N 72 32041

NASA CONTRACTOR REPORT

NASA CR-112122

FLIGHT INSTRUMENTATION SPECIFICATION FOR PARAMETER IDENTIFICATION-USER'S GUIDE

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION · WASHINGTON, D.C. · MAY 1972

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May, 1972

SCIP2

FLIGHT INSTRUMENTATION SPECIFICATION

FOR PARAMETER IDENTIFICATION

USER'S GUIDE

Contract No. NAS 1-10791

Prepared for:

Langley Research Center
National Aeronautics and Space Administration
Hampton, Virginia 23365

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FOREWORD

The development of this program was supported under NASA Contract No. NAS 1-10791, by Langley Research Center, Hampton, Virginia. Project monitors were W. H. Bryant and W. F. Hodge. At Systems Control, Inc., the project engineers were J. D. Powell and J. A. Sorensen. Project programmers were G. Plevyak and N. Taniguchi. Project manager was J. S. Tyler, Jr.

The SCIP2 Program Documentation is divided into two sections: the User's Guide and the Program Description. Section I details the operation of the SCIP2 program with a brief general description and purpose of the program. Section II describes the program structure in detail. A summary of the equations coded in the program is found in the Appendix. An accompanying document, NASA CR-112121, contains the technical details of analytical techniques and a preliminary study which makes use of these techniques.

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I

INTRODUCTION

SCIP2 is a digital computer program which can be used to investigate the effects of instrumentation errors on the accuracy of aircraft stability and control derivatives identified from flight test data. The program is based on the assumptions that the aircraft differential equations of motion are linear and consist of small perturbations about a quasisteady flight condition. It is also assumed that a Newton-Raphson optimization technique is used for identifying the estimates of the parameters. The full theoretical development of the program equations appears in a companion document entitled "Analysis of Instrumentation Error Effects on the Identification Accuracy of Aircraft Parameters". A summary of the equations which are coded in the program are contained in the Appendix of this User's Guide.

The uses which can be made of SCIP2 include:

1. The determination of the effect of instrumentation errors on the statistical accuracy of the stability and control derivatives and other parameters identified from flight test data can be made. This includes the mean error and standard deviation of each of the parameters identified. The contribution of each error source on each parameter is determined.
2. The effects of such variables as aircraft type and flight condition, control input sequence, and data sampling rate on the accuracy of the identified parameters can be determined.
3. Tradeoff studies can be made between instrument quality and identification accuracy.
4. Different combinations of instruments can be studied for use in collecting the flight data.
5. Tradeoff studies between fewer instruments with greater quality and more instruments can be made.

6. The necessary instrument accuracy required in a flight test program to allow identifying aircraft parameters to a desired level of certainty can be specified.

II

PROGRAM EXECUTION INFORMATION

2.1 Machine Requirements

This program was developed on the UNIVAC 1108 machine and then converted to the CDC 6600. Thus, it may be executed on either machine with very little change.

2.2 Storage Requirements

It requires $(71,500)_8$ words to load and $(56,600)_8$ words to execute this program on the CDC 6600. This requirement results from compiling the program under FORTRAN 2.3 RUN COMPILER. The core requirement may be reduced by removing double precision arrays or by assigning a single buffer to two scratch files.

It is also possible to reduce core requirement by using the overlay feature of the SCOPE operating system and also by using blank commons in place of labeled commons.

2.3 Execution Time

The execution time for the program varies with the various options of the program. The shortest case will be the ESTIM=1 Short Period Ensemble Analysis without lag, and the largest will be the ESTIM=3 Lateral Simulated Data Analysis with lag.

It took 6.55 seconds of CPU time to execute a five second trajectory Short Period ESTIM=4 Ensemble Analysis without lag, whereas 14.28 seconds to execute the same case under MODE=1 of the Simulated Data Analysis.

The execution time increases if lag is present since it requires to integrate equations with a smaller integration step.

2.4 Multiple Case

The program allows execution of more than one case per job. This is accomplished by having sets of input data one after another. Each case starts with POD card (see Section 3.0).

III

INPUT ELEMENT DESCRIPTIONS

There are three methods for providing input data to the SCIP2 program:

1. By means of the BLOCK DATA subprogram,
2. By data card input at execution time, and
3. By a combination of 1. and 2. above.

3.1 Data Card Input

Data card input is optional except for the program options data (POD) card. All data not set in the BLOCK DATA subprogram or data to be changed may be flagged for input on the POD card. The required POD card has a fixed field format as follows: (A6,4X,30L1).

The POD card selects the error analysis type: ensemble (ENSMBL) or simulated data (SIMDAT). Card columns 11 through 40 are divided into 30 logical fields of length 1. If a T appears within one of these fields, then the option corresponding to that field is exercised. If the field is blank or contains an F, then that option is ignored. Fields 2 through 22 (card columns 11-32) are reserved for input options. Fields 23 through 30 are reserved for other program options.

Table 3.1 shows the correspondence between the input option field and the group of data controlled by the option.

3.2 Input Elements

Table 3.1 lists and describes the input groups (namelist identifier, if applicable), variables in each group, the unit, and the type of each variable.

"Card Field" gives the column number of the input option on the POD card. Blank under "Namelist Identifier" indicates fixed field data. Under "Type", the variable types are given as:

A - hollerith data read in A6 format

F - floating point number

I - integer number

Note that all hollerith data are read in fixed format and all numbers are in namelist format.

3.3 BLOCK DATA SUBROUTINE

The BLOCK DATA subroutine may be thought of as the SCIP2 data base and is useful when most parameters for a study remain fixed for many runs while several parameters change for each run of the study. If it is desired to study the effects of different instrument groups for a specific aircraft then a BLOCK DATA subroutine may be constructed consisting of the nominal aircraft and instrumentation model. Then, for succeeding runs those parameters requiring changes may be changed by data card at execution time.

A nominal BLOCK DATA subroutine is provided with SCIP2. It consists of the LABEL COMMON blocks which will contain program inputs. These are defined in the Table 3.2.

NOTE: The following order for parameters and instruments is used by the SCIP2 program.

FULL LONGITUDINAL PARAMETERS	FULL LONGITUDINAL MEASUREMENTS	SHORT PERIOD LONGITUDINAL PARAMETERS	SHORT PERIOD LONGITUDINAL MEASUREMENTS	LATERAL PARAMETERS	LATERAL MEASUREMENTS
M_q	θ	M_q	θ	Y_β	β
M_w	q	M_w	q	L_β	p
Z_w	α	Z_w	α	N_β	r
M_u	u	M_{δ_e}	n_z	L_p	ϕ
Z_u	n_x	Z_{δ_e}	$\dot{q}$	N_p	n_y
X_u	n_z			L_r	$\dot{p}$
X_w	$\dot{q}$			N_r	$\dot{r}$
M_{δ_e}				Y_{δ_a}	
Z_{δ_e}				L_{δ_a}	
				N_{δ_a}	
				Y_{δ_r}	
				L_{δ_r}	
				N_{δ_r}	

3.4 Sample Input

3.4.1 Example No. 1

The following input is for running the Ensemble Analysis subprogram with the full longitudinal equations of motion. Only the parameters of the F and G matrices are estimated. Seven instruments are used to measure the output. The output from this example is presented in Section 4.2.

```
ENSMBL    TT TTTTT TTTTTTT T TT   TTTTTT
FULL
PAG   PRG   AOAV  AVPT  AXACC NORAC PAACC
 $RFTRAJ   THETAO=-.556,  ALPHAO=-.7,  VEL=178.9,   $
 $OPTONS ESTIM=1 $
 $MISC          NMC=1, DT=0.05,  $
 $LONGDR
   MQ=-0.037694,  MW=-0.050715,  ZW=-2.070174,  MU=-0.000620,
   ZU=-.384407,  XU=-.042662,  XW=0.070207,  MDE=-24.38,     ZDE=0.,
 $END
 $CONSEQ
   NOP=100,
   DELE=20*1.0,20*-1.0,  100*0.0,
 $END
 $PITATT WTHETA=.5, BTHETA=0.2,ETHETA=.005 $
 $PITRAT WQ=.5, BQ=0.2, EQ=.005 $
 $AOAVAN WALPHA=.5, BALPHA=.3, EALPHA=.005 $
 $AVPTUS WU=.5, BU=1., EU=.005 $
 $AXIACC WNX=.1, BNX=.001, ENX=.005, GNX=.5 $
 $NORMAC WNZ=.025, BNZ=.001, ENZ=.005, GNZ=.5 $
 $PANACC WQDOT=.5, BQDOT=.2, EQDOT=.005 $
 $CGUNCR EXCG=.5, EZCG=.5 $
 $CGAPL EAX=2. , EAZ=2. $
 $ABVANE EVX=5.  $
```

3.4.2 Example No. 2

The following input is for running the Ensemble Analysis subprogram with the lateral equations of motion. The parameters, the initial conditions, and all the output instrument biases except b_ϕ are estimated. Seven instruments are used to measure the output.

```
ENSMBL     TT TTTTT TTTTTTT T TT    TTTTTT
LAT
AOSV  RRG    YRG    RAG    LATAC RAACC YAACC
 $RFTRAJ  THETA0=-.556,   ALPHA0=-.7, VEL=178.9, $
 $OPTONS  ESTIM=4,             $
 $MISC   DT=0.1,            $
 $LATDR
  YBETA=-.163,     LBETA=-23.26, NBETA=5.504, LP=-11.53, NP=-1.363,
  LR=2.692, NR=1.214, YDELA=0., LDELA=53.79, NDELA=.2103, NDELR=-6.172,
  XZI=0.,
 $END
 $CONSEQ
  NOP=50,
   DELR=20*0.5,5*-1.0,5*1.0,100*0.0,
   DELA=5*0.5,5*-3.5,20*-0.05,  100*0.0,
 $END
 $AOSVAN  WBETA=.005, BBETA=0., EBETA=.005,  $
 $ROLRAT  WP    =.005, BP    =0., EP    =.005,  GP   =.5,   $
 $YAWRAT  WR    =.005, BR    =0., ER   =.005,   GR  =.5,   $
 $ROLATT  WPHI  =.005, BPHI =.2, EPHI =.005,   $
 $LATACC  WNY   =.001, BNY   =0.,      ENY =.005,   $
 $RANACC  WPDOT=.005, BPDOT=0., EPDOT=.005, GPDOT=.5,   $
 $YANACC  WRDOT=.005, BRDOT=0., ERDOT=.005, GRDOT=.5,   $
 $CGUNCR  EXCG =.5   , EZCG =.5,       $
 $CGAPL   EAX  =2.0, EAZ=2.0,   $
 $ABVANE  EVX  =5.0,  $
```

3.4.3 Example No. 3

The following input is for running the Ensemble Analysis subprogram with the longitudinal equations in the short period mode. Only the parameters are estimated. Four instruments are used to measure the output. The angle-of-attack vane is omitted.

```
ENSMBL     TT TTTTT TT    TT T T     TTTTTT
SPL
PAG    PRG                            NORAC PAACC
 $RFTRAJ  THETA0=-.556,  ALPHA0=-.7,   VEL=178.9,   $
 $OPTONS  ESTIM=1,   $
 $MISC   NMC=1,   DT=0.05,    $
 $LONGDR
   MQ=-0.037594,   MW=-0.050715,  ZW=-2.070174,
   MDE=-24.380927,   ZDE=0.0,
 $END
 $CONSEQ
   DELE=20*1.0,20*-1.0,   100*0.0,
 $END
 $PITATT  WTHETA=0.25,   BTHETA=0.1,   ETHETA=0.005,   $
 $PITRAT  WQ=0.2,   BQ=0.1,   EQ=0.005,   $
 $NORMAC  WNZ=0.025,   BNZ=0.01,   ENZ=0.005,   GNZ=0.5,   $
 $PANACC  WQDOT=0.3,   BQDOT=0.1,   EQDOT=0.005,   $
 $CGUNCR  EXCG=0.5,     $
 $CGAPL  EAX=1.0,   $
```

3.4.4 Example No. 4

The following input is for running the Simulated Data Analysis subprogram with the longitudinal equations in the short period mode. This is a special case with no instrument errors. Two runs are made with parameters perturbed 5% in the second run. The output is the result of applying the modified Newton-Raphson algorithm to estimate the difference in the parameters.

```
SIMDAT     TT TTTTT TTT  TT      T TTTTTT
SPL
PAG    PRG    AOAV                NORAC PAACC
 $RFTRAJ  THETA0=-.556,  ALPHA0=-.7,  VEL=178.9,  $
 $OPTIONS  ESTIM=1,  $
 $MISC  NMC=1,  DT=0.05, MODE=2,  $
 $LONGDR
   MQ=-0.037594,  MW=-0.050715,  ZW=-2.070174,
   MDE=-24.380927,  ZDE=0.0,
 $END
 $CONSEQ
   DELE=20*1.0,20*-1.0,  100*0.0,
 $END
 $PITATT  WTHETA=0.25, $
 $PITRAT  WQ=0.2, $
 $AOAVAN  WALPHA=0.5, $
 $NORMAC  WNZ=0.025, $
 $PANACC  WQDOT=0.3, $
SIMDAT     TT    T                T TTTTTT
SPL
PAG    PRG    AOAV                NORAC PAACC
 $LONGDR
   MQ=-0.0396,  MW=-0.0533,   ZW=-2.18,
    MDE=-25.6,  ZDE=0.0,
 $END
```

3.4.5 Example No. 5

The following input is for running the Simulated Data Analysis subprogram with the short period (longitudinal) equations. This is an example of Mode 1, and each of the error sources is applied individually to the output measurements. The contribution due to noise is set equal to

$$\left[\frac{\partial^2 J}{\partial p^2}\right]^{-1} .$$

```
SIMDAT      TT TTTTT TTT   TT T T     TTTTTT
SPL
PAG    PRG    AOAV                    NORAC PAACC
 $RFTRAJ  THETA0=-.556,  ALPHA0=-.7,  VEL=178.9,   $
 $OPTIONS  ESTIM=1,   $
 $MISC   NMC=1,   DT=0.05, MODE=1,   $
 $LONGDR
   MQ=-0.037594,  MW=-0.050715,  ZW=-2.070174,
   MDE=-24.380927,  ZDE=0.0,
 $END
 $CONSEQ
   DELE=20*1.0,20*-1.0,  100*0.0,
 $END
 $PITATT  WTHETA=0.25,   BTHETA=0.1,   ETHETA=0.005,   $
 $PITRAT  WQ=0.2,   BQ=0.1,   EQ=0.005,   $
 $AOAVAN  WALPHA=0.5,   BALPHA=0.1,   EALPHA=0.005,   $
 $NORMAC  WNZ=0.025,  BNZ=0.01,  ENZ=0.005,  GNZ=0.5,  $
 $PANACC  WQDOT=0.3,  BQDOT=0.1,   EQDOT=0.005,   $
 $CGUNCR  EXCG=0.5,      $
 $CGAPL   EAX=1.0,   $
```

3.4.6 <u>Example No. 6</u>

The following input is for running the Simulated Data Analysis subprogram with the short period equations. This is an example of Mode 2, which is the Monte Carlo option. Twenty Monte Carlo runs are made. Mean errors are constant in each run. Random errors except noise are randomly set at the beginning of each run and held constant during the run. Noise errors are randomly set at each sample point.

```
SIMDAT      TT TTTTT TTT   TT T TT    TTTTTT
SPL
PAG    PRG    AOAV                    NORAC PAACC
 $RFTRAJ  THETA0=-.556,  ALPHA0=-.7,  VEL=178.9,   $
 $OPTIONS  ESTIM=1,   $
 $MISC   NMC=20, MODE=2,   DT=0.05,  $
 $LONGDR
   MQ=-0.037594,  MW=-0.050715,  ZW=-2.070174,
   MDE=-24.380927,  ZDE=0.0,
 $END
 $CONSEQ
   DELE=20*1.0,20*-1.0,  100*0.0,
 $END
 $PITATT  WTHETA=0.25,   BTHETA=0.1,   ETHETA=0.005,   $
 $PITRAT  WQ=0.2,   BQ=0.1,   EQ=0.005,   $
 $AOAVAN  WALPHA=0.5,   BALPHA=0.1,   EALPHA=0.005,   $
 $NORMAC  WNZ=0.025,  BNZ=0.01,  ENZ=0.005,  GNZ=0.5,  $
 $PANACC  WQDOT=0.3,  BQDOT=0.1,   EQDOT=0.005,   $
 $CGUNCR  EXCG=0.5,      $
 $CGAPL  EAX=1.0,   $
 $ABVANE  EVX=10.0,   $
```

3.4.7 Example No. 7

The following input is for running the Simulated Data Analysis subprogram with the lateral equations. This is an example of Mode 3, which is just one pass through the program with a fixed set of instrument errors.

```
SIMDAT      TT TTTTT TTTTTTT T TT   TTTTTT
LAT
AOSV   RRG   YRG   RAG   LATAC RAACC YAACC
 $REFTRAJ  THETA0=-.556,  ALPHA0=-.7, VEL=178.9, $
 $OPTIONS  ESTIM=1,       $
 $MISC  DT=0.1,       MODE=3,  $
 $LATDR
  YBETA=-.163,      LBETA=-23.26, NBETA=5.504, LP=-11.53, NP=-1.363,
  LR=2.692, NR=1.214, YDELA=0., LDELA=53.79, NDELA=.2103, NDELR=-6.172,
  XZI=0.,
 $END
 $CONSEQ
  NOP=50,
   DELR=20*0.5,5*-1.0,5*1.0,100*0.0,
   DELA=5*0.5,5*-1.0,20*-0.05,  100*0.0,
 $END
 $AOSVAN  WBETA=.005, BBETA=.3, EBETA=.005,   $
 $ROLRAT  WP    =.005, BP    =.2, EP    =.005,  GP  =.5,  $
 $YAWRAT  WR    =.005, BR    =.2, ER    =.005,   GR =.5,  $
 $ROLATT  WPHI  =.005, BPHI  =.2, EPHI  =.005,  $
 $LATACC  WNY   =.001, BNY   =.001,  ENY =.005,  $
 $RANACC  WPDOT=.005, BPDOT=.2, EPDOT=.005, GPDOT=.5,  $
 $YANACC  WRDOT=.005, BRDOT=.2, ERDOT=.005, GRDOT=.5,  $
 $CGUNCP  EXCG =.5   , EZCG =.5,     $
 $CGAPL   EAX  =2.0, EAZ=2.0,   $
 $ABVANE  EVX  =5.0,  $
```

3.5 Discussion of Input Options

Several of the input options require elaboration. Each will be discussed below, separately.

3.5.1 Inputs (23) = T

This is the special input option. By setting INPUTS (23) = T (field 33 on the POD card), the user may iterate through the Simulated Data Analysis portion of the SCIP2 program. In the iterate mode, the program makes a single pass through the ensemble analysis (retaining the required partial derivatives and covariance for the simulated data pass). From this point on, the SCIP2 program processes the new data only in the simulated data analysis and only for a single iteration, always using the necessary results from the ensemble analysis generated from the original input data. This allows the user to vary any of the input parameters from their nominal values and study the effects via the simulated data analysis. (Note that, if any of the aircraft parameters are changed on subsequent iterations all must be re-input because of units conversions within the program. All other inputs carry no added restrictions in this iterate mode.)

In particular, the aircraft parameters may be perturbed from their nominal values in this way and the effects studied (see Section 3.4.4, Example No. 4).

3.5.2 PERT and NDXP

If INPUTS (23) = T, (that is, the program is being operated in the iterate mode), then the aircraft parameters in the Lateral equations may be perturbed from the nominal input by the percentage indicated by PERT. If NDXP = 0, then all lateral parameters are perturbed one at a time (the others fixed at nominal values). If NDXP = $1 \leq n \leq 13$, then the n^{th} lateral parameter only is perturbed.

3.5.3 NMC = 1, MODE = 1

If NMC = 1 and MODE = 1 is input to SCIP2, then the covariance matrix generated by the ensemble analysis phase is used in the simulated data analysis rather than regenerating the covariance matrix using a Monte Carlo process. This saves computational time since, theoretically, these covariances are identical and since in MODE 1 it is desired to examine the effects of the error sources other than white noise.

TABLE 3.1

CARD FIELD	NAMELIST IDENTIFIER	VARIABLE	UNITS	TYPE	Description
11		EQNS	-	A	FULL - Full Longitudinal Analysis SPL - Short Period Longitudinal Analysis LAT - Lateral Analysis
12		INSLON(1)	-	A	PAG - Pitch angle gyro (longitudinal instruments)
		INSLON(2)	-	A	PRG - Pitch rate gyro (longitudinal instruments)
		INSLON(3)	-	A	AOAV - Angle of attack vane (longitudinal instruments)
		INSLON(4)	-	A	AVPT - Axial velocity pilot tube (longitudinal instruments)
		INSLON(5)	-	A	AXACC - Axial accelerometer (longitudinal instruments)
		INSLON(6)	-	A	NORAC - Normal accelerometer (longitudinal instruments)
		INSLON(7)	-	A	PAACC - Pitch angle accelerometer (longitudinal instruments)
12		INSLAT(1)	-	A	AOSV - Angle of side slip vane (lateral instruments)
		INSLAT(2)	-	A	RRG - Roll rate gyro (lateral instruments)
		INSLAT(3)	-	A	YRG - Yaw rate gyro (lateral instruments)
		INSLAT(4)	-	A	RAG - Roll angle gyro (lateral instruments)
		INSLAT(5)	-	A	LATAC - Lateral accelerometer (lateral instruments)
		INSLAT(6)	-	A	RAACC - Roll angle accelerometer (lateral instruments)
		INSLAT(7)	-	A	YAACC - Yaw angle accelerometer (lateral instruments)

NOTE: Instrument list input order must be preserved although any instrument may be omitted from the list and its field left blank.

CARD FIELD	NAMELIST IDENTIFIER	VARIABLE	UNITS	TYPE	Description
13		UNITS	-	A	FT/SEC, KM/SEC, M/SEC - Program internal units

Table 3.1 (Continued)

CARD FIELD	NAMELIST IDENTIFIER	VARIABLE	UNITS	TYPE	DESCRIPTION
13	GRAVTY	GRAV	$\left\{ \begin{array}{l} ft/sec^2 \\ km/sec^2 \\ m/sec^2 \end{array} \right\}$	F	gravitational constant for corresponding units (UNITS) above
14	RFTRAJ	THETAO	degrees	F	θ_o initial pitch attitude
		ALPHAO	degrees	F	α_o initial angle of attack
		VEL	$\left\{ \begin{array}{l} ft/sec \\ km/sec \\ m/sec \end{array} \right\}$	F	V_T total velocity
15	OPTONS	ESTIM	----	I	Estimate option 1 - parameters only 2 - initial conditions and parameters 3 - biases, parameters and those initial conditions which do not correlate with biases 4 - initial conditions, parameters and those biases which do not correlate with any initial conditions

Table 3.1 (Continued)

CARD FIELD	NAMELIST IDENTIFIER	VARIABLE	UNITS	TYPE	DESCRIPTION
16	MISC	DT	sec	F	integration step size and increment of trajectory data
		NMC	-	I	number of Monte Carlo runs if SIMDAT option is exercized
		MODE	-	I	Simulated Data error computation modes 1 - Monte Carlo on white measurement noise; single run for each non-zero random and mean error source 2 - Monte Carlo on white measurements noise and all random error sources simultaneously with white noise random at each time point and random errors fixed for each run. 3 - Single run; perturbed trajectory with non-zero error sources and white noise
		PERT	-	F	The percentage perturbation in the parameters for an iteration run
		NDXP	-	I	0 - perturb all parameters by PERT and run again $1 \leq n \leq 13$ - perturb parameter n by PERT (all others as before) and run again

Table 3.1 (Continued)

CARD FIELD	NAMELIST IDENTIFIER	VARIABLE	UNITS	TYPE	DESCRIPTION
16	MISC	DTS	sec	F	sample rate for lags
		TAU	sec	F	time to the first sample point for lagged controls

Table 3.1 (Continued)

CARD FIELD	NAMELIST IDENTIFIER	VARIABLE	UNITS	TYPE	DESCRIPTION	
17	LONGDR	MQ	1/sec	F	M_q	longitudinal parameters
		MW	1/ft-sec	F	M_w	
		ZW	1/sec	F	Z_w	
		MU	1/ft-sec	F	M_u	
		ZU	1/sec	F	Z_u	
		XU	1/sec	F	X_u	
		XW	1/sec	F	X_w	
		MDE	1/deg-sec^2	F	$M_{\delta e}$	
		ZDE	ft/deg-sec^2	F	$Z_{\delta e}$	
17	LATDR	YBETA	1/sec	F	Y_β	lateral parameters
		LBETA	1/sec^2	F	L_β	
		NBETA	1/sec^2	F	N_β	
		LP	1/sec	F	L_p	
		NP	1/sec	F	N_p	
		LR	1/sec	F	L_r	
		NR	1/sec	F	N_r	
		YDELA	1/sec	F	$Y_{\delta a}$	
		LDELA	1/sec^2	F	$L_{\delta a}$	
		NDELA	1/sec^2	F	$N_{\delta a}$	
		YDELR	1/sec	F	$Y_{\delta r}$	
		LDELR	1/sec^2	F	$L_{\delta r}$	
		NDELR	1/sec^2	F	$N_{\delta r}$	
		XXI	slug ft^2	F	I_{xx}	moments and products of inertia
		XZI	slug ft^2	F	I_{xz}	
		ZZI	slug ft^2	F	I_{zz}	

Table 3.1 (Continued)

CARD FIELD	NAMELIST IDENTIFIER	VARIABLE	UNITS	TYPE	DESCRIPTION
18	CONSEQ	NOP	-	I	number of data points in aircraft control program
		DELE	degrees	F	NOP points for elevator deflection
		DELA	degrees	F	NOP points for aileron deflection
		DELR	degrees	F	NOP points for rudder deflection
19	FICERR	EDELT	degrees	F	perturbation in initial Θ
		EDELQ	deg/sec	F	perturbation in initial q
		EDELW	ft/sec	F	perturbation in initial w
		EDELU	ft/sec	F	perturbation in initial u

longitudinal

Table 3.1 (Continued)

CARD FIELD	NAMELIST IDENTIFIER	VARIABLE	UNITS	TYPE	DESCRIPTION
19	LICERR	EDELB	degrees	F	δ_β perturbation in initial β (lateral)
		EDELP	deg/sec	F	δ_p perturbation in initial p (lateral)
		EDELR	deg/sec	F	δ_r perturbation in initial r (lateral)
		EDELF	degrees	F	δ_ϕ perturbation in initial ϕ (lateral)
20	PITATT	WTHETA	degrees	F	w_θ - noise (pitch attitude errors)
		BTHETA	degrees	F	b_θ - bias (pitch attitude errors)
		ETHETA	-	F	e_θ - scaling (pitch attitude errors)
21	PITRAT	WQ	deg /sec	F	w_q - noise (pitch rate errors)
		BQ	deg /sec	F	b_q - bias (pitch rate errors)
		EQ	-	F	e_q - scaling (pitch rate errors)
22	AOAVAN	WALPHA	degrees	F	w_α - noise (angle of attack vane errors)
		BELPHA	degrees	F	b_α - bias (angle of attack vane errors)
		EALPHA	-	F	e_α - scaling (angle of attack vane errors)
23	AVPTUB	WU	ft/sec	F	w_u - noise (axial velocity pitot tube errors)
		BU	ft/sec	F	b_u - bias (axial velocity pitot tube errors)
		EU	-	F	e_u - scaling (axial velocity pitot tube errors)

Table 3.1 (Continued)

CARD FIELD	NAMELIST IDENTIFIER	VARIABLE	UNITS	TYPE	DESCRIPTION	
24	AXIACC	WNX	g's	F	w_{nx} - noise	axial accelerometer errors
		BNX	g's	F	b_{nx} - bias	
		ENX	-	F	e_{nx} - scaling	
		GNX	degrees	F	γ_{nx} - misalignment	
25	NORMAC	WNZ	g's	F	w_{nz} - noise	normal accelerometer errors
		BNZ	g's	F	b_{nz} - bias	
		ENZ	-	F	e_{nz} - scaling	
		GNZ	degrees	F	γ_{nz} - misalignment	
26	PANACC	WQDOT	deg/sec^2	F	$w_{\dot{q}}$ - noise	pitch angular accelerometer
		BQDOT	deg/sec^2	F	$b_{\dot{q}}$ - bias	
		EQDOT	-	F	$e_{\dot{q}}$ - scaling	

Table 3.1 (Continued)

CARD FIELD	NAMELIST IDENTIFIER	VARIABLE	UNITS	TYPE		DESCRIPTION
20	AOSVAN	WBETA	degrees	F	w_β - noise	angle of sideslip vane errors
		BBETA	degrees	F	b_β - bias	
		EBETA	-	F	e_β - scaling	
21	ROLRAT	WP	deg/sec	F	w_p - noise	roll rate errors
		BP	deg/sec	F	b_p - bias	
		EP	-	F	e_p - scaling	
		GP	degrees	F	γ_p - misalignment	
22	YAWRAT	WR	deg/sec	F	w_r - noise	yaw rate errors
		BR	deg/sec	F	b_r - bias	
		ER	-	F	e_r - scaling	
		GR	degrees	F	γ_r - misalignment	
23	ROLATT	WPHI	degrees	F	w_ϕ - noise	roll attitude errors
		BPHI	degrees	F	b_ϕ - bias	
		EPHI	-	F	e_ϕ - scaling	
24	LATACC	WNY	g's	F	w_{ny} - noise	lateral accelerometer errors
		BNY	g's	F	b_{ny} - bias	
		ENY	-	F	e_{ny} - scaling	
25	RANACC	WPDOT	deg/sec^2	F	$w_{\dot{p}}$ - noise	roll angular accelerometer errors
		BPDOT	deg/sec^2	F	$b_{\dot{p}}$ - bias	
		EPDOT	-	F	$e_{\dot{p}}$ - scaling	
		GPDOT	degrees	F	$\gamma_{\dot{p}}$ - misalignment	

Table 3.1 (Continued)

CARD FIELD	NAMELIST IDENTIFIER	VARIABLE	UNITS	TYPE	DESCRIPTION	
26	YANACC	WRDOT	deg/sec^2	F	W_r - noise	yaw angular accelerometer errors
		BRDOT	deg/sec^2	F	b_r - bias	
		ERDOT	-	F	e_r - scaling	
		GRDOT	degrees	F	γ_r - misalignment	
27	LAGS1	FTHETA	1/sec	F	f_θ	lag errors in longitudinal instruments
		FQ	1/sec	F	f_q	
		FALPHA	1/sec	F	f_α	
		FU	1/sec	F	f_u	
		FNX	1/sec	F	f_{nx}	
		FNZ	1/sec	F	f_{nz}	
		FQDOT	1/sec	F	$f_{\dot{q}}$	
27	LAGS2	FBETA	1/sec	F	f_β	lag errors in lateral instruments
		FP	1/sec	F	f_p	
		FR	1/sec	F	f_r	
		FPHI	1/sec	F	f_ϕ	
		FNY	1/sec	F	f_{ny}	
		FPDOT	1/sec	F	$f_{\dot{p}}$	
		FRDOT	1/sec	F	$f_{\dot{r}}$	
28	CGUNCR	EXCG	ft	F	e_{cgx}	C.G. uncertainties
		EYCG	ft	F	e_{cgy}	
		EZCG	ft	F	e_{cgz}	

Table 3.1 (Continued)

CARD FIELD	NAMELIST IDENTIFIER	VARIABLE	UNITS	TYPE		DESCRIPTION
29	CPTERR	WDE	degrees	F	w_{δ_e}	control surface position transmitter noise errors
		WDA	degrees	F	w_{δ_a}	
		WDR	degrees	F	w_{δ_r}	
		BDE	degrees	F	b_{δ_e}	control surface position transmitter bias errors
		BDA	degrees	F	b_{δ_a}	
		BDR	degrees	F	b_{δ_r}	
		EDE	-	F	$e_{\delta e}$	control surface position transmitter scale factors
		EDA	-	F	$e_{\delta a}$	
		EDR	-	F	$e_{\delta r}$	
		FDE	1/sec	F	$f_{\delta e}$	control surface position transmitter lags
		FDA	1/sec	F	$f_{\delta a}$	
		FDR	1/sec	F	$f_{\delta r}$	
30	CGAPL	EAX	ft	F	e_{ax}	C.G. accelerometer location errors
		EAY	ft	F	e_{ay}	
		EAZ	ft	F	e_{az}	
31	ABVANE	EVX	ft	F	e_{vx}	vane location error
32	ERRMAT	T	-	F	T	7 x 7 matrix of general errors

Table 3.2

LABEL COMMON BLOCK NAME	VARIABLE OR ARRAY NAME	DIMENSION (IF APPLICABLE)	DESCRIPTION
BIASES	BLONG	7	longitudinal instrument biases
	BLAT	7	lateral instrument biases
CGNCRT	ECGVEC	3	C. G. uncertainties (e_{cgx}, e_{cgy}, e_{cgz})
CNFLCT	SPLCNF	3	short period initial conditions conflict vector. SPLCNF(n)=T implies that the n^{th} initial condition correlates with a bias error and is to be treated as an error source.
	FULCNF	4	full longitudinal conflict vector, FULCNF(n)=T implies that the n^{th} initial condition correlates with a bias and is to be treated as an error source.
	LATCNF	4	same as FULCNF but for lateral analysis
	SPLBCN	5	short period bias conflict vector, SPLBCN(n)=T implies that the n^{th} bias correlates with an initial condition and is to be treated as an error source.
	FULBCN	7	Same as SPLBCN but for the full longitudinal analysis
	LATBCN	7	same as SPLBCN but for the lateral analysis
CONTRL	NP	1	number of data points to the end of trajectory at intervals of DT
	DELE	300	NP elevator deflection at intervals of DT
	DELA	300	NP aileron deflections at intervals of DT
	DELR	300	NP rudder deflections at intervals of DT
CPERRV	WDE	1	Standard deviation for control measurement noise for δ_e
	WDA	1	Similar to WDE but for δ_a

Table 3.2 (Continued)

LABEL COMMON BLOCK NAME	VARIABLE OR ARRAY NAME	DIMENSION (IF APPLICABLE)	DESCRIPTION
	WDR	1	Similar to WDE but for δ_r
	BDE	1	Bias error for control measurement for δ_e
	BDA	1	Similar to BDE but for δ_a
	BDR	1	Similar to BDE but for δ_r
	EDE	1	Scaling error for control measurement for δ_e
	EDA	1	Similar to EDE but for δ_a
	EDR	1	Similar to EDE but for δ_r
	FDE	1	Control measurement lag for δ_e
	FDA	1	Similar to FDE but for δ_a
	FDR	1	Similar to FDE but for δ_r
DDDPBK	ROWDLO	9	row numbers for which a non-zero element of $\partial D/\partial p$ exists (longitudinal analysis)
	ROWDLA	13	row numbers for which a non-zero element of $\partial D/\partial p$ exists (lateral analysis)
	COLDLA	13	same as ROWDLA but for the column number
DFDPBK	ROWFLO	9	row numbers for which non-zero element of $\partial F/\partial p$ exist (longitudinal analysis)
	COLFLO	9	same as ROWFLO but for column numbers
	ROWFLA	13	row numbers for which non-zero element $\partial F/\partial p$ exist (lateral analysis)
	COLFLA	13	same as ROWFLA but for column numbers

Table 3.2 (Continued)

LABEL COMMON BLOCK NAME	VARIABLE OR ARRAY NAME	DIMENSION (IF APPLICABLE)	DESCRIPTION
DGDPBK	ROWGLO	9	row numbers for which non-zero element of $\partial G/\partial p$ exist (longitudinal analysis)
	ROWGLA	13	row numbers for which non-zero element of $\partial G/\partial p$ exist (lateral analysis)
	COLGLA	13	same as ROWGLA but for column numbers
DHDPBK	ROWHLO	9	row numbers for which non-zero element of $\partial H/\partial p$ exist (longitudinal analysis)
	COLHLO	9	same as ROWHLO but for column numbers
	ROWHLA	13	row numbers for which non-zero element of $\partial H/\partial p$ exist (lateral analysis)
	COLHLA	13	same as ROWHLA but for column numbers
DMATRX	DLONG		D-matrix for the longitudinal analysis
	DLAT		D-matrix for the lateral analysis
FMATRX	FFLONG	4x4	F-matrix for the longitudinal analysis
	FFLAT	4x4	F-matrix for the lateral analysis
GMATRX	GLONG	4	G-matrix for the longitudinal analysis
	GLAT	4x2	G-matrix for the lateral analysis
	XXI	1	Moment of inertia I_{xx}
	XZI	1	Product of inertia I_{xz}
	ZZI	1	Moment of inertia I_{zz}
HMATRX	HLONG	7x4	H-matrix for the longitudinal analysis
	HLAT	7x4	H-matrix for the lateral analysis
LAGERR	FLONG		diagonal elements of the lag error matrix F_m for the longitudinal analysis
	FLAT		diagonal elements of the lag error matrix F_m for the lateral analysis

Table 3.2 (Continued)

LABEL COMMON BLOCK NAME	VARIABLE OR ARRAY NAME	DIMENSION (IF APPLICABLE)	DESCRIPTION
LOCCG	CGLOC		accelerometer location error vector (e_{cgx}, e_{cgy}, e_{cgz})
	EVX		vane location error
MISALN	GMLONG		misalignment error vector (γ_θ, γ_q, γ_α, γ_u, γ_{nx}, γ_{nz}, $\gamma_{\dot{q}}$) for the longitudinal analysis
	GMLAT		misalignment error vector (γ_β, γ_p, γ_r, γ_ϕ, γ_{ny}, $\gamma_{\dot{p}}$, $\gamma_{\dot{r}}$) for the lateral analysis
MISCEL	DT	-	integration step size
	NMC	-	number of Monte Carlo runs to be executed (if ENORSD=SIMDAT)
	GRAV	-	gravitational constant
	UNITS	-	units of gravitational constant
	RADDEG	-	radians per degree
	NDXP	-	index for perturbing lateral parameters in iterate mode
	PERT	-	percentage perturbation of lateral parameters in iterate mode
	TIME		time of the sample point
	DTS		time between the two successive sample points
	TAU		time to the first sample point for lagged controls
MISCL1	NUM1		number of elements in the control variable
	NUM2		not used

Table 3.2 (Continued)

LABEL COMMON BLOCK NAME	VARIABLE OR ARRAY NAME	DIMENSION (IF APPLICABLE)	DESCRIPTION
	MODM2		variable MODE - 2
	I1		running counter of the Monte Carlo runs
	SWICH		flag, if non-zero, to indicate that the initial condition eror is being considered
	IU1		scratch unit to save $\hat{x}$, $\frac{\partial \hat{x}}{\partial p}$, $\hat{y}$, $R^{-1} \frac{\partial \hat{y}}{\partial p}$
	IU2		scratch unit to save δp for each of MODE = 2 Monte Carlo runs
NAMVAR	NAMVAR	7x2	an array containing the hollerith names of the measured output states for longitudinal and lateral analysis
	NAMIC	4x2	an array containing the hollerith names of the aircraft states for longitudinal and lateral analysis
	NAMVAN	4	an array containing the hollerith names for (e_{ax}, e_{ay}, e_{az}) and e_{vx}
	NAMCG	3	an array containing the hollerith names for C-G location error, (e_{cgx}, e_{cgy}, e_{cgz})
NOISE	WLONG	7	standard deviations for noise vector (longitudinal)
	WLAT	7	standard deviations for noise vector (lateral)
OPTNS	ENORSD	-	program option - ENSMBL for ensemble analysis, SIMDAT for simulated data analysis
	EQNS	-	equations option - FULL for full longitudinal analysis; SPL for short period longitudinal analysis; LAT for lateral analysis

Table 3.2 (Continued)

LABEL COMMON BLOCK NAME	VARIABLE OR ARRAY NAME	DIMENSION (IF APPLICABLE)	DESCRIPTION
	ESTIM	-	parameter estimation option: 1. estimate parameters only 2. estimate initial conditions also 3. estimate biases as well as 1 & 2* 4. estimate i.c.'s as well as 1 and biases*
	MODE	-	if ENORSD = SIMDAT, then MODE represents the Monte Carlo options: 1. Monte Carlo on noise 2. Monte Carlo on noise and random errors 3. one pass with all error simultaneously
	INSLON	7	desired instruments (longitudinal) INSLON (1) = PAG INSLON (2) = PRG INSLON (3) = AOAV INSLON (4) = AVPT INSLON (5) = AXACC INSLON (6) = NORAC INSLON (7) = PAACC
	INSLAT	7	desired instruments (lateral) INSLAT (1) = AOSV INSLAT (2) = RRG INSLAT (3) = YRG INSLAT (4) = RAG INSLAT (5) = LATACC INSLAT (6) = RAACC INSLAT (7) = YAACC
RANDOM	IRN	-	random number generator starting number (UNIVAC-1108 only)

* Estimate option 3 estimates those i.c.'s which do not correlate with any bias.
Estimate option 4 estimates those biases which do not correlate with any i.c.'s.

Table 3.2 (Continued)

LABEL COMMON BLOCK NAME	VARIABLE OR ARRAY NAME	DIMENSION (IF APPLICABLE)	DESCRIPTION
REFTRJ	VELOC	3	reference trajectory parameter vector (α_o, θ_o, V)
SCALING	EPLONG	7	$(e_{\dot\theta}, e_q, e_\alpha, e_u, e_{nx}, e_{nz}, e_{\dot q})$
	EPLAT	7	$(e_\beta, e_p, e_r, e_\phi, e_{ny}, e_{\dot p}, e_{\dot r})$

IV

OUTPUT DESCRIPTION

4.1 Printed Output Control

The output from this program is controlled by elements 25 through 30 of the INPUTS vector. If the element is "TRUE", then the output associated with it is produced, otherwise not. The output quantities of both the Longitudinal or Lateral analysis are the same except for the parameter headings.

4.1.1 Measurement Vector

If INPUTS (25) is "TRUE", then the measurement vector $\hat{y}$ is printed at every sample point (every DTS-seconds). This applies to both subprograms (e.g., ENSEMBLE ANALYSIS or SIMULATED DATA ANALYSIS).

4.1.2 Ensemble Analysis

Besides the measurement vector $\hat{y}$, the following quantities may be printed from the ensemble analysis:

(a) INPUTS (26) controls the printout of the covariance matrices,

$$\left[\frac{\partial^2 J}{\partial P^2}\right]^{-1} \text{ and } \left[\frac{\partial^2 J}{\partial P^2}\right]^{-1} + \left[\left(\frac{\partial P}{\partial e}\right) E(ee^T)\left(\frac{\partial P}{\partial e}\right)^T\right].$$

$\left[\frac{\partial^2 J}{\partial P^2}\right]^{-1}$ is the convariance due to noise and

$\left(\frac{\partial P}{\partial e}\right) E(ee^T)\left(\frac{\partial P}{\partial e}\right)^T$ is the covariance due to the random error sources.

(b) INPUTS (27) controls the printout of the normalized covariance matrices described above. The relation between the normalized and unnormalized covariance matrix is given by following equations:

- diagonal elements $C_{ii} = \sqrt{C'_{ii}}$
- off-diagonal elements $C_{ij} = \dfrac{C'_{ij}}{C_{ii}\ C_{jj}}$

where the primed variables are the unnormalized covariance matrix elements and the unprimed variables are normalized.

(c) INPUTS (28) controls the printout of the partial derivative matrix, $\left[\dfrac{\partial P}{\partial e}\right]$.

(d) INPUTS (29) controls the printout of the mean expected errors, $\left[\dfrac{\partial P}{\partial e}\right] E(e)$.

4.1.3 Simulated Data Analysis, Mode = 1

(a) INPUTS (26) controls the printout of the covariance matrices,

$$\left[\frac{\partial^2 J}{\partial P^2}\right]^{-1} \quad \text{and} \quad \left[\frac{1}{N}\sum_{i=1}^{N}\left(P_i P_i^T\right) + \sum_{j=1}^{q}\left(P_j\ P_j^T\right)\right]$$

where P_i is the error vector due to the noise.
N is the number of Monte Carlo runs.
P_j is the error vector due to the j^{-th} of q random error sources.

If N=1, then $\frac{1}{N}\sum_{i=1}^{N}\left(P_i P_i^T\right)$ is replaced by $\left[\frac{\partial^2 J}{\partial P^2}\right]^{-1}$.

(b) INPUTS (27) controls the printout of the normalized covariance matrices described in 4.1.3 (a).

(c) INPUTS (28) controls the printout of the error vector

$\left[\frac{\partial^2 J}{\partial P^2}\right]^{-1}\left(\frac{\partial J}{\partial P}\right)$ resulting from each of the random and mean error sources. Each error vector is printed columnwise up to 10 error sources across the page.

(d) INPUTS (29) controls the printout of the mean error vector, $\sum P_i$.

4.1.4 Simulated Data Analysis, Mode = 2

(a) INPUTS (26) controls the printout of the covariance matrix,

$$\frac{1}{N}\sum_{i=1}^{N}(P_i - \overline{P})(P_i - \overline{P})^T ,$$

where N is the number of Monte Carlo runs and P_i is the error vector resulting from applying all the error sources at once, and $\overline{P}$ is the average error vector described in (c).

(b) INPUTS (27) controls printout of the normalized covariance matrix described in 4.1.4 (a).

(c) INPUTS (30) controls the printout of the average error vector, $\frac{1}{N}\sum_{i=1}^{N} P_i$,
where N is the number of Monte Carlo runs and P_i is the error vector resulting from applying all the error sources at once.

4.1.5 Simulated Data Analysis, Mode = 3

The error vector is always printed when MODE=3 of the Simulated Data subprogram is executed.

4.2 SAMPLE OUTPUT

The following is an example of the output which results when input, such as presented in Section 3.4.1, is used. Explanatory comments appear in parentheses.

(SUMMARY OF INPUT)

ENSEMBLE ** FULL LONGITUDINAL ANALYSIS
PARAMETERS ESTIMATE ONLY

INPUT SUMMARY

ENSMBL T T F T T T T T F T T T T T T F T F T T F F F T T T T T T

ESTIM= 1 MODE= 0 SAMPLE POINTS= 100 SAMPLE RATE= .050 MONTE CARLO 0 RUNS

MQ	=-3.769400E-02	MW	=-2.905756E+00	MU	=-3.552338E-02	XW	= 7.020700E-02	XU	=-4.266200E-02
ZW	=-2.070174E+00	ZU	=-3.844070E-01	MDE	=-2.438000E+01	ZDE	= 0.		

ERROR VECTORS

	BIASES	SCALE	MISALIGN	LAG	NOISE
THETA	2.0000000E-01	5.0000000E-03	0.	0.	5.0000000E-01
Q	2.0000000E-01	5.0000000E-03	0.	0.	5.0000000E-01
ALPHA	3.0000000E-01	5.0000000E-03	0.	0.	5.0000000E-01
U	1.0000000E+00	5.0000000E-03	0.	0.	5.0000000E-01
NX	1.0000000E-03	5.0000000E-03	5.0000000E-01	0.	1.0000000E-01
NZ	1.0000000E-03	5.0000000E-03	5.0000000E-01	0.	2.5000000E-02
Q-DOT	2.0000000E-01	5.0000000E-03	0.	0.	5.0000000E-01

	I. C.		ACCEL		C. G.		VANE
THETA	0.	AX	2.0000000E+00	CG X	5.0000000E-01	VX	5.0000000E+00
Q	0.	AY	0.	CG Y	0.		
W	0.	AZ	2.0000000E+00	CG Z	5.0000000E-01		
U	0.						

(THE STATE MEASUREMENT AND CONTROL SEQUENCE WHICH ARE USED TO COMPUTE THE INSTRUMENT OUTPUT AND PARAMETER SENSITIVITIES)

SCIP2 STATE MEASUREMENT AND CONTROL SEQUENCE

TIME (SEC)	THETA (DEG)	Q (DEG/SEC)	ALPHA (DEG)	U (FT/SEC)	NX (G*S)	NZ (G*S)	Q-DOT (DEG/SEC**2)	DEL-E (DEG)
.0500	-.06	-2.43	-.06	-.00	-.00	.01	-48.14	2.00
.1000	-.24	-4.80	-.23	-.01	-.00	.05	-46.53	2.00
.1500	-.54	-7.07	-.49	-.01	-.00	.10	-44.68	2.00
.2000	-.95	-9.19	-.83	-.01	-.01	.17	-40.91	2.00
.2500	-1.46	-11.15	-1.23	-.01	-.01	.25	-37.18	2.00
.3000	-2.06	-12.90	-1.68	.00	-.01	.34	-33.62	2.00
.3500	-2.74	-14.44	-2.17	.02	-.01	.43	-28.55	2.00
.4000	-3.50	-15.76	-2.67	.05	-.02	.54	-23.91	2.00
.4500	-4.31	-16.83	-3.19	.10	-.02	.64	-19.22	2.00
.5000	-5.18	-17.68	-3.69	.16	-.03	.74	-14.57	2.00
.5500	-6.08	-18.29	-4.19	.24	-.03	.84	-10.07	2.00
.6000	-7.00	-18.69	-4.66	.34	-.03	.93	-5.80	2.00
.6500	-7.94	-18.88	-5.09	.46	-.04	1.02	-1.82	2.00
.7000	-8.89	-18.88	-5.49	.60	-.04	1.10	1.80	2.00
.7500	-9.83	-18.71	-5.85	.76	-.04	1.17	5.03	2.00
.8000	-10.76	-18.38	-6.16	.95	-.04	1.23	7.84	2.00
.8500	-11.66	-17.93	-6.42	1.16	-.05	1.28	10.20	2.00
.9000	-12.55	-17.37	-6.64	1.39	-.05	1.32	12.12	2.00
.9500	-13.40	-16.72	-6.80	1.65	-.05	1.35	13.60	2.00
1.0000	-14.22	-16.02	-6.92	1.92	-.05	1.37	14.64	2.00
1.0500	-14.88	-10.41	-6.88	2.23	-.05	1.36	111.55	-2.00
1.1000	-15.26	-4.90	-6.57	2.56	-.05	1.29	108.60	-2.00
1.1500	-15.37	.41	-6.05	2.91	-.05	1.18	103.61	-2.00
1.2000	-15.22	5.43	-5.33	3.28	-.04	1.03	96.89	-2.00
1.2500	-14.84	10.08	-4.45	3.65	-.04	.85	88.76	-2.00
1.3000	-14.22	14.29	-3.45	4.03	-.03	.65	79.53	-2.00
1.3500	-13.41	18.02	-2.36	4.41	-.02	.43	69.53	-2.00
1.4000	-12.43	21.23	-1.22	4.78	-.01	.19	59.64	-2.00
1.4500	-11.30	23.92	-.05	5.14	-.01	-.05	48.33	-2.00
1.5000	-10.05	26.07	1.11	5.49	.00	-.28	37.67	-2.00
1.5500	-8.70	27.69	2.25	5.81	.01	-.52	27.27	-2.00
1.6000	-7.29	28.80	3.34	6.10	.01	-.74	17.33	-2.00
1.6500	-5.83	29.43	4.37	6.37	.02	-.95	8.03	-2.00
1.7000	-4.35	29.62	5.31	6.61	.03	-1.14	-.50	-2.00
1.7500	-2.87	29.40	6.15	6.82	.03	-1.31	-8.16	-2.00
1.8000	-1.42	28.82	6.89	6.99	.04	-1.46	-14.86	-2.00
1.8500	.00	27.93	7.52	7.13	.04	-1.59	-20.57	-2.00
1.9000	1.37	26.78	8.05	7.23	.05	-1.70	-25.25	-2.00
1.9500	2.68	25.42	8.45	7.30	.05	-1.78	-28.91	-2.00
2.0000	3.91	23.90	8.76	7.33	.05	-1.84	-31.58	-2.00
2.0500	5.00	19.85	8.89	7.33	.05	-1.87	-81.43	0.00
2.1000	5.90	15.79	8.82	7.29	.05	-1.85	-80.65	0.00
2.1500	6.58	11.81	8.57	7.22	.05	-1.80	-78.20	0.00
2.2000	7.08	8.00	8.16	7.12	.05	-1.72	-74.30	0.00
2.2500	7.39	4.40	7.61	7.00	.04	-1.61	-69.19	0.00
2.3000	7.52	1.09	6.95	6.86	.04	-1.47	-63.10	0.00
2.3500	7.50	-1.89	6.21	6.71	.03	-1.32	-56.25	0.00
2.4000	7.34	-4.52	5.41	6.54	.03	-1.16	-48.88	0.00
2.4500	7.06	-6.78	4.57	6.37	.02	-.99	-41.20	0.00
2.5000	6.67	-8.64	3.72	6.19	.02	-.82	-33.40	0.00
2.5500	6.20	-10.12	2.87	6.01	.01	-.64	-25.46	0.00
2.6000	5.66	-11.21	2.05	5.84	.01	-.48	-18.15	0.00
2.6500	5.08	-11.94	1.26	5.67	.00	-.32	-11.61	0.00
2.7000	4.48	-12.32	.53	5.51	-.00	-.17	-4.35	0.00

(Continued...The State Measurement and Control Sequence which are used to Compute the Instrument Output and Parameter Sensitivities)

(Cont'd) SCIP2 STATE MEASUREMENT AND CONTROL SEQUENCE

TIME (SEC)	THETA (DEG)	Q (DEG/SEC)	ALPHA (DEG)	U (FT/SEC)	NX (G*S)	NZ (G*S)	Q-DOT (DEG/SEC**2)	DEL-E (DEG)
2.7500	3.86	-12.38	-.14	5.36	-.01	-.03	1.73	0.00
2.8000	3.24	-12.16	-.74	5.22	-.01	.09	7.16	0.00
2.8500	2.65	-11.68	-1.26	5.10	-.02	.20	11.88	0.00
2.9000	2.08	-10.98	-1.70	4.98	-.02	.29	15.87	0.00
2.9500	1.55	-10.10	-2.06	4.88	-.02	.36	19.11	0.00
3.0000	1.07	-9.08	-2.34	4.79	-.02	.42	21.61	0.00
3.0500	.64	-7.95	-2.54	4.71	-.02	.46	23.38	0.00
3.1000	.28	-6.76	-2.67	4.65	-.02	.48	24.47	0.00
3.1500	-.03	-5.52	-2.72	4.59	-.02	.50	24.91	0.00
3.2000	-.28	-4.27	-2.71	4.55	-.02	.49	24.77	0.00
3.2500	-.46	-3.05	-2.64	4.51	-.02	.48	24.10	0.00
3.3000	-.58	-1.87	-2.52	4.48	-.02	.46	22.98	0.00
3.3500	-.65	-.76	-2.36	4.46	-.02	.42	21.46	0.00
3.4000	-.66	.27	-2.17	4.44	-.02	.39	19.64	0.00
3.4500	-.62	1.20	-1.94	4.43	-.02	.34	17.57	0.00
3.5000	-.54	2.02	-1.70	4.42	-.02	.29	15.32	0.00
3.5500	-.42	2.73	-1.44	4.41	-.02	.24	12.97	0.00
3.6000	-.27	3.32	-1.18	4.40	-.01	.19	10.57	0.00
3.6500	-.09	3.79	-.92	4.40	-.01	.14	8.18	0.00
3.7000	.11	4.14	-.66	4.38	-.01	.08	5.86	0.00
3.7500	.32	4.38	-.42	4.37	-.01	.04	3.63	0.00
3.8000	.54	4.50	-.19	4.35	-.01	-.01	1.56	0.00
3.8500	.77	4.53	.02	4.33	-.01	-.05	-.35	0.00
3.9000	1.00	4.47	.21	4.31	-.00	-.09	-2.06	0.00
3.9500	1.22	4.33	.37	4.28	-.00	-.12	-3.55	0.00
4.0000	1.43	4.12	.51	4.25	-.00	-.15	-4.82	0.00
4.0500	1.63	3.85	.63	4.21	-.00	-.17	-5.86	0.00
4.1000	1.81	3.54	.72	4.17	-.00	-.19	-6.68	0.00
4.1500	1.98	3.19	.79	4.12	-.00	-.20	-7.26	0.00
4.2000	2.13	2.82	.83	4.07	.00	-.21	-7.64	0.00
4.2500	2.26	2.43	.85	4.01	.00	-.22	-7.81	0.00
4.3000	2.37	2.04	.85	3.95	.00	-.21	-7.80	0.00
4.3500	2.47	1.65	.83	3.89	.00	-.21	-7.62	0.00
4.4000	2.54	1.28	.80	3.82	.00	-.20	-7.30	0.00
4.4500	2.59	.92	.75	3.75	.00	-.19	-6.86	0.00
4.5000	2.63	.59	.69	3.68	-.00	-.18	-6.32	0.00
4.5500	2.65	.29	.63	3.60	-.00	-.17	-5.70	0.00
4.6000	2.66	.02	.55	3.53	-.00	-.15	-5.02	0.00
4.6500	2.66	-.21	.47	3.45	-.00	-.13	-4.30	0.00
4.7000	2.64	-.40	.39	3.37	-.00	-.12	-3.56	0.00
4.7500	2.62	-.56	.31	3.29	-.00	-.10	-2.83	0.00
4.8000	2.59	-.69	.24	3.22	-.00	-.08	-2.11	0.00
4.8500	2.55	-.78	.16	3.14	-.00	-.07	-1.42	0.00
4.9000	2.51	-.83	.09	3.06	-.00	-.05	-.78	0.00
4.9500	2.47	-.85	.02	2.98	-.00	-.04	-.18	0.00
5.0000	2.42	-.85	-.04	2.91	-.00	-.03	.36	0.00

$$\left(\text{The matrix } \left[\frac{\partial^2 J}{\partial p^2}\right]^{-1}\right)$$

D2JDP2 MATRIX INVERSE

	MQ	MW	ZW	MU	ZU	XU	XW	MDE	ZDE
MQ	1.028E-04	-7.880E-05	-7.530E-05	-3.609E-05	-2.199E-05	1.017E-06	-1.311E-06	4.036E-04	-3.473E-04
MW	-7.880E-05	1.176E-04	9.390E-05	-3.554E-04	-2.902E-04	-2.477E-07	2.328E-07	-4.744E-04	-1.766E-04
ZW	-7.530E-05	9.390E-05	1.024E-04	-3.082E-04	-2.616E-04	1.997E-06	9.448E-07	-2.764E-04	1.624E-04
MU	-3.609E-05	-3.554E-04	-3.082E-04	5.450E-03	4.289E-03	6.078E-05	5.487E-05	1.493E-03	2.175E-03
ZU	-2.199E-05	-2.902E-04	-2.616E-04	4.289E-03	3.502E-03	2.917E-05	2.797E-05	1.171E-03	1.777E-03
XU	1.017E-06	-2.477E-07	1.997E-06	6.078E-05	2.917E-05	3.017E-05	-3.283E-06	3.939E-05	-4.593E-05
XW	-1.311E-06	2.328E-07	9.448E-07	5.487E-05	2.797E-05	-3.283E-06	4.507E-05	8.922E-07	4.270E-05

(The normalized version of the previous matrix, i.e.

$$\sigma_{ii} = P_{ii} = \sqrt{P'_{ii}}$$

$$P_{ij} = \frac{P'_{ij}}{\sqrt{P'_{ii}}\ \sqrt{P'_{jj}}}$$

see Section 4.1.2)

NORMALIZED D2JDP2 INVERSE

	MQ	MW	ZW	MU	ZU	XU	XW	MDE	ZDE
MQ	1.014E-02	-7.168E-01	-7.342E-01	-4.823E-02	-3.665E-02	1.826E-02	-1.926E-02	6.081E-01	-3.832E-01
MW	-7.168E-01	1.084E-02	8.557E-01	-4.439E-01	-4.522E-01	-4.158E-03	3.198E-03	-6.683E-01	-1.822E-01
ZW	-7.342E-01	8.557E-01	1.012E-02	-4.126E-01	-4.368E-01	3.593E-02	1.391E-02	-4.173E-01	1.796E-01
MU	-4.823E-02	-4.439E-01	-4.126E-01	7.383E-02	9.817E-01	1.499E-01	1.107E-01	3.090E-01	3.295E-01
ZU	-3.665E-02	-4.522E-01	-4.368E-01	9.817E-01	5.918E-02	8.975E-02	7.039E-02	3.022E-01	3.360E-01
XU	1.826E-02	-4.158E-03	3.593E-02	1.499E-01	8.975E-02	5.493E-03	-8.902E-02	1.095E-01	-9.354E-02
XW	-1.926E-02	3.198E-03	1.391E-02	1.107E-01	7.039E-02	-8.902E-02	6.713E-03	2.030E-03	7.115E-02
MDE	6.081E-01	-6.683E-01	-4.173E-01	3.090E-01	3.022E-01	1.095E-01	2.030E-03	6.546E-02	2.818E-01
ZDE	-3.832E-01	-1.822E-01	1.796E-01	3.295E-01	3.360E-01	-9.354E-02	7.115E-02	2.818E-01	8.940E-02

$$\left(\text{The matrix} \left[\frac{\partial^2 J}{\partial p^2}\right]^{-1} + \left[\frac{\partial p}{\partial e} E(ee^T) \frac{\partial p}{\partial e}^T\right] \right)$$

ENSEMBLE COVARIANCE

	MQ	MW	ZW	MU	ZU	XU	XW	MDE	ZDE
MQ	7.047E-04	-2.830E-04	-6.318E-04	-4.281E-04	-4.415E-04	-1.023E-04	1.189E-04	3.231E-04	-7.446E-03
MW	-2.830E-04	6.866E-04	7.228E-04	-6.567E-03	-5.345E-03	-4.700E-04	2.160E-04	-2.791E-03	-4.631E-04
ZW	-6.318E-04	7.228E-04	1.042E-03	-5.374E-03	-4.626E-03	-6.412E-04	3.454E-04	-1.921E-03	4.558E-03
MU	-4.281E-04	-6.567E-03	-5.374E-03	9.770E-02	7.526E-02	2.027E-03	4.791E-04	3.167E-02	3.857E-02
ZU	-4.415E-04	-5.345E-03	-4.626E-03	7.526E-02	6.149E-02	5.148E-03	-2.449E-03	2.316E-02	3.208E-02
XU	-1.023E-04	-4.700E-04	-6.412E-04	2.027E-03	5.148E-03	5.676E-03	-4.121E-03	-2.131E-04	1.784E-03
XW	1.189E-04	2.160E-04	3.454E-04	4.791E-04	-2.449E-03	-4.121E-03	3.114E-03	8.094E-04	-1.376E-03
MDE	3.231E-04	-2.791E-03	-1.921E-03	3.167E-02	2.316E-02	-2.131E-04	8.094E-04	2.618E-02	1.776E-02
ZDE	-7.446E-03	-4.631E-04	4.558E-03	3.857E-02	3.208E-02	1.784E-03	-1.376E-03	1.776E-02	1.097E-01

(The normalized version of the previous matrix)

NORMALIZED COVARIANCE

	MQ	MW	ZW	MU	ZU	XU	XW	MDE	ZDE
MQ	2.655E-02	-4.069E-01	-7.373E-01	-5.159E-02	-6.706E-02	-5.116E-02	8.026E-02	7.521E-02	-8.470E-01
MW	-4.069E-01	2.620E-02	8.545E-01	-8.017E-01	-8.226E-01	-2.381E-01	1.477E-01	-6.584E-01	-5.336E-02
ZW	-7.373E-01	8.545E-01	3.228E-02	-5.326E-01	-5.778E-01	-2.636E-01	1.917E-01	-3.677E-01	4.263E-01
MU	-5.159E-02	-8.017E-01	-5.326E-01	3.126E-01	9.710E-01	8.607E-02	2.746E-02	6.261E-01	3.726E-01
ZU	-6.706E-02	-8.226E-01	-5.778E-01	9.710E-01	2.480E-01	2.755E-01	-1.770E-01	5.771E-01	3.907E-01
XU	-5.116E-02	-2.381E-01	-2.636E-01	8.607E-02	2.755E-01	7.534E-02	-9.802E-01	-1.748E-02	7.149E-02
XW	8.026E-02	1.477E-01	1.917E-01	2.746E-02	-1.770E-01	-9.802E-01	5.581E-02	8.964E-02	-7.446E-02
MDE	7.521E-02	-6.584E-01	-3.677E-01	6.261E-01	5.771E-01	-1.748E-02	8.964E-02	1.618E-01	3.315E-01
ZDE	-8.470E-01	-5.336E-02	4.263E-01	3.726E-01	3.907E-01	7.149E-02	-7.446E-02	3.315E-01	3.312E-01

(The vector $\frac{\partial p}{\partial e} E(e)$)

(G) EXPECTED MEAN ERROR

MQ	-8.82475E-02	MW	2.13709E-02	ZW	8.03769E-02	MU	5.99639E-02	ZU	4.70834E-02
XU	-2.73064E-03	XW	-9.92309E-03	MDE	1.67975E-01	ZDE	1.18290E+00		

(The standard deviations and mean values of e and the sensitivities $\frac{\partial p}{\partial e}$)

SENSITIVITY DERIVATIVES

PARAMETER	ERROR SOURCE BIASES THETA	Q	ALPHA	U	NX	NZ	Q-DOT	SCALE THETA	Q	ALPHA
INPUT	2.000E-01	2.000E-01	3.000E-01	1.000E+00	1.000E-03	1.000E-03	2.000E-01	5.000E-03	5.000E-03	5.000E-03
MQ	2.869E-03	4.964E-04	-3.855E-03	-1.760E-03	6.620E-04	-1.194E-01	-2.973E-03	-7.117E-02	-2.320E-01	-7.988E-02
MW	-1.968E-02	6.836E-03	-6.490E-02	-4.946E-03	-1.119E-02	-5.173E-01	6.530E-03	6.458E-02	2.105E-01	8.986E-02
ZW	-5.469E-03	9.842E-03	-5.624E-02	-7.514E-03	-6.845E-03	-6.331E-01	3.837E-03	5.503E-02	2.352E-01	5.058E-02
MU	4.162E-01	-5.446E-02	9.660E-01	5.727E-03	2.396E-01	7.409E+00	-7.389E-02	-2.321E-01	3.456E-01	6.826E-01
ZU	1.996E-01	-1.005E-01	7.612E-01	5.572E-02	1.638E-01	8.037E+00	-6.402E-02	-3.541E-01	1.768E-01	5.210E-01
XU	4.024E-02	1.655E-02	1.033E-02	7.452E-02	3.661E-02	-5.841E-01	2.782E-03	2.210E-02	-1.096E-02	1.831E-02
XW	-4.125E-03	5.202E-04	9.616E-03	-5.526E-02	-5.244E-04	2.868E-02	3.310E-05	5.923E-03	-1.227E-03	1.346E-02
MDE	1.977E-01	-7.741E-04	2.763E-01	-1.311E-02	9.627E-02	1.072E+00	-4.765E-02	-7.926E-01	-2.569E+00	-5.459E-01
ZDE	-3.805E-02	-7.333E-02	3.791E-01	2.499E-02	6.816E-03	4.677E+00	-3.359E-02	3.419E-01	1.236E+00	-4.368E-01

PARAMETER	ERROR SOURCE U	NX	NZ	Q-DOT	MISALN NX	NZ	C. G. CG X	CG Z	ACCEL AX	AZ
INPUT	5.000E-03	5.000E-03	5.000E-03	5.000E-03	5.000E-01	5.000E-01	5.000E-01	5.000E-01	2.000E+00	2.000E+00
MQ	-8.418E-03	-2.054E-04	1.956E+00	-1.564E+00	-1.139E-04	-1.076E-03	-4.186E-02	1.536E-04	-4.025E-02	1.536E-04
MW	-2.287E-02	1.840E-04	-1.748E+00	1.406E+00	5.702E-05	9.791E-04	8.634E-03	-1.191E-04	7.187E-03	-1.191E-04
ZW	-3.508E-02	2.173E-04	-2.313E+00	2.007E+00	9.301E-05	1.325E-03	3.774E-02	-1.561E-04	3.600E-02	-1.561E-04
MU	2.186E-02	5.385E-03	2.898E+00	-3.721E+00	4.113E-03	-2.233E-03	3.688E-02	-2.841E-03	3.959E-02	-2.841E-03
ZU	2.108E-01	2.651E-03	2.164E+00	-2.722E+00	2.224E-03	-1.981E-03	2.829E-02	-1.411E-03	3.052E-02	-1.411E-03
XU	3.420E-01	-1.523E-04	-1.839E-02	-3.529E-01	7.216E-05	7.811E-05	-1.328E-03	1.043E-04	-1.234E-03	1.043E-04
XW	-2.361E-01	4.373E-03	8.673E-02	1.269E-01	2.495E-03	-4.532E-05	-2.639E-03	-2.290E-03	-2.616E-03	-2.290E-03
MDE	-9.505E-02	-5.540E-04	6.949E-01	-2.107E+01	8.849E-05	-4.319E-04	8.708E-02	2.704E-04	8.933E-02	2.704E-04
ZDE	1.271E-01	3.112E-03	-1.076E+01	9.494E+00	1.779E-03	6.028E-03	5.747E-01	-2.224E-03	5.621E-01	-2.224E-03

PARAMETER	ERROR SOURCE VANE VX
INPUT	5.000E+00
MQ	-1.610E-03
MW	1.447E-03
ZW	1.737E-03
MU	-2.705E-03
ZU	-2.226E-03
XU	-9.430E-05
XW	-2.216E-05
MDE	-2.245E-03
ZDE	1.262E-02

DETERMINANT OF D2JDP2 = 3.59220404E+08

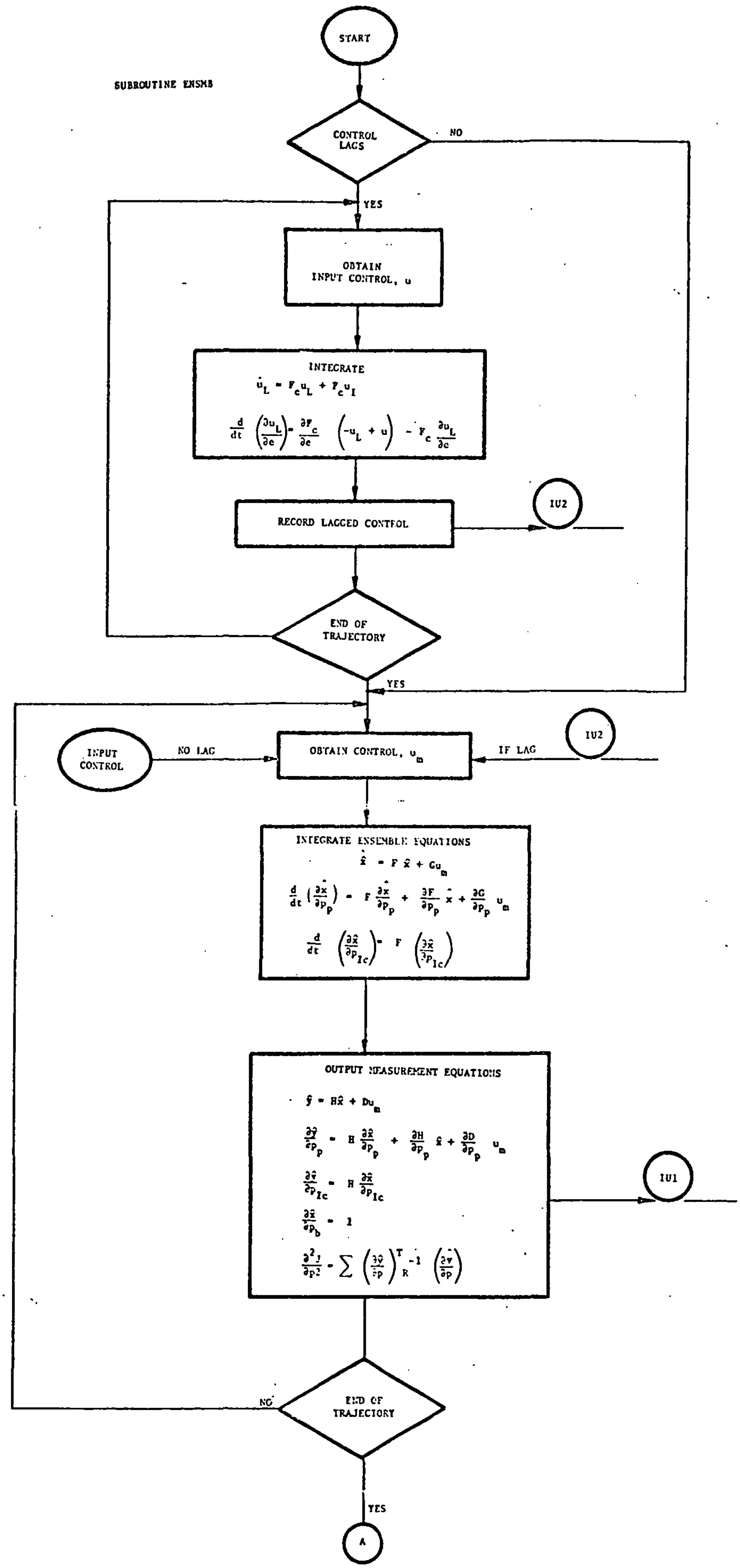
PROGRAM FUNCTIONAL ORGANIZATION

The program consists of two subprograms: the Ensemble Analysis Program and the Simulated Data Analysis Program.

The main program for the Ensemble Analysis is SUBROUTINE ENSMB. It evaluates ensemble equations to construct $\left(\frac{\partial^2 J}{\partial p^2}\right)$ matrix and then evaluates $\left(\frac{\partial(\delta p)}{\partial e}\right)$.

The Simulated Data Analysis Program is further subdivided into MODE1 and MODE2 subprograms, SMODE1 and SMODE2, respectively. The Simulated Data Analysis Program also requires the $\left(\frac{\partial^2 J}{\partial p^2}\right)$ matrix, and this task is accomplished by executing the ENSMB subprogram first.

The figures 5-1, 5-2, and 5-3 show the flow of ENSMB, SMODE1, and SMODE2, respectively.



SUBROUTINE ENSMB
START
CONTROL LAGS
NO
YES
OBTAIN INPUT CONTROL, u
INTEGRATE
RECORD LAGGED CONTROL
IU2
END OF TRAJECTORY
YES
INPUT CONTROL
NO LAG
OBTAIN CONTROL, u_m
IF LAG
IU2
INTEGRATE ENSEMBLE EQUATIONS
OUTPUT MEASUREMENT EQUATIONS
IU1
NO
END OF TRAJECTORY
YES
A

FIGURE 5-1

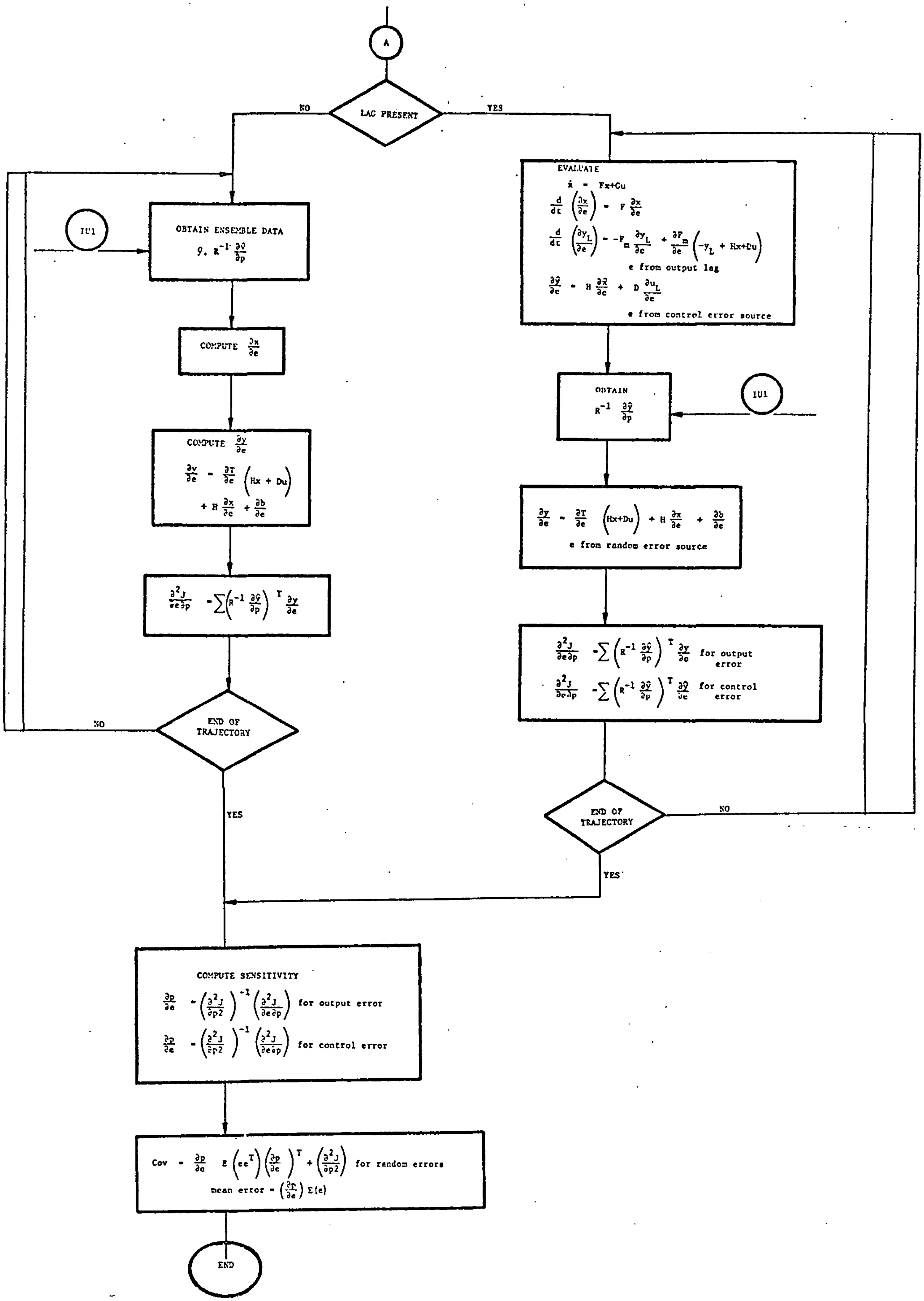


FIGURE 5-1 (Continued)

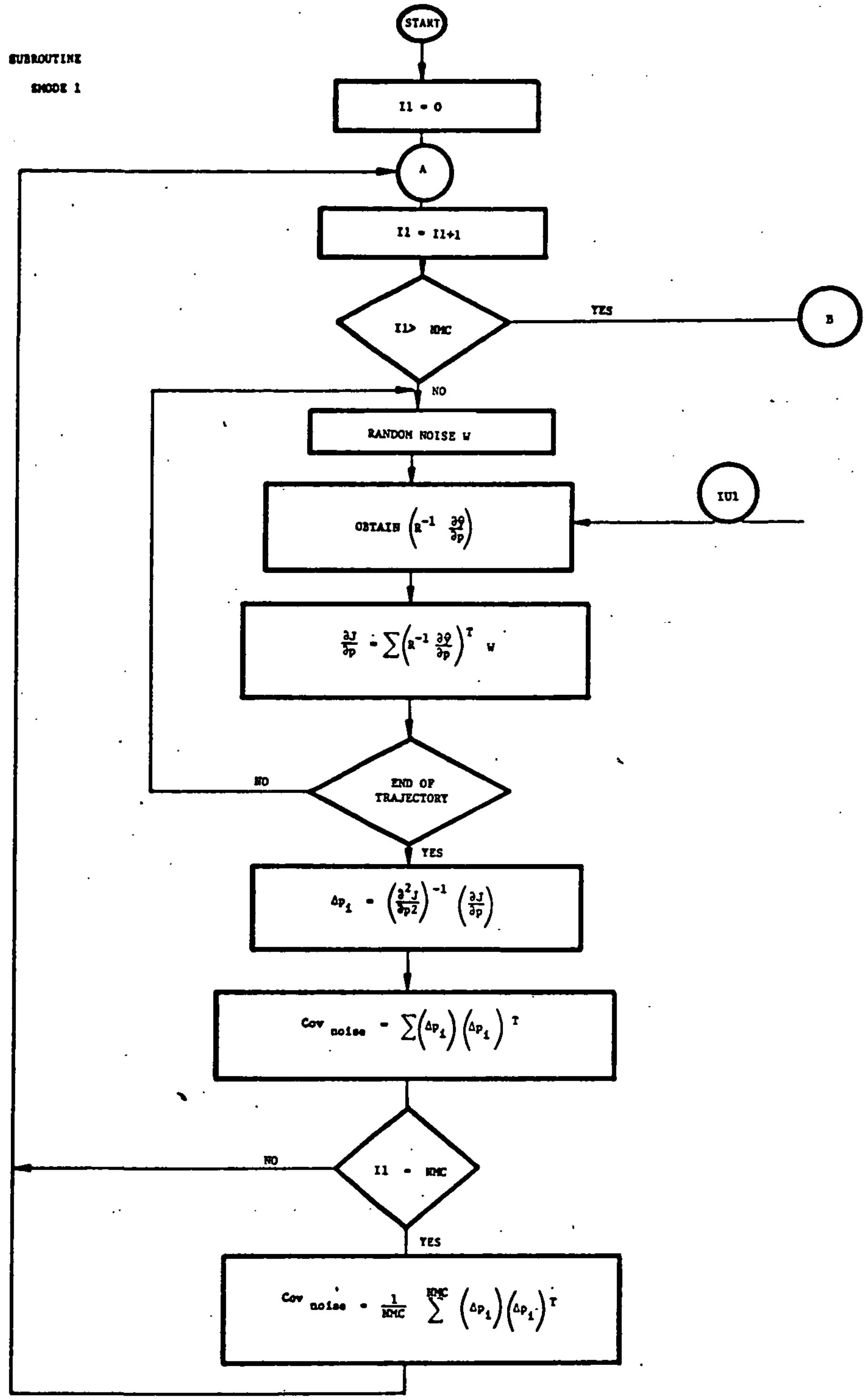

SUBROUTINE
SMODE 1
START
I1 = 0
A
I1 = I1+1
I1> NMC
YES
B
NO
RANDOM NOISE W
IU1
OBTAIN $\left(R^{-1}\ \frac{\partial g}{\partial p}\right)$
$\frac{\partial J}{\partial p} = \sum\left(R^{-1}\ \frac{\partial g}{\partial p}\right)^{T} W$
NO
END OF TRAJECTORY
YES
$\Delta p_i = \left(\frac{\partial^2 J}{\partial p^2}\right)^{-1} \left(\frac{\partial J}{\partial p}\right)$
$Cov_{noise} = \sum\left(\Delta p_i\right)\left(\Delta p_i\right)^{T}$
NO
I1 = NMC
YES
$Cov_{noise} = \frac{1}{NMC} \sum^{NMC} \left(\Delta p_i\right)\left(\Delta p_i\right)^{T}$

FIGURE 5-2

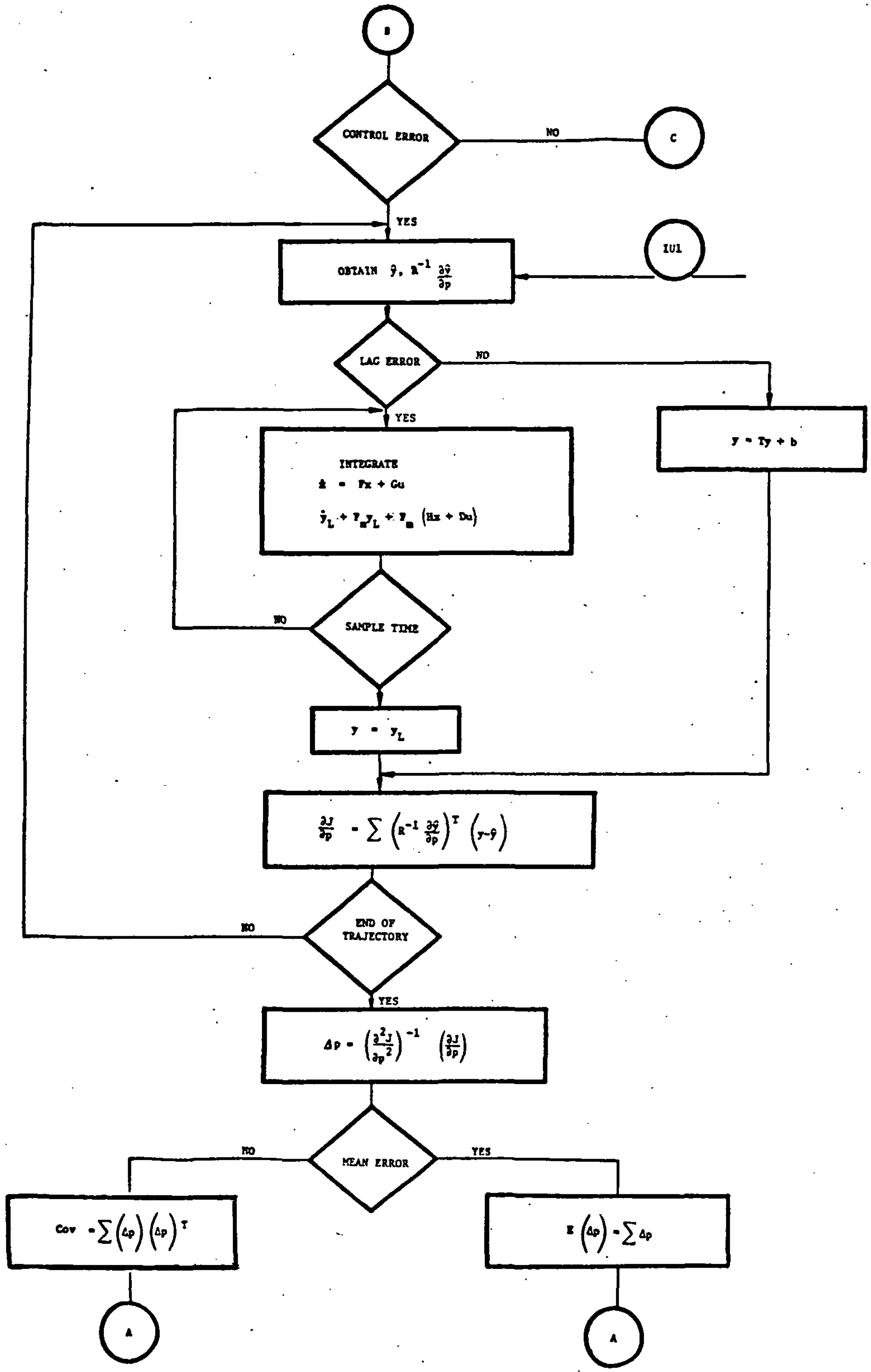


FIGURE 5.2 (Continued)

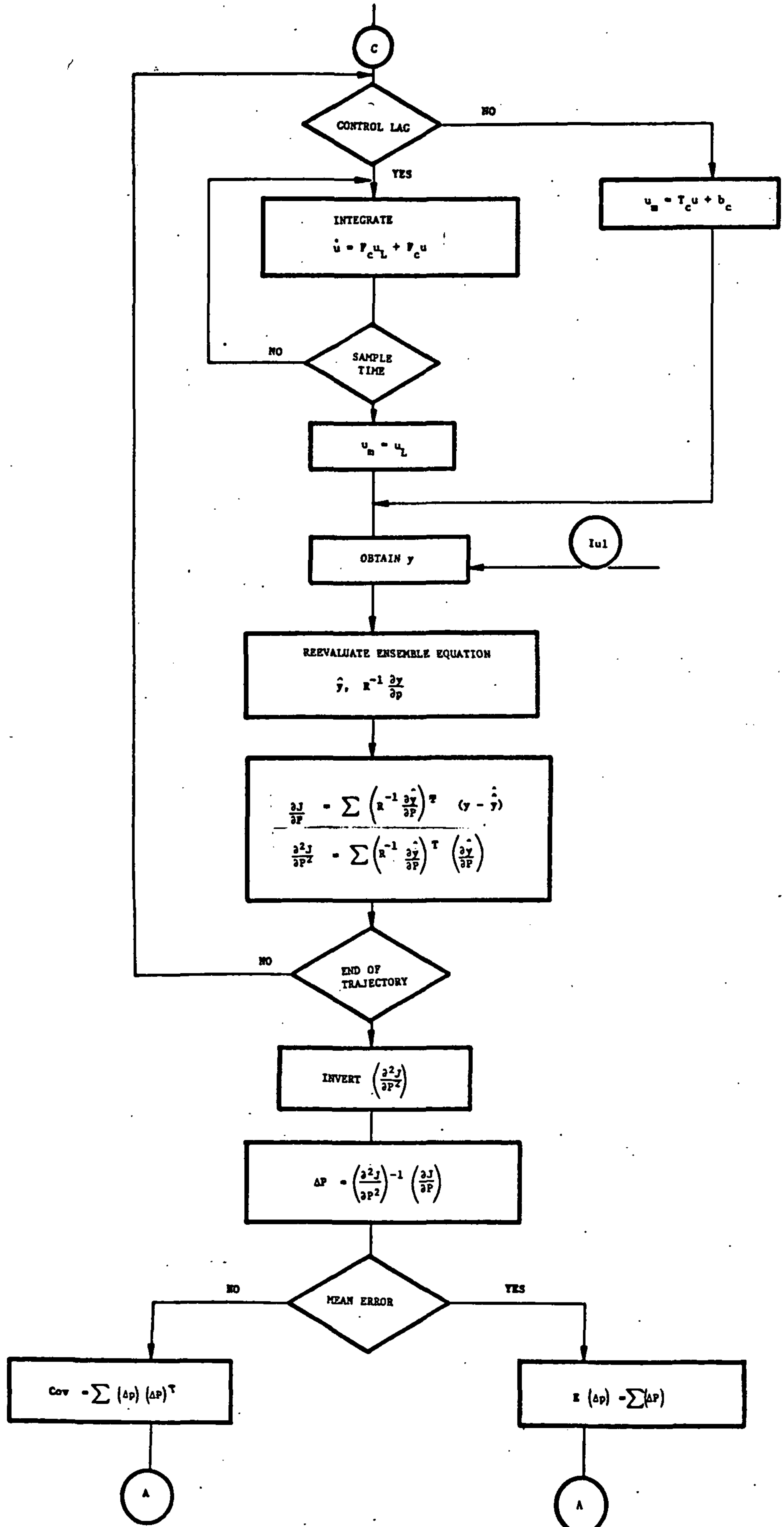


FIGURE 5-2 (Continued)

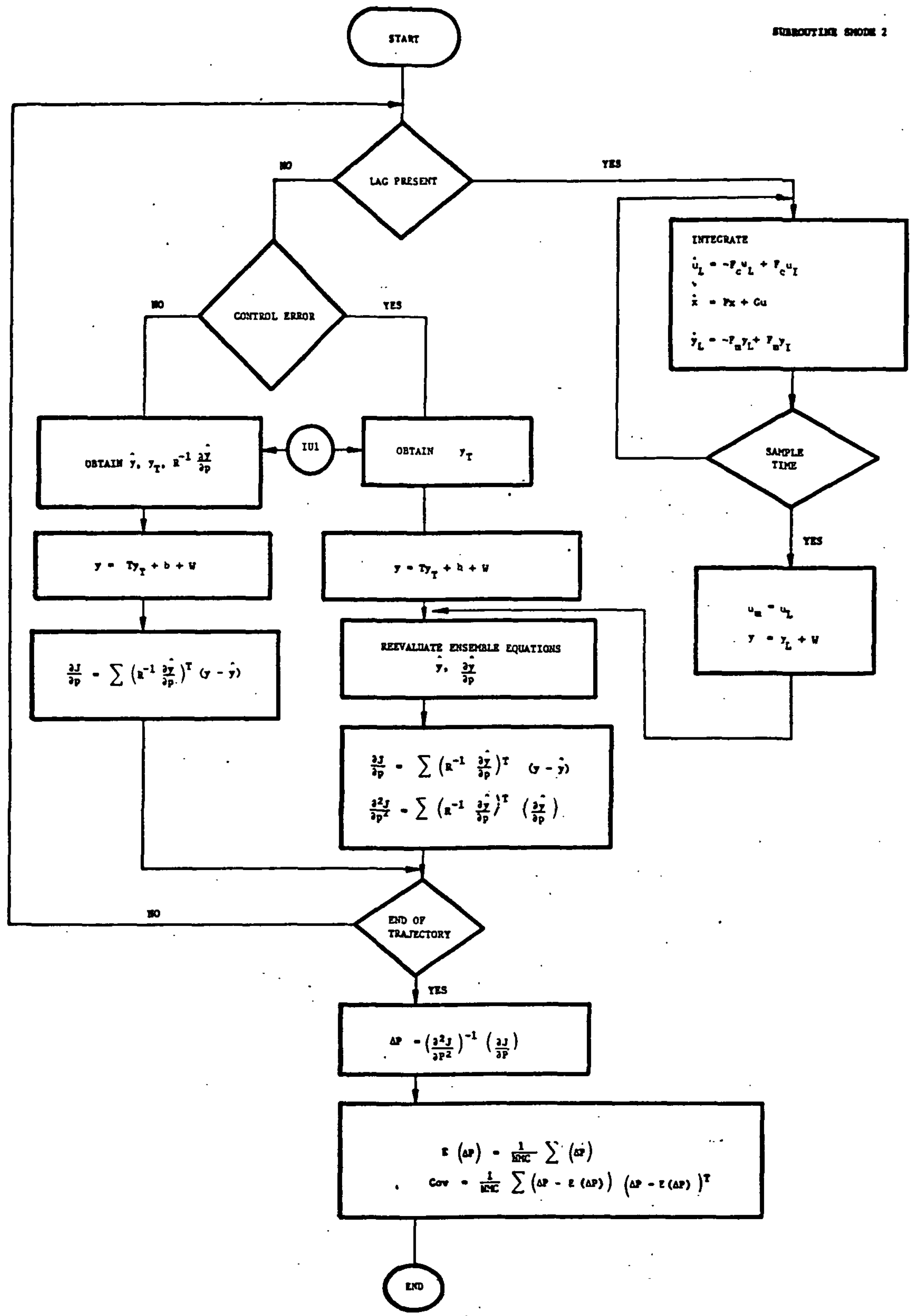

SUBROUTINE SMODE 2
START
LAG PRESENT
NO
YES
CONTROL ERROR
NO
YES
INTEGRATE
OBTAIN $\hat{y}$, y_T, R^{-1} $\frac{\partial \hat{y}}{\partial p}$
IU1
OBTAIN y_T
SAMPLE TIME
YES
$y = Ty_T + b + W$
$y = Ty_T + b + W$
REEVALUATE ENSEMBLE EQUATIONS
$\hat{y}$, $\frac{\partial \hat{y}}{\partial p}$
$y = y_L + W$
END OF TRAJECTORY
NO
YES
END

FIGURE 5-3

VI

SUBPROGRAM DESCRIPTIONS

The subroutines in the program are described in this section. The function and argument list for each subroutine are given.

6.1 BLOCK DATA

The BLOCK DATA subroutine is used to initialize variables in labeled commons at load time (see Table 3.2). This subroutine also includes all the labeled commons for the entire program for the storage allocation purpose (CDC-6600).

6.2 CNSTRT

This subroutine computes the T-matrix during the Simulated Data Mode=1 Analysis when random error sources are applied one at a time.

Calling Sequence - CALL CNSTRT(INDEX)

where

INDEX = n means that the n^{th} random error source is being considered. The error sources are numbered as follows:

$1 \leq$ INDEX $\leq 7 \Longrightarrow$ bias errors (b's)

$8 \leq$ INDEX $\leq 14 \Longrightarrow$ scaling errors (e's)

$15 \leq$ INDEX $\leq 21 \Longrightarrow$ misalignment errors (γ's)

$22 \leq$ INDEX $\leq 25 \Longrightarrow$ initial condition error (x_o's)

$26 \leq$ INDEX $\leq 28 \Longrightarrow$ center of gravity position errors (ε_{cg}'s)

6.3 CONSTT

This subroutine computes the T-matrix for the Simulated Data Mode=2 Analysis by applying the errors all at once.

Calling Sequence - CALL CONSTT(ERRORS)

where

ERRORS is a vector of scaling errors, e , stored accordingly to the measurement order, i.e., θ, q, α, u, n_x, n_z, $\dot{q}$ for the longitudinal and β, p, r, ϕ, n_y, $\dot{p}$, and $\dot{r}$ for the lateral.

6.4 DERIV

This subroutine computes the time derivatives of the state vector and the partial derivatives of the state vector with respect to parameters. It computes:

$$\frac{d}{dt}(x) = Fx + Du$$

by calling DERIV1, and

$$\frac{d}{dt}\left(\frac{\partial x}{\partial p}\right) = F\frac{\partial x}{\partial p} + \frac{\partial F}{\partial p}x + \frac{\partial G}{\partial p}u \ ,$$

by calling DERIV2.

Calling Sequence - CALL DERIV(XMAT,T,DX,K,L,M)

where

XMAT is the M x L matrix of the function

T is the integration variable, time

DX is the derivative being computed

K is not used

L is the number of columns in XMAT and DX

M is the number of rows in XMAT and DX

6.5 SUBROUTINE DERIVU

This subroutine evaluates time derivatives of the control variable when control output lag is present.

Calling Sequence - CALL DERIVU(UL,ULDOT)

where

UL is the control vector, u_L.

ULDOT is the time derivative of the control vector, $\frac{d}{dt}(u_L)$.

Equation

$$\dot{u}_L = -F_C\, u_L + F_C\, u_I$$

6.6 SUBROUTINE DERVU1

This subroutine evaluates time derivatives of the control vector as well as those of the partial derivatives of the control vector with respect to error sources.

Calling Sequence - CALL DERVU1(UL,ULDOT,PDUDE,PDUDED,NX)

where

UL is the control vector, u_L.

ULDOT is the time derivative of the control vector, $\frac{d}{dt}(u_L)$.

PDUDE is the partial derivatives of the control vector with respect to error sources, $\left(\frac{\partial u_L}{\partial e}\right)$.

PDUDED is the time derivative of PDUDE, $\frac{d}{dt}\left(\frac{\partial u_L}{\partial e}\right)$

NX is the number of components in the control vector, u_L.

Equation:

$$\dot{u}_L = -F_C\, u_L + F_C\, u_I$$

$$\frac{d}{dt}\left(\frac{\partial u_L}{\partial e}\right) = -F_C \frac{\partial u_L}{\partial e} + \frac{\partial F_C}{\partial e}(-u_L + u)$$

6.7 SUBROUTINE DERIVX

This subroutine computes the time derivative of the aircraft state vector, x.

Calling Sequence - CALL DERIVX(X,XDOT)

where

X is the aircraft state vector

XDOT is the time derivative of the aircraft state vector

Equation:

$$\dot{x} = Fx + Gu$$

6.8 SUBROUTINE DERIVY

This subroutine evaluates the time derivative of the lagged output measurement state vector, y_L.

Calling Sequence - CALL DERIVY(YL,YLDOT,YI,X,U)

where

YL is the lagged output measurement state vector, y_L.

YLDOT is the time derivative of y_L.

YI is the indicated output vector, y_I.

X is the aircraft state vector, x.

U is the input control vector, u.

Equation:

$$\dot{y}_L = - F_M \, y_L + F_M \, y_I$$

where

$$y_I = T(Hx + Du)$$

6.9 DERIV1

This subroutine computes the time derivative of the state vector, $\hat{x}$:

$$\frac{d}{dt}(\hat{x}) = F\hat{x} + Gu_m .$$

Calling Sequence - CALL DERIV1(F,X,G,U,L,M,N,DXDT)

where

F is the matrix F

X is the state vector $\hat{x}$

G is the matrix G

U is the control vector u_m

L, M, and N are used to specify sub-matrix of F and G which are used; i.e., L x M sub-matrix of F and L x N sub-matrix of G.

DXDT is the time derivative of state vector $\hat{x}$, $\frac{d}{dt}(\hat{x})$.

6.10 DERIV2

This subroutine computes the time derivatives of the partial derivatives of the state vector with respect to the parameters

$$\frac{d}{dt}\left(\frac{\partial \hat{x}}{\partial p}\right) = F\left(\frac{\partial \hat{x}}{\partial p}\right) + \frac{\partial F}{\partial p}\hat{x} + \frac{\partial G}{\partial p}u_m .$$

Calling Sequence - CALL DERIV2(FMAT,PDXDP,X,U,ROW1,COL1,ROW2,COL2,M,N,
L,DXDPDT,NEQ)

where

FMAT is the matrix F

PDXDP is the matrix of the partial derivatives, $\frac{\partial \hat{x}}{\partial p}$.

X is the state vector, $\hat{x}$

U is the control vector, u_m

ROW1 and COL1 are used to specify the non-zero element of $\left(\frac{\partial F}{\partial p}\right)$ matrix, i.e., ROW1(i) = m and COL1(i) = n

$$\left(\frac{\partial F}{\partial p_i}\right)_{m,n} = 1$$

ROW2 and COL2 are similarly used to specify the non-zero element of $\left(\frac{\partial G}{\partial p}\right)$ matrix.

M, N, and L are used to specify the sub-matrices of F and G which are used; i.e., M x N sub-matrix of F and M by L sub-matrix of G, respectively.

DXDPDT is the matrix containing the time derivatives, $\frac{d}{dt}\left(\frac{\partial \hat{x}}{\partial p}\right)$.

NEQ is the number of columns in $\frac{d}{dt}\left(\frac{\partial \hat{x}}{\partial p}\right)$ matrix. Note NEQ includes the derivatives $\frac{d}{dt}\left(\frac{\partial \hat{x}}{\partial e}\right) = F\left(\frac{\partial \hat{x}}{\partial e}\right)$ corresponding to the initial condition errors.

6.11 SUBROUTINE DERVX1

This subroutine evaluates time derivatives of the aircraft state vector with respect to the initial condition errors.

Calling Sequence - CALL DERVX1(DXDE,DXDED,NX)

where

DXDE is the partial derivative, $\frac{\partial \hat{x}}{\partial e}$

DXDED is the time derivative of the above, $\frac{d}{dt}\left(\frac{\partial \hat{x}}{\partial e}\right)$

NX is the row dimension of $\left(\frac{\partial \hat{x}}{\partial e}\right)$ matrix.

Equation:

$$\frac{d}{dt}\left(\frac{\partial \hat{x}}{\partial e}\right) = F\left(\frac{\partial \hat{x}}{\partial e}\right)$$

6.12 SUBROUTINE DERVX2

This subroutine computes the partial derivatives of the simulated aircraft state vector with respect to the control error sources.

Calling Sequence - CALL DERVX2(DXH,DXHD,NX,DUDE)

where

DXH is the partial derivatives, $\frac{\partial \hat{x}}{\partial e}$

DXHD is the time derivatives of $\frac{\partial \hat{x}}{\partial e}$

NX is the number of elements in the aircraft state vector, x

DUDE is the partial derivative of the control vector with respect to the control error sources, $\frac{\partial u_L}{\partial e}$

Equation:

$$\frac{d}{dt}\left(\frac{\partial \hat{x}}{\partial e}\right) = H \frac{\partial \hat{x}}{\partial e} + G \frac{\partial u_L}{\partial e}$$

6.13 SUBROUTINE DERVY1

This subroutine evaluates time derivatives of the lagged output measurement vector with the lag error sources.

Calling Sequence - CALL DERVY1(DYDE,DYDED,XX,YYL,YYI,UU,NX)

where

DYDE is the partial derivative, $\frac{\partial y_L}{\partial e}$

DYDED is the time derivative of $\frac{\partial y_L}{\partial e}$

XX is the aircraft state vector, x

YYL is the lagged output vector, y_L

YYI is the indicated output vector, y_I

UU is the input control vector, u

NX is the number of components in output measurement vector, y

Equation:

$$\frac{d}{dt}\left(\frac{\partial y_L}{\partial e}\right) = \frac{\partial F_m}{\partial e} (Hx + Du - y_L) - F_m\left(\frac{\partial y_L}{\partial e}\right)$$

6.14 DMTMY1

This subroutine computes the product of a double precision matrix and a single precision matrix and stores the result in a single precision matrix, C = A x B.

Calling Sequence - CALL DMTMY1(A,B,C,L,M,N,N1,N2,N3)

where

A is a double precision matrix of dimension N1 by M

B is a single precision matrix of dimension N2 by N

C is a single precision matrix of dimension N3 by N

L is the number of rows of A used to compute the product

M is the number of columns of A and the number of rows of B used to compute the product

N is the number of columns of B used to compute the product

N1 is the row dimension of A

N2 is the row dimension of B

N3 is the row dimension of C

Note that the multiplication is performed only by using the L by M sub-matrix of A and M by N sub-matrix of B. Thus, only L by N sub-matrix of C is computed.

6.15 SUBROUTINE ENSMB

This subroutine is used to evaluate the ensemble equations for both the Ensemble Analysis and the Simulated Data Analysis.

If the Ensemble Analysis is being performed, this subroutine also computes quantities necessary to do the error sensitivity study during the trajectory calculation.

The output from the Ensemble Analysis is then the sensitivity derivative, $\left(\frac{\partial p}{\partial e}\right)$, and the covariance matrix $\left(\frac{\partial p}{\partial e}\right) E\ (ee^T) \left(\frac{\partial p}{\partial e}\right)^T$.

If the Simulated Data Analysis is being performed, then the nominal trajectory data such as the state vector, $\hat{x}$, the partial derivatives of the state vector, $\frac{\partial \hat{x}}{\partial p}$, the simulated states, $\hat{y}$, and the weighted partial derivatives of the simulated states, $R^{-1}\left(\frac{\partial \hat{y}}{\partial p}\right)$, are computed and stored on a scratch file, IU1, to be used during the Simulated Data Analysis.

6.16 SUBROUTINE ENSMBL

This subroutine evaluates ensemble equations by integrating for one sample period and forms $\left(\frac{\partial^2 J}{\partial p^2}\right)$ matrix.

Calling Sequence - CALL ENSMBL(KKQS,STATES,NSTEP,DELT)

where

KKQS is the number of vector equations to be integrated

STATES is the vector equations

NSTEP is the number of integration steps until sample time

DELT is the integration step-size

6.17 SUBROUTINE ERRSET

This subroutine sets up a vector of flags ERRNDX corresponding to every error source.

ERRNDX(i) = N = 0: means the i^{th} error source is absent

$\neq$ 0: means the i^{th} error source occupies n^{th} position in ERRVEC vector.

This subroutine also sets up a vector ERRVEC and NAMERR where non-zero error value and the names of non-zero error sources are stored. ERRVEC and NAMERR are packed arrays. If ERRNDX(i) = N $\neq$ 0, then the i^{th} error value is stored in ERRVEC(n) and hollerith name is stored in NAMERR(n,1) and NAMERR (n,2).

Calling Sequence - CALL ERRSET(BIAS,EP,GM,EIC,FF,NAMPAR,NAMICC)

where

BIAS is a vector of bias errors (b's)

EP is a vector of scaling errors (e's)

GM is a vector of misalignment (γ's)

EIC is a vector of initial condition errors (x(0))

FF is a vector of lag errors (f's)

NAMPAR is a vector of hollerith names for parameters

NAMICC is a vector of hollerith names for initial conditions

6.18 SUBROUTINE ESTNAM

This subroutine sets up a vector of hollerith names for all parameters to be estimated.

Calling Sequence - CALL ESTNAM

6.19 SUBROUTINE GET

This subroutine brings the simulated state vector, measurement vector and partial derivatives into memory from the scratch file (IU1) to be used during the Simulated Data Analysis.

Calling Sequence - CALL GET(ITM)

where

ITM is the sample data point number.

6.20 SUBROUTINE GETU

This subroutine retrieves control vector, u_L, and the partial derivatives with respect to error source, $\left(\frac{\partial u_L}{\partial e}\right)$, from the scratch file when control lags are present.

Calling Sequence - CALL GETU(ITM,NS,DUDE)

where

ITM is the sample point number

NS is the number of integration steps to the next sample point

DUDE is the partial derivative, $\left(\frac{\partial u_L}{\partial e}\right)$

6.21 SUBROUTINE GETY

This subroutine retrieves output measurement vector $\hat{y}$ from the scratch file during the Simulated Data Analysis if the control error is present.

Calling Sequence - CALL GETY(ITM)

where

ITM is the sample point number

6.22 SUBROUTINE INPUTX

This subroutine controls most of SCIP2 input. This subroutine reads all namelist data and constructs F, G, H, and D matrices.

Calling Sequence - CALL INPUTX

6.23 SUBROUTINE INTEG

This subroutine controls the integration of aircraft dynamic equations. It integrates one time step, Δt_s, for each call to INTEG.

Calling Sequence - CALL INTEG(KKQS,STATES,I)

where

KKQS is the number of vector equations to be integrated
STATES is the KKQS vector equations
I is the sample time point number

6.24 SUBROUTINE MATADD

This subroutine performs matrix addition or matrix subtraction.

Calling Sequence - CALL MATADD(A,B,C,N,M,NA,NB,NC,L)

where

A is a NA by M matrix

B is a NB by M matrix

C is a NC by M matrix

N and M specify the submatrix for which addition or subtraction is to be performed

NA, NB, and NC specify the row number of matrices A, B, and C, respectively.

L is a flag to specify addition or subtraction

=0: addition

≠0: subtraction

6.25 SUBROUTINE MATMPY

This subroutine multiplies two matrices, $C = A \cdot B$.

Calling Sequence - CALL MATMPY(A,B,C,L,M,N,N1,N2,N3)

where

A is a N1 by M matrix

B is a N2 by N matrix

C is a N3 by N product matrix

L is the number of rows in A for which multiplication is performed

M is the number of columns in A and the number of rows in B for which multiplication is performed

N is the number of columns in B and C for which multiplication is performed

N1, N2, N3 are the row dimensions of A, B, and C matrices, respectively.

6.26 SUBROUTINE MATPNT

This subroutine prints out covariance matrices with the parameter names top to bottom and across the page. It prints 10 columns at a time.

Calling Sequence - CALL MATPNT(MATRIX,N1,N2,NX,HEAD)

where

MATRIX is the covariance matrix

N1 and N2 specify the dimensions of submatrix to be printed

NX is the row dimension of MATRX

HEAD is the header vector. It may contain up to 40 characters

6.27 SUBROUTINE MEANER

This subroutine constructs T-matrix for each of mean error sources or F_M matrix if output lags are present.

Calling Sequence - CALL MEANER(LERR,IERR)

where

LERR is the lag error vector

IERR is the flag to indicate the end of mean error sources

=0: continue with mean error sources

≠0: finished mean error sources

6.28 SUBROUTINE OPDB

This subroutine controls the print out of input summary for the SCIP2 program.

Calling Sequence - CALL OPDB(BIAS,EPS,GM,F,W,EIC,NAMPAR)

where

BIAS is the bias error vector

EPS is the output scale error vector

GM is the misalignment error vector

F is the output measurement lag error vector

W is the output measurement noise vector

EIC is the initial condition error vector

NAMPAR is the array containing the hollerith names of the output measurement states

6.29 SUBROUTINE OTHERR

This subroutine constructs T-matrix for random error sources.

Calling Sequence - CALL OTHERR(BERR,EERR,GERR,ICERR,IERTN)

where

BERR is the bias error vector

EERR is the scaling error vector

GERR is the misalignment vector

ICERR is the initial condition error vector

IERTN is the flag to indicate the end of random error sources

=0: not yet end

=1: end of random error sources

6.30 SUBROUTINE PACK

This subroutine moves vectors into temporary storage area to form a packed vector for simultaneous integration.

Calling Sequence - CALL PACK(V1,IS,NUM)

where

V1 is the vector to be moved to temporary storage area

IS is the starting location -1 in the temporary storage area of V1

NUM is the number of elements in V1 to be moved to the temporary storage area

6.31 SUBROUTINE PACK2

This subroutine moves two dimensional arrays into temporary storage area to form a packed vector.

Calling Sequence - CALL PACK2(A,J2,N1,N2,NX)

where

A is a two dimensional array to be moved to temporary storage area

J2 is the starting location -1 in the temporary storage area of A

N1 is the number of rows of A to be moved

N2 is the number of columns of A to be moved

NX is the row dimension of A

6.32 SUBROUTINE PERTRB

This subroutine computes the T-matrix by calling CNSTRT or TCONST for a given error source.

Calling Sequence - CALL PERTRB(ERROR,IB,IERTN)

where

ERROR is the standard deviation of the error source

IB is the error number

IERTN is the flag to indicate the presence (IERTN=0) or absence (IERTN=0) of error number IB

6.33 SUBROUTINE PRINTF

This subroutine prints $\left(\frac{\partial p}{\partial e}\right)$ matrix for Ensemble Analysis and (δp) vectors corresponding to random error sources for MODE=1 of the Simulated Data Analysis.

Calling Sequence - CALL PRINTF(HEAD,MATRIX)

where

HEAD is a header vector of up to 40 characters

MATRIX is the matrix containing either $\left(\frac{\partial p}{\partial e}\right)$ matrix or (δp) vectors.

6.34 SUBROUTINE PRINTE

This subroutine controls the printout of normalized covariance matrix.

Calling Sequence - CALL PRINTE(COV,HEAD)

where

COV is the covariance matrix

HEAD is the header vector

6.35 SUBROUTINE PRINTS

This subroutine prints measurement vector and control vector at each sample time point.

Calling Sequence - CALL PRINTS(NN,Y)

where

NN is the sample point number

Y is the measurement vector

6.36 SUBROUTINE PRINTV

This subroutine prints the expected values of δp vector.

Calling Sequence - CALL PRINTV(HEAD,EVDP)

where

HEAD is the header vector

EVDP is the expected value vector

6.37 SUBROUTINE PRTLS1

This subroutine controls the computation of $\frac{\partial y}{\partial e}$ term for the error sensitivity study of the Ensemble Analysis,

$$\frac{\partial y}{\partial e} = TH \frac{\partial x}{\partial p} + \frac{\partial T}{\partial p} (Hx + Du) + \frac{\partial B}{\partial e} .$$

Calling Sequence - CALL PRTLS1(INDX)

where

INDX is the sample point number

6.38 SUBROUTINE PUT

This subroutine stores the simulated state vector, the measurement vector and their partial derivatives with respect to parameters on a scratch file to be used during the Simulated Data Analysis.

Calling Sequence - CALL PUT(ITM)

where

ITM is the sample point number

6.39 SUBROUTINE RN

This function computes a normally distributed random number with zero mean and unit variance.

Calling Sequence - RAND=RN(I)

where

RAND is the random number returned by the function

I is a dummy variable (CDC-6600)

6.40 SUBROUTINE RESTOR

This subroutine either saves or restores the input errors during the MODE 2 of the Simulated Data Analysis.

Calling Sequence - CALL RESTOR(BIAS,EPS,GM,EIC,N)

where

- BIAS is a bias error vector
- EPS is a scaling error vector
- GM is a misalignment vector
- EIC is an initial condition error vector
- N is a flag to save or restore data
  - =0: save
  - >0: restore

6.41 SUBROUTINE RK4

This subroutine integrates a matrix of differential equations one step using a 4th order Runge-Kutta method.

Calling Sequence - CALL RK4(X,T,DT,K,L,M)

where

- X is a matrix of the initial values and temporary storage area. Upon completion of this subroutine, the integrated matrix is stored in place of the initial values.
- T is the integration variable
- DT is the integration step-size
- K is the number of rows of X-matrix to be integrated
- L is 4 times the column dimension of X
- M is the maximum row dimension of X

6.42 SUBROUTINE RUNKUT

This subroutine integrates a vector equation by using a 4th order Runge-Kutta scheme.

Calling Sequence - CALL RUNKUT(N,T,DT,X,DX,KUTTA,SAVD)

where

N is the number of elements in the vector

T is the integration variable

DT is the integration step-size

X is the vector function

DX is the derivative of X

KUTTA is the counter

SAVD is the temporary storage area

6.43 PROGRAM SCIP2

This is the main program of the SCIP2 program. It controls the input, output of input summary, the Ensemble Analysis and the Simulated Data Analysis.

6.44 SUBROUTINE SETNDX

This subroutine sets up the error index for each error source and the error name for the output header.

Calling Sequence - CALL SETNDX(A,M,NE,NAME)

where

A is the array containing the error source

M is the dimension of A

NE is the number of non-zero elements in A

NAME is the array containing the hollerith names of the error source in A

6.45 SUBROUTINE SMDATA

This is the main driver for the Simulated Data Analysis. It calls SMODE1 for MODE=1 option or SMODE2 for MODE=2 option.

Calling Sequence - CALL SMDATA(EPS,EIC,W,BIAS,GM,FF)

where

EPS is the output scale error vector
EIC is the initial condition error vector
W is the noise vector
BIAS is the bias error vector
GM is the misalignment vector
FF is the lag error vector

6.46 SUBROUTINE SMODE1

This subroutine performs MODE1 of the Simulated Data Analysis.

Calling Sequence - CALL SMODE1(EPS,EIC,W,BIAS,GM,FF,EPSC,BIASC,FFC)

where

EPS is the output scale error vector
EIC is the initial condition error vector
W is the noise vector
BIAS is the bias error vector
GM is the misalignment vector
FF is the output lag error vector
EPSC is the control scale error vector
BIASC is the control bias error vector
FFC is the control lag error vector

6.47 SUBROUTINE SMODE2

This subroutine performs MODE2 of the Simulated Data Analysis.

Calling Sequence - CALL SMODE2(EPS,EIC,W,BIAS,GM,FF,EPSC,BIASC,FFC,WC)

where

EPS is the output scale error vector

EIC is the initial condition error vector

W is the output noise vector

BIAS is the output bias error vector

GM is the misalignment vector

FF is the output lag error vector

EPSC is the control scale error vector

BIASC is the control bias error vector

FFC is the control lag error vector

WC is the control noise vector

6.48 SUBROUTINE SYMVRT

This subroutine inverts a variably dimensional symmetric matrix. The calculation is done in double precision.

Calling Sequence - CALL SYMVRT(A,N,M,DET)

where

A is the matrix to be inverted. Upon exit from this subroutine, A contains the inverse.

N is the dimension of submatrix of A to be inverted

M is the maximum row dimension of A

DET is the absolute value of the determinant of A

6.49 SUBROUTINE TCONST

This subroutine constructs T-matrix, the scaling matrix for the output measurements, corresponding to mean errors.

Calling Sequence - CALL TCONST(INDEX)

where

INDEX is the index for the error sources

6.50 SUBROUTINE TUNIT

This subroutine constructs T-matrix corresponding to zero scaling error.

Calling Sequence - CALL TUNIT

6.51 SUBROUTINE UNPACK

This subroutine unpacks vectors from temporary storage area.

Calling Sequence - CALL UNPACK(V1,IS,NUM)

where

V1 is the vector where values are to be moved from the temporary storage area

IS is the starting location -1 in the temporary storage area where V1 is stored

NUM is the number of values to be moved

6.52 SUBROUTINE UNPAK2

This subroutine unpacks two dimensional array from the temporary storage area.

Calling Sequence - CALL UNPAK2(A,J2,N1,N2,NX)

where

A is the two dimensional array where the values are to be stored

J2 is the starting location -1 in the temporary storage where the values start

N1 is the row number of the submatrix of A to be filled

N2 is the column number of the submatrix of A to be filled

NX is the row dimension of the matrix A

6.53 SUBROUTINE YPRTLS

This subroutine computes the simulated state vector, $\hat{y}$, its partial derivatives, $\frac{\partial \hat{y}}{\partial p}$,with respect to the parameters, and $R^{-1} \frac{\partial \hat{y}}{\partial p}$ to form $\frac{\partial^2 J}{\partial p^2}$ matrix.

Calling Sequence - CALL YPRTLS

VII

LABELED COMMON DESCRIPTIONS

VII

LABELED COMMON DESCRIPTIONS

The labeled commons used in the program and the variables in the labeled commons are described in this section. The BLOCK DATA subprogram includes all the labeled commons and defines the length of blocks. The labeled commons in any other subroutine may be cut off at the last variable referenced in that subroutine. Thus, they may be shorter.

Common /BIASES/ BLONG(7), BLAT(7)

BLONG The bias error for the measured state vector of the longitudinal analysis;

BLONG(1) = B_θ

BLONG(2) = B_q

BLONG(3) = B_α

BLONG(4) = B_u

BLONG(5) = B_{nx}

BLONG(6) = B_{nz}

BLONG(7) = $B_{\dot{q}}$.

BLAT The bias error for the measured state vector or the lateral analysis;

BLAT(1) = B_β

BLAT(2) = B_p

BLAT(3) = B_r

BLAT(4) = B_ϕ

BLAT(5) = B_{ny}

BLAT(6) = $B_{\dot{p}}$

BLAT(7) = $B_{\dot{r}}$.

Common /CGNCRT/ ECGVEC(3)

ECGVEC The vector of the center of gravity position error;

ECGVEC(1) = e_{cgx}

ECGVEC(2) = e_{cgy}

ECGVEC(3) = e_{cyz}.

Common /CNFLCT/ SPLCNF(3), FULCNF(4), LATCNF(4), SPLBCN(5), FULBCN(7), LATBCN(7)

SPLCNF	A conflict vector for the ESTIM=3 short period analysis. If an element is set to TRUE, the corresponding initial condition error is not estimated but treated as error source.
FULCNF	A conflict vector similar to SPLCNF but for the full longitudinal analysis.
LATCNF	A conflict vector similar to SPLCNF but for the lateral analysis.
SPLBCN	A conflict vector for the ESTIM=4 short period analysis. If an element of SPLBCN is set to TRUE, the corresponding bias error is not estimated but treated as error source.
FULBCN	A conflict vector similar to SPLBCN but for the full longitudinal analysis.
LATBCN	A conflict vector similar to SPLBCN but for the lateral analysis.

Common /CNTDAT/ TC(2), BC(2), FC(2), UL(2), UM(2)

TC	A vector containing the diagonal elements of the input control scale matrix.
BC	A vector containing the bias errors for the input control vector.
FC	A vector containing the diagonal element of the F_c-matrix for the input control lag.
UL	A vector containing the lagged input control vector.
UM	A vector containing the sampled input control vector.

Common /CONTRL/ NOP, DELE(300), DELA(300), DELR(300)

NOP	The number of sample points.
DELE	The vector of control input sequence, δ_e.
DELA	The vector of control input sequence, δ_a.
DELR	The vector of control input sequence, δ_r.

DELE, DELA, and DELR are in degrees.

Common /CPERRV/ WDE, WDA, WDR, BDE, BDA, BDR, EDE, EDA, EDR, FDE, FDA, FDR

WDE	The standard deviation, $W_{\delta e}$, of the noise for the input control vector, δ_e, of the longitudinal equation.
WDA	Similar to WDE but for the control vector, δ_a, of the lateral equation.
WDR	Similar to WDE but for the control vector, δ_r, of the lateral equation.
BDE	The bias error for the control vector, δ_e.
BDA	The bias error for the control vector, δ_a.
BDR	The bias error for the control vector, δ_r.
EDE	The scaling error for the control vector, δ_e.
EDA	The scaling error for the control vector, δ_a.
EDR	The scaling error for the control vector, δ_r.
FDE	An element of the F_C-matrix for the control vector, δ_e.
FDA	An element of the F_C-matrix for the control vector, δ_a.
FDR	An element of the F_C-matrix for the control vector, δ_r.

Common /DDDPBK/ ROWDLO(9), ROWDLA(13), COLDLA(13)

ROWDLO — The vector of row indices for non-zero elements of $\left(\frac{\partial D}{\partial p}\right)$ matrix for the longitudinal analysis.

ROWDLO(i) = n means $\left(\frac{\partial D}{\partial p_i}\right)_{n,1}$ is the only non-zero element.

ROWDLA — The vector similar to ROWDLO but for the lateral analysis

COLDLA — The vector of column indices for non-zero elements of $\left(\frac{\partial D}{\partial p}\right)$ matrix for the lateral analysis.

$\left.\begin{array}{l}\text{ROWDLA(i)} = n \\ \text{COLDLA(i)} = m\end{array}\right\}$ means $\left(\frac{\partial D}{\partial p_i}\right)_{n,m}$ is the only non-zero element.

Common /DFDPBK/ ROWFLO(9), COLFLO(9), ROWFLA(13), COLFLA(13)

ROWFLO	The vector of row indices for non-zero elements of $\left(\frac{\partial F}{\partial p}\right)$ matrix for the longitudinal analysis.
COLFLO	The vector of column indices for non-zero elements of $\left(\frac{\partial F}{\partial p}\right)$ matrix for the longitudinal analysis.
ROWFLA	The vector of row indices for non-zero elements of $\left(\frac{\partial F}{\partial p}\right)$ matrix for the lateral analysis.
COLFLA	The vector of column indices for non-zero elements of $\left(\frac{\partial F}{\partial p}\right)$ matrix for the lateral analysis.

Common /DGDPBK/ ROWGLO(9), ROWGLA(13), COLGLA(13)

ROWGLO	The vector of row indices for non-zero elements of $\left(\frac{\partial G}{\partial p}\right)$ matrix for longitudinal analysis.
ROWGLA	The vector of row indices for non-zero element of $\left(\frac{\partial G}{\partial p}\right)$ matrix for lateral analysis.
COLGLA	The vector of column indices for non-zero elements of $\left(\frac{\partial G}{\partial p}\right)$ matrix for the lateral analysis.

Common /DHDPBK/ ROWHLO(9), COLHLO(9), ROWHLA(13), COLHLA(13)

ROWHLO	A vector of row indices of non-zero elements of $\left(\frac{\partial H}{\partial p}\right)$ matrix for the longitudinal analysis.
COLHLO	A vector of column indices of non-zero elements of $\left(\frac{\partial H}{\partial p}\right)$ matrix for the longitudinal analysis.
ROWHLA	A vector of row indices of non-zero element of $\left(\frac{\partial H}{\partial p}\right)$ matrix for the lateral analysis.
COLHLA	A vector of column indices of non-zero elements of $\left(\frac{\partial H}{\partial p}\right)$ matrix for the lateral analysis.

Common /DMATRX/ DLONG(7), DLAT(7,2)

DLONG The D-matrix for the longitudinal equation;

$$\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \frac{Z_{\delta e}}{g} \\ M_{\delta e} \end{bmatrix}$$

DLAT The D-matrix for the lateral equation;

$$\begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \frac{VY_{\delta a}}{kg} & \frac{VY_{\delta r}}{kg} \\ L_{\delta a} & L_{\delta r} \\ N_{\delta a} & N_{\delta r} \end{bmatrix}$$

Common /ERRMAT/ NERR, THMAT(7,4), PDYDE(7,45), PDXDE(4,45), PDPDE(24,45), ERRVEC(45), ERRNDX(45)

NERR	Number of non-zero error sources.
THMAT	The matrix resulting from multiplying the scale matrix T and the H-matrix.
PDYDE	The partial derivatives of the measured states with respect to the error sources. Each column of PDYDE matrix represents derivatives of state with respect to a particular error source.
PDXDE	The partial derivatives of the aircraft states with respect to error sources.
PDPDE	The sensitivity of parameter estimates with respect to error sources. Each column of PDPDE matrix represents sensitivity of estimates with respect to a particular error source.
ERRVEC	The vector of non-zero errors. All non-zero errors are packed into the first NERR location.
ERRNDX	The vector of error source flags. ERRNDX (i) = n = 0: means that the i-th error source is absent $\neq 0$: means that the i-th error source occupies n-th position in ERRVEC array.

Common /EXPMAT/ EVDP(24), EDPDPN(24,24), PDJDP(24)

EVDP	The vector of expected value of δp, $E(\delta p)$.
EDPDPN	The covariance matrix, $E(\delta p \delta p^T)$.
PDJDP	The partial derivative of the performance function, J, with respect to parameters.

$$J = \sum (y_i - \hat{y}_i)^T R^{-1} (y_i - \hat{y}_i)$$

$$\frac{\partial J}{\partial p} = -\sum \left(\frac{\partial \hat{y}_i}{\partial p_p} \right)^T R^{-1} (y - \hat{y}_i)$$

Common /FMATRX/ FFLONG(4,4), FFLAT(4,4)

FFLONG The F-matrix for the longitudinal equations;

$$F = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & Mq & Mw & Mu \\ -\frac{g}{k} \sin \theta_o & \frac{V}{k} \cos \alpha_o & Zw & Zu \\ -\frac{g}{k} \cos \theta_o & -\frac{V}{k} \sin \alpha_o & Xw & Xu \end{bmatrix}$$

FFLAT The F-matrix for the lateral equations;

$$F = \begin{bmatrix} Y_\beta & \sin \alpha_o & -\cos \alpha_o & \frac{g}{V} \cos \theta_o \\ L_\beta & L_p & L_r & 0 \\ N_\beta & N_p & N_r & 0 \\ 0 & 1 & \tan \theta_o & 0 \end{bmatrix}$$

Common /GENERR/ T(7,7), TT(7,7), NOT, NDX(7)

T The optional input scale matrix.

TT The scale matrix; for the longitudinal equations, the non-zero elements are:

$$TT(1,1) = 1 + e_\theta$$

$$TT(2,2) = 1 + e_q$$

$$TT(3,2) = -\left(\frac{e_{vx} + e_{cgx}}{V}\right)$$

$$TT(3,3) = 1 + e_\alpha$$

$$TT(4,4) = 1 + e_u$$

$$TT(5,5) = 1 + e_{nx}$$

$$TT(5,6) = -\frac{\gamma_{nx}}{k}$$

$$TT(5,7) = \frac{e_{az} + e_{cgz}}{kg}$$

$$TT(6,5) = \frac{\gamma_{nz}}{k}$$

$$TT(6,6) = 1 + e_{nz}$$

$$TT(6,7) = -\left(\frac{e_{ax} + e_{cgx}}{kg}\right)$$

$$TT(7,7) = 1 + e_{\dot{q}}$$

for the lateral equations, the non-zero elements are:

$$TT(1,1) = 1 + e_\beta$$

$$TT(1,3) = -\left(\frac{e_{vx} + e_{cgx}}{V}\right)$$

$$TT(2,2) = 1 + e_p$$

Common /GENERR/ (Continued)

$$TT(2,3) = -\frac{\gamma_p}{k}$$

$$TT(3,2) = \frac{\gamma_r}{k}$$

$$TT(3,3) = 1 + e_r$$

$$TT(4,4) = 1 + e_\phi$$

$$TT(5,5) = 1 + e_{ny}$$

$$TT(5,6) = \left(\frac{e_{ax} + e_{cgx}}{k\ g}\right)$$

$$TT(5,7) = -\left(\frac{e_{az} + e_{cgz}}{k\ g}\right)$$

$$TT(6,6) = 1 + e_{\dot{p}}$$

$$TT(6,7) = -\frac{\gamma_{\dot{p}}}{k}$$

$$TT(7,6) = \frac{\gamma_{\dot{r}}}{k}$$

$$TT(7,7) = 1 + e_{\dot{r}}$$

NOT A flag to indicate whether or not the error source is present in TT matrix.
=TRUE: error source is present in TT matrix
=FALSE: no error source present in TT matrix

NDX A vector of indices of the non-zero element of TT matrix.

Common /GMATRX/ GLONG(4), GLAT(4,2), XXI, XZI, ZZI

GLONG The G-matrix for the longitudinal equations;

$$G = \begin{bmatrix} 0 \\ M_{\delta_e} \\ Z_{\delta_e} \\ 0 \end{bmatrix}$$

GLAT The G-matrix for the lateral equations;

$$G = \begin{bmatrix} Y_{\delta_a} & Y_{\delta_r} \\ L_{\delta_a} & L_{\delta_r} \\ N_{\delta_a} & N_{\delta_r} \\ 0 & 0 \end{bmatrix}$$

XXI Moment of inertia about x, I_{xx}

XZI Product of inertia about x-z, I_{xz}

ZZI Moment of inertia about z, I_{zz}

$$C\dot{x} = Fx + Gu$$

Common /HEAD/ ENSMBL(2), SIMDAT(3), LONGNS(7), LATNS(7)

ENSMBL	Two word array containing hollerith data; ENSMBL(1) = 'ENSEMB' ENSMBL(2) = 'LE** ' for print out.
SIMDAT	Three word array containing hollerith data; SIMDAT(1) = 'SIMULA' SIMDAT(2) = 'TED DA' SIMDAT(3) = 'TA '
LONGNS	Seven word array containing the longitudinal instrument names.
LATNS	Seven word array containing the lateral instrument names.

Common /HMATRX/ HLONG(7,4), HLAT(7,4)

HLONG The H-matrix for the longitudinal equation;

$$
\begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & \dfrac{k \cos \alpha_o}{V} & \dfrac{-k \sin \alpha_o}{V} \\
0 & 0 & 0 & 1 \\
0 & 0 & \dfrac{X_w}{g} & \dfrac{X_u}{g} \\
0 & 0 & \dfrac{Z_w}{g} & \dfrac{Z_u}{g} \\
0 & M_q & M_w & M_u
\end{bmatrix}
$$

HLAT The H-matrix for the lateral equation;

$$
\begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
\dfrac{VY_\beta}{kg} & 0 & 0 & 0 \\
L_\beta & L_p & L_r & 0 \\
N_\beta & N_p & N_r & 0
\end{bmatrix}
$$

Common /HNDMAT/ H(7,4), D(7,4), F(4,4), G(4,2)

H	The H-matrix for the case. It may either be HLONG or HLAT depending on the input option.
D	The D-matrix for the case.
F	The F-matrix for the case.
G	The G-matrix for the case.

Common /ICERRS/ EICLON(4), EICLAT(4)

EICLON Initial condition errors for longitudinal equation;

EICLON(1) = δ_θ

EICLON(2) = δ_q

EICLON(3) = δ_w

EICLON(4) = δ_u.

EICLAT Initial condition errors for lateral equation;

EICLAT(1) = δ_β

EICLAT(2) = δ_p

EICLAT(3) = δ_r

EICLAT(4) = δ_ϕ.

Common /INPUTT/ INPUTS(30)

INPUTS	Input and output options; INPUTS(1) through INPUTS(22) controls input and INPUTS(25) through INPUTS(30) controls output. INPUTS(23) is a special option.

```
Common  /LABELS/    FLA(5), SPL(6), LATAN(3)
```

FLA	Header array for "Full Longitudinal Analysis" option; FLA(1) = 'FULL L' FLA(2) = 'ONGITU' FLA(3) = 'DINAL ' FLA(4) = 'ANALYS' FLA(5) = 'IS '.
SPL	Header array for "Short Period Longitudinal Analysis" option; SPL(1) = 'SHORT ' SPL(2) = 'PERIOD' SPL(3) = ' LONGI' SPL(4) = 'TUDINA' SPL(5) = 'L ANAL' SPL(6) = 'YSIS '.
LATAN	Header array for "Lateral Analysis" option; LATAN(1) = 'LATERA' LATAN(2) = 'L ANAL' LATAN(3) = 'YSIS '.

Common /LAGERR/ FLONG(7), FLAT(7)

FLONG	The diagonal elements of F_M-matrix when output measurement lags are present in the longitudinal equations. FLONG contains f_θ, f_q, f_α, f_u, f_{nx}, f_{nz}, and $f_{\dot{q}}$, respectively.
FLAT	The diagonal elements of F_M-matrix when output measurement lags are present in the lateral equations. FLAT contains f_β, f_p, f_r, f_ϕ, f_{ny}, $f_{\dot{p}}$, and $f_{\dot{r}}$, respectively.

Common /LIMITS/ JEQS, KEQS, LEQS, MEQS, NEQS, NUM, MX1, MX2, NSTNDX(7), MONTE, NUMERR(11)

JEQS	Temporary variable, NEQS + 1.
KEQS	Number of vector equations, $\frac{\partial x}{\partial p}$, to be integrated in the ensemble equations
LEQS	Temporary variable, NEQS + MX2.
MEQS	Total number of parameters, including initial conditions and bias errors to be estimated by the program.
NEQS	Number of parameters to be estimated when ESTIM = 1.
NUM	Number of output measurement instruments.
MX1, MX2	Number of elements in the state vector, x.
NSTNDX	A vector of flag to indicate which instruments are present NSTNDX(i) = 0: indicates that i^{th} instrument is absent NSTNDX(i) = j > 0: indicates that i^{th} instrument is the j^{th} instrument among those present. Note: $i \geq j$.
MONTE	Flag to indicate whether dynamic equations are being integrated by the ensemble analysis program (if false) or by the simulated data analysis program (if true).
NUMERR	A vector containing the number of error sources; NUMERR(1) = NB Number of non-zero bias error sources NUMERR(2) = NE Number of output scale error sources NUMERR(3) = NG Number of misalignment error sources NUMERR(4) = NF Number of output lags NUMERR(5) = NCGA Number of error sources in center of gravity position

Common /LIMITS/ (Continued)

NUMERR(6) = NCGB	Sum of accelerometer position error sources and the vane position error source.
NUMERR(7) = NIC	Number of initial condition error sources.
NUMERR(8) = NBC	Number of bias error sources for input control.
NUMERR(9) = NEC	Number of scale error source for input control.
NUMERR(10)= NFC	Number of input control lag error sources.
NUMERR(11)= NCR	Number of random error sources for input control.

Common /LOCCG/ EAX, EAY, EAZ, EVX

EAX, EAY, EAZ	Accelerometer location error for x, y and z component
EVX	Vane location error

Common /LOGICL/ FULTST,SPLTST,LATEST,ITERAT

FULTST	Logical variable, if true, to indicate that the full longitudinal equations be executed.
SPLTST	Logical variable, if true, to indicate that the short period longitudinal equations be executed.
LATEST	Logical variable, if true, to indicate that the lateral equations be executed.
ITERAT	Logical variable, if true, to indicate the SIMULATED DATA phase of the INPUTS(23) option.

Common /MEANIT/ IA2, IB2, IC2

IA2	Pointer to run down the input control error sources.
IB2	Pointer used to pick out a particular input control error.
IC2	Not used.

Common /MISALN/ GMLONG(7), GMLAT(7)

GMLONG Misalignment error sources for the longitudinal equations;

GMLONG(1) = γ_θ

GMLONG(2) = γ_q

GMLONG(3) = γ_α

GMLONG(4) = γ_u

GMLONG(5) = γ_{nx}

GMLONG(6) = γ_{nz}

GMLONG(7) = $\gamma_{\dot{q}}$.

GMLAT Misalignment error sources for the lateral equations;

GMLAT(1) = γ_β

GMLAT(2) = γ_p

GMLAT(3) = γ_r

GMLAT(4) = γ_ϕ

GMLAT(5) = γ_{ny}

GMLAT(6) = $\gamma_{\dot{p}}$

GMLAT(7) = $\gamma_{\dot{r}}$.

Common /MISCEL/ DT, NMC, GRAV, UNITS, RADDEG, NDXP, PERT, TIME, DTS, TAU

DT	Integration step-size.
NMC	Number of Monte Carlo runs to be executed in the Simulated Data Study.
GRAV	Acceleration due to the gravity.
UNITS	Hollerith data for the unit of the gravity.
RADDEG	Conversion factor from degrees to radians.
NDXP	Flag used to perturb parameters under INPUTS(23) option for the lateral equations. =0: perturb all parameters $1 \leq n \leq 13$: n^{th} parameter by the amount specified by PERT
PERT	Amount in percent the parameters are to be perturbed.
TIME	Time of the trajectory.
DTS	Sample rate.
TAU	Time to the first sample point of the input control variable.

Common /MISCL1/ NUM1, NUM2, MODM2, I1, SWICH, IU1, IU2

NUM1	Number of components in the control variable, =1: for the longitudinal equations =2: for the lateral equations
NUM2	Not used.
MODM2	Variable MODE-2.
I1	Running counter of the Monte Carlo runs.
SWICH	Flag, if non-zero, to indicate that the initial condition error is being considered.
IU1	Scratch unit to save $\hat{x}$, $\frac{\partial \hat{x}}{\partial p}$, $\hat{y}$, $R^{-1} \frac{\partial \hat{y}}{\partial p}$.
IU2	Scratch unit to save δp for each of MODE=2 Monte Carlo runs.

Common /NAMVAR/ NAMVAR(7,2), NAMIC(4,2), NAMVAN(4), NAMCG(3), NAMERR(45,2), NAMEST(24)

NAMVAR	An array containing the hollerith names of measurement states for the longitudinal and the lateral equations.
NAMIC	An array containing the hollerith names of dynamic states for the longitudinal and the lateral equations.
NAMVAN	An array containing the hollerith names of the accelerometer location and vane location error sources.
NAMCG	An array containing the hollerith names of the center of gravity location error.
NAMERR	An array containing the hollerith names of the error sources.
NAMEST	An array containing the hollerith names of the parameters being estimated.

Common /NOISE/ WLONG(7), WLAT(7)

WLONG	An array containing the standard deviations of the white measurement noise for the longitudinal states.
WLAT	An array containing the standard deviations of the white measurement noise for the lateral states.

Common /NSTATE/ XN(4), PDXDP(4,17), YN(7), PDYDP(7,24)

XN	The simulated aircraft state vector, $\hat{x}$.
PDXDP	The partial derivatives of the simulated aircraft state with respect to parameters and the initial conditions, $\frac{\partial \hat{x}}{\partial p}$.
YN	The simulated measurement state, $\hat{y}$.
PDYDP	The partial derivatives of the simulated measured state with respect to parameters and the initial conditions, $\frac{\partial \hat{y}}{\partial p}$.

Common /OPTNS/ ENORSD, EQNS, ESTIM, MODE, INSLON(7), INSLAT(7)

ENORSD	Option word containing either hollerith data ENSMBL or SIMDAT depending on whether the Ensemble Analysis or the Simulated Data Analysis is to be exercised.
EQNS	Option word containing either hollerith data FULL, SPL, or LAT depending on whether the Full Longitudinal equations, the Short Period Longitudinal equations, or the Lateral equations are to be used.
ESTIM	Option to specify the parameters to be estimated. =1: parameters only =2: parameters and the initial condition errors. =3: parameter, bias errors, and those initial conditions not correlated with bias errors =4: parameters, initial condition errors, and those bias errors not correlated with initial condition errors.
MODE	Option specifying the mode of the Simulated Data Analysis.
INSLON	An input vector of the instrument names of the longitudinal measured state.
INSLAT	An input vector of the instrument names of the lateral measured state.

Common /OTHRIT/ IA1, IB1, IC1

IA1	Variable used to run down the output measurement error sources.
IB1	Variable used to pick out an error source.
IC1	Variable used to run down the non-zero error sources.

Common /OUTDAT/ FM(7), BVEC(7), WVEC(7), YL(7)

FM	A vector containing the diagonal element of the F_M-matrix for the output measurement lag.
BVEC	A vector containing the random bias errors.
WVEC	A vector containing the random noise errors.
YL	A vector containing the lagged output state.

Common /REFTRJ/ THETAO, ALPHAO, VEL

THETAO	Initial pitch altitude, θ_o.
ALPHAO	Initial angle-of-attack, α_o.
VEL	Total velocity, V.

Common /SCALNG/ EPLONG(7), EPLAT(7)

EPLONG Scale factors for the longitudinal measurement;

EPLONG(1) = e_{∂}

EPLONG(2) = e_q

EPLONG(3) = e_α

EPLONG(4) = e_u

EPLONG(5) = e_{nx}

EPLONG(6) = e_{nz}

EPLONG(7) = $e_{\dot{q}}$.

EPLAT Scale factors for the lateral measurement;

EPLAT(1) = e_β

EPLAT(2) = e_p

EPLAT(3) = e_r

EPLAT(4) = e_ϕ

EPLAT(5) = e_{ny}

EPLAT(6) = $e_{\dot{p}}$

EPLAT(7) = $e_{\dot{r}}$.

Common /STATES/ X(4), U(2), R(7), D2JDP2(24,24)

X	The aircraft state vector, x.
U	The input control, u.
R	The diagonal element of the weighting matrix R^{-1}, $R^{-1}(i) = \left(\frac{1}{W(i)}\right)^2$.
D2JDP2	The inverse of the second partial derivatives of J with respect to the parameters, $\left[\frac{\partial^2 J}{\partial p^2}\right]^{-1}$.

APPENDIX A
SUMMARY OF EQUATIONS CODED IN ANALYSIS PROGRAM

A.1 Explanation of Time Increments Used by Program

The three time steps which are used in the program are:

Δt_L - This is the time step of the Runge-Kutta integration package. It is set small enough so the effect of the highest frequency dynamics is correctly simulated. This term is usually governed by the control or output measurement lag with the smallest time constant.

Δt_s - This is the sample time increment used by the identification process. When measurement lags are ignored, it is also used as the integration step.

τ - This is the time delay that governs when sampling of the control input is made after time zero. Normally, $0 \leq \tau \leq \Delta t_s$. Use of τ enables sampling the control input at different time points than the output measurements.

A.2 Simulated Data Analysis Subprogram - Mode 1

A.2.1 Simulated Airplane Equations

The equations governing the simulated airplane are:

$$\dot{x} = Fx + Gu_{input}; \quad x(0) = \hat{x}_0 \tag{A.1}$$

$$y_T = Hx + Du_{input} \tag{A.2}$$

(true output)

$$y_I = Ty_T + B \tag{A.3}$$

(indicated output - no lags)

$$\dot{y}_L = -F_m y_L + F_m y_I; \quad y_L(0) = y_I(0) \tag{A.4}$$

(effect of lags)

$$y_i = y_{Li} + w_i \tag{A.5}$$

(recorded output. If lags are present, this samples y_L every Δt_s seconds starting at time Δt_s.)

A.2.2 Control Input Equations

The equations governing the recorded control input are:

$$u = u_{input} \tag{A.6}$$

(true control which is input to program)

$$u_I = T_c u + B_c \tag{A.7}$$

(indicated control with no lags)

$$\dot{u}_L = -F_c u_L + F_c u_I; \quad u_L(0) = u_I(0) \tag{A.8}$$

(effect of lags)

$$u_{mi} = u_{Li} + w_{ci}^{*} \tag{A.9}$$

(recorded input. If lags are present, this samples u_L every Δt_s seconds starting at time τ.)

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* Note The control measurement noise is only used in the Monte Carlo Mode (Mode 2) of the Simulated Data Analysis. It is set to zero otherwise (Mode 1).

A.2.3 Ensemble Analysis Subprogram Equations

The random errors are first analyzed. To do this, the following equations are first integrated and evaluated in the ensemble analysis subprogram:

$$\dot{\hat{x}} = F\hat{x} + Gu \; ; \quad \hat{x}(0) = \hat{x}_0 \tag{A.10}$$

(Δt_s integration step)

$$\frac{d}{dt}\left(\frac{\partial \hat{x}}{\partial p_p}\right) = F\left(\frac{\partial \hat{x}}{\partial p_p}\right) + \frac{\partial F}{\partial p_p}\hat{x} + \frac{\partial G}{\partial p_p}u \; ; \quad \frac{\partial \hat{x}}{\partial p_p} = 0 \tag{A.11}$$

$$\frac{d}{dt}\left(\frac{\partial \hat{x}}{\partial p_{IC}}\right) = F\left(\frac{\partial \hat{x}}{\partial p_{IC}}\right) \; ; \quad \frac{\partial \hat{x}}{\partial p_{IC}}(0) = 1 \tag{A.12}$$

(for each initial condition estimated)

$$\frac{\partial \hat{y}}{\partial p_p} = H\frac{\partial \hat{x}}{\partial p_p} + \frac{\partial H}{\partial p_p}\hat{x} + \frac{\partial D}{\partial p_p}u \tag{A.13}$$

(from Eq. A.2)

$$\frac{\partial \hat{y}}{\partial p_{IC}} = H\frac{\partial \hat{x}}{\partial p_{IC}} \tag{A.14}$$

(for each initial condition estimated)

$$\frac{\partial \hat{y}}{\partial p_b} = 1 \tag{A.15}$$

(for each bias term estimated)

$$\frac{\partial \hat{y}_i}{\partial p} \triangleq \left[\frac{\partial \hat{y}_i}{\partial p_p} \quad \frac{\partial \hat{y}_i}{\partial p_{IC}} \quad \frac{\partial \hat{y}_i}{\partial p_b}\right] \tag{A.16}$$

$$\frac{\partial^2 J}{\partial p^2} = \sum_{i=1}^{n} \left[\frac{\partial \hat{y}_i}{\partial p}^T R^{-1} \frac{\partial \hat{y}_i}{\partial p} \right] \tag{A.17}$$

$$\text{Invert } \frac{\partial^2 J}{\partial p^2} \triangleq \left[\frac{\partial^2 J}{\partial p^2} \right]^{-1} \tag{A.18}$$

A.2.4 Simulated Data Analysis Subprogram Equations for Random Errors

Next, each of the random output measurement errors is sequenced. The object is to evaluate:

$$\frac{\partial J}{\partial p} = - \sum_{i=1}^{n} (y_i - \hat{y}_i)^T R^{-1} \frac{\partial \hat{y}_i}{\partial p} \tag{A.19}$$

and

$$\delta p = - \left[\frac{\partial^2 J}{\partial p^2} \right]^{-1} \left[\frac{\partial J}{\partial p} \right]^T \tag{A.20}$$

First, the effect of each unestimated output measurement bias is computed. This affects only the residual of Eq. (A.19) as:

$$(y_i - \hat{y}_i) = y_{Ii} - \hat{y}_i = B \tag{A.21}$$

Then, each of the output transformation errors of T is sequenced. Again, the effect on Eq. (A.19) is:

$$(y_i - \hat{y}_i) = T(H\hat{x}_i + Du_i) - (H\hat{x}_i + Du_i) = (T - I)\ (H\hat{x}_i + Du_i) \tag{A.22}$$

Then, each of the unestimated initial condition errors is sequenced. This requires the integration of Eq. (A.1) with $x(0) = x_0$. Then, from Eq. (A.2),

$$(y_i - \hat{y}_i) = (y_{Ti} - \hat{y}_i) = H(x_i - \hat{x}_i) \tag{A.23}$$

Next, the control measurement errors due to T_c and B_c are sequenced. To do this, the previous results of integrating Eq. (A.10) are first stored. These state values represent the true airplane equations in this case. So

$$x_i = \hat{x}_i \tag{A.24}$$

Then, Eqs. (A.10), (A.11), and (A.12) are reintegrated using the Δt_s integration step and modified u_{mi}. Equations (A.12) - (A.18) are then reevaluated. For bias errors

$$u_{mi} = u_i + B_c \tag{A.25}$$

For scale factor errors

$$u_{mi} = T_c u_i \tag{A.26}$$

For the random errors, the total parameter covariance is

$$E\{\delta p \delta p^T\} = E_{noise} + \sum_{j=1}^{r} (\delta p_j \delta p_j^T) \tag{A.27}$$

where r is the number of random error sources. E_{noise} is the covariance of the parameter estimate errors due to the output noise w_i. E_{noise} is either set to Eq. (A.18) or computed using the Monte Carlo option with

$$(y_i - \hat{y}_i) = w_i \tag{A.28}$$

at each time point.

A.2.5 Mean Errors

The mean errors are also sequenced. These include some elements in the T matrix (Eq. (A.3) and all elements in F_m and F_c (Eqs. (A.4) and (A.8)). If there are no lag errors input, the evaluation is just like Eq. (A.22).

If there are control measurement lag errors, Eq. (A.8) needs to be evaluated with $u_I = u$, over each interval Δt_s. The integration step is Δt_L. The stored u_{mi} is sampled every Δt_s but beginning τ seconds after time zero.

If there are output lags, Eq. (A.4) needs evaluation. This requires reintegration of Eq. (A.1), with $x(0) = \hat{x}_0$, and Eq. (A.4) of the form

$$\dot{y}_L = -F_m\, y_L + F_m\, (Hx + Du) \qquad \text{(A.29)}$$

The step size is Δt_L. The output of Eq. (A.29) is sampled every Δt_s seconds with

$$y_i = y_{Li} \qquad \text{(A.30)}$$

Again, Eqs. (A.10) - (A.18) need to be reevaluated in case of control lags. Equations (A.10) - (A.12) use an integration step size of Δt_s, however. The effect on Eq. (A.19) is

$$y_i - \hat{y}_i = y_{Li} - (H\hat{x}_i + Du_{mi}) \qquad \text{(A.31)}$$

A.3 Simulated Data Analysis Subprogram - Mode 2

The random errors contained in B, part of T, B_c T_c, and x_o are generated at the beginning of each run using the input standard deviations and the random number generator. They are held constant during each single Monte Carlo run. The random noise w_i and w_{ci} are regenerated each sample point during each run. Each of the mean errors in T plus elements of F_m and F_c are set equal to the values input and are not changed during any of the runs.

For output measurement errors in T, B and w_i only, the residual $(y_i - \hat{y}_i)$ in Eq. (A.19) is computed by

$$y_i - \hat{y}_i = T(H\hat{x}_i + Du_i) + B + w_i - (H\hat{x}_i + Du_i) \tag{A.32}$$

For random initial conditions added, Eq. (A.1) must be integrated each time and Eq. (A.32) gets changed to

$$y_i - \hat{y}_i = T(Hx_i + Du_i) + B + w_i - (H\hat{x}_i + Du_i) \tag{A.33}$$

For non-lag control measurement errors, Eqs. (A.7) and (A.9) get combined so that at each sample point

$$u_{mi} = T_c u + B_c + w_{ci} \tag{A.34}$$

where w_{ci} is randomly generated each time point. Because of this change, Eqs. (A.10) - (A.12) require integration each pass through, and Eqs. (A.13) - (A.18) require re-evaluation each pass through. With these changes, Eq. (A.33) becomes

$$y_i - \hat{y}_i = T(Hx_i + Du_i) + B + w_i - (H\hat{x}_i + Du_{mi}) \tag{A.35}$$

For lags in the control input measurements and output measurements, two integration step sizes have to be used. First, Eqs. (A.1) - (A.4) are evaluated using the Δt_L step. The resulting y_L is sampled every Δt_s seconds starting at time Δt_s. Then, Eq. (A.5) is evaluated and the resulting y_L stored. Next, Eqs. (A.7) - (A.8) are evaluated using the Δt_L step. The resulting u_L is sampled every Δt_s seconds starting at time τ. Then, Eq. (A.9) is evaluated and the resulting u_{mi} stored. Next, Eqs. (A.10) - (A.12) are evaluated using the Δt_s step and the stored u_{mi}. Then, Eqs. (A.13) - (A.18) are evaluated. Then, the residual for Eq. (A.19) is computed using

$$y_i - \hat{y}_i = y_i - (H\hat{x} + Du_{mi}) \tag{A.36}$$

In Mode 2, w_{ci} is used just like w_i.

In Mode 2 , several Monte Carlo runs are made. In each run, the values of the random elements in T, B, and $\hat{x}_o$ are randomly generated at the beginning of the run. For comparison, the standard deviations used to generate these values are the same as those values used one at a time in Mode 1. These random values remain constant throughout a run, but change from run to run. The white noise vector w_i is randomly generated, and it changes every sample point throughout the run. Those mean error sources in T, F_m, and F_c which aren't random are held constant throughout all the runs. The error Δp_j in the parameter vector obtained from each run is saved. For m Monte Carlo runs, the mean error in p is

$$\overline{\Delta p} \triangleq E\{\Delta p\} = \frac{1}{m} \sum_{j=1}^{m} \Delta p_j \tag{A.37}$$

The standard deviation about this mean is

$$E\{\delta p \delta p^T\} = \frac{1}{m} \sum_{j=1}^{m} (\Delta p_j - \overline{\Delta p})(\Delta p_j - \overline{\Delta p})^T \tag{A.38}$$

For small values of the error sources, the results of Eq. (A.38) should match those of Eq. (A.27). Also, Eq. (A.37) should match the value of the mean obtained in Mode 1.

A.4 Ensemble Error Analysis Subprogram

A.4.1 Output Errors

The basic equation which is used to compute changes in the parameters is

$$\delta p = -\left[\frac{\partial^2 J}{\partial p^2}\right]^{-1} \frac{\partial J}{\partial p}^T$$

$$= +\left[\sum_{i=1}^{n}\left\{\frac{\partial \hat{y}_i}{\partial p}^T R^{-1} \frac{\partial \hat{y}_i}{\partial p}\right\}\right]^{-1} \sum_{i=1}^{n} \frac{\partial \hat{y}_i}{\partial p}^T R^{-1} (y_i - \hat{y}_i)^T \qquad \text{(A.20)}$$

The y_i are the sampled measurements taken from the aircraft (Eqs. (A.1) - (A.5)) and the $\hat{y}_i$ are the simulated values obtained from the measured control input (Eqs. (A.6) - (A.9) and Eq. (A.10)). The term $\frac{\partial \hat{y}_i}{\partial p}$ comes from Eqs. (A.11) - (A.16).

It is assumed that if lag errors exist, lag terms are present in all control input and system output measurement equations. If the measurements of y_i have lags, the dynamic equations can be written as

$$\dot{x} = Fx + Gu \qquad \text{(A.1)}$$

$$\dot{y}_L = -F_m y_L + F_m(T\,[H\,x + D\,u] + B\,) \qquad \text{(A.39)}$$

Otherwise, the output equations are of the form

$$y = T(Hx + Du) + B \qquad \text{(A.40)}$$

The sensitivity of y_i to each error e is computed. For biases,

$$\frac{\partial y}{\partial e} = 1 \tag{A.41}$$

For errors due to the matrix T, the sensitivity can be found as

$$\frac{\partial y}{\partial e} = \frac{\partial T}{\partial e}(Hx + Du) \tag{A.42}$$

For initial condition errors,

$$\frac{\partial y}{\partial e} = H\frac{\partial x}{\partial e} \tag{A.43}$$

where the term $\frac{\partial x}{\partial e}$ comes from integrating

$$\frac{d}{dt}\left(\frac{\partial x}{\partial e}\right) = F\frac{\partial x}{\partial e} \; ; \; \frac{\partial x}{\partial e}(0) = I \tag{A.44}$$

When output lags are present, the sensitivity differential equation comes from Eq. (A.39), and is

$$\frac{d}{dt}\left(\frac{\partial y_L}{\partial e}\right) = \frac{\partial F_m}{\partial e}\left[- y_L + Hx + Du\right] - F_m\frac{\partial y_L}{\partial e} \tag{A.45}$$

The results of Eqs. (A.41) through (A.45) are combined into a general $\frac{\partial y_i}{\partial e}$ for each error e which affects the output measurements.

A.4.2 Control Input Errors

With respect to Eq. (A.20), the error effect on the term $\hat{y}_i$ is computed. The differential equations of the simulated aircraft are

$$\dot{u}_L = -F_c u_L + F_c(T_c u + B_c) \;;\; u_L(0) = u_I(0) \tag{A.46}$$

$$\dot{\hat{x}} = F\hat{x} + Gu_{Li} \tag{A.47}$$

$$\hat{y}_i = H\hat{x}_i + Du_{Li} \tag{A.48}$$

For control measurement lags the following equations, that come from Eqs. (A.46 and (A.47), are first integrated.

$$\frac{d}{dt}\left(\frac{\partial\hat{x}}{\partial e}\right) = F\frac{\partial\hat{x}}{\partial e} + G\frac{\partial u_L}{\partial e} \;; \quad \frac{\partial\hat{x}}{\partial e}(0) = 0 \tag{A.49}$$

$$\frac{d}{dt}\left(\frac{\partial u_L}{\partial e}\right) = -F_c\frac{\partial u_L}{\partial e} + \frac{\partial F_c}{\partial e}(-u_L + u) \;; \quad \frac{\partial u_L}{\partial e}(0) = \frac{\partial u_i}{\partial e}(0) \tag{A.50}$$

Then, from Eq. (A.48)

$$\frac{\partial\hat{y}_i}{\partial e} = H\frac{\partial\hat{x}_i}{\partial e} + D\frac{\partial u_{Li}}{\partial e} \tag{A.51}$$

For control scale factor errors, the program first integrates

$$\frac{d}{dt}\frac{\partial\hat{x}}{\partial e} = F\frac{\partial\hat{x}}{\partial e} + G\frac{\partial T_c}{\partial e}u \;; \quad \frac{d\hat{x}}{de}(0) = 0 \tag{A.52}$$

Then, the sensitivity is computed as

$$\frac{\partial\hat{y}_i}{\partial e} = H\frac{\partial\hat{x}_i}{\partial e} + D\frac{\partial T_c}{\partial e}u_i \tag{A.53}$$

For control biases, the program integrates

$$\frac{\partial}{\partial t}\left(\frac{\partial \hat{x}}{\partial e}\right) = F \frac{\partial \hat{x}}{\partial e} + G \frac{\partial B_c}{\partial e} ; \quad \frac{\partial \hat{x}}{\partial e}(0) = 0 \tag{A.54}$$

Then, the sensitivity becomes

$$\frac{\partial \hat{y}}{\partial e} = H \frac{\partial \hat{x}}{\partial e} + D \frac{\partial B_c}{\partial e} \tag{A.55}$$

A.4.3 Effect on Parameter Estimates

The sensitivity of parameter estimates due to output measurement is of the form

$$\frac{\partial}{\partial e}(\delta p) = \left[\frac{\partial^2 J}{\partial p^2}\right]^{-1} \sum_{i=1}^{n} \frac{\partial \hat{y}_i}{\partial p}^T R^{-1} \frac{\partial y_i}{\partial e} \tag{A.56}$$

where $\frac{\partial y_i}{\partial e}$ comes from evaluating Eqs. (A.41) through (A.45).

The sensitivity of parameter estimates due to control input errors is of the form

$$\frac{\partial}{\partial e}(\delta p) = -\left[\frac{\partial^2 J}{\partial p^2}\right]^{-1} \sum_{i=1}^{n} \frac{\partial \hat{y}_i}{\partial p}^T R^{-1} \frac{\partial \hat{y}_i}{\partial e} \tag{A.57}$$

where $\frac{\partial \hat{y}_i}{\partial e}$ comes from evaluating Eqs. (A.51), (A.53), and (A.55).

For random errors, the total parameter covariance is

$$E\{\delta p\ \delta p^T\} = E_{noise} + \frac{\partial}{\partial e}(\delta p) E\{e\ e^T\} \frac{\partial}{\partial e}(\delta p)^T \tag{A.58}$$

For mean errors, the mean parameter error is

$$E\{\delta p\} = \frac{\partial(\delta p)}{\partial e} E\{e\} \tag{A.59}$$

N72-32041

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. 32-1562	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle SUMMARY REPORT ON THE DEVELOPMENT, DESIGN AND TEST OF A 66-W/kg (30-W/lb) ROLL-UP SOLAR ARRAY		5. Report Date September 15, 1972
		6. Performing Organization Code
7. Author(s) W. A. Hasbach, R. G. Ross, Jr.		8. Performing Organization Report No.
9. Performing Organization Name and Address JET PROPULSION LABORATORY California Institute of Technology 4800 Oak Grove Drive Pasadena, California 91103		10. Work Unit No.
		11. Contract or Grant No. NAS 7-100
12. Sponsoring Agency Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION Washington, D.C. 20546		13. Type of Report and Period Covered Technical Report
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report summarizes the results of a program to develop a 23-m^2 (250-ft^2) roll-up solar array with a power-to-weight ratio exceeding 66 W/kg (30 W/lb). Descriptions of the system design and fabrication of a full-scale engineering development unit are included, the system and development test program results are described, and conclusions are drawn. Special test equipment and test procedures are included, together with comparisons of experimental and analytical results.

17. Key Words (Selected by Author(s)) Control and Guidance Interplanetary Spacecraft, Advanced Propulsion, Electric Structural Engineering	18. Distribution Statement Unclassified -- Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
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