.1.)

The most common program outputs are the RMS model predictions, which are illustrated in the sample run in Section 7. The program prints the RMS values of each of the state elements and each of the observations. The actual observation noise and its effective value (adjusted for fraction of attention) are given, along with the noise-to-signal ratio in dB and the fraction of attention in percent. The RMS control and control-rate inputs are also presented and the associated additive motor noise (RMS and dB). The program also prints the estimator gains of the human operator's Kalman filter.

The system performance is indicated by several metrics. The total cost is the value of the complete quadratic performance index J (u), given in Equation B-7 of Volume I. The "scanning" cost is that portion of the basic cost functional which depends upon the fraction of attention f_i. This is the portion of the total cost that is minimized to obtain the optimal attention allocation. (See Section B.3 in Volume I.) Finally the performance cost is that portion of the total cost which neglects the contribution of the control and control rate terms; this is the cost that is used to compare overall system performance. The gradient of the cost with respect to the attention on each observation indicates the relative incremental importance of each instrument; that is, if the pilot has some spare capacity he would allocate it first to the instrument with the largest gradient. The gradients also can be used to determine whether the operator is using an instrument primarily for displacement information or for rate information.

A number of informative or diagnostic messages may be produced by the program. These generally are caused by improper program inputs, an ill-conditioned system (e.g. unobservable or uncontrollable states), or numerical inaccuracies and computer roundoff. For example, if an observation threshold is very small relative to the RMS value of the observation, the describing function calculation in subroutine XGAIN will result in an "argument too small" error printed out by the system exponent routine. If the program output indicates that maximum iterations were reached in the observation noise calculation or the attention allocation optimization, the program can be rerun using the latest values of the observation noise or attention allocation as initial conditions. Some states may be unobservable or uncontrollable, such as the disturbance shaping states, and the program will produce an informative diagnostic that the grammian and/or Ricotti solution are of reduced rank.

SECTION VII

SAMPLE RUN

The sample case used to illustrate the inputs and outputs of Program PIREP is the C-135B Low Visibility Approach Simulation discussed in Section 5.2 of Volume I. Figure 1 shows the input data for the sample run, and Figure 2 presents the resulting output listing obtained from a remote terminal.

```
FAA LOW-VISIBILITY DATA--LONGITUDINAL
 $PIRDAT ICODE=1,KTRG=2,NX=18,NX1=4,NU=1,NW=2,NY=13,
 A(1,1)=-.219, A(5,1)=.03632,0.,.2553,0.,0.,-.0006349,
 A(3,2)=.592,.00355, A(10,2)=.0007198,
 A(2,3)=-.592,-1.18,-.00708,-.09922,0.,.6274,0.,0.,.00246,
 A(4,4)=-1.4, A(10,4)=.7167,
 A(6,6)=-.000001,
 A(5,5)=-.03632,.025,-.2553,0.,0.,.0006349, A(17,5)=-.005,
 A(5,7)=.09922,.9997,-.6274,3.33,0.,-.003899,
 A(16,7)=.0207,-.1999,
 A(8,8)=-3.33, A(16,8)=-.0207,
 A(5,9)=-32.164,0.,.8068,0.,0.,-.00098, A(18,9)=-3.82,
 A(5,10)=-6.358,
 A(7,10)=233.,0.,1.,-1.,0.,2.,0.,2.,-.0932,-.7708,
 A(15,11)=.1999,-.00502,
 A(11,12)=1.,-2.,0.,-2.,.0932,.7708,
 A(14,13)=-.001852, A(13,14)=1.,-.08888,
 A(15,15)=-.2, A(16,16)=-.2, A(17,17)=-2.,.0667, A(18,18)=-.0667,
 B(5,1)=-.4686,0.,-7.269,0.,0.,-.8928,
 E(1,1)=1.66, E(2,2)=1.27,2.19,.0131, E(10,2)=.00266,
 C(8,1)=15.318, C(8,3)=37.64, C(8,4)=-13980.,
 C(6,5)=-.025,1.5,-15.318,0.,.00355,
 C(3,6)=.0109,0.,-1., C(9,6)=.0525,
 C(4,7)=.0109,0.,-.9997,59.98,-37.64,0.,.2525, C(13,7)=.2095,
 C(13,8)=-.2095,
 C(1,9)=57.3, C(8,9)=48.408,57.3,3.82,
 C(2,10)=57.3, C(8,10)=13980.,0.,57.3,.0139,-.944,-7.8,
 C(12,11)=2.0229,-.0508,
 C(11,12)=-.0139,.944,7.8,
 C(11,13)=.00001289, C(11,14)=.3479,
 C(12,15)=-1.024, C(13,16)=-1.024,
 C(9,17)=-1.,2.0667, C(9,18)=1.,-.0667,
 D(8,1)=-436.14,
 QY(1)=.04,.16,4.,196.,.0004,.02,.000025,.0011,.0625,.25,
 QR(1)=50.,
 T=.2,IDENTW=0,W0(1)=2*1.,
 IDENTU=2,VU(1)=-25., IDENTY=2,VY(1)=10*-20.,3*-18.,
 TH(1)=2.,1.,.1,.05,20.,3.,50.,7.,1.,.2,.57,.015,.015,
 IDENTP=1,PY0(1)=24128.,148580.,.1213,46.69,97290.,1781.,6959.,
  451.6,1.360,.0387,.091698,.00009708,.0003926,
 GAMC(1)=10*1.,3*0.,
 IDENTA=2, ATTN(1)=6*.02,2*.07,2*.37,3*1. $
```

Figure 1. Sample Run Input Data.

```
PROGRAM PIREP:FAA LOW-VISIBILITY DATA--LONGITUDINAL


          NO. OF STATES               18
          NOISE SHAPING STATES         4
          NO. OF CONTROLS              1
          NO. OF NOISE SOURCES         2
          NO. OF OUTPUTS              13
          KTRG                         2


           SYSTEM DYNAMICS ARE: XDOT=AX+BU+EW,         Y=CX=DU

       A   MATRIX:

  -.2190        0.          0.          0.           0.              0.
                0.          0.          0.           0.              0.
                0.          0.          0.           0               0.
                0.          0.

    0.          0.         -.5920       0.           0.              0.
                0.          0.          0.           0.              0.
                0.          0.          0.           0.              0.
                0.          0.

    0.          .5920      -1.180       0.           0.              0.
                0.          0.          0.           0.              0.
                0.          0.          0.           0.              0.
                0.          0.

    0.         3.5500E-03  -7.0800E-03  -1.400       0.              0.
                0.          0.          0.           0.              0.
                0.          0.          0.           0.              0.
                0.          0.

   3.6320E-02   0.        -9.9200E-02   0.         -3.6320E-02       0.
               9.09220E-02  0.         -32.16       -6.358           0.
                0.          0.          0.           0.              0.
                0.          0.

    0.          0.          0.          0.          2.5000E-02     -1.0000E-06
                .9997       0.          0.           0.              0.
                0.          0.          0.           0.              0.
                0.          0.
```

Figure 2. Sample Run Output Listing.

```
  .2553       0.              .6274       0.           -.2553         0.
             -.6274           0.          .8068         233.0         0.
              0.              0.          0.            0.            0.
              0.              0.

  0.          0.              0.          0.            0.            0.
              3.330          -3.330       0.            0.            0.
              0.              0.          0.            0.            0.
              0.              0.

  0.          0.              0.          0.            0.            0.
              0.              0.          0.            1.000         0.
              0.              0.          0.            0.            0.
              0.              0.

-6.3490E-04   7.1980E-04     2.4600E-03   .7167        6.3490E-04     0.
            -3.8990E-03       0.        -9.8000E-04    -1.000         0.
              0.              0.          0.            0.            0.
              0.              0.

  0.          0.              0.          0.            0.            0.
              0.              0.          0.            0.            0.
              1.000           0.          0.            0.            0.
              0.              0.

  0.          0.              0.          0.            0.            0.
              0.              0.          0.            2.000         0.
             -2.000           0.          0.            0.            0.
              0.              0.

  0.          0.              0.          0.            0.            0.
              0.              0.          0.            0.            0.
              0.              0           1.000         0.            0.
              0.              0.

  0.          0.              0.          0.            0.            0.
              0.              0.          0.            2.000         0.
             -2.000         -1.8520E-03 -8.8880E-02     0.            0.
              0.              0.

  0.          0.              0.          0.            0.            0.
              0.              0.          0.          -9.3200E-02     .1999
             9.3200E-02       0.          0.           -.2000         0.
              0.              0.

  0.          0.              0.          0.            0.            0.
             2.0700E-02     -2.0700E-02   0.           -.7708       -5.0200E-03
              .7708           0.          0.            0.           -.2000
              0.              0.
```

Figure 2. Sample Run Output Listing (Continued).

```
  0.           0.            0.           0.         -5.0000E-03     0.
              -.1999         0.           0.           0.            0.
               0.            0.           0.           0.            0.
              -2.000         0.

  0.           0.            0.           0.           0.            0.
               0.            0.          -3.820        0.            0.
               0.            0.           0.           0.            0.
              6.6700E-02  -6.6700E-02


PROGRAM PIREP:FAA LOW-VISIBILITY DATA--LONGITUDINAL



         OPEN-LOOP EIGENVALUES:
                -3.330        0.        J
                -.8150        .9365     J
                -.8150       -.9365     J
                -2.000        0.        J
                -.1687E-01    .1699     J
                -.1687E-01   -.1699     J
                -.2190        0.        J
                -.2000        0.        J
                -.6670E-01    0.        J
                -.5553E-01    0.        J
                -.9998E-06    0.        J
                -.3335E-01    0.        J
                -2.000        0.        J
                -1.400        0.        J
                -.5900        .4862E-01 J
                -.5900        .4862E-01 J
                -.2000        0.        J
                 .9721E-12    0.        J



    B   MATRIX:

  0.

  0.

  0.

  0.
```

Figure 2. Sample Run Output Listing (Continued).

```
-.4686
 0.
-7.269
 0.
 0.
-.8928
 0.
 0.
 0.
 0.
 0.
 0.
 0.
 0.

   C  MATRIX:

PROGRAM PIREP:FAA LOW-VISIBILITY DATA--LONGITUDINAL

 0.           0.          0.          0.          0.              0.
              0.          0.          57.30       0.              0.
              0.          0.          0.          0.              0.
              0.          0.

 0.           0.          0.          0.          0.              0.
              0.          0.          0.          57.30           0.
              0.          0.          0.          0.              0.
              0.          0.

 0.           0.          0.          0.          0.          1.0900E-02
              0.          0.          0.          0.              0.
              0.          0.          0.          0.              0.
              0.          0.
```

Figure 2. Sample Run Output Listing (Continued).

```
0.          0.          0.           0.          0.            0.
           1.0900E-02   0.           0.          0.            0.
            0.          0.           0.          0.            0.
            0.          0.

0.          0.          0.           0.          0.           -1.000
            0.          0.           0.          0.            0.
            0.          0.           0.          0.            0.
            0.          0.

0.          0.          0.           0.        -2.5000E-02     0.
           -.9997       0.           0.          0.            0.
            0.          0.           0.          0.            0.
            0.          0.

0.          0.          0.           0.          1.500         0.
            59.98       0.           0.          0.            0.
            0.          0.           0.          0.            0.
            0.          0.

15.32       0.          37.64      -1.3980E+04  -15.32         0.
           -37.64       0.           48.41      1.3980E+04     0.
            0.          0.           0.          0.            0.
            0.          0.

0.          0.          0.           0.          0.           5.2500E-02
            0.          0.           57.30       0.            0.
            0.          0.           0.          0.            0.
           -1.000       1.000

0.          0.          0.           0.         3.5500E-03     0.
            .2525       0.           3.820       57.30         0.
            0.          0.           0.          0.            0.
            2.067     -6.6700E-02

0.          0.          0.           0.          0.            0.
            0.          0.           0.         1.3900E-02     0.
          -1.3900E-02  1.2890E-05    .3479       0.            0.
            0.          0.

0.          0.          0.           0.          0.            0.
            0.          0.           0.         -.9440         2.023
            .9440       0.           0.         -1.024         0.
            0.          0.

0.          0.          0.           0.          0.            0.
            .2095      -.2095        0.         -7.800       -5.0800E-02
            7.800       0.           0.          0.           -1.024
            0.          0.
```

Figure 2. Sample Run Output Listing (Continued).

```
      D  MATRIX:
     0.
     0.
     0.
     0.
     0.
     0.
     0.
   -436.1
     0.
     0.
     0.
     0.
     0.


       E  MATRIX:
1 PROGRAM PIREP:FAA LOW-VISIBILITY DATA--LONGITUDINAL

    1.660       0.
    0.          1.270
    0.          2.190
    0.        1.3100E-02
    0.          0.
    0.          0.
    0.          0.
```

Figure 2. Sample Run Output Listing (Continued).

```
  D  MATRIX:

 0.
 0.
 0.
 0.
 0.
 0.
 0.
-436.1
 0.
 0.
 0.
 0.
 0.
  E  MATRIX:

PROGRAM PIREP:FAA LOW-VISIBILITY DATA--LONGITUDINAL


 1.660       0.
 0.          1.270
 0.          2.190
 0.         1.3100E-02
```

Figure 2. Sample Run Output Listing (Continued).

```
 0.            0.
 0.            0.
 0.            0.
 0.            0.
 0.            0.
 0.           2.6600E-03
 0.            0.
 0.            0.
 0.            0.
 0.            0.
 0.            0.
 0.            0.
 0.            0.
 0.            0.

          COST FUNCTIONAL WEIGHTINGS
        STATE

 0.            0.            0.            0.            0.            0.
               0             0.            0.            0.            0.
               0.            0.            0.            0.            0.
               0.            0.
      OUTPUT
4.0000E-02     .1600         4.000         196.0         4.0000E-04    2.0000E-02
              2.5000E-05    1.1000E-03    6.2500E-02     .2500         0.
               0.            0.
    CONTROL

 0.
```

Figure 2. Sample Run Output Listing (Continued).

```
     CT.RATE

   50.00
 GRAMMIAN IS15X15 OF RANK  8
 RICCATI SOLN IN 12 ITERATIONS
 RICCATI SOLN IS PSD--RANK  9

  FEEDBACK CONTROL IS TN.UDOT+U=-LOPT.X, WHERE OPTIMAL GAINS(LOPT):

 -5.5367E-03 -6.6794E-04  -1.4294E-02   3.790      5.6961E-03  -4.6334E-04
              1.2194E-02  -4.5790E-12  -.1897      -5.397        5.0829E-12
             -2.1380E-08   5.9030E-10  2.1021E-08  1.2302E-08    6.9238E-10
             -8.5880E-04  -7.7962E-04

     TN MATRIX:

   .1012

          EIGENVALUES:
                  .1012     0.

  FEEDBACK CONTROL IS ALSO UDOT=-LX(X)-LU(U) WHERE 00  PTIMAL GAINS, LX,L
U:

 -5.4694E-02  -6.5983E-03   -.1412       37.44      5.6269E-02  -4.5771E-03
                .1205      -4.5233E-11  -1.874      -53.32        5.0212E-11
              -2.1120E-07   5.8312E-09  2.0766E-07  1.2153E-10    6.8397E-09
              -8.4836E-03  -7.7015E-03   9.878

 PROGRAM PIREP:FAA LOW-VISIBILITY DATA--LONGITUDINAL
```

Figure 2. Sample Run Output Listing (Continued).

```
       CLOSED-LOOP EIGENVALUES:       J
              -5.595       5.426      J
              -5.595      -5.426      J
              -3.330       0.         J
              -2.005       0.         J
              -2.000       0.         J
              -1.400       0.         J
              -.5406E-01   .1756      J
              -.5406E-01  -.1756      J
              -.2190       0.         J
              -.1163       .2403E-01  J
              -.1163      -.2403E-01  J
              -.7457E-01   0.         J
              -.3335E-01   0.         J
              -.5553E-01   0.         J
              -.5900       .4862E-01  J
              -.5900      -.4862E-01  J
              -.2000       0.         J
              -.2000       0.         J
               .2793E-10   0.         J

       CONTROLLER TIME DELAY:       .200

       VARIANCE OF RANDOM TURBULENCE:

 1.000     1.000

      MOTOR NOISE:
                      (RATIOS IN DB)
-25.00

      OBSERVATIONAL THRESHOLDS:

 2.000     1.000       .1000     5.0000E-02    20.00          3.000
           50.00      7.000       1.000        .2000          .5700
          1.5000E-02  1.5000E-02

      SENSOR NOISE:
                      (RATIOS IN DB)

-20.00    -20.00      -20.00      -20.00      -20.00         -20.00
          -20.00      -20.00      -20.00      -20.00         -18.00
          -18.00      -18.00
```

Figure 2. Sample Run Output Listing (Continued).

```
    ATTENTIONAL ALLOCATION:

  2.0000E-02  2.0000E-02  2.0000E-02   2.0000E-02   2.0000E-02   2.0000E-02
              4.5000E-02  4.5000E-02    .3950        .3950        1.000
               1.000       1.000
RICCATI SOLN IN 14 ITERATIONS
RICCATI SOLN IS PSD--RANK 17
ARGUMENT TOO SMALL
ERROR NUMBER   0030 DETECTED BY EXP
CALLED FROM XGAIN   AT  LINE 16
CALLED FROM PIREP   AT  LINE 309
RICCATI SOLN IN 13 ITERATIONS
RICCATI SOLN IS PSD--RANK 18
ARGUMENT TOO SMALL
ERROR NUMBER   0030 DETECTED BY EXP
CALLED FROM XGAIN   AT LINE 16
CALLED FROM PIREP   AT LINE 309
RICCATI SOLN IN  2 ITERATIONS
RICCATI SOLN IS PSD--RANK 18
ARGUMENT TOO SMALL
ERROR NUMBER   0030 DETECTED BY EXP
CALLED FROM XGAIN   AT LINE 16
CALLED FROM PIREP   AT LINE 309


PROGRAM PIREP:FAA LOW-VISIBILITY DATA--LONGITUDINAL


RICCATI SOLN IN  2 ITERATIONS
RICCATI SOLN IS PSD--RANK 17
ARGUMENT TOO SMALL
ERROR NUMBER   0030 DETECTED BY EXP
CALLED FROM XGAIN   AT LINE 16
CALLED FROM PIREP   AT LINE 309

    URMS AND MOTOR NOISE VARIANCE

 8.4559E-03

 7.1028E-07

 7.1035E-07
```

Figure 2. Sample Run Output Listing (Continued).

```
     YRMS AND NOISE VARIANCE AT ITERATION  4)
  .7299       .2820       .1068      1.6624E-02      9.797     1.508
              90.50       32.96       .7955          .3849      1.3525E-03
             2.0560E-02  7.4545E-02

 2.2157E+04  1.2492E+05   .1470       62.52        8.8719E+04   1636.
             1.6958E+04   1096.       1.155        3.2361E-02  9.1059E-02
             9.7038E-05  3.9160E-04

 2.2140E+04  1.2495E+05   .1470       62.46        8.8668E+04   1635.
             1.6958E+04   1096.       1.154        3.2364E-02  9.1078E-02
             9.7039E-05  3.9162E-04
ARGUMENT TOO SMALL
ERROR NUMBER   0030 DETECTED BY EXP
CALLED FROM GRAD    AT  LINE 43
CALLED FROM PIREP   AT  LINE 366

    COST GRADIENT WRTO F:

-7.4693E-07 -1.3267E-06  -.1277    -1.6666E-06 -1.7799E-03 -5.3387E-04
            -8.2388E-02  -.1507    -2.0398E-02  -.4265     -1.2317E-07
            -4.2801E-03  -.1375

    TOTAL COST, J(U)=  1.838        SAMPLING COST=  .9655

         OPTIMAL ESTIMATOR GAINS:


PROGRAM PIREP:FAA LOW-VISIBILITY DATA--LONGITUDINAL


-8.9403E-06 -9.1135E-07  8.4356E-02  6.2153E-05 -1.2820E-05 -2.3715E-04
             1.3725E-03  7.1820E-03 -6.3054E-02  -3.168     -5.7072E-03
             -43.83       23.65

 4.1072E-07  6.7587E-07  1.1325E-02  3.5044E-05 -1.7212E-06 -1.2266E-04
             7.0989E-04 -2.1454E-03  2.1737E-02   3.612      1.6696E-03
             -11.05       26.97

 4.5407E-07  1.1661E-06  7.1253E-02  8.5161E-05 -1.0829E-05 -2.9828E-04
             1.7262E-03 -3.4171E-03  7.3073E-02   6.462      2.9516E-03
             -20.66       47.49
```

Figure 2. Sample Run Output Listing (Continued).

```
 3.6807E-09   5.4754E-09  -1.5119E-04  7.5079E-08   2.2977E-08  -2.6104E-07
              1.5107E-06  -3.4765E-05 -4.2936E-05   2.6712E-02   1.0848E-05
             -8.8901E-02    .1756

-2.8537E-06   1.0155E-07   6.5156E-02 -5.4730E-06  -9.9024E-06  -7.4258E-06
              4.2980E-05  -1.5907E-03  4.3023E-02  -9.7853E-02   8.2179E-04
             -10.50       -5.897

-1.0225E-05  -6.6614E-07  1.810        2.3453E-04  -2.7514E-04  -8.3553E-04
              4.8355E-03  -2.2799E-03   1.021       -1.694      -2.0404E-03
             -45.90       -29.52

-5.5998E-07   1.0243E-07   9.9762E-02  8.5964E-05  -1.5162E-05  -3.0085E-04
              1.7411E-03   2.6114E-03  7.8138E-02   1.548        5.4603E-04
             -6.423         19.37

-8.5289E-07  -1.1185E-07    .1055      7.7615E-05  -1.6027E-05  -2.7177E-04
              1.5728E-03   6.0611E-04  7.5833E-02    .3407      -1.8091E-04
             -4.084         4.864

 3.3784E-08   1.7329E-09  -2.9323E-04 -3.7753E-08   4.4565E-08   1.4920E-07
             -8.6348E-07   1.1191E-05  3.6001E-04   9.0728E-03   9.3742E-06
                .1912      5.1344E-02

 9.7701E-09   4.0936E-09  -1.0771E-04  3.8935E-08   1.6369E-08  -1.3987E-07
              8.0944E-07   1.0619E-05  1.1853E-04   1.9987E-02   1.5252E-05
             -5.6536E-03    .1550

 2.9503E-08   8.1743E-10  -2.6610E-04 -4.7255E-08   4.0441E-08   1.8416E-07
             -1.0658E-06   4.6813E-06  2.9013E-04   4.5583E-03   4.4408E-06
                .1749      1.5112E-02

 8.5614E-09   1.8309E-09  -5.4262E-05  1.9004E-08   8.2467E-09  -6.9909E-08
              4.0459E-07   1.3019E-05  1.3976E-04   9.0290E-03   9.8669E-06
              3.2559E-02   7.2465E-02

 2.4077E-08   1.0449E-09  -1.6453E-04 -5.7854E-08   2.5006E-08   1.9965E-07
             -1.1554E-06   3.8316E-06  3.4057E-04   4.7448E-03   6.2600E-06
                .1549      1.1614E-02

 6.2962E-09   1.7407E-09  -3.7468E-05  2.4124E-08   5.6943E-09  -8.7846E-08
              5.0839E-07   1.2666E-05  1.1000E-04   8.6061E-03   9.3377E-06
              1.8268E-02   7.1373E-02

 1.0314E-08  -2.2535E-10  -1.5379E-04 -5.6081E-09   2.3373E-08   4.1106E-08
             -2.3790E-07   5.8771E-07 -1.9682E-06  -1.2356E-04  -2.2555E-06
              5.0202E-02   1.8062E-03

-1.5221E-09  -6.1624E-10   9.2903E-05  2.6695E-07  -1.4119E-08  -9.3338E-07
              5.4017E-06   1.4302E-06  1.2604E-04   6.3149E-04  -1.6153E-06
             -2.3328E-03   2.8479E-02
```

Figure 2. Sample Run Output Listing (Continued).

```
   1.0017E-07   1.4586E-08  -1.0792E-02  -7.3344E-06  1.6401E-06   2.5751E-0
               -1.4903E-04   4.8686E-06  -7.4985E-03 -8.1507E-03   3.5549E-0
                 .4168      -9.0083E-02

  -2.2388E-07   1.3039E-08  -1.6272E-03  -1.7543E-06  2.4730E-07   5.1701E-0
               -2.9921E-05  -3.2479E-05  -1.6542E-03  1.2681E-02   8.7088E-0
                -.8829       5.6533E-02

  -3.6797E-11  -1.1939E-10  -6.1114E-08  -9.7787E-10  9.2881E-12   3.4325E-0
               -1.9865E-08  -4.5070E-06  -7.8754E-07 -5.0134E-04  -1.5610E-0
                2.2468E-03   2.0441E-03


PROGRAM PIREP:FAA LOW-VISIBILITY DATA--LONGITUDINAL


                  RMS MODEL PREDICTIONS
INDEX       X            Y           VY           VYEFF       PY(DB)      FC (%)
 1      2.508        .7299        .9152        148.9        -3.0         .5
 2      .8561        .2820        .3534        353.4        -3.0         .5
 3      1.648        .1068        .1338        .3834        -3.0         .5
 4      .6238E-02    .1662E-01    .2084E-01    7.907        -3.0         .5
 5      3.020        9.797        12.28        297.9        -3.0         .5
 6      9.797        1.508        1.891        40.44        -3.0         .5
 7      1.525        90.50        75.62        130.2        -6.5        1.1
 8      1.476        32.96        27.54        33.10        -6.5        1.1
 9      .1274E-01    .7955        .2244        1.075       -16.0        9.9
10      .4922E-02    .3849        .1085        .1799       -16.0        9.9
11      .1258E-01    .1352E-02    .3018E-03    .3018       -18.0       25.0
12      .3953E-02    .2056E-01    .4588E-02    .9851E-02 -18.0       25.0
13      .1159E-01    .7455E-01    .1663E-01    .1979E-01 -18.0       25.0
14      .3879E-02    0.           0.           0.            0.0        0.0
15      .9212E-02    0.           0.           0.            0.0        0.0
16      .7678E-02    0.           0.           0.            0.0        0.0
17      .1405        0.           0.           0.            0.0        0.0
18      .2802        0.           0.           0.            0.0        0.0

            U            VU          PU(DB)        UDOT
   1      .8456E-02    .8428E-03    -25.00        .5373E-01

   TOTAL ATT'N= 4.00      TOTAL COST=    1.838          PERF.  COST=    1.694
             TIME     17.26.2      DATE              05/01/76

         ALL CASES PROCESSED
```

Figure 2. Sample Run Output Listing (Continued).

```
 EOR
1  CSB     SCOPE  3.4.3        CYBR-393H 03/08/76
 17.09.49.KF3K3PF    FROM   /K3
 17.09.49.IP  00000320 WORDS  - FILE INPUT   , DC 00
 17.09.49.KF3LG,T300,CM125000.  D760023,HOFFMAN,617
 17.09.49./272-7517.
 17.09.51.ATTACH,SBINOP1,PIREPFILES1,CY=5,MR=1.
 17.09.52.LDSET,PRESET=ZERO.
 17.09.53.SBINOP1.
 17.26.22.    STOP
 17.26.22.   126.938 CP  SECONDS EXECUTION TIME
 17.26.22.OP  00002624 WORDS - FILE OUTPUT   , DC 40
 17.26.22.MS    3584  WORDS  (        0 MAX USED)
 17.26.22.SCM 100000  WORDS MAXIMUM
 17.26.22.CPA    128.257 SEC.        46.146 ADJ.
 17.26.22.IO       1.914 SEC.         1.036 ADJ.
 17.26.22.CM    3442.217 KWS.        41.347 ADJ.
 17.26.22.CRUS                       88.531
 17.26.22.COST                $       3.24
 17.26.22.PP       3.599 SEC.      DATE 05/01/76
 17.26.22.EJ  END OF JOB, K3   D760023
..BYE

COMMAND- LOGOUT
```

Figure 2. Sample Run Output Listing (Continued).

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2. Kleinman, D.L.: A Description of Computer Programs Useful in Linear Systems Studies. TR-75-4, University of Connecticut, Department of Electrical Engineering, October 1975.

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