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NORTH ATLANTIC (NAT) AIDED INERTIAL NAVIGATION SYSTEM SIMULATION

Volume II: Computer Program NATNAV User's Manual

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JULY 1973

FINAL REPORT

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16. Abstract

A user's manual is provided for Program NATNAV (North ATlantic NAVigation), a digital computer simulation program developed to evaluate the performance of navigation systems for future commercial NAT aircraft operations. Error models for aided-inertial navigation systems with external measurements from Doppler radar, Omega, satellite-ranging or air data are simulated. The covariance matrix error analysis method is used to calculate the navigation error histories, using the recursive navigation technique to incorporate measurements. A 34th-order error state vector requires the numerical integration of up to 585 independent, first-order differential equations to propagate the covariance matrix. The program provides for an optimum initial alignment of the INS prior to taxi. A dead-reckoning option is also available. Independent measurements using Doppler radar, Omega or satellite-ranging may be used to update the position and velocity estimates using the optimum recursive Kalman filter. Optionally, suboptimum filter gains may be used instead. The outputs of the simulation are the standard deviations of the position and velocity errors, resolved into along-track, cross-track and vertical components. NATNAV is written entirely in Fortran IV for operation on the CDC-3800 digital computer at the Naval Research Laboratory. The program was developed with a highly modular structure for ease of program checkout, to simplify the user's understanding of the program, and to facilitate any modifications which might be required for future applications. Programming details of the simulation describe functions of the various routines, flow charts, common storage and definition of Fortran variables. The usage of the program is illustrated with an example which presents typical input data and results. The hardware requirements, the deck setup, program options and operating procedures are all described. Certain restrictions and potential modifications are discussed, and a complete listing of the Fortran source program is included.

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PREFACE

This report was prepared by Aerospace Systems, Inc. (ASI), Burlington, Massachusetts, for the Department of Transportation under Contract No. DOT-TSC-473. The study was sponsored by the Traffic Programs Division of the Transportation Systems Center (TSC), Cambridge, Massachusetts. Mr. Gilbert A. Gagne served as Technical Monitor on the contract.

This is the second volume of the two-volume final report, which documents the results of research performed during the contract period June 1972 to January 1973. Volume I is the Final Technical Report; Volume II is a user's manual for the digital computer simulation program NATNAV.

The effort was directed by Mr. John Zvara, President and Technical Director of ASI. Mr. William C. Hoffman served as Principal Investigator. Professor Walter M. Hollister and Dr. Kenneth R. Britting, both in the Department of Aeronautics and Astronautics at the Massachusetts Institute of Technology (MIT), contributed to the study as technical consultants and co-investigators. Professor Robert W. Simpson, Director of the MIT Flight Transportation Laboratory, and Arthur E. Bryson, Jr., Chairman, Department of Aeronautics and Astronautics, Stanford University, also served as technical consultants.

The authors are indebted to Mr. James Hauser, of the Naval Research Laboratory (NRL) Electromagnetic Propagation Branch, for his assistance during the final implementation of the program on the NRL CDC-3800 computer. We are also grateful to the staff of the NRL Research Computation Center for their support and cooperation.

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SECTION 1

INTRODUCTION

This report describes the digital computer simulation program NATNAV (North ATlantic NAVigation) which was developed by Aerospace Systems, Inc. (ASI) to analyze various inertial aircraft navigation systems utilizing external measurements of position and/or velocity from the following sources:

- Doppler Radar
- Air Data
- OMEGA
- Satellite Surveillance (2-satellite ranging)

The companion volume to this report (Ref. 1) contains a complete description of the mathematical models and analysis techniques implemented in the NATNAV simulation. It also presents a discussion of several results obtained with the simulation and some recommendations for applications of NATNAV. The availability of Volume 1, and the user's familiarity with it, are presupposed in this report.

NATNAV is written entirely in Fortran IV for operation on the CDC-3800 digital computer at the Naval Research Laboratory (Refs. 2 and 3). Slightly modified versions have been run on PDP-10 and CDC-6600 computers. The program was developed with a highly modular structure for ease of program checkout, to simplify the user's understanding of the program, and to facilitate any modifications which might be required for future applications.

Sections 2 through 5 contain programming details of the simulation: functions of the various routines, flow charts, common storage and definition of Fortran variables. The usage of the program is presented in Sections 6 through 9, which describe the hardware requirements, the inputs and outputs, program options and operating procedures. Certain restrictions and potential modifications are discussed in Section 10. Finally, a complete listing of the Fortran source program is contained in Section 11.

SECTION 2

PROGRAM DESCRIPTION

The following discussion is presented to provide the user with an understanding of the organization and general operation of Program NATNAV. The modular structure of NATNAV is illustrated by the block diagram of Figure 1. Each subroutine and function is indicated, and the arrows show the calling sequences among the programs. Brief abstracts of each program are presented in Table 1. Table 2 summarizes all external references in NATNAV, excluding system routines. The Fortran library routines indicated in Table 2 are defined in Table 3.

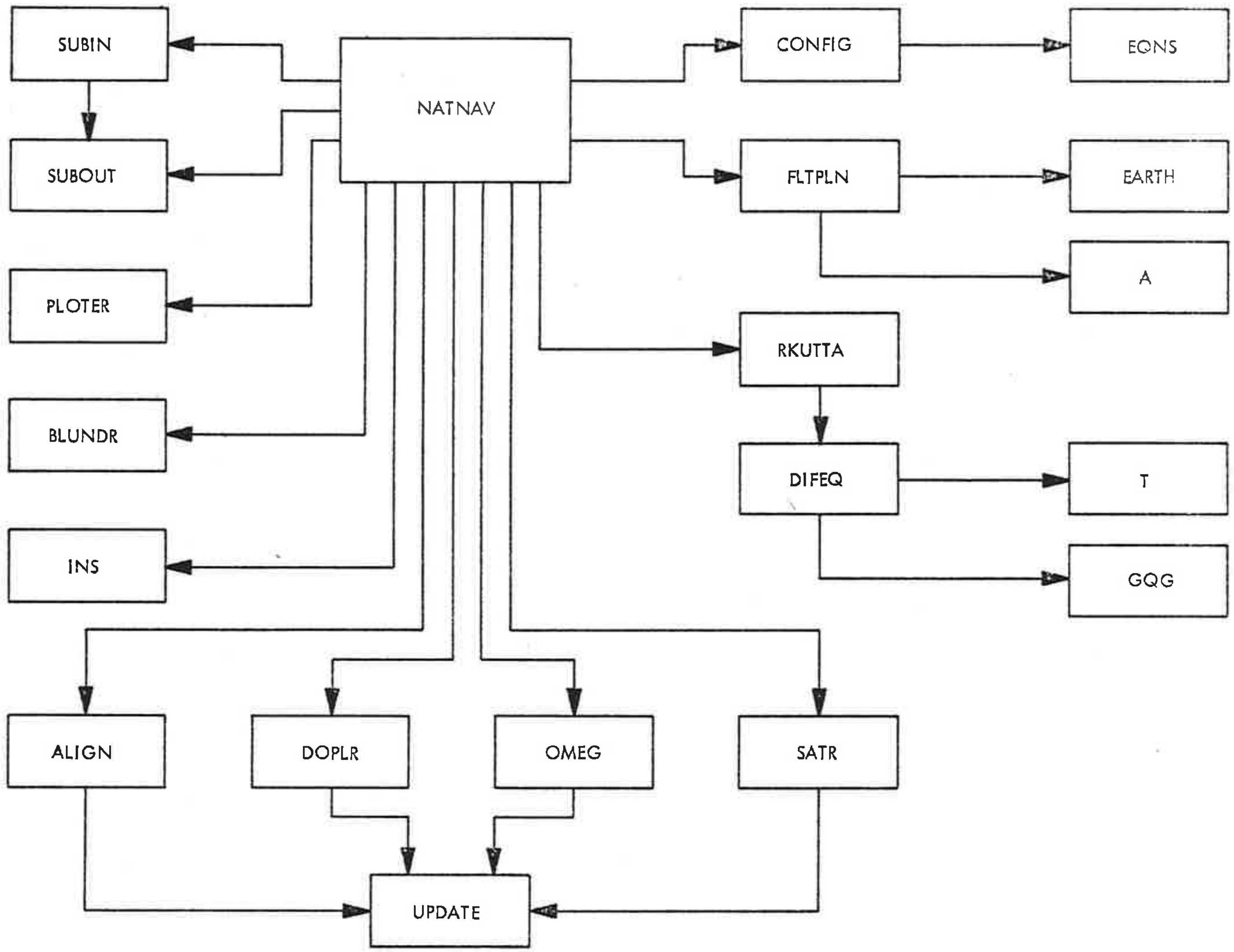

Figure 1. Modular Structure of Program NATNAV.

Table 1. NATNAV Program Abstracts.

NATNAV	Initializes the simulation, regulates the integration of the covariance terms, controls the measurement updates and governs the print and plot outputs. [Main Program]
SUBIN	Reads all input data and documents it on the printed output. [Called by NATNAV]
SUBOUT	Prints time histories of the position and velocity errors in track-referenced coordinates. Also saves data for plotting at completion of run. [Called by NATNAV and SUBIN]
EQNS	Initializes the array of covariance elements to be propagated, and sets the indices for integrating the appropriate differential equations. [Called by CONFIG]
CONFIG	Establishes the array of covariance elements to be integrated for the system configuration selected by the user. [Called by NATNAV]
FLTPLN	Calculates the nominal position, speed, track and heading of the aircraft as functions of time, assuming constant velocity between waypoints. [Called by NATNAV]
EARTH	Calculates the approximate geocentric distance and gravitational acceleration as functions of lattitude and altitude. [Called by FLTPLN]
A	Calculates local speed of sound as function of altitude. [Called by FLTPLN]
INS	Initializes the INS covariances and driving noise strengths; calculates the system matrix elements, transformation matrix and torquing rates for the INS. [Called by NATNAV]
ALIGN	Calculates the measurement vectors and optimal filter gains for updating the covariance matrix during the alignment phase. [Called by NATNAV]
DOPLR	Calculates the measurement vectors and optimal filter gains for doppler radar measurements. [Called by NATNAV]
OMEG	Calculates the measurement vectors and optimal filter gains for two Omega line-of-position measurements. [Called by NATNAV]
SATR	Calculates the measurement vectors and optimal filter gains for two satellite ranging measurements. [Called by NATNAV]

Table 1. (Continued).

UPDATE	Updates the covariance matrix for optimum or sub-optimum measurements. Stores optimum filter gains for print out if desired. [Called by ALIGN, DOPLR, OMEG, SATR]
RKUTTA	Integrates the covariance differential equations using a fourth-order Runge-Kutta procedure. [Called by NATNAV]
DIFEQ	Calculates the derivatives of the covariance elements. [Called by RKUTTA]
T	Calculates the elements of the matrix product $F \times P$. [Called by DIFEQ]
GQG	Calculates the elements of the noise matrix product $G \times Q \times G^T$. [Called by DIFEQ]
BLUNDR	Sets the new system error quantities after the occurence of a specified blunder or malfunction. Supplied by user. [Called by NATNAV]
PLOTER	Plots the time histories of the position and velocity errors in track-referenced coordinates, if desired. [Called by NATNAV]

Table 2. Program NATNAV External References*.

ROUTINE	SUBROUTINE REFERENCES			LIBRARY ROUTINE REFERENCES	
NATNAV	ALIGN CONFIG DOPLR FLTPN	INS OMEG PLOTR RKUTTA	SATR SUBIN SUBOUT	AMIN1 DATE TIMEF	
SUBIN					
SUBOUT				INT SQRT	
CONFIG	EQNS				
EQNS					
FLTPLN	A	EARTH		ASIN ATAN2 COS	LOG SIN SQRT
EARTH				SIN	
A				SQRT	
INS				COS	SIN
ALIGN	UPDATE				
DOPLR	UPDATE			COS	SIN
OMEG	UPDATE			ATAN2 COS	SIN
SATR	UPDATE			COS SIN	SQRT
UPDATE					
RKUTTA	DIFEQ				
DIFEQ	GQG	T			

*Excluding System Routines.

Table 2. (Continued)*.

ROUTINE	SUBROUTINE REFERENCES	LIBRARY ROUTINE REFERENCES
T		
GQG		
PLOTER		AXIS PLOT SYMBOL LINE PLOTS NUMBER SCALE

*Excluding System Routines.

Table 3. Fortran Library Routines.

AMIN1 $(x_1, x_2, \ldots)$	Determines minimum argument [Called by NATNAV]
ASIN (x)	Arcsine of x [Called by EARTH, FLTPLN]
ATAN2 (x_1, x_2)	Arctangent of $\frac{x_1}{x_2}$ [Called by FLTPLN, OMEG]
AXIS	Plots axis with lable, tick marks, and tick mark annotation [Called by PLOTER]
COS (x)	Cosine of x [Called by FLTPLN, INS, DOPLR, OMEG, SATR]
DATE*	Current month, day, year, and Julian day [Called by NATNAV]
INT	Real to integer conversion [Called by SUBOUT]
LINE	Plots x vs y curve [Called by PLOTER]
LOG (x)	Natural log of x [Called by FLTPLN]
NUMBER	Draws a special number [Called by PLOTER]
PLOT	Conveys data to the subroutine for plotting [Called by PLOTER]
PLOTS	Initializes entry for plotter package or erases plotter package [Called by PLOTER]
SCALE	Scales an array to produce an axis with reasonable engineering units [Called by PLOTER]
SIN (x)	Sine of x [Called by EARTH, FLTPLN, INS, DOPLR, OMEG, SATR]
SQRT (x)	Square root of x [Called by SUBOUT, FLTPLN, A, SATR]
SYMBOL	Labels plot or plots symbols for data points [Called by PLOTER]
TIMEF	Current time in floating point format [Called by NATNAV]

*DATE is currently a non-standard library routine at NRL. A Compass deck, available from NRL, must be included with the NATNAV source deck (Ref. 4).

SECTION 3

FLOW CHARTS

The following pages present narrative flow charts for each routine in Program NATNAV. These flow charts are included to show the organization and logic of NATNAV, and to assist the user in following the detailed program listing. The flow chart of the main program, NATNAV, will provide the user with a general understanding of the overall simulation procedure. More detailed operations are furnished by the individual subroutine and function flow charts.

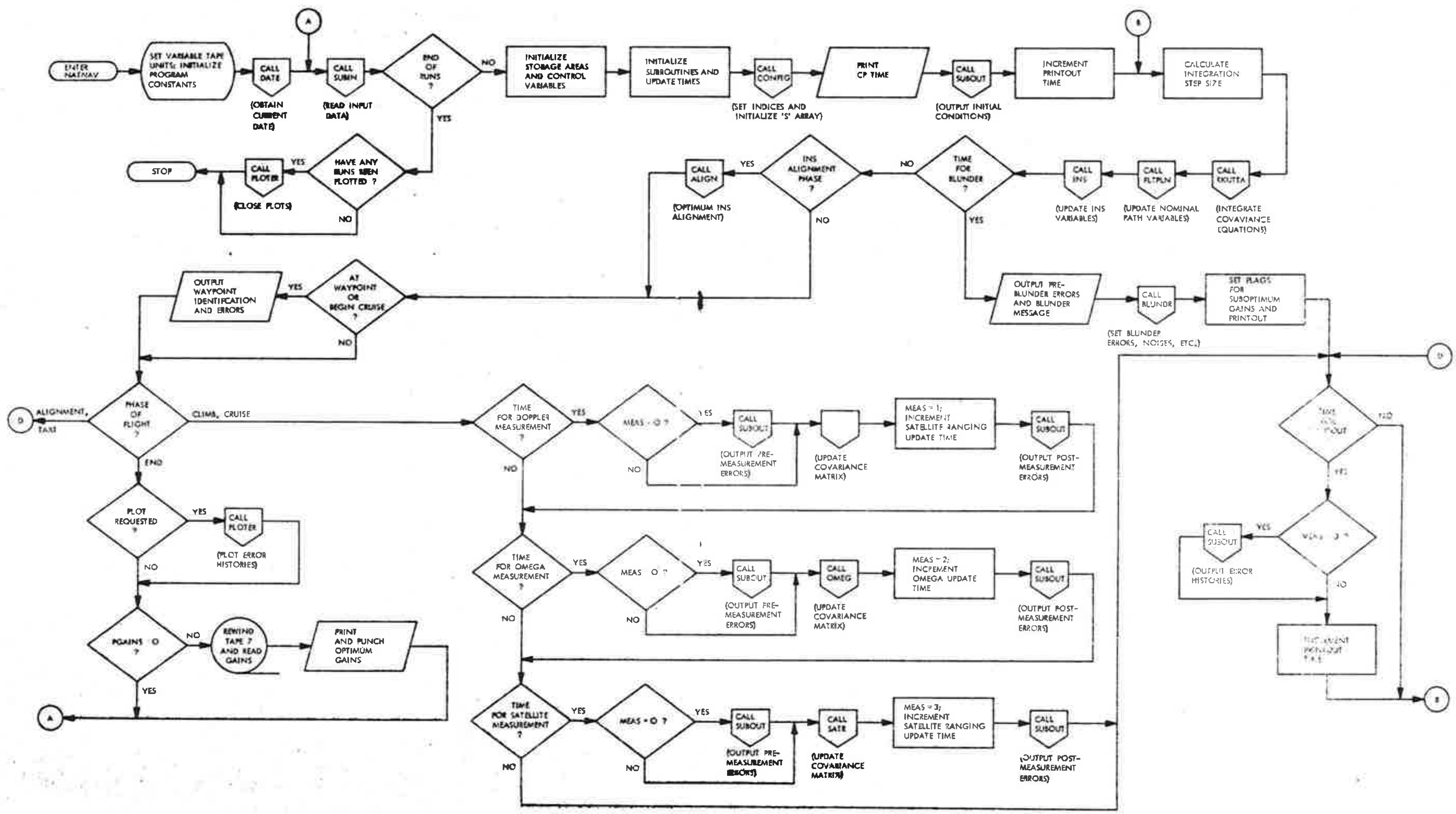

Figure 2. Flow Chart of Main Program NATNAV.

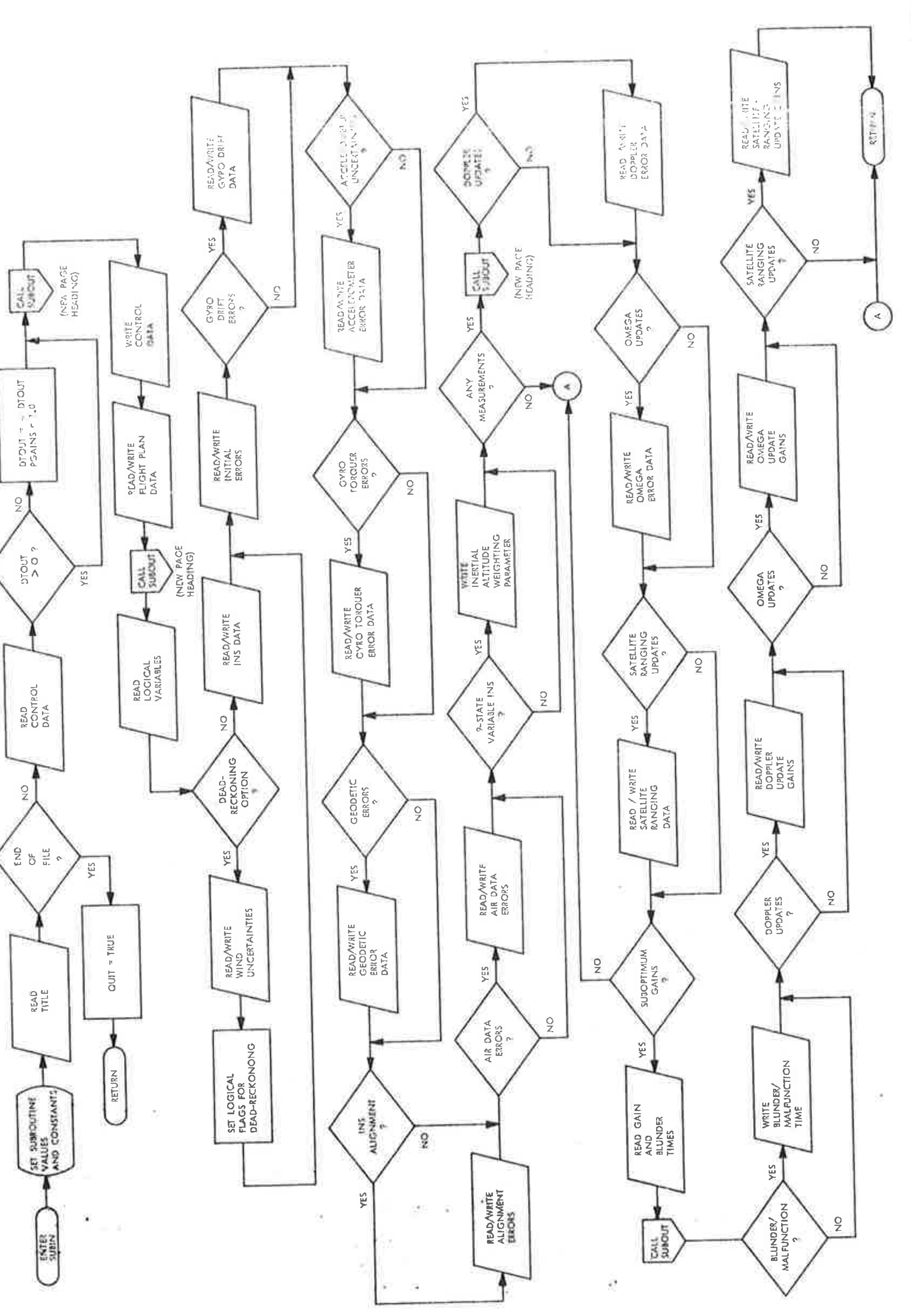

Figure 3. Flow Chart of Subroutine SUBIN.

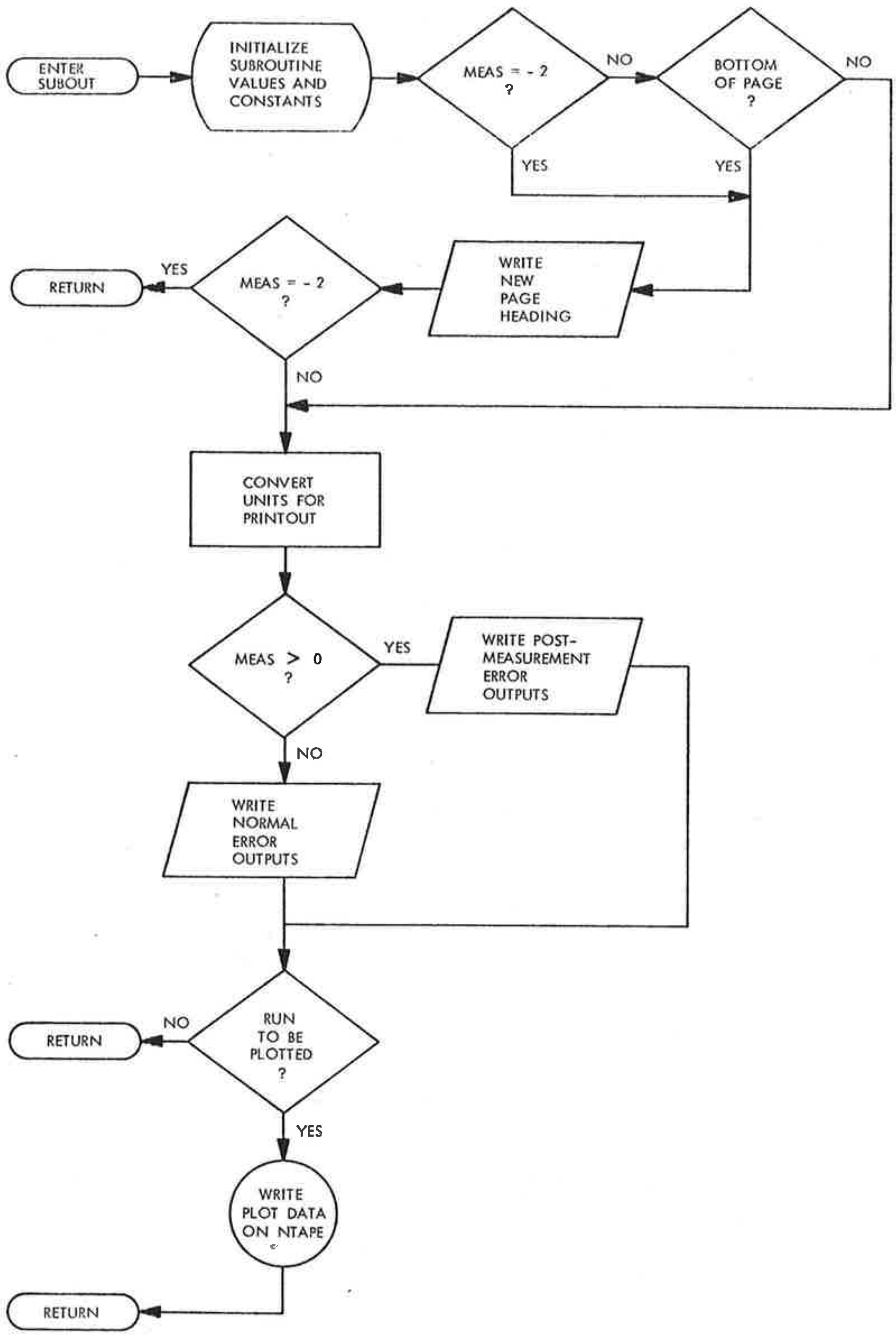

Figure 4. Flow Chart of Subroutine SUBOUT.

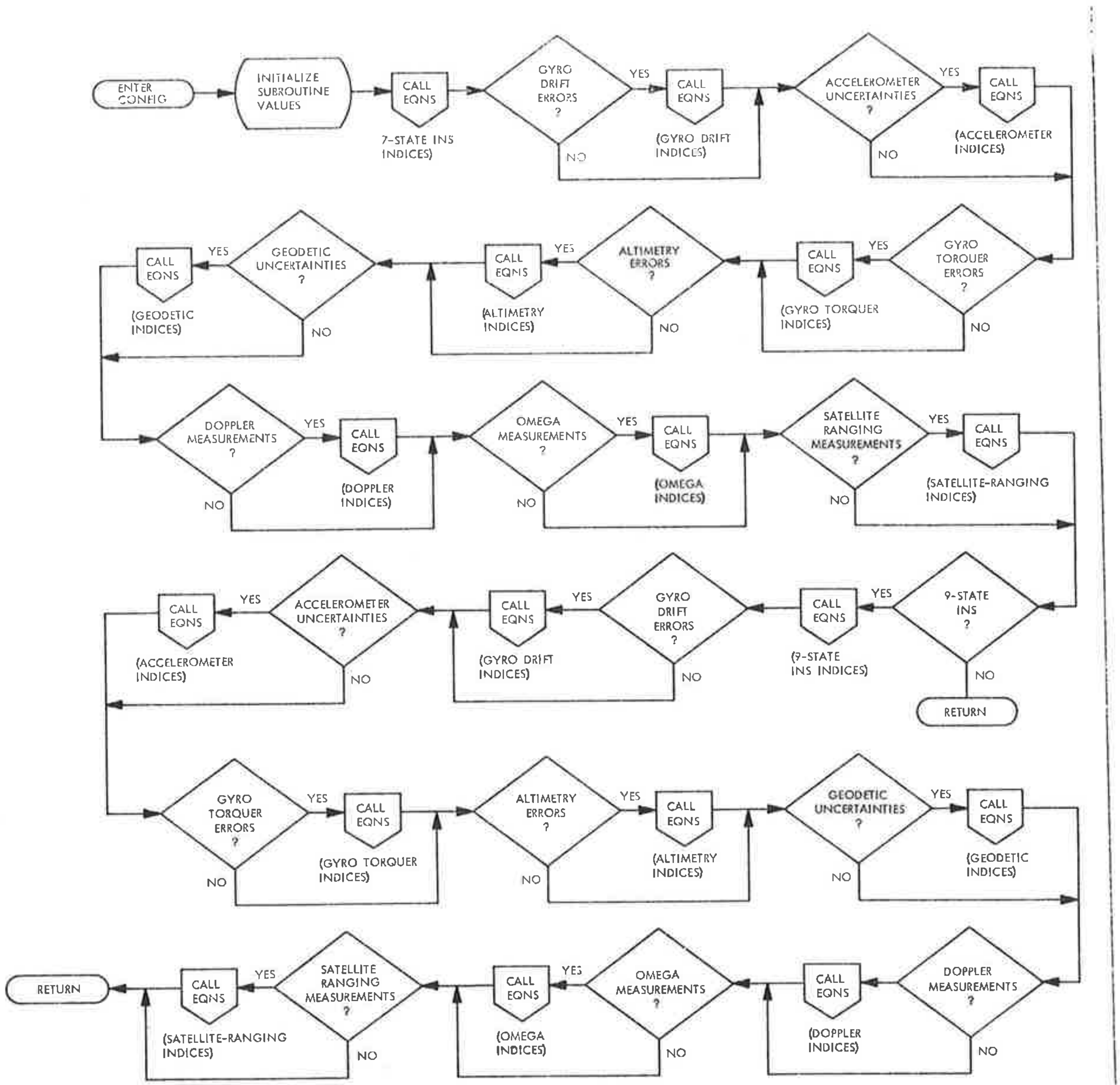

Figure 5. Flow Chart of Subroutine CONFIG.

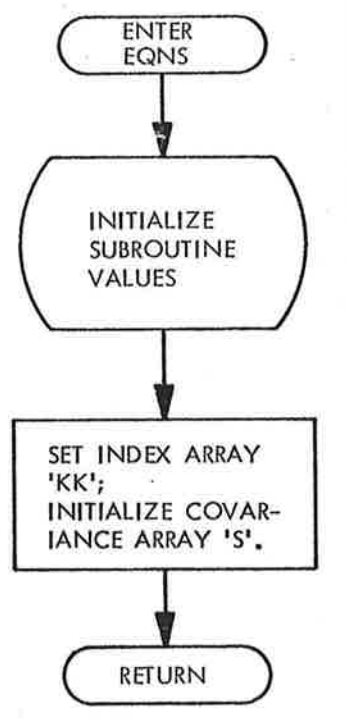

Figure 6. Flow Chart of Subroutine EQNS.

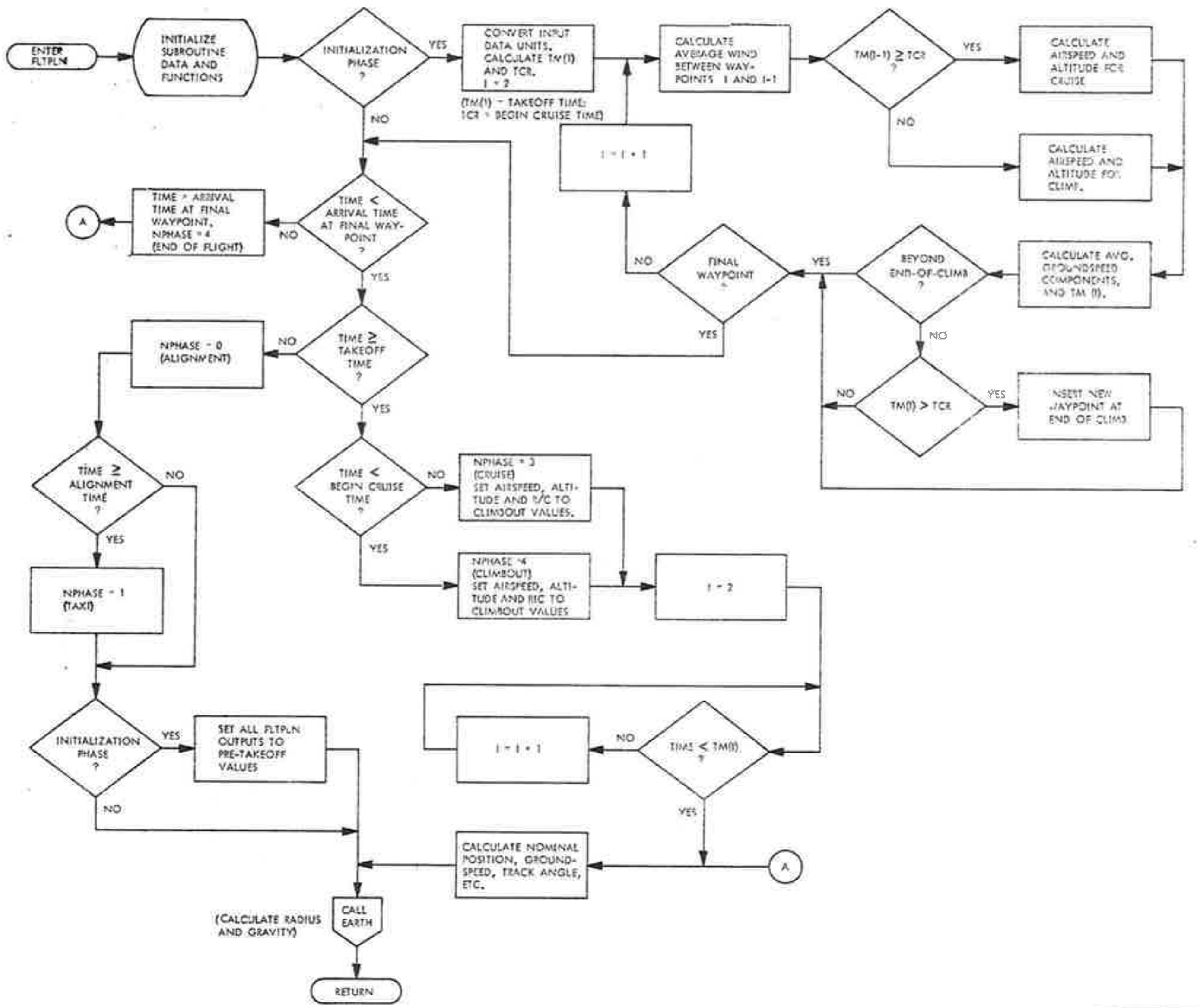

Figure 7. Flow Chart of Subroutine FLTPLN.

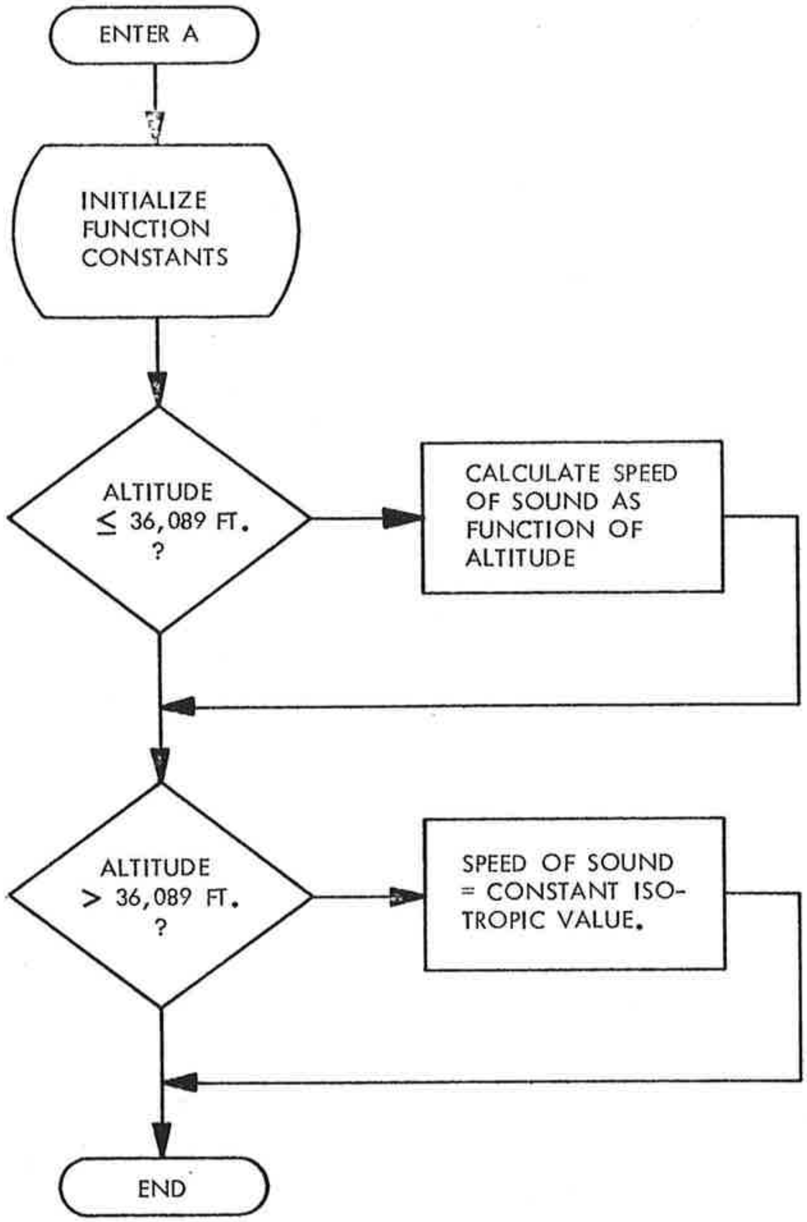

Figure 8. Flow Chart of Function A.

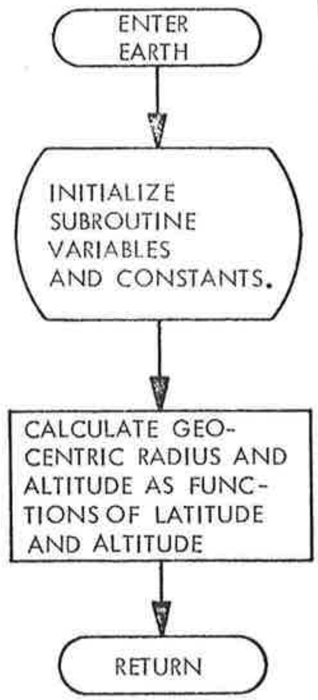

Figure 9. Flow Chart of Subroutine EARTH.

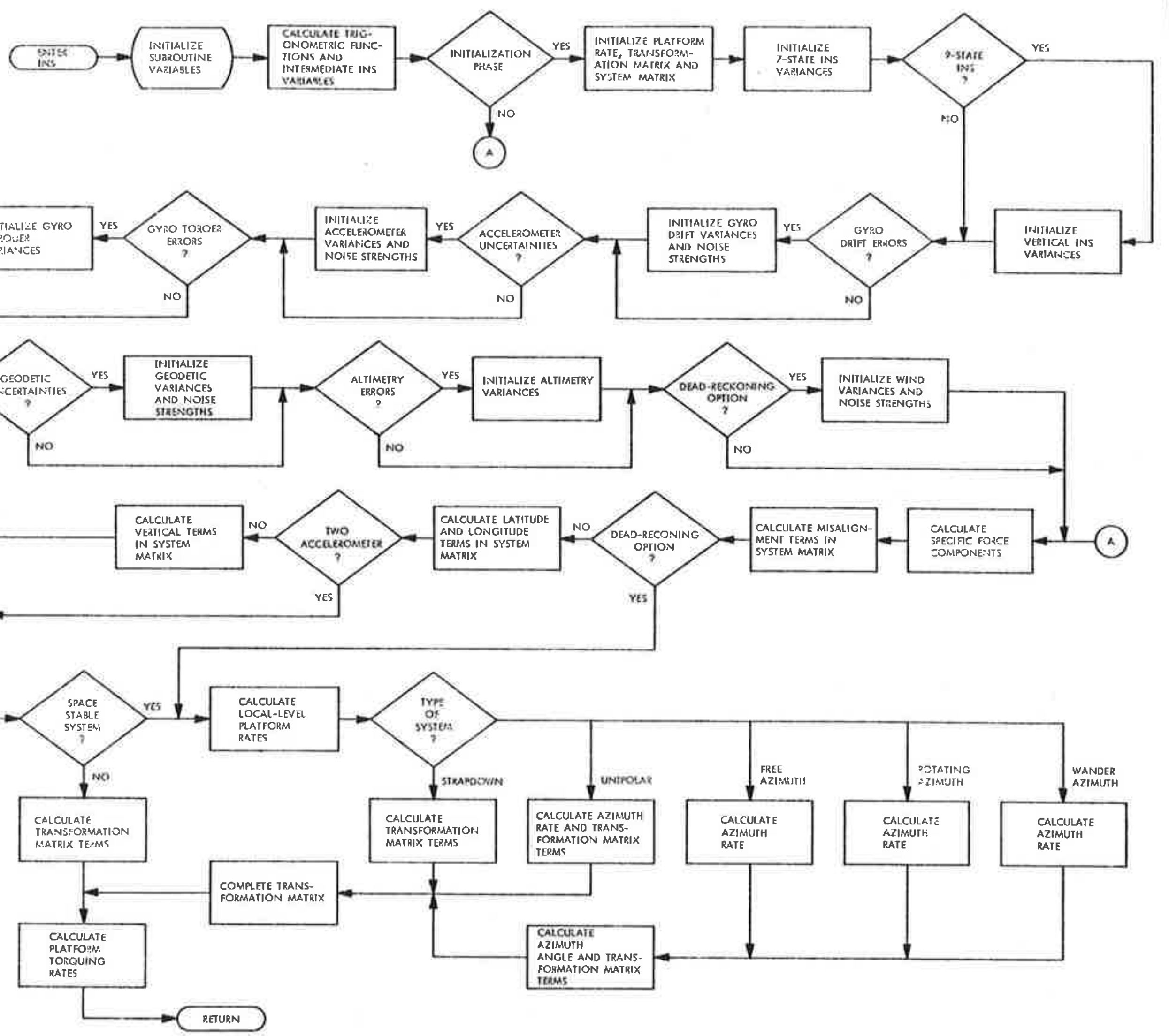

Figure 10. Flow Chart of Subroutine INS.

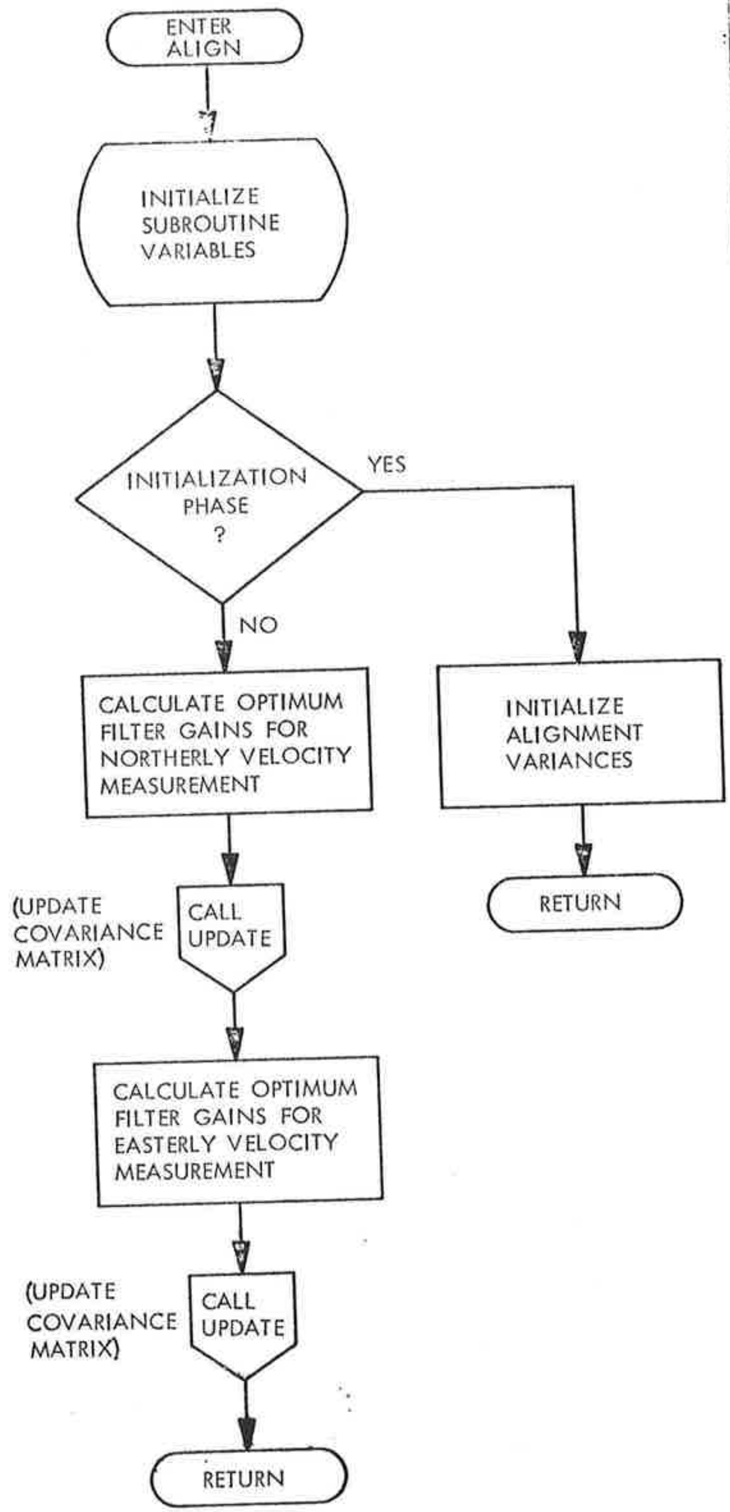

Figure 11. Flow Chart of Subroutine ALIGN.

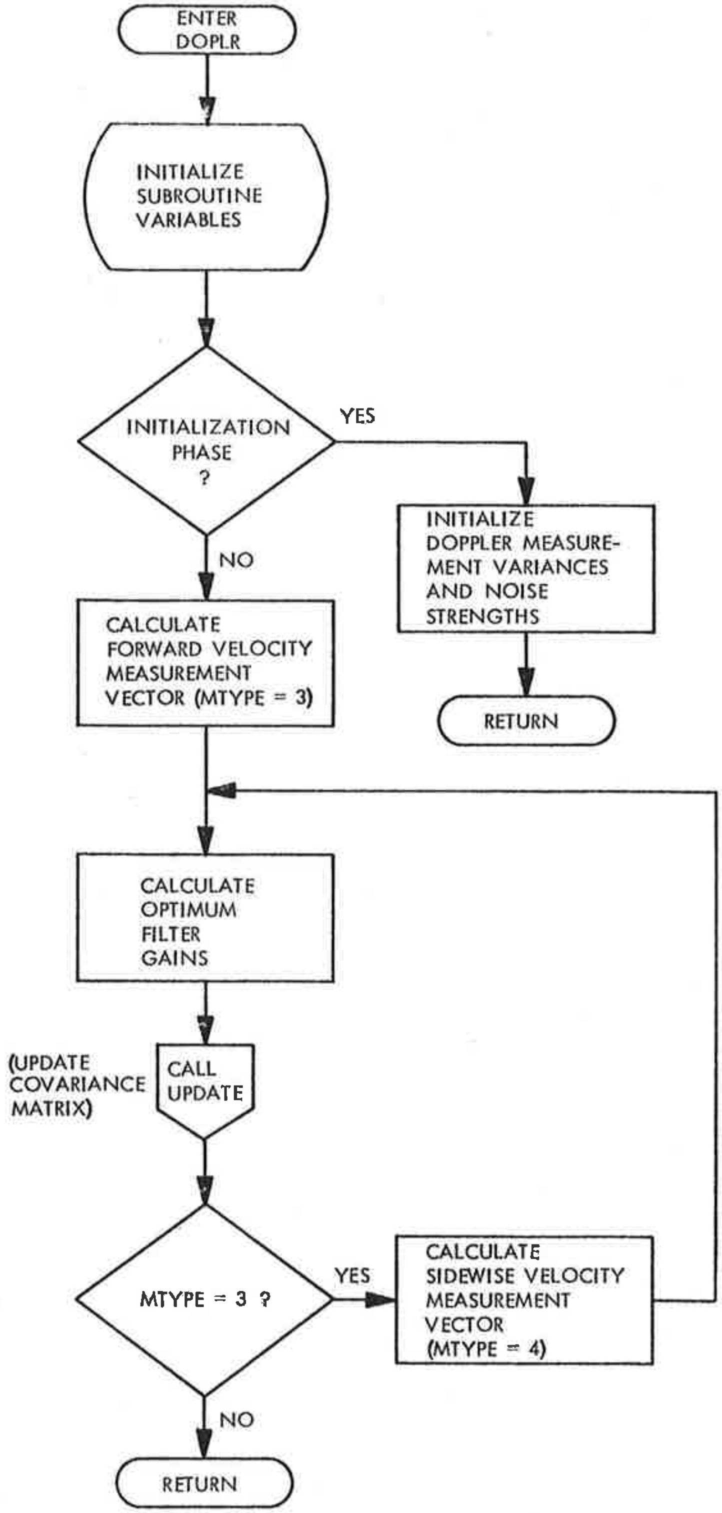

Figure 12. Flow Chart of Subroutine DOPLR.

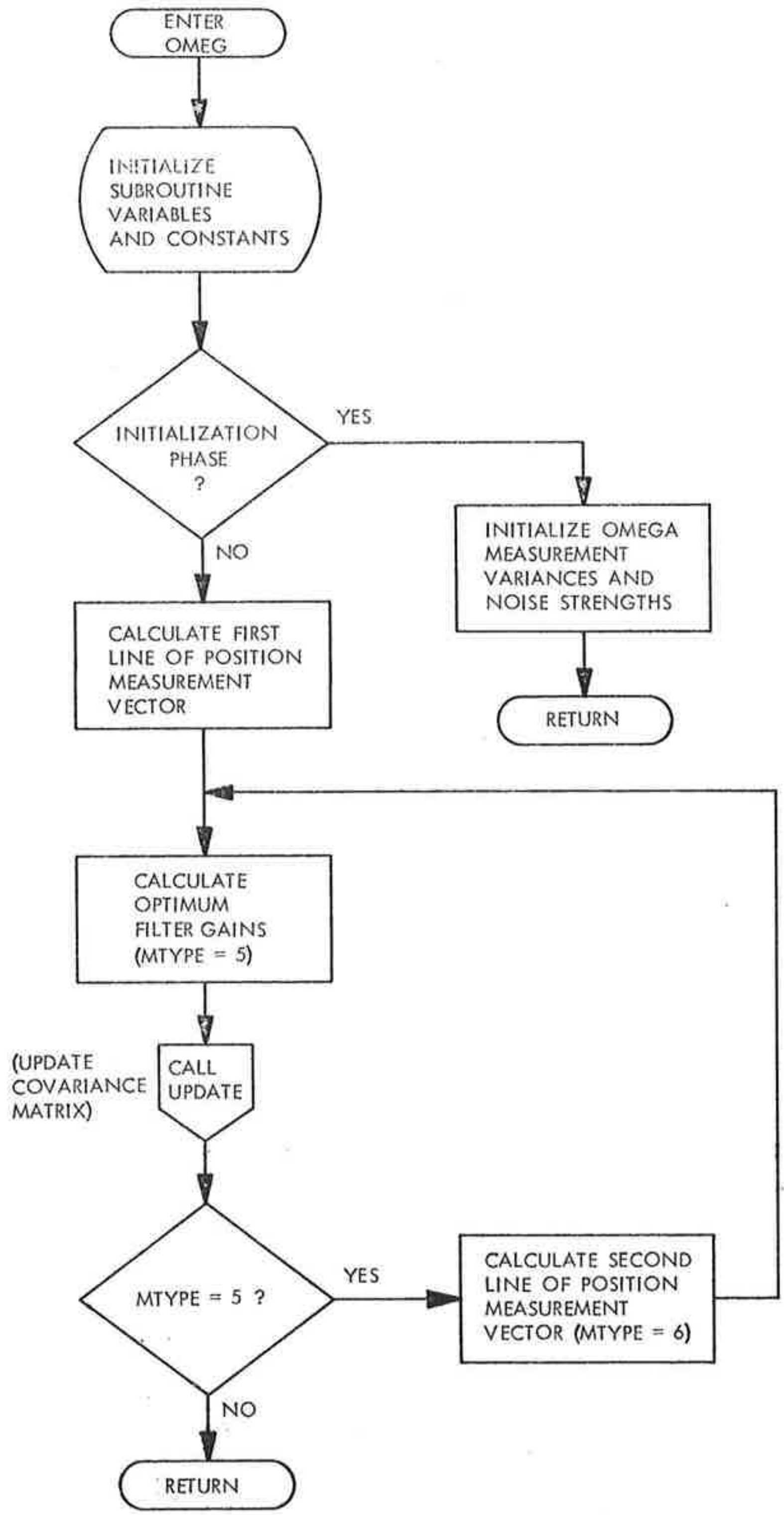

Figure 13. Flow Chart of Subroutine OMEG.

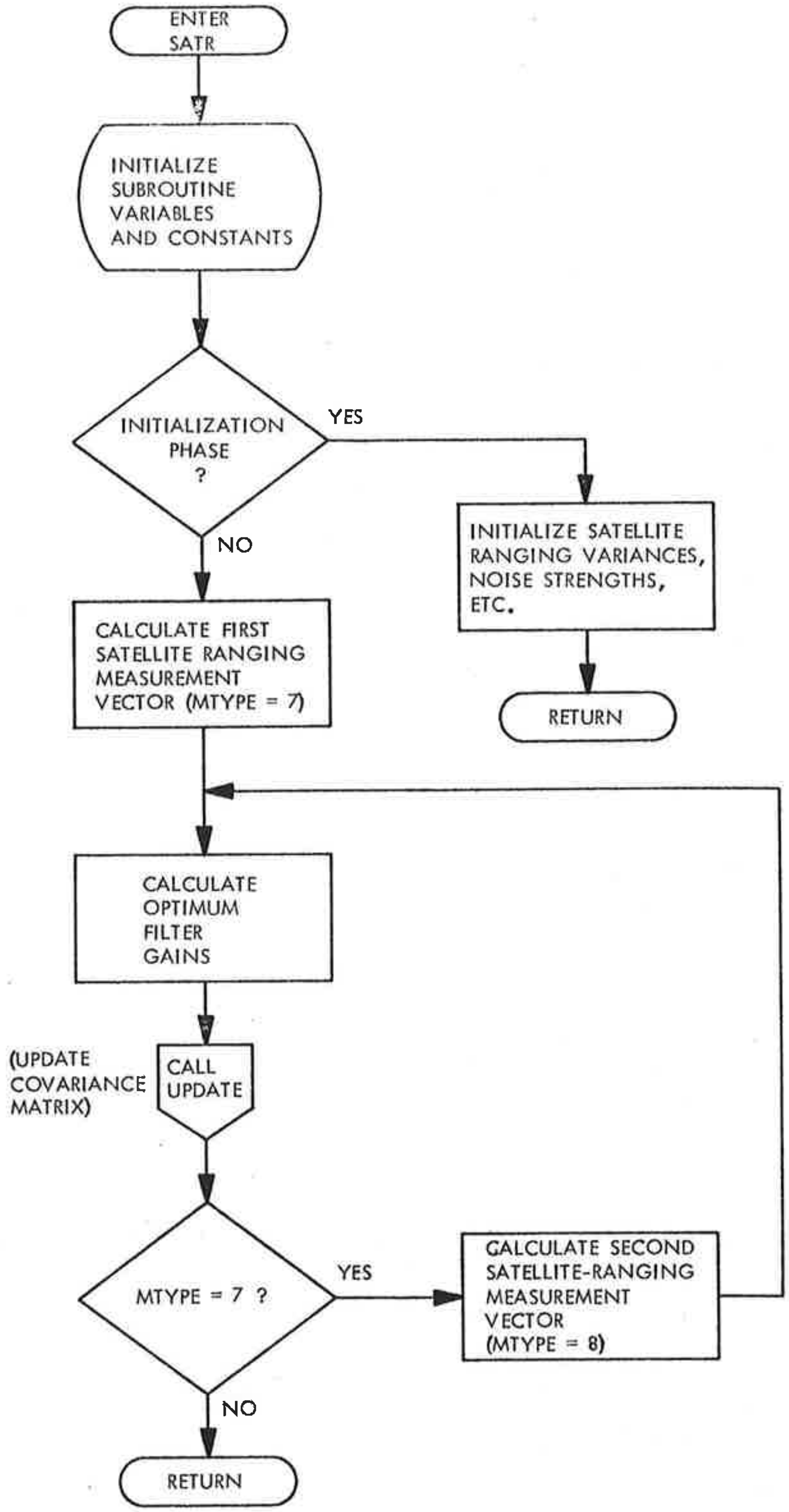

Figure 14. Flow Chart of Subroutine SATR.

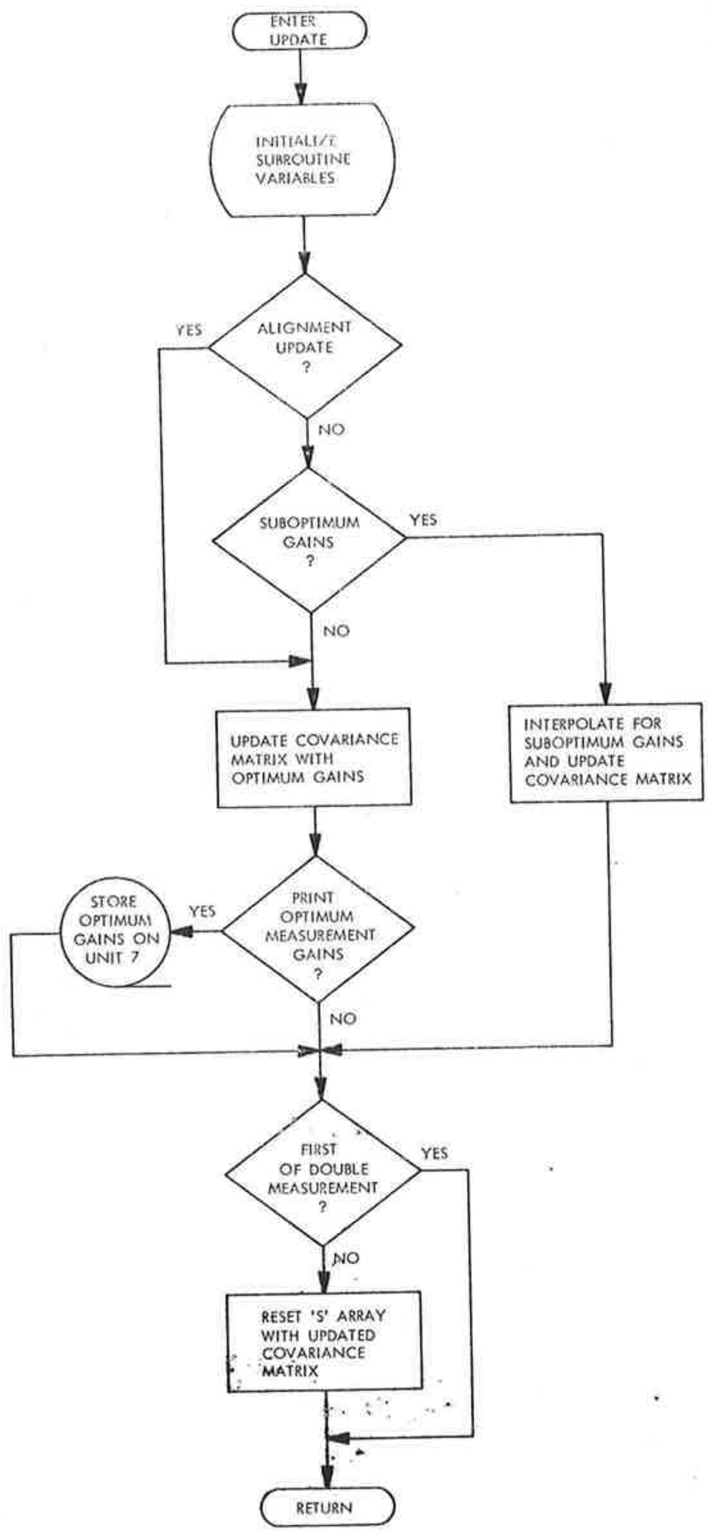

Figure 15. Flow Chart of Subroutine UPDATE.

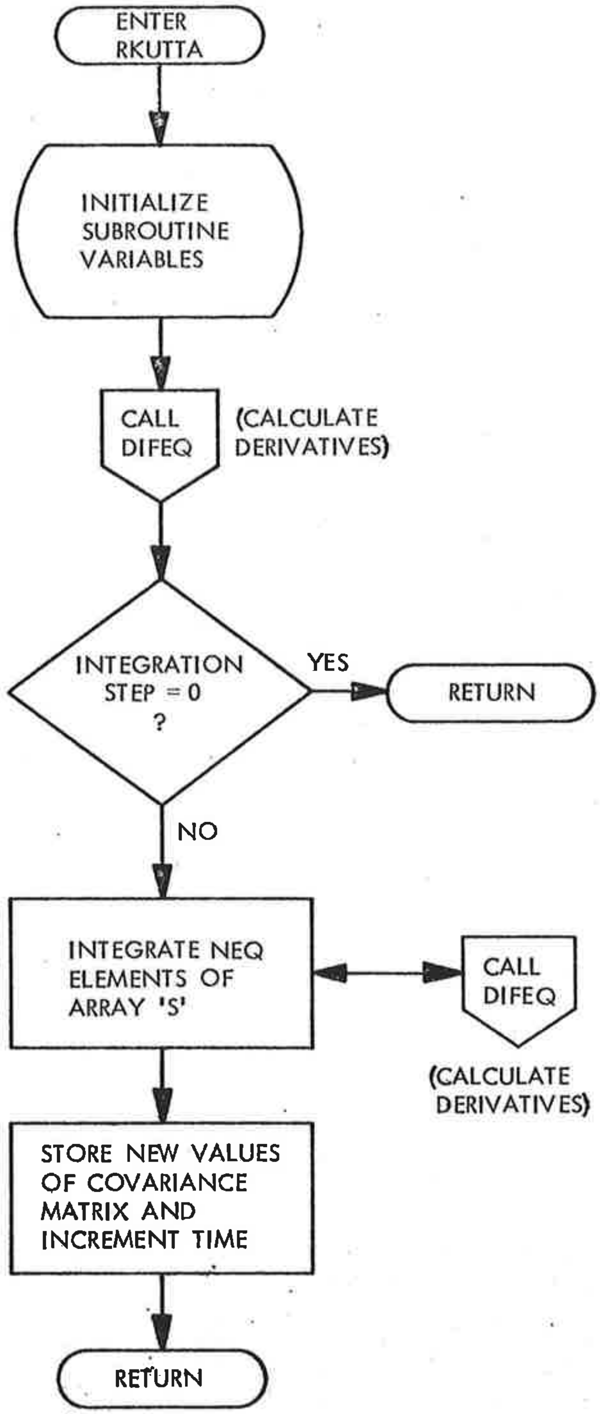

Figure 16. Flow Chart of Subroutine RKUTTA.

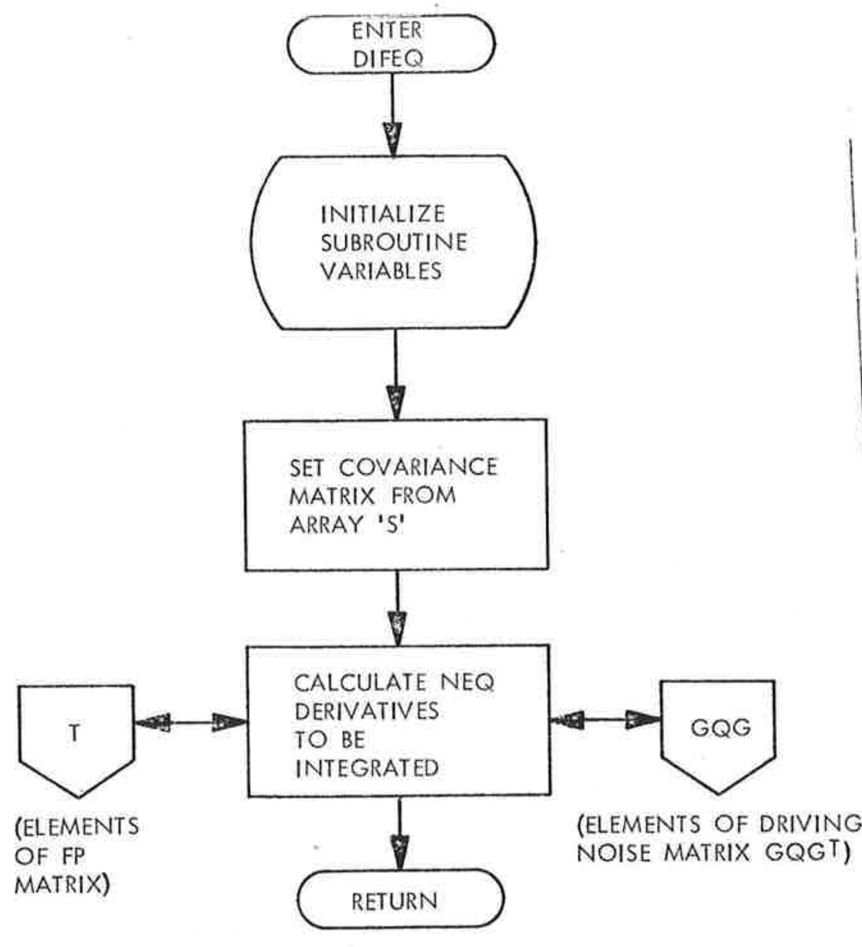

Figure 17. Flow Chart of Subroutine DIFEQ.

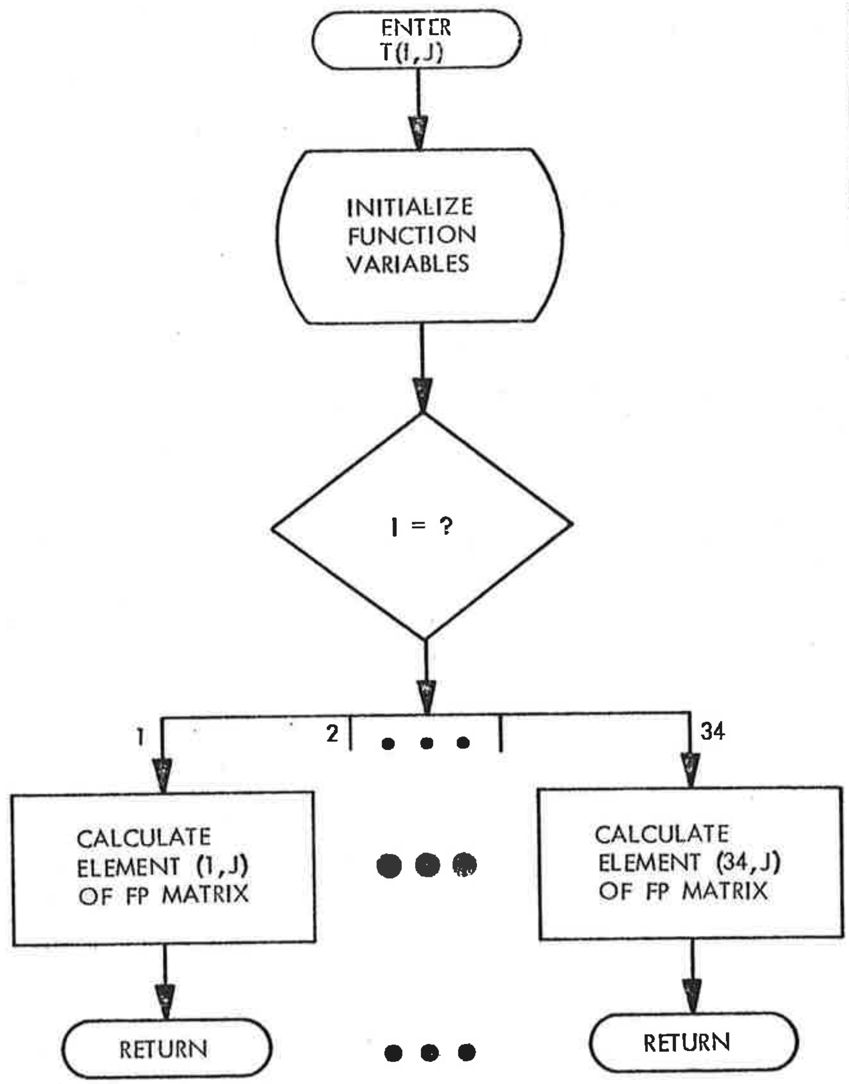

Figure 18. Flow Chart of Function T.

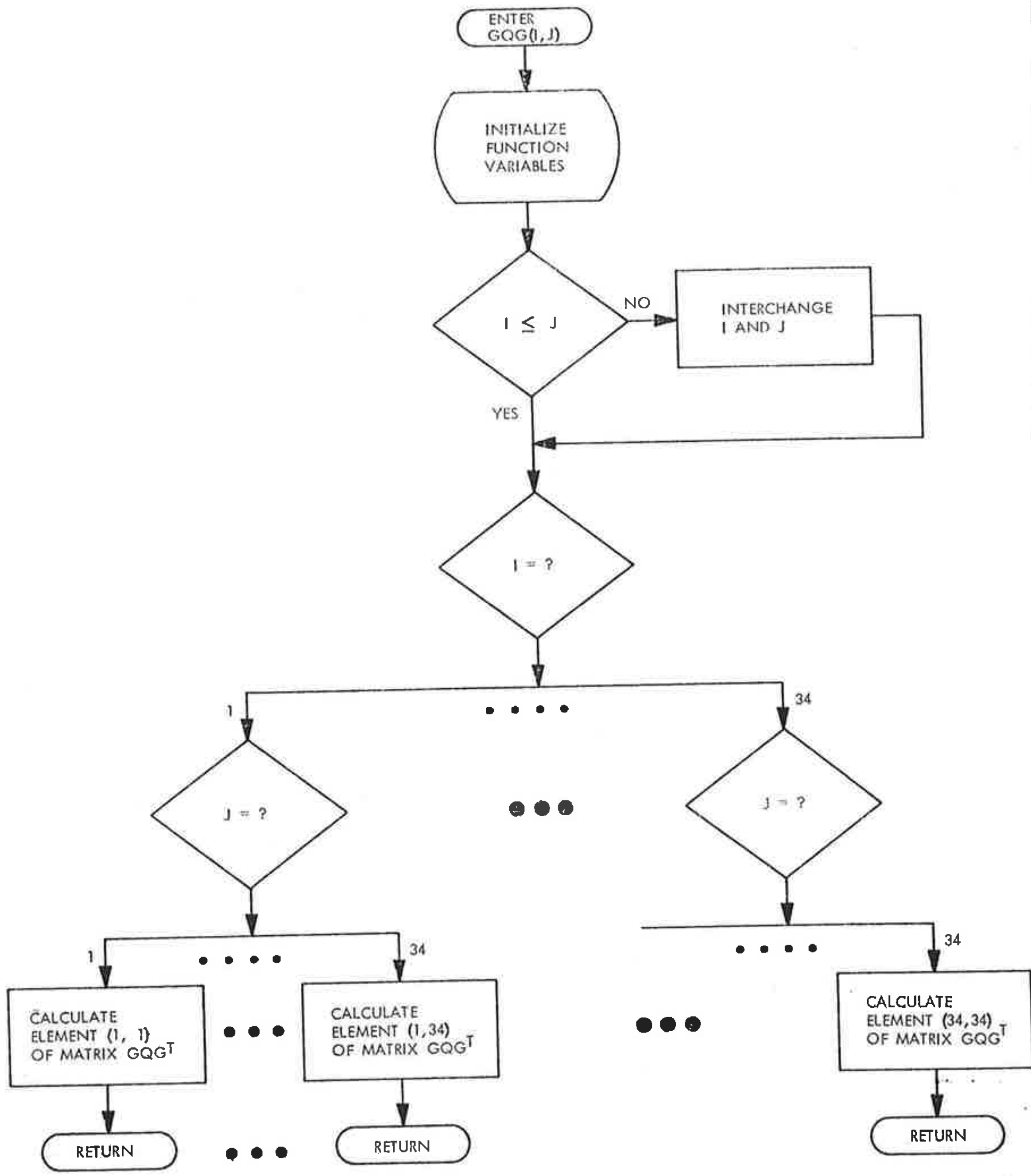

Figure 19. Flow Chart of Function GQG.

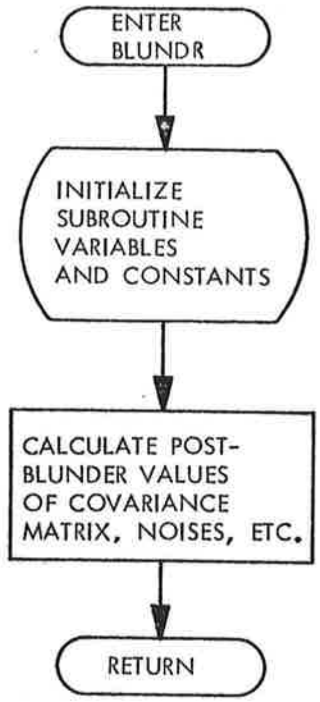

Figure 20. Flow Chart of Subroutine BLUNDR.

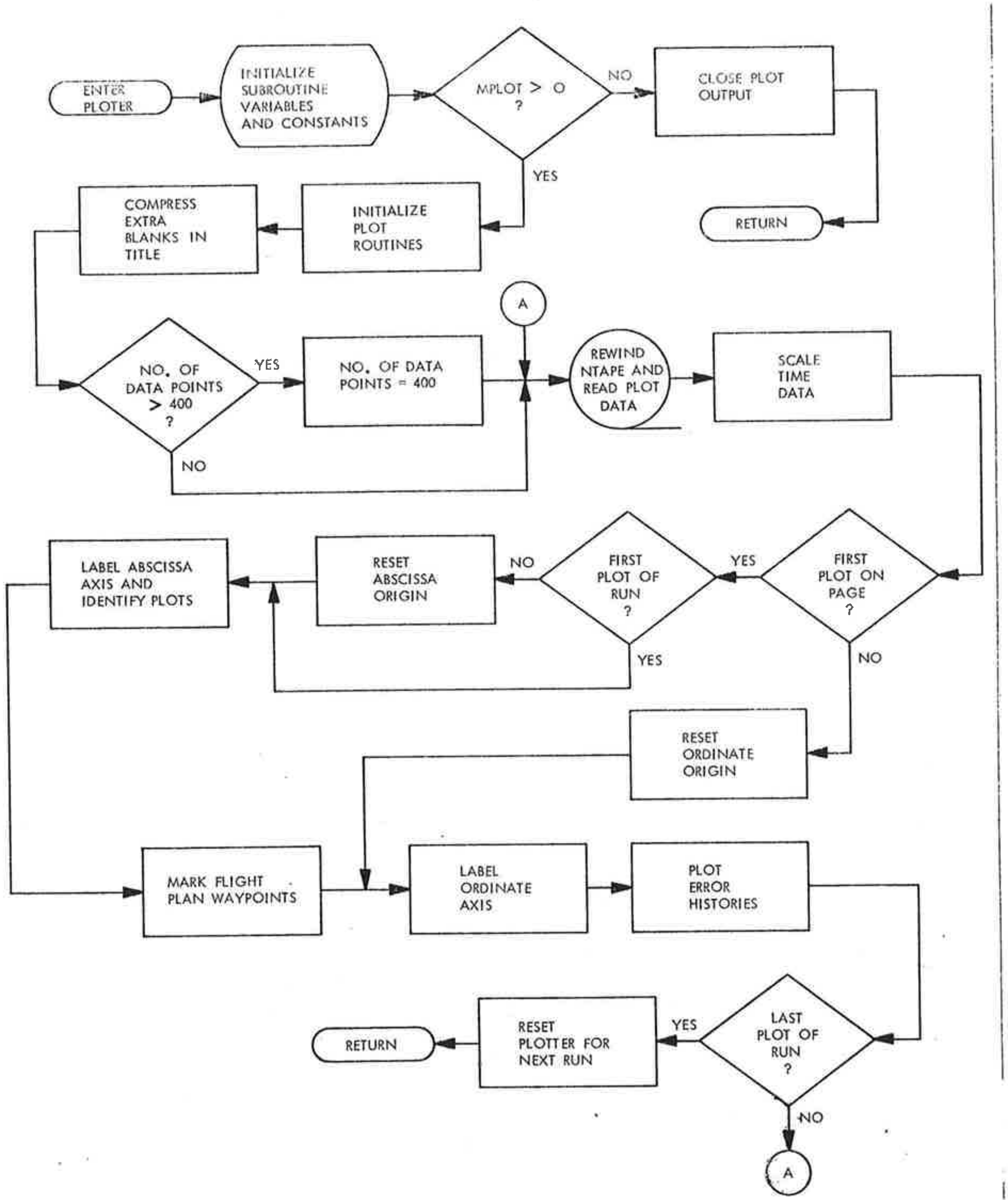

Figure 21. Flow Chart of Subroutine PLOTER.

SECTION 4

COMMON STORAGE

In keeping with the modularity goal of NATNAV, most related Fortran variables used by more than one program are organized into a number of common blocks, as shown in Table 4. The Fortran variables contained in each common block, and the lengths of each (in decimal), are given in Table 5.

Table 4. Program NATNAV Common Block Organization.

SUB-ROUTINES	COMMON BLOCK																						
	BALIGN	BALT	BCONST	BCOVAR	BDOPLR	BDRKN	BFLTPN	BINDEX	BINIT	BINS1	BINS2	BINS3	BINTEG	BLOGIC	BLU	BNOM	BOMEGA	BPLOT	BSATR	BSUBOP	BTIME	BTITLE	BUPDAT
NATNAV	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SUBIN	X	X			X	X	X			X	X		X	X	X		X	X	X	X		X	
SUBOUT		X	X	X						X	X			X	X	X		X			X	X	
CONFIG								X					X	X									
EQNS				X				X					X										
FLTPLN			X				X		X							X							
EARTH																X							
A																							
INS		X	X	X		X			X	X	X	X		X		X					X		
ALIGN	X		X	X					X							X							X
DOPLR			X	X	X				X					X		X							X
OMEG			X	X					X							X	X						X
SATR			X	X					X					X		X			X				X
UPDATE				X				X					X	X						X	X		X
RKUTTA				X				X					X								X		
DIFEQ				X				X					X										
T				X	X					X	X	X		X		X	X		X				
GQG					X					X	X	X				X	X		X				
BLUNDR	X	X	X	X	X	X	X			X	X			X			X		X				
PLOTER							X											X				X	

Table 5. Common Block Contents and Lengths.

BALIGN	(4)	SALIN1	(1)	SALIN2	(1)	RALIN1	(1)
		RALIN2	(1)				
BALT	(4)	TAUH	(1)	SALT	(1)	TAUHD	(1)
		SALTD	(1)				
BCONST	(6)	RADPDG	(1)	DEGPRD	(1)	FTPNM	(1)
		NMPFT	(1)	MINPRD	(1)	OMIE	(1)
BCOVAR	(1156)	P	(1156)				
BDOPLR	(13)	TDF	(1)	TDS	(1)	SNDF	(1)
		SNDS	(1)	SBDF	(1)	SBDS	(1)
		SRDF	(1)	SRDS	(1)	DTDOP	(1)
		QDF	(1)	QDS	(1)	RDF	(1)
		RDS	(1)				
BDRKN	(4)	SVWN	(1)	SVWE	(1)	DVWN	(1)
		DVWE	(1)				
BFLTPN	(149)	DTA	(1)	DTT	(1)	HØ	(1)
		VCL	(1)	RC	(1)	MCR	(1)
		HCR	(1)	NWPTS	(1)	LAT	(20)
		LON	(20)	THETAW	(20)	VW	(20)
		TCR	(1)	TM	(20)	VN	(20)
		VE	(20)				
BINDEX	(1755)	II	(585)	JJ	(585)	KK	(585)
BINIT	(1)	INIT	(1)				
BINS1	(16)	ISYS	(1)	EEØ	(1)	ENØ	(1)
		EDØ	(1)	DLAØ	(1)	DLOØ	(1)
		RDLAØ	(1)	RDLOØ	(1)	DHØ	(1)
		RDHØ	(1)	AKAP	(1)	PHIDOT	(1)
		OMS2	(1)	FN	(1)	FE	(1)
		FD	(1)				

Table 5. (Continued).

BINS2	(37)	TGX	(1)	TGY	(1)	TGZ	(1)
		QWGX	(1)	QWGY	(1)	QWGZ	(1)
		SGX	(1)	SGY	(1)	SGZ	(1)
		QVGX	(1)	QVGY	(1)	QVGZ	(1)
		TAX	(1)	TAY	(1)	TAZ	(1)
		QWAX	(1)	QWAY	(1)	QWAZ	(1)
		SAX	(1)	SAY	(1)	SAZ	(1)
		QVAX	(1)	QVAY	(1)	QVAZ	(1)
		TAUX	(1)	TAUY	(1)	TAUZ	(1)
		DX	(1)	DY	(1)	DZ	(1)
		SVX	(1)	SVY	(1)	SVZ	(1)
		QVX	(1)	QVY	(1)	QVZ	(1)
		QWH	(1)				
BINS3	(40)	C11	(1)	C12	(1)	C13	(1)
		C21	(1)	C22	(1)	C23	(1)
		C31	(1)	C32	(1)	C33	(1)
		F12	(1)	F13	(1)	F17	(1)
		F21	(1)	F23	(1)	F31	(1)
		F32	(1)	F37	(1)	F62	(1)
		F63	(1)	F64	(1)	F66	(1)
		F67	(1)	F68	(1)	F69	(1)
		F71	(1)	F73	(1)	F74	(1)
		F76	(1)	F77	(1)	F78	(1)
		F79	(1)	F91	(1)	F92	(1)
		F94	(1)	F96	(1)	F97	(1)
		F98	(1)	WX	(1)	WY	(1)
		WZ	(1)				
BINTEG	(1173)	S	(585)	SD	(585)	DT	(1)
		DTØ5	(1)	NEQ	(1)		
BLOGIC	(12)	GYROS	(1)	ACCEL	(1)	TORQ	(1)
		ALTSF	(1)	GRAVD	(1)	INS9	(1)
		TWOACC	(1)	DOPLER	(1)	OMEGA	(1)
		SATRNG	(1)	SUBOPT	(1)	DREKON	(1)
BLU	(2)	NN	(1)	MM	(1)		

Table 5. (Continued).

BNOM	(35)	NPHASE	(1)	H	(1)	HDOT	(1)
		ALATR	(1)	ALAT	(1)	ALON	(1)
		ALONR	(1)	ALB	(1)	ALBDOT	(1)
		VG	(1)	VA	(1)	VELN	(1)
		VELE	(1)	VELW	(1)	TRK	(1)
		HDG	(1)	CRB	(1)	THW	(1)
		R	(1)	RI	(1)	RI2	(1)
		G	(1)	SL	(1)	CL	(1)
		TL	(1)	SL2	(1)	CL2	(1)
		CLI	(1)	RICLI	(1)	CTRK	(1)
		STRK	(1)	ALAT2	(1)	CHDG	(1)
		SHDG	(1)	RCL	(1)		
BOMEGA	(17)	IOM1	(1)	IOM2	(1)	IOM3	(1)
		IOM4	(1)	TOM1	(1)	TOM2	(1)
		SNOM1	(1)	SNOM2	(1)	SBOM1	(1)
		SBOM2	(1)	SROM1	(1)	SROM2	(1)
		DTOM	(1)	QOM1	(1)	QOM2	(1)
		ROM1	(1)	ROM2	(1)		
BPLOT	(3)	DTPLOT	(1)	NPLOT	(1)	NTAPE	(1)
BSATR	(19)	SATLAT	(2)	SATLON	(2)	HSAT	(2)
		TSAT1	(1)	TSAT2	(1)	SNSAT1	(1)
		SNSAT2	(1)	SBSAT1	(1)	SBSAT2	(1)
		SRSAT1	(1)	SRSAT2	(1)	DTSAT	(1)
		QSAT1	(1)	QSAT2	(1)	RSAT1	(1)
		RSAT2	(1)				
BSUBOP	(4103)	NK	(1)	TSUBK	(20)	KSUBDF	(680)
		KSUBDS	(680)	KSUBØ1	(680)	KSUBØ2	(680)
		KSUBS1	(680)	KSUBS2	(680)	PGAINS	(1)
		TBLUND	(1)				
BTIME	(1)	TIME	(1)				
BTITLE	(17)	TITLE	(10)	NRUN	(1)	NPAGE	(1)
		DTOUT	(1)	LINE	(1)	MO	(1)
		IDAY	(1)	IYEAR	(1)		
BUPDAT	(36)	ALFA	(1)	KOPT	(34)	MTYPE	(1)

SECTION 5

FORTRAN VARIABLES

Table 6 presents definitions of all principal Fortran variables used in Program NATNAV. Where appropriate, mathematical definitions are also indicated (see Ref. 1). The units of each variable are those used internally by NATNAV, and occasionally differ from the input units. The points of definition of each variable are enclosed in the brackets.

The error covariance matrix P is a 34 × 34 symmetric matrix; hence it contains only 585 independent elements which must be calculated by numerical integration. These elements are contained in the array S. To further reduce the number of differential equations to be integrated, the array S contains only the covariances of those errors which are specifically requested by the input. The correspondence is established by subroutines CONFIG and EQNS via the index array KK. The arrays II and JJ are used to decode an entry in KK to obtain the appropriate row and column of P. Table 7 depicts this relationship.

<u>Example:</u> If KK(70) = 99, then from Table 6A, II(99) = 7 and JJ(99) = 18. Therefore, S(70) = P(7,18) = cross-covariance between longitude rate error, $\dot{\ell}$, and azimuth gyro torquer scale factor error, τ_z.

Table 6. Definitions of Principal Fortran Variables in Program NATNAV.

A	=	local speed of sound, ft/min [A]
ACCEL	=	.TRUE. for accelerometer measurement uncertainties [input card 5]
AKAP	=	κ = inertial altitude weighting parameter [input card 7]
AL1	=	$\dot{\ell}(\dot{\lambda} + \omega_{ie})$, rad^2/min^2 [INS]
ALAT	=	L = terrestrial latitude, rad [FLTPLN]
ALON	=	ℓ = terrestrial longitude, rad [FLTPLN]
ALAT2	=	2L, rad [FLTPLN]
ALATD	=	L = terrestrial latitude, deg [SUBOUT]
ALOND	=	ℓ = terrestrial longitude, deg [SUBOUT]
ALATR	=	$\dot{L}$ = terrestrial latitude rate, rad/min [FLTPLN]
ALONR	=	$\dot{\ell}$ = terrestrial longitude rate, rad/min [FLTPLN]
ALB	=	λ = celestial longitude, rad [FLTPLN]
ALBDOT	=	$\dot{\lambda} = \dot{\ell} + \omega_{ie}$ = celestial longitude rate, rad/min [FLTPLN]
ALFA	=	$\alpha = h^T P h + R$ [ALIGN,DOPLR,OMEG,SATR]
ALPHA	=	$\theta - \chi$, rad [FLTPLN]
ALT	=	h = altitude, ft [EARTH]
ALTSF	=	.TRUE. for altimeter scale factor [input card 5]
AX,AY	=	coordinate of lower left corner of first character with respect to previously defined origin for plotting routine, in [PLOTER]
AXLEN, AYLEN	=	lengths of x and y axes for plotting routine, in [PLOTER]
AZA,AZB	=	azimuth to Omega stations, rad [OMEG]
C	=	latitude sensitivity factor for gravitational acceleration [EARTH]
C11,C12, ... C33	=	elements of I.N.S. transformation matrix [INS]

Table 6. (Continued).

CH2	=	$\cos^2 \chi$ [SUBOUT]
CHDG	=	$\cos \psi$ [INS]
CL	=	cos L [INS]
CL2	=	cos 2L [INS]
CLB	=	$\cos \lambda$ [INS]
CLI	=	1/cos L [INS]
CLL	=	$\cos^2 L$ [SUBOUT]
CLOM(I)	=	cosine of the i^{th} Omega station latitude [OMEG]
CPTIME	=	computer time, sec [NATNAV]
CRB	=	δ = wind crab angle, rad [FLTPLN]
CRSAT(I)	=	distance of i^{th} satellite from earth's axis, ft [SATR]
CTRK	=	$\cos \chi$ [INS]
DALT	=	σ of altitude error, ft [SUBOUT]
DEGPRD	=	conversion factor, 57.29578 deg/rad [SUBOUT]
DHØ	=	initial σ of altitude error, ft [input card 8]
DLA2	=	variance of latitude error, rad^2 [SUBOUT]
DLAØ, DLOØ	=	initial σ's of latitude and longitude error, rad [input card 8]
DLAT	=	latitude difference between waypoints, rad [FLTPLN]
DLON	=	longitude difference between waypoints, rad [FLTPLN] longitude difference to satellite, rad [SATR]
DLØ2	=	variance of longitude error, rad^2 [SUBOUT]
DOPLER	=	.TRUE. for Doppler measurements [input card 5]
DREKON	=	.TRUE. for dead reckoning option [input card 5]
DT	=	integration step-size, min [NATNAV]

Table 6. (Continued).

DT1	=	maximum integration step-size, min [input card 2]
DTØ5	=	DT/2, min [FLTPLN]
DTA	=	I.N.S. alignment time, min [input card 3]
DTDOP	=	interval between Doppler updates, min [input card 19]
DTOM	=	interval between Omega updates, min [input card 21]
DTOUT	=	normal printout interval, min [input card 2]
DTPLOT	=	plot output interval, min [input card 2]
DTSAT	=	interval between satellite ranging updates, min [input card 23]
DTT	=	taxi time, min [input card 3]
DVD	=	σ of altitude rate error, ft/min [SUBOUT]
DVE2	=	variance of latitude rate error, rad/min [SUBOUT]
DVN2	=	variance of longitude rate error, rad/min [SUBOUT]
DVX,DVY	=	increments for tick mark annotation of abscissa and ordinate [PLOTER]
DX,DY	=	distance between tick marks of abscissa and ordinate, in [PLOTER]
DX,DY,DZ	=	correlation distances for geodetic uncertainties, nm [input card 15]
	=	inverse of above, 1/ft [INS]
DXDOT	=	σ of along-track velocity error, nm [SUBOUT]
DYDOT	=	σ of cross-track velocity error, nm [SUBOUT]
DVWN, DVWE	=	correlation distances of wind uncertainties for dead-reckoning, nm [input card 6]
	=	inverse of above, 1/ft [INS]
EDØ,EEØ, ENØ	=	initial σ's of platform north, east and down misalignment angles, rad [input card 8]
ED,EE,EN	=	σ's of platform misalignment angles, arc-min [SUBOUT]
F	=	flattening of reference earth ellipsoid [EARTH]

Table 6. (Continued).

F12, ... F98	=	elements of inertial navigation system matrix [INS]
FD, FE, FN	=	specific force components, ft/min^2 [INS]
FTPMS	=	conversion factor, 983.567 ft/msec [SATR]
FTPNM	=	conversion factor, 6076.12 ft/nm [NATNAV]
G	=	gravitational acceleration, ft/min^2 [EARTH]
GE	=	equitorial gravitational acceleration, ft/min^2 [EARTH]
GRAVD	=	.TRUE. for geodetic uncertainties [input card 5]
GYROS	=	.TRUE. for gyro drift uncertainties [input card 6]
H	=	h = altitude of aircraft, ft [FLTPLN]
H3, ... H8 H22, ... H26	=	elements of measurement geometry vector [ALIGN, DOPLR, OMEG, SATR]
HØ	=	h_0 = airport elevation, ft [input card 3]
HCR	=	h_{cr} = aircraft cruise altitude, ft [input card 3]
HDG	=	ψ = heading angle of aircraft, rad [FLTPLN]
HDOT	=	$\dot{h}$ = altitude rate, ft/min [FLTPLN]
HSAT(I)	=	altitude of the i^{th} satellite, ft [SATR]
HSYNCH	=	altitude for synchronous satellite, ft [SATR]
IDAY, MONTH, IYEAR	=	date of computer run [NATNAV]
II, JJ, KK	=	indices relating elements of covariance matrix to differential equations [EQNS]
INIT	=	.TRUE. if program is in initialization phase [NATNAV]
INS9	=	.TRUE. for 9-state I.N.S. model [SUBIN] .FALSE. for 7-state I.N.S. model

Table 6. (Continued).

IOM1, IOM2	=	Omega stations for 1st L.O.P. measurement [input card 20]
IOM3, IOM4	=	Omega stations for 2nd L.O.P. measurement [input card 20]
ISYS	=	type of inertial navigation system: [input card 7] 1 = space stabilized; 2 = local level; 3 = free azimuth; 4 = strapdown; 5 = rotating azimuth; 6 = unipolar; 7 = wander azimuth
KOPT	=	optimum filter gains for covariance update [ALIGN,DOPLR, OMEG,SATR]
KSUB	=	suboptimum filter gains for covariance update [UPDATE]
KSUBØ1, KSUBØ2	=	histories of suboptimum filter gains for Omega updates [input cards 36-45]
KSUBDF, KSUBDS	=	histories of suboptimum filter gains for Doppler updates [input cards 26-35]
KSUBS1, KSUBS2	=	histories of suboptimum filter gains for satellite ranging updates [input cards 46-55]
LAT(I)	=	latitude of i^{th} waypoint, rad [input card 4]
LINE	=	count of printout lines for each page [NATNAV,SUBIN,SUBOUT]
LON(I)	=	longitude of i^{th} waypoint, rad [input card 4]
MCR	=	aircraft cruise Mach number [input card 3]
MEAS	=	index for subroutine SUBOUT to determine printout format [NATNAV]
MINPRD	=	conversion factor, 3437.747 arc-min/rad [NATNAV]
MM	=	logical unit number for printout [NATNAV]
MPLOT	=	number of runs to be plotted in a job [NATNAV]
MTYPE	=	index for UPDATE to indicate type of measurement [ALIGN, DOPLR,OMEG,SATR]

Table 6. (Continued).

MU	=	flag to indicate climb (1) or cruise (0) phase during initialization [FLTPLN]
NEQ	=	number of differential equations to be integrated for covariance matrix propagation [EQNS]
NK	=	number of points in suboptimal filter gain histories (NK $\leq$ 20) [input card 24]
NMPFT	=	conversion factor, 1.64579×10^{-4} nm/ft [NATNAV]
NN	=	logical unit number for input [NATNAV]
NPAGE	=	count of number of printout pages [NATNAV, SUBIN, SUBOUT]
NPHASE	=	index to current phase of flight: 0 = I.N.S. alignment [FLTPLN] 1 = taxi 2 = climbout 3 = cruise 4 = end of flight
NPLOT	=	number of points in plot arrays [NATNAV, SUBOUT]
NPTS	=	number of points in plot arrays [PLOTER]
NRUN	=	run number [input card 2]
NTAPE	=	magnetic tape used to store data for plotting [NATNAV]
NWPTS	=	number of waypoints in flight plan [input card 3]
OMEGA	=	.TRUE. for Omega measurements [input card 5]
OMIE	=	ω_{ie} = earth angular velocity, rad/min [FLTPLN]
OMIPNX, OMIPNY, OMIPNZ	=	rotation rate of platform coordinates relative to inertial space [INS]
OMLAT(I), OMLON(I)	=	latitude and longitude coordinates of i^{th} Omega station, rad [OMEG]
OMS2	=	ω_s^2 = square of Schuler frequency, $(\text{rad/min})^2$ [INS]
P	=	error covariance matrix [multiple programs]

Table 6. (Continued).

PGAINS	=	flag to cause printout of optimum filter gains at completion of run; no printout if PGAINS = 0 [SUBIN]
PHIDOT	=	$\dot{\phi}$ = azimuth rotation rate of I.N.S., rad/min [input card 7, INS]
PHVEL	=	phase velocity of Omega signals, ft/μsec [OMEG]
LTAPE	=	plot output tape [PLOTER]
PLTARRAY	=	buffer array for plot routines [PLOTER]
PSI	=	ψ = platform rotation angle, rad [INS]
PSIDOT	=	$\dot{\psi}$ = platform rotation rate, rad/min [INS]
QDF,QDS	=	driving noises for exponentially correlated Doppler measurement errors, ft^2/min^3 [DOPLR]
QOM1, QOM2	=	driving noises for exponentially correlated Omega measurement errors, $\mu sec^2/min$ [OMEG]
QSAT1, QSAT2	=	driving noises for exponentially correlated satellite ranging measurement errors, ft^2/min [SATR]
QUIT	=	.TRUE. if last run has been processed [SUBIN]
QVAX, QVAY, QVAZ	=	driving noises for exponentially correlated accelerometer errors, ft^2/min^5 [INS]
QVGX, QVGY, QVGZ	=	driving noises for exponentially correlated gyro drift errors, rad^2/min^3 [INS]
QVX,QVY, QVZ	=	driving noises for exponentially correlated geodetic errors, ft^2/min^5 [INS]
QWAX, QWAY, QWAZ	=	strength of white accelerometer measurement uncertainties, ft^2/min^3 [input cards 12, 13]
QWAX, QWAY	=	driving noises for exponentially correlated winds (dead-reckoning option), ft^2/min^3 [INS]

Table 6. (Continued).

QWGX, QWGY, QWGZ	=	strength of white gyro drift noises, rad^2/min [input cards 10,11]
QWH	=	variance of altimeter random error, ft^2 [INS]
R	=	r = geocentric radius to aircraft, ft [FLTPLN]
RADPDG	=	conversion factor, 0.01745329 rad/deg [NATNAV]
RALIN1, RALIN2	=	variances of alignment noises, $(ft/min)^2$ [ALIGN]
RC	=	aircraft rate of climb, ft/min [input card 3]
RCL	=	r cos L, ft [INS]
RDF, RDS	=	variances of random Doppler measurement errors, $(ft/min)^2$ [DOPLR]
RDHØ	=	initial σ of altitude rate error, ft/min [input card 9]
RDLAØ, RDLOØ	=	initial σ's of latitude and longitude rate errors, rad/min [input card 8]
RE	=	equatorial radius of earth, ft [EARTH]
RI	=	$1/r$, ft^{-1} [INS]
RI2	=	$1/r^2$, ft^{-2} [INS]
RICLI	=	$1/(r \cos L)$, ft^{-1} [INS]
RNM	=	geocentric radius to aircraft, nm [SUBOUT]
ROM1, ROM2	=	variances of random Omega measurement noises, μsec^2 [OMEG]
RPSN	=	line-of-sight vector to satellite, ft [SATR]
RSAT1, RSAT2	=	variances of random satellite ranging measurement noises, ft^2 [SATR]
RSYNCH	=	geocentric radius to synchronous satellite, ft [SATR]
S	=	array of independent terms of covariance matrix [EQNS,RKUTTA UPDATE]

Table 6. (Continued).

SALIN1, SALIN2	=	σ's of alignment random errors, ft/min [input card 16]
SALT	=	σ of altimeter random noise, ft [input card 17]
SALTD	=	σ of altitude rate random noise, ft/min [input card 17]
SATLON(I)	=	longitude coordinate of i^{th} satellite, rad [input card 22]
SATRNG	=	.TRUE. for satellite ranging measurements [input card 5]
SAX,SAY, SAZ	=	initial σ's of accelerometer measurement uncertainties, ft/min^2 [input card 12]
SBDF,SBDS	=	σ's of forward and side Doppler scale factor errors [input card 18]
SBOM1, SBOM2	=	σ's of 1st and 2nd Omega L.O.P. bias measurement errors, μsec [input card 20]
SBSAT1, SBSAT2	=	σ's of satellite ranging biases, ft [input card 22]
SD	=	derivative of S [DIFEQ]
SGX,SGY, SGZ	=	initial σ's of exponentially-correlated gyro drift rates, rad/min [input card 10]
SH2	=	$\sin^2 x$ [SUBOUT]
SHDG	=	$\sin \psi$ [INS]
SL	=	sin L [INS]
SL2	=	sin 2L [INS]
SLOM(I)	=	sine of i^{th} Omega station latitude [OMEG]
SNDF, SNDS	=	σ's of forward and side Doppler correlated noises, ft/min [input card 18]
SNOM1, SNOM2	=	σ's of 1st and 2nd Omega L.O.P. correlated measurement errors, μsec [input card 20]
SNSAT1, SNSAT2	=	σ's of satellite ranging correlated noise, ft [input card 22]

Table 6. (Continued).

SRDF,SRDS	=	σ's of Doppler forward and side random measurement noises, ft/min [input card 18]
SROM1, SROM2	=	σ's of 1st and 2nd Omega L.O.P. random measurement noises, μsec [input card 21]
SRSAT(I)	=	distance of i^{th} satellite north of equator, ft [SATR]
SRSAT1, SRSAT2	=	σ's of satellite ranging random measurement noises, ft [input card 23]
STAT	=	Hollerith array for printout of OMEGA stations [SUBIN]
STRK	=	sin χ [INS]
SUBOPT	=	.TRUE. for suboptimum filtering [input card 5]
SVWE, SVWN	=	σ's of correlated wind uncertainties (dead-reckoning option), ft/min [input card 6]
SVX,SVY, SVZ	=	initial σ's of geodetic uncertainties, ft/min^2 [input card 15]
T,TIME	=	t = elapsed time, min [NATNAV,RKUTTA]
TAUH	=	σ of altimeter scale factor error [input card 17]
TAUHD	=	σ of altitude rate scale factor error, [input card 17]
TAUX, TAUY, TAUZ	=	σ's of gyro torquer scale factor errors [input card 14]
TAX,TAY, TAZ	=	correlation times for accelerometer measurement uncertainties, min [input card 12]
TBLUND	=	time at which blunder/malfunction occurs, min [input card 24]
TCR	=	time at which cruise phase begins, min [FLTPLN]
TDF,TDS	=	correlation times for forward and sidewise Doppler measurement errors, min [input card 18]
TF	=	time at final waypoint, min [NATNAV]
TGX,TGY, TGZ	=	gyro drift correlation times, min [input card 10]

Table 6. (Continued).

THETAW(I)	=	wind direction at i^{th} waypoint, rad [input card 4]
THW	=	θ = current wind direction, rad [FLTPLN]
TIMEH, TIMEM	=	time in hours and minutes [SUBOUT]
TITLE	=	output heading [input card 1]
TL	=	tan L [INS]
TM(I)	=	arrival time at i^{th} waypoint, min [FLTPLN]
TOM1, TOM2	=	correlation times for 1st and 2nd Omega L.O.P. measurement errors, min [input card 20]
TORQ	=	.TRUE. for gyro torque scale factor errors [input card 5]
TOS	=	Hollerith array for printout of type of I.N.S. [SUBIN]
TPSI	=	time of previous platform rotation update, min [INS]
TRK	=	χ = aircraft track angle, rad [FLTPLN]
TSAT1, TSAT2	=	correlation time of satellite ranging measurement errors, min [input card 22]
TSUBK	=	times at which suboptimum filter gains are stores; min [input card 25]
TWOACC	=	.TRUE. for 2-accelerometer case [input card 7]
	=	.FALSE. for 3-accelerometer case
VA	=	current airspeed, ft/min [FLTPLN]
VCL	=	airspeed during climbout, ft/min [input card 3]
VCR	=	airspeed during cruise, ft/min [FLTPLN]
VE(I),VN(I)	=	easterly and northerly groundspeed components out of i^{th} waypoint, ft/min [FLTPLN]
VELE,VELN	=	current east and north groundspeed components, ft/min [FLTPLN]
VELW	=	current wind speed, ft/min [FLTPLN]

Table 6. (Continued).

VFWD, VSIDE	=	forward and side components of groundspeed, ft/min [DOPLR]
VG	=	current groundspeed, ft/min [FLTPLN]
VW(I)	=	wind speed at i^{th} waypoint, ft/min [input card 4]
WX, WY, WZ	=	gyro torquing rates, rad/min [INS]
X(400), Y(400)	=	arrays for storage of data to be plotted [PLOTER]
XK(20,34,6)	=	suboptimum filter gain histories [UPDATE]
XX, XY	=	σ's of along-track and cross-track position errors, nm [SUBOUT]

Table 7. Correspondence of Elements of Index Array KK to Row and Column of Covariance Matrix P.

		INS Errors									Gyro Drifts			Accelerometer Uncertainties			Gyro Torquer Errors			Geodetic Uncertainties			Altimeter Scale Factor	Doppler Measurement Errors				Omega Measurement Errors				Satellite Ranging Errors			
II(KK)	JJ(KK)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
		ϵ_N	ϵ_E	ϵ_D	δL	$\delta \ell$	$\delta \dot{L}$	$\delta \dot{\ell}$	δh_i	$\delta \dot{h}_i$	δ_x	δ_y	δ_z	α_x	α_y	α_z	τ_x	τ_y	τ_z	ξg	ηg	Δg	τ_h	b_{df}	n_{df}	b_{ds}	n_{ds}	$b_{\Omega 1}$	$n_{\Omega 2}$	$b_{\Omega 2}$	$n_{\Omega 2}$	b_{s1}	n_{s1}	b_{s1}	n_{s2}
1	ϵ_N	1	2	3	4	5	6	7	456	457	29	30	31	56	57	479	79	80	81	133	134	510	118	168	169	170	171	248	249	250	251	344	345	346	347
2	ϵ_E		8	9	10	11	12	13	458	459	32	33	34	58	59	480	82	83	84	135	136	511	119	172	173	174	175	252	253	254	255	348	349	350	351
3	ϵ_D			14	15	16	17	18	460	461	35	36	37	60	61	481	85	86	87	137	138	512	120	176	177	178	179	256	257	258	259	352	353	354	355
4	δL				19	20	21	22	462	463	38	39	40	62	63	482	88	89	90	139	140	513	121	180	181	182	183	260	261	262	263	356	357	358	359
5	$\delta \ell$					23	24	25	464	465	41	42	43	64	65	483	91	92	93	141	142	514	122	184	185	186	187	264	265	266	267	360	361	362	363
6	$\delta \dot{L}$						26	27	466	467	44	45	46	66	67	484	94	95	96	143	144	515	123	188	189	190	191	268	269	270	271	364	365	366	367
7	$\delta \dot{\ell}$							28	468	469	47	48	49	68	69	485	97	98	99	145	146	516	124	192	193	194	195	272	273	274	275	368	369	370	371
8	δh_i								470	471	473	474	475	486	487	488	498	499	500	517	518	519	507	538	539	540	541	554	555	556	557	570	571	572	573
9	$\delta \dot{h}_i$									472	476	477	478	489	490	491	501	502	503	520	521	522	508	542	543	544	545	558	559	560	561	574	575	576	577
10	δ_x										50	51	52	73	74	495	103	104	105	150	151	526	125	204	205	206	207	284	285	286	287	380	381	382	383
11	δ_y											53	54	75	76	496	106	107	108	152	153	527	126	208	209	210	211	288	289	290	291	384	385	386	387
12	δ_z												55	77	78	497	109	110	111	154	155	528	127	212	213	214	215	292	293	294	295	388	389	390	391
13	α_x													70	71	492	112	113	114	156	157	529	128	216	217	218	219	296	297	298	299	392	393	394	395
14	α_y														72	493	115	116	117	158	159	530	129	220	221	222	223	300	301	302	303	396	397	398	399
15	α_z															494	504	505	506	531	532	533	509	546	547	548	549	562	563	564	565	578	579	580	581
16	τ_x																0	100	101	160	161	534	130	224	225	226	227	304	305	306	307	400	401	402	403
17	τ_y																	0	102	162	163	535	131	228	229	230	231	308	309	310	311	404	405	406	407
18	τ_z																		0	164	165	536	132	232	233	234	235	312	313	314	315	408	409	410	411
19	ξg																			147	148	523	166	240	241	242	243	320	321	322	323	416	417	418	419
20	ηg																				149	524	167	244	245	246	247	324	325	326	327	420	421	422	423
21	Δg																					525	537	550	551	552	553	566	567	568	569	582	583	584	585
22	τ_h																						0	236	237	238	239	316	317	318	319	412	413	414	415
23	b_{df}																							0	196	197	198	328	329	330	331	424	425	426	427
24	n_{df}																								199	200	201	332	333	334	335	428	429	430	431
25	b_{ds}																									0	202	336	337	338	339	432	433	434	435
26	n_{ds}																										203	340	341	342	343	436	437	438	439
27	$b_{\Omega 1}$																											0	276	277	278	440	441	442	443
28	$n_{\Omega 1}$																												279	280	281	444	445	446	447
29	$b_{\Omega 2}$																													0	282	448	449	450	451
30	$n_{\Omega 2}$																														283	452	453	454	455
31	b_{s1}																															0	372	373	374
32	n_{s1}																																375	376	377
33	b_{s2}																																	0	378
34	n_{s2}																																		379

Example: $KK(70) = 99 \longrightarrow \begin{cases} II(99) = 7 \\ JJ(99) = 18 \end{cases}$

$\therefore S(70) = P(7,18) = P(18,7)$

$= \langle \delta \dot{\ell} \; \tau_z \rangle$

SECTION 6

HARDWARE REQUIREMENTS

Program NATNAV requires approximately $26,000_{10}$ ($62,000_8$) words of core to operate on the CDC 3800 computer (word length = 48 bits). Although this is not an excessively large requirement, it could be reduced more than 30 percent by using program overlays. The core requirements, including library and system routines, are summarized in Table 8; the lengths of the NATNAV programs are those obtained with the * option (fast execution) of the CDC-3800 FORTRAN compiler (Ref. 2).

Other hardware requirements include standard system peripherals: card reader, line printer, up to three magnetic tapes (maximum) or disc, and a plotter. The logical unit assignments are summarized in Table 9. Normally, the disc file is used instead of assigning actual magnetic tapes.

Table 8. Program NATNAV Core Requirements.

Routine	Length (48-bit words) Octal	Decimal
NATNAV	1,111	585
SUBIN	4,575	2,429
SUBOUT	707	455
CONFIG	663	435
EQNS	110	72
FLTPLN	656	430
EARTH	72	58
A	62	50
INS	703	451
ALIGN	61	49
DOPLR	256	174
OMEG	330	216
SATR	261	177
UPDATE	416	270
RKUTTA	4,627	2,455
DIFEQ	132	90
T	436	286
GQG	553	363
BLUNDR	24	20
PLOTER	3,216	1,678
	24,767	10,743
BLOCK COMMON	20,683	8,603
Library Routines	5,226	2,710
System Routines	7,105	3,653
Total	61,671	25,709

Table 9. Logical Unit Assignments.

Logical Unit	Corresponding FORTRAN Variable or Logical Unit Number	Remarks
Card Reader	NN (60)	Standard card input; Logical Unit Number assigned in Data Statement in NATNAV.
Printer	MM (61)	Standard printout; Logical Unit Number assigned in Data Statement in NATNAV.
Magnetic Tape	NTAPE (49)	Read/write tape used if Plotting Option is chosen. Logical Unit Number assigned in Data Statement in NATNAV.
Magnetic Tape	7	Read/write tape used if printout of optimum gains option is desired.
Magnetic Tape	LTAPE (5)	Plot output tape used if plotting option is chosen. Logical Unit Number assigned in Data Statement in PLOTER

SECTION 7

NATNAV INPUT DESCRIPTION

All NATNAV data input is accomplished via punched cards. The input variables, their units, and the required formats are presented in Table 10. Where appropriate, typical input values are also given. Some inputs may require more than one card, e.g. card 4. Other cards may or may not be required, depending upon the options selected by the user.

A sample data deck is shown in Table 11. This data is the nominal Boston to Shannon flight, with Omega updates every 15 minutes; the output of this run is presented in Section 8.

Table 10. NATNAV Input Structure.

COLUMNS	QUANTITY	FORMAT	TYPICAL VALUE
	Card 1: Mandatory		
1 - 80	TITLE = Title of run	10A8	
	Card 2: Mandatory		
11 - 20	DT = maximum integration step size [min]	E10.1	1.0
21 - 30	DTOUT = printout interval [min] (if DTOUT < 0, optimum gains will be printed)	E10.1	5.0
31 - 40	DTPLOT = plot output interval (no plot if DTOUT = 0.0)	E10.1	5.0
41 - 42	NRUN = run number	I2	
	Card 3: Mandatory		
1 - 2	NWPTS = number of waypoints (≤ 20)	I2	
11 - 20	DTA = I.N.S. alignment time [min]	E10.2	15.0
21 - 30	DTT = taxi time [min]	E10.2	5.0
31 - 40	HØ = airport elevation [ft]	E10.2	
41 - 50	VCL = A/C climb speed [kt]	E10.2	280.0
51 - 60	RC = A/C rate of climb [ft/min]	E10.2	1,500.0
61 - 70	MCR = cruise Mach number	E10.2	0.82
71 - 80	HCR = cruise altitude [ft]	E10.2	35,000.0

Table 10. (Continued).

COLUMNS	QUANTITY	FORMAT	TYPICAL VALUE
	<u>Card 4:</u> Mandatory (I = 1,NWPTS)		
	Card 4 is repeated for each waypoint in the flight plan, and may require up to 20 cards depending on the value of NWPTS.		
1 - 10	LAT(I) = latitude at waypoint I [deg]	E10.2	
11 - 20	LON(I) = longitude at waypoint I [deg]	E10.2	
21 - 30	VW(I) = wind direction at waypoint I [deg]	E10.2	
31 - 40	THETAW(I) = wind speed at waypoint I [kt]	E10.2	
	<u>Card 5:</u> Mandatory		
1 - 5	GYROS = 1 (TRUE) if using gyro drift uncertainty option	L5	1
6 - 20	ACCEL = 1 (TRUE) if using accelerometer uncertainty option	L5	1
11 - 15	TORQ = 1 (TRUE) if using gyro torquer error option	L5	1
16 - 20	GRAVD = 1 (TRUE) if using geodetic uncertainty option	L5	1
21 - 25	ALTSF = 1 (TRUE) if using altimeter uncertainty option	L5	1

Table 10. (Continued).

COLUMNS	QUANTITY	FORMAT	TYPICAL VALUE
	Card 5: (Cont.)		
26 - 30	SUBOPT = 1 (TRUE) if using sub-optimum filtering option	L5	0
31 - 35	DOPLER = 1 (TRUE) if using Doppler update option	L5	
36 - 40	OMEGA = 1 (TRUE) if using Omega update option	L5	
41 - 45	SATRNG = 1 (TRUE) if using satellite ranging option	L5	
46 - 50	DREKON = 1 (TRUE) if using dead reckoning option	L5	0
	Card 6: Reguired if DREKON = TRUE		
1 - 10	SVWN = standard deviation of wind, north [kt]	E10.3	15.0
11 - 20	SVWE = standard deviation of wind, east [kt]	E10.3	15.0
21 - 30	DVWN = correlation distance of wind, north [nm]	E10.3	800.0
31 - 40	DVWE = correlation distance of wind, east [nm]	E10.3	800.0

Table 10. (Continued).

COLUMNS	QUANTITY	FORMAT	TYPICAL VALUE
	Card 7: Required if DREKON = FALSE		
1	ISYS = I.N.S. system type	I1	6
11 - 20	TWOACC = { 1 (TRUE) for 2-accelerometer case; Ø (FALSE) for 3-accelerometer case	L10	1
21 - 30	PHIDOT = azimuth rotation rate [rpm] (if ISYS = 5)	E10.3	1.0
31 - 40	AKAP = inertial altitude weighting parameter (if TWOACC = FALSE)	E10.3	3.0
	Card 8: Mandatory		
1 - 10	ENØ = initial platform tilt angle, north [arc-min]	E10.2	60.0
11 - 20	EEØ = initial platform tilt angle, east [arc-min]	E10.2	60.0
21 - 30	EDØ = initial platform tilt angle, down [arc-min]	E10.2	300.0
31 - 40	DLAØ = initial position error, latitude [arc-min]	E10.2	0.2
41 - 50	DLOØ = initial position error, longitude [arc-min]	E10.2	0.2
51 - 60	DHØ = initial position error, altitude [ft]	E10.2	2.0

Table 10. (Continued).

COLUMNS	QUANTITY	FORMAT	TYPICAL VALUE
	Card 8: (Cont.)		
61 - 70	RDLAØ = initial rate error, latitude [arc-min/min]	E10.2	0.0
71 - 80	RDLOØ = initial rate error, longitude [arc-min/min]	E10.2	0.0
	Card 9: Mandatory		
1 - 10	RDHØ = initial rate error, altitude [ft/min]	E10.2	0.0
	Card 10: Required if GYROS = TRUE		
1 - 10	TGX = } Correlation times of correlated noise for gyro drift uncertainties in x, y and z direction [min]	E10.2	120.0
11 - 20	TGY =	E10.2	120.0
21 - 30	TGZ =	E10.2	120.0
31 - 40	SGX = } Standard deviation of correlated noise in x, y and z direction [arc-min/hr]	E10.2	0.753
41 - 50	SGY =	E10.2	0.753
51 - 60	SGZ =	E10.2	4.630
61 - 70	QWGX = } Strength of random noise for gyro drift uncertainties in x and y direction [arc-min^2/hr]	E10.2	3.24×10^{-4}
71 - 80	QWGY =	E10.2	3.24×10^{-4}

Table 10. (Continued).

COLUMNS	QUANTITY	FORMAT	TYPICAL VALUE
	Card 11: Required if GYROS = TRUE		
1 - 10	QWGZ = strength of random noise in z direction [arc-min^2/hr]	E10.2	3.24×10^{-4}
	Card 12: Required if ACCEL = TRUE		
1 - 10	TAX = } Correlation time of correlated noise of accelerometer uncertainties in x, y and z directions [min]	E10.2	40.0
11 - 20	TAY =	E10.2	40.0
21 - 30	TAZ =	E10.2	240.0
31 - 40	SAX = } Standard deviation of correlated noise of accelerometer uncertainies in x, y and z directions [g]	E10.2	1.0×10^{-4}
41 - 50	SAY =	E10.2	1.0×10^{-4}
51 - 60	SAZ =	E10.2	9.2×10^{-4}
61 - 70	QWAX = } Strength of random noise of accelerometer uncertainties in x and y direction [ft^2/sec^3]	E10.2	0.0
71 - 80	QWAY	E10.2	0.0
	Card 13: Required if ACCEL = TRUE		
1 - 10	QWAZ = strength of random noise of accelerometer uncertainties in z direction [ft^2/sec^3]	E10.2	0.0

Table 10. (Continued).

COLUMNS	QUANTITY		FORMAT	TYPICAL VALUE
	Card 14:	Required if TORQ = TRUE		
1 - 10	TAUX =	Standard deviation of torquer errors in x, y and z directions [%]	E10.4	0.05
11 - 20	TAUY =		E10.4	0.05
21 - 30	TAUZ =		E10.4	0.05
	Card 15:	Required if GRAVD = TRUE		
1 - 10	SVX =	Standard deviation of geodetic uncertainties in x, y and z directions [g]	E10.2	2.4×10^{-5}
11 - 20	SVY =		E10.2	2.4×10^{-5}
21 - 30	SVZ =		E10.2	2.4×10^{-5}
31 - 40	DX =	Correlation distances of geodetic uncertainties in x, y and z directions [g]	E10.2	20.0
41 - 50	DY =		E10.2	20.0
51 - 60	DZ =		E10.2	20.0
	Card 16:	Required if DTA $\neq \emptyset$		
1 - 10	SALIN1 =	Standard deviation of alignment random errors [kt]	E10.2	0.0222
11 - 20	SALIN2 =		E10.2	0.0222

Table 10. (Continued).

COLUMNS	QUANTITY	FORMAT	TYPICAL VALUE
	Card 17: Required if ALTSF = TRUE		
1 - 10	TAUH = standard deviation of altimeter scale factor error [%]	E10.2	0.3
11 - 20	SALT = standard deviation of altimeter random error [ft]	E10.2	10.0
21 - 30	TAUHD = standard deviation of V.S.I. scale factor error [%]	E10.2	5.0
31 - 40	SALTD = standard deviation of V.S.I. random error [ft/min]	E10.2	50.0
	Card 18: Required if DOPLER = TRUE		
1 - 10	TDF = } Correlation time of correlated noise for forward and	E10.3	5.0
11 - 20	TDS = } sidewise velocity [min]	E10.3	5.0
21 - 30	SNDF = } Standard deviation of correlated noise for forward	E10.3	0.5
31 - 40	SNDS = } and sidewise velocity [kt]	E10.3	0.5
41 - 50	SBDF = } Standard deviation of scale factor errors for forward	E10.3	0.25
51 - 60	SBDS = } and sidewise velocity [%]	E10.3	0.25
61 - 70	SRDF = } Standard deviation of random errors for forward	E10.3	0.1
71 - 80	SRDS = } and sidewise velocity [kt]	E10.3	0.1

Table 10. (Continued).

COLUMNS	QUANTITY		FORMAT	TYPICAL VALUE
	<u>Card 19:</u>	Required if DOPLER = TRUE		
1 - 10	DTDOP = interval between Doppler measurements [min]		E10.3	10.0
	<u>Card 20:</u>	Required if OMEGA = TRUE		
1	IOM1 =	Indices of Omega stations for first line of position (L.O.P.)	I1	2
6	IOM2 =		I1	4
11	IOM3 =	Indices of Omega stations for second L.O.P.	I1	1
16	IOM4 =		I1	4
21 - 30	TOM1 =	Correlation times for correlated noise for first and second L.O.P. [min]	E10.3	30.0
31 - 40	TOM2 =		E10.3	30.0
41 - 50	SNOM1 =	Standard deviation of correlated noise for first and second L.O.P. [μsec]	E10.3	5.0
51 - 60	SNOM2 =		E10.3	10.0
61 - 70	SBOM1 =	Standard deviation of bias errors for first and second L.O.P. [μsec]	E10.3	1.0
71 - 80	SBOM2 =		E10.3	1.0

Table 10. (Continued).

COLUMNS	QUANTITY	FORMAT	TYPICAL VALUE
	Card 21: Required if OMEGA = TRUE		
1 - 10	SROM1 = } Standard deviation of random errors for first and second L.O.P. [μsec]	E10.3	0.5
11 - 20	SROM2 =	E10.3	0.5
21 - 30	DTOM = interval between Omega measurements [min]	E10.3	15.0
	Card 22: Required if SATRNG = TRUE		
1 - 10	SATLON(1) = } Longitude of satellites 1 and 2 [deg]	E10.2	- 10.0
11 - 20	SATLON(2) =	E10.2	- 70.0
21 - 30	TSAT1 = } Correlation times of correlated noise for satellites 1 and 2 [min]	E10.2	10.0
31 - 40	TSAT2 =	E10.2	10.0
41 - 50	SNSAT1 = } Standard deviation of correlated noise for satellites 1 and 2 [μsec]	E10.2	0.2
51 - 60	SNSAT2 =	E10.2	0.2
61 - 70	SBSAT1 = } Standard deviation of bias errors for satellites 1 and 2 [μsec]	E10.2	0.1
71 - 80	SBSAT2 =	E10.2	0.1

Table 10. (Continued).

COLUMNS	QUANTITY	FORMAT	TYPICAL VALUE
	<u>Card 23:</u> Required if SATRNG = TRUE		
1 - 10	SRSAT1 = Standard deviation of random errors for	E10.2	0.1
11 - 20	SRSAT2 = satellites 1 and 2 [μsec]	E10.2	0.1
21 - 30	DTSAT = interval between satellite ranging measurements [min]	E10.2	20.0
	<u>Card 24:</u> Required if SUBOPT = TRUE		
1 - 2	NK = number of points in suboptimal filter history (NK ≤ 20)	I2	
11 - 20	TBLUND = time at which a blunder/ malfunction occurs [min]	E10.2	
	<u>Card 25:</u> Required if SUBOPT = TRUE		
1 - 80	TSUBK(I) = times corresponding to suboptimal gain points [min], I = 1,NK	8E10.2	

Table 10. (Continued).

COLUMNS	QUANTITY	FORMAT	TYPICAL VALUE
	Cards 26 - 35 are repeated as a group NK times, once for each value of TSUBK.		
	Cards 26 - 30: Required if SUBOPT = TRUE and DOPLER = TRUE		
1 - 80	KSUBDF(I,J) = Doppler forward gains at TSUBK(I); J = 1,34	8E10.2	
	Cards 31 - 35: Required if SUBOPT = TRUE and DOPLER = TRUE		
1 - 80	KSUBDS(I,J) = Doppler side gains at TSUBK(I); J = 1,34	8E10.2	
	Cards 36 - 45 are repeated as a group NK times, once for each value of TSUBK.		
	Cards 36 - 40: Required if SUBOPT = TRUE and OMEGA = TRUE		
1 - 80	KSUBØ1(I,J) = Omega first L.O.P. gains at TSUBK(I); J = 1,34	8E10.2	

Table 10. (Continued).

COLUMNS	QUANTITY		FORMAT	TYPICAL VALUE
	<u>Cards 41 - 45:</u>	Required if SUBOPT = TRUE and OMEGA = TRUE		
1 - 80	KSUBØ2(I,J) =	Omega second L.O.P. gains at TSUBK(I); J = 1,34	8E10.2	
	Cards 46 - 55 are repeated as a group NK times, once for each value of TSUBK.			
	<u>Cards 46 - 50:</u>	Required if SUBOPT = TRUE and SATRNG = TRUE		
1 - 80	KSUBS1(I,J) =	Satellite #1 gains at TSUBK(I); J = 1,34	8E10.2	
	<u>Cards 51 - 55:</u>	Required if SUBOPT = TRUE and SATRNG = TRUE		
1 - 80	KSUBS2(I,J) =	Satellite #2 gains at TSUBK(I); J = 1,34	8E10.2	

Table 11. Input Data for NATNAV Sample Case.

Column	1	6	11	16	21	26	31	36	41	46	51	61	71
Card 1:	BOSTON - SHANNON WITH OMEGA UPDATES EVERY 15 MINUTES												
Card 2:			1.0		-5.0		5.0		35				
Card 3:	10		15.0		5.0		19.0		280.0		1500.0	.82	35000.0
Card 4a:	42.363		-71.005		10.0		320.0						
Card 4b:	43.825		-66.083		30.0		300.0						
Card 4c:	46.207		-62.979		40.0		270.0						
Card 4d:	48.538		-58.562		40.0		270.0						
Card 4e:	51.0		-50.0		40.0		270.0						
Card 4f:	53.0		-40.0		40.0		270.0						
Card 4g:	54.0		-30.0		40.0		270.0						
Card 4h:	54.0		-20.0		40.0		270.0						
Card 4i:	54.0		-15.0		40.0		270.0						
Card 4j:	52.702		-8.917		40.0		270.0						
Card 8:	1	1	1	1	1	0	0	1	0	0			
Card 10:	6		1		0.0		3.0						
Card 11:	60.0		60.0		300.0		0.20		0.20		2.0	0.0	0.0
Card 12:	0.0												
Card 13:	120.0		120.0		120.0		.7527		.7527		4.630	.000324	.000324
Card 14:	.000324												
Card 15:	40.0		40.0		240.0		.0001		.0001		.000924	0.0	0.0
Card 16:	0.0												
Card 17:	0.05		0.05		0.05								
Card 18:	.000024		.000024		.000024		20.0		20.0		20.0		
Card 19:	.02216		.02216										
Card 20:	0.3		10.0		5.0		50.0						
Card 23:	2	4	1	4	30.0		30.0		5.0		10.0	0.1	0.1
Card 24:	0.1		0.1		15.0								

SECTION 8

PROGRAM NATNAV OUTPUTS

Each page of the Program NATNAV printout begins with a heading line containing an identifying title, date, run number and page number. All input data for a run is repeated with descriptive identification. Figure 22 illustrates the printout formats for the sample run whose input data was presented in Table 11. Page one of the printout repeats the program control data and the flight plan; page two describes the INS errors; page three presents the Doppler, Omega and/or satellite ranging measurement errors.

The simulation results begin on page four. The printed output presents the nominal aircraft latitude (LAT), longitude (LON) and track angle (TRK) as functions of time. At each printout time, the standard deviation of the INS misalignment angles, and the position and velocity errors relative to the track are also shown:

EPSN,EPSE,EPSD	North, East and Down platform misalignment angles.
DX,DY	Along- and cross-track position errors.
DH	Vertical position error.
DXDOT,DYDOT	Along- and cross-track speed errors.
DHDOT	Vertical speed error.

In addition to the printouts at the specified interval, the program also prints at each waypoint and after each external measurement.

If the automatic plotting option is selected, the time histories of the position and velocity errors will be plotted with appropriate identification, as shown in Figure 23. The error history data is temporarily stored on logical unit NTAPE (normally 49) during the run. This data could be saved for later analysis, e.g. collision risk studies, by equipping this unit as a magnetic tape prior to execution. The information is recorded in binary format with odd parity; each logical record contains the following data (in order):

TIME	Simulation time (hours).
EN,EE,ED	North, East, Down platform misalignment angles (deg).
DH	Altitude error (ft).
DX,DY	Along- and cross-track position errors (nm).
DHDOT	Altitude rate error (ft/min).
DXDOT,DYDOT	Along- and cross-track speed errors (kt).

If the update gain printout option is selected, the 34 optimum filter gains for each measurement will be printed at the completion of the run. The gains are temporarily recorded on logical unit 7, which could be saved for future analysis in the same manner as the plot data above. Each logical record contains the following data:

TIME	Simulation time (minutes).
MTYPE	Flag indicating type of measurement: 3,4 = forward and sidewise Doppler measurements 5,6 = 1st and 2nd Omega L.O.P. measurements 7,8 = 1st and 2nd satellite ranging measurements
KOPT	34 optimum filter gains.

```
PROGRAM NATNAV:  BOSTON-SHANNON WITH OMEGA UPDATES EVERY 15 MIN.            01/15/73    RUN NO.  35    PAGE   1

                                  NATNAV INPUTS
                    -------------------------------------------------

                    INTEGRATION STEP-SIZE  =   1.00     MINUTES
                       PRINTOUT INTERVAL  =   5.00     MINUTES
                    PLOT OUTPUT INTERVAL  =   5.00     MINUTES

                                 FLIGHT PLAN DATA
                                 - - - - - - - - -

                      INS ALIGNMENT TIME  =   15.00    MINUTES
                      TAXI TIME           =    5.00    MINUTES
                      AIRPORT ELEVATION   =     19.    FEET
                      A/C CLIMB SPEED     =    260.    KNOTS
                      A/C RATE OF CLIMB   =   1500.    FT/MIN
                      CRUISE MACH NUMBER  =    .820
                      CRUISE ALTITUDE     =  35000.    FEET

                                 ROUTE OF FLIGHT
```

WAYPOINT	LATITUDE (DEG)	LONGITUDE (DEG)	WIND DIRECTION (DEG)	WIND SPEED (KTS)
1	42.36 N	71.01 W	320.0	10.0
2	43.63 N	66.68 W	300.0	30.0
3	46.21 N	62.96 W	270.0	40.0
4	46.54 N	56.56 W	270.0	40.0
5	51.30 N	50.00 W	270.0	40.0
6	53.00 N	40.00 W	270.0	40.0
7	54.00 N	30.00 W	270.0	40.0
8	54.00 N	20.00 W	270.0	40.0
9	54.00 N	15.00 W	270.0	40.0
10	52.70 N	8.92 W	270.0	40.0

Figure 22. Printout for NATNAV Sample Case.

```
PROGRAM NATNAV: BOSTON-SHANNON WITH OMEGA UPDATES EVERY 15 MIN.          01/15/73   RUN NO. 35   PAGE  2

                                          I.N.S. DATA
                                          - - - - - - -

            2- ACCELEROMETER CASE          TYPE 6 SYSTEM      UNIPOLAR      7 - STATE VARIABLE I.N.S. MODEL

  INITIAL CONDITIONS  ------------------  PLATFORM TILT ANGLES              NORTH -       60.00 (ARC-MIN)
    (1-SIGMA)                                                                EAST  -       60.00 (ARC-MIN)
                                                                             DOWN  -      300.00 (ARC-MIN)

                                          POSITION ERRORS                   LATITUDE  -     .20 (ARC-MIN)
                                                                             LONGITUDE -     .20 (ARC-MIN)
                                                                             ALTITUDE  -    2.00 (FEET)

                                          RATE ERRORS                       LATITUDE  -    0.00 (ARC-MIN/MIN)
                                                                             LONGITUDE -    0.00 (ARC-MIN/MIN)
                                                                             ALTITUDE  -    0.00 (FEET/MIN)

                                                                               X            Y            Z

  GYRO DRIFT UNCERTAINTIES       CORRELATION TIMES OF CORRELATED NOISE (MIN)   120.00       120.00       120.00
                                 S.D. OF CORRELATED NOISE (ARC-MIN/HR)          .753         .753        4.630
                                 STRENGTH OF RANDOM NOISES (ARC-MIN2/HR)       .3240E-03    .3240E-03    .3240E-03

  ACCELEROMETER MEASUREMENT      CORRELATION TIMES OF CORRELATED NOISE (MIN)   40.00        40.00        240.00
      UNCERTAINTIES              S.D. OF CORRELATED NOISE (G)                  .1000E-03    .1000E-03    .9200E-03
                                 STRENGTH OF RANDOM NOISE (FT2/SEC3)           0.           0.           0.

  GYRO TORQUER SCALE             STANDARD DEVIATION (PERCENT)                  .0500        .0500        .0500
      FACTOR ERRORS

  GEODETIC UNCERTAINTIES         STANDARD DEVIATION (G)                        .2400E-04    .2400E-04    .2400E-04
                                 CORRELATION DISTANCES (NM)                    20.00        20.00        20.00

  ALIGNMENT RANDOM ERRORS        STANDARD DEVIATION (KNOTS)                    .0222        .0222

  ALTIMETER SCALE FACTOR ERROR   STANDARD DEVIATION -    .300 PERCENT
  ALTIMETER RANDOM ERROR         STANDARD DEVIATION - 10.000 FT

  V.S.I. SCALE FACTOR ERROR      STANDARD DEVIATION -   5.000 PERCENT
  V.S.I. RANDOM ERROR            STANDARD DEVIATION - 50.000 FT/MIN
```

Figure 22. (Continued).

PROGRAM NATNAV: BOSTON-SHANNON WITH OMEGA UPDATES EVERY 15 MIN. 01/15/73 RUN NO. 35 PAGE 3

OMEGA MEASUREMENT DATA

	FIRST L.O.P.	SECOND L.O.P.
OMEGA STATIONS	TRINIDAD N DAKOTA	NORWAY N DAKOTA
CORRELATION TIMES (MIN)	30.000	30.000
S.D. OF CORRELATED NOISE (MICRO-SEC)	5.000	10.000
S.D. OF BIAS ERRORS (MICRO-SEC)	1.000	1.000
S.D. OF RANDOM ERRORS (MICRO-SEC)	.500	.500

INTERVAL BETWEEN MEASUREMENTS - 15.000 MINUTES

(CP TIME = 46.290)

Figure 22. (Continued).

PROGRAM NATNAV: BOSTON-SHANNON WITH OMEGA UPDATES EVERY 15 MIN. 01/15/73 RUN NO. 35 PAGE 4

TIME (HR)	LAT (DEG)	LON (DEG)	TRK (DEG)	EPSN (MIN)	EPSE (MIN)	EPSD (MIN)	DX (NM)	DY (NM)	DH (FT)	DXDOT (KTS)	DYDOT (KTS)	DHDOT (FT/MIN)
0: 0	42.36 N	71.00 W	0.00	60.0000	60.0000	300.0000	.200	.146	2.0	0.000	0.000	0.0
0: 5	42.36 N	71.00 W	0.00	.3492	.3643	15.2133	.200	.148	2.0	.021	.020	0.0
0:10	42.36 N	71.00 W	0.00	.3435	.3613	9.0815	.200	.148	2.0	.020	.020	0.0
0:15	42.36 N	71.00 W	0.00	.3429	.3692	7.5854	.200	.148	2.0	.044	.042	0.0
WAYPOINT 1												
0:20	42.36 N	71.00 W	67.86	.3580	.4207	7.6207	.157	.194	10.0	.261	.309	90.1
0:25	42.51 N	70.50 W	67.86	.3709	.5010	7.6693	.164	.201	24.7	.636	.757	90.1
0:30	42.66 N	70.00 W	67.86	.3763	.5636	7.7322	.195	.238	46.2	1.056	1.355	90.1
0:35	42.82 N	69.49 W	67.86	.3761	.5921	7.8062	.268	.336	68.3	1.483	2.024	90.1
	OMEGA MEAS.:			.3752	.5736	7.4854	.259	.282	68.3	1.453	1.827	90.1
0:40	42.97 N	68.99 W	67.86	.3785	.5719	7.5693	.372	.428	90.6	1.838	2.445	90.1
BEGIN CRUISE												
0:43	43.07 N	68.65 W	67.86	.3861	.5555	7.6311	.467	.559	105.5	2.055	2.822	50.0
0:45	43.15 N	68.36 W	67.86	.3928	.5522	7.6627	.518	.636	105.5	2.151	2.993	50.0
0:50	43.40 N	67.51 W	67.86	.4226	.5360	7.7621	.685	.882	105.5	2.377	3.438	50.0
	OMEGA MEAS.:			.4153	.5154	5.8696	.570	.476	105.5	1.992	1.960	50.0
0:55	43.66 N	66.66 W	67.86	.4417	.5217	5.9789	.713	.618	105.5	2.141	2.339	50.0
WAYPOINT 2												
0:56	43.62 N	66.08 W	42.64	.4601	.5206	6.0624	.924	.577	105.5	2.638	2.150	50.0
1: 0	43.99 N	65.87 W	42.64	.4706	.5166	6.1067	.983	.622	105.5	2.666	2.250	50.0
1: 5	44.49 N	65.23 W	42.64	.5032	.5084	6.2556	1.163	.773	105.5	2.777	2.522	50.0
	OMEGA MEAS.:			.4687	.5075	4.9259	.832	.446	105.5	2.105	1.666	50.0
1:10	44.98 N	64.59 W	42.64	.4307	.4992	5.0967	.936	.516	105.5	2.266	2.014	50.0
1:15	45.48 N	63.94 W	42.64	.4938	.4926	5.2939	1.039	.619	105.5	2.393	2.318	50.0
1:20	45.98 N	63.28 W	42.64	.5113	.4972	5.5173	1.140	.753	105.5	2.469	2.544	50.0
	OMEGA MEAS.:			.4772	.4917	4.5757	.875	.473	105.5	2.118	1.747	50.0
WAYPOINT 3												
1:22	46.21 N	62.98 W	52.07	.4804	.4924	4.6723	.879	.526	105.5	2.147	1.933	50.0
1:25	46.44 N	62.55 W	52.07	.4852	.4959	4.7935	.904	.566	105.5	2.212	2.096	50.0
1:30	46.87 N	61.74 W	52.07	.5017	.5067	5.0360	.957	.670	105.5	2.290	2.367	50.0
1:35	47.30 N	60.93 W	52.07	.5278	.5239	5.2963	1.019	.806	105.5	2.324	2.578	50.0
	OMEGA MEAS.:			.4988	.5178	4.4865	.835	.517	105.5	2.100	1.805	50.0
1:40	47.73 N	60.12 W	52.07	.5127	.5266	4.7213	.868	.564	105.5	2.207	2.122	50.0
1:45	48.16 N	59.30 W	52.07	.5298	.5331	4.9732	.921	.668	105.5	2.311	2.410	50.0
WAYPOINT 4												
1:49	48.54 N	58.56 W	65.99	.5476	.5400	5.2071	.922	.678	105.5	2.316	2.689	50.0
1:50	48.57 N	58.45 W	65.99	.5500	.5414	5.2375	.931	.895	105.5	2.326	2.712	50.0
	OMEGA MEAS.:			.5273	.5373	4.4684	.776	.592	105.5	2.095	1.927	50.0
1:55	48.86 N	57.47 W	65.99	.5294	.5400	4.6962	.824	.664	105.5	2.287	2.239	50.0
2: 0	49.15 N	56.49 W	65.99	.5356	.5418	4.9345	.899	.772	105.5	2.463	2.519	50.0
2: 5	49.43 N	55.50 W	65.99	.5516	.5486	5.1821	.998	.914	105.5	2.599	2.731	50.0
	OMEGA MEAS.:			.5294	.5451	4.4860	.798	.601	105.5	2.244	1.944	50.0
2:10	49.72 N	54.51 W	65.99	.5285	.5450	4.6991	.868	.672	105.5	2.451	2.248	50.0

Figure 22. (Continued).

PROGRAM NATNAV: BOSTON-SHANNON WITH OMEGA UPDATES EVERY 15 MIN. 01/15/73 RUN NO. 35 PAGE 5

TIME (HR)	LAT (DEG)	LON (DEG)	TRK (DEG)	EPSN (MIN)	EPSE (MIN)	EPSD (MIN)	DX (NM)	DY (NM)	DH (FT)	DXDOT (KTS)	DYDOT (KTS)	DHDOT (FT/MIN)
2:15	50.01 N	53.51 W	65.99	.5377	.5456	4.9233	.964	.779	105.5	2.609	2.520	50.0
2:20	50.29 N	52.50 W	65.99	.5611	.5529	5.1551	1.079	.917	105.5	2.704	2.725	50.0
	OMEGA	MEAS.:		.5309	.5406	4.5150	.830	.609	105.5	2.277	1.972	50.0
2:25	50.56 N	51.49 W	65.99	.5330	.5409	4.7210	.899	.660	105.5	2.472	2.278	50.0
2:30	50.87 N	50.47 W	65.99	.5449	.5461	4.9384	.991	.766	105.5	2.626	2.548	50.0
WAYPOINT 5												
2:32	51.00 N	50.00 W	72.00	.5546	.5479	5.0414	1.013	.876	105.5	2.638	2.689	50.0
2:35	51.12 N	49.42 W	72.00	.5691	.5528	5.1653	1.072	.954	105.5	2.679	2.791	50.0
	OMEGA	MEAS.:		.5352	.5431	4.5316	.826	.642	105.5	2.279	2.042	50.0
2:40	51.34 N	48.34 W	72.00	.5369	.5401	4.7362	.885	.714	105.5	2.461	2.345	50.0
2:45	51.56 N	47.26 W	72.00	.5490	.5456	4.9526	.966	.822	105.5	2.635	2.611	50.0
2:50	51.78 N	46.18 W	72.00	.5742	.5529	5.1776	1.066	.962	105.5	2.726	2.807	50.0
	OMEGA	MEAS.:		.5399	.5477	4.5371	.829	.648	105.5	2.325	2.065	50.0
2:55	51.99 N	45.06 W	72.00	.5431	.5454	4.7421	.884	.720	105.5	2.516	2.362	50.0
3: 0	52.21 N	43.99 W	72.00	.5574	.5451	4.9576	.963	.829	105.5	2.656	2.620	50.0
3: 5	52.43 N	42.89 W	72.00	.5638	.5530	5.1807	1.061	.966	105.5	2.735	2.808	50.0
	OMEGA	MEAS.:		.5483	.5471	4.5485	.829	.656	105.5	2.329	2.084	50.0
3:10	52.65 N	41.78 W	72.00	.5517	.5449	4.7535	.883	.729	105.5	2.513	2.377	50.0
3:15	52.87 N	40.66 W	72.00	.5645	.5450	4.9609	.962	.838	105.5	2.651	2.631	50.0
WAYPOINT 6												
3:17	53.00 N	40.00 W	80.46	.5777	.5439	5.1005	.909	.949	105.5	2.656	2.797	50.0
3:20	53.05 N	39.53 W	80.46	.5889	.5540	5.1920	1.031	1.009	105.5	2.677	2.865	50.0
	OMEGA	MEAS.:		.5539	.5476	4.5733	.810	.691	105.5	2.293	2.142	50.0
3:25	53.17 N	38.30 W	80.46	.5558	.5463	4.7784	.865	.765	105.5	2.472	2.437	50.0
3:30	53.28 N	37.19 W	80.46	.5676	.5472	4.9920	.944	.876	105.5	2.605	2.694	50.0
3:35	53.40 N	36.02 W	80.46	.5915	.5554	5.2096	1.040	1.017	105.5	2.660	2.883	50.0
	OMEGA	MEAS.:		.5566	.5498	4.5967	.820	.697	105.5	2.302	2.155	50.0
3:40	53.52 N	34.84 W	80.46	.5582	.5479	4.7952	.874	.773	105.5	2.464	2.459	50.0
3:45	53.64 N	33.66 W	80.46	.5701	.5487	4.9999	.952	.884	105.5	2.621	2.710	50.0
3:50	53.75 N	32.48 W	80.46	.5942	.5582	5.2078	1.047	1.025	105.5	2.699	2.891	50.0
	OMEGA	MEAS.:		.5595	.5510	4.6122	.829	.707	105.5	2.319	2.187	50.0
3:55	53.87 N	31.29 W	80.46	.5616	.5493	4.8060	.882	.783	105.5	2.500	2.476	50.0
4: 0	53.99 N	30.10 W	80.46	.5741	.5507	5.0067	.959	.894	105.5	2.636	2.722	50.0
WAYPOINT 7												
4: 0	54.00 N	30.00 W	90.00	.5757	.5511	5.0236	.944	.927	105.5	2.606	2.776	50.0
4: 5	54.00 N	28.69 W	90.00	.5988	.5611	5.2115	1.031	1.059	105.5	2.663	2.946	50.0
	OMEGA	MEAS.:		.5642	.5534	4.6309	.825	.734	105.5	2.368	2.236	50.0
4:10	54.00 N	27.66 W	90.00	.5606	.5520	4.8250	.878	.811	105.5	2.480	2.530	50.0
4:15	54.00 N	26.47 W	90.00	.5761	.5536	5.0234	.953	.925	105.5	2.608	2.784	50.0
4:20	54.00 N	25.26 W	90.00	.6005	.5642	5.2223	1.045	1.069	105.5	2.661	2.908	50.0
	OMEGA	MEAS.:		.5671	.5558	4.6445	.843	.741	105.5	2.335	2.261	50.0

Figure 22. (Continued).

PROGRAM NATNAV: BOSTON-SHANNON WITH OMEGA UPDATES EVERY 15 MIN. 01/15/73 RUN NO. 35 PAGE 6

TIME (HR)	LAT (DEG)	LON (DEG)	TRK (DEG)	EPSN (MIN)	EPSL (MIN)	EPSU (MIN)	DX (NM)	DY (NM)	DH (FT)	DXDOT (KTS)	DYDOT (KTS)	DHDOT (FT/MIN)
4:25	54.00 N	24.05 W	90.00	.5683	.5544	4.8332	.895	.820	105.5	2.506	2.553	50.0
4:30	54.00 N	22.64 W	90.00	.5794	.5565	5.0243	.968	.934	105.5	2.631	2.802	50.0
4:35	54.00 N	21.63 W	90.00	.6021	.5661	5.2149	1.058	1.079	105.5	2.697	2.960	50.0
		OMEGA MEAS.:		.5691	.5589	4.6541	.861	.752	105.5	2.354	2.283	50.0
4:40	54.00 N	20.42 W	90.00	.5717	.5562	4.8391	.912	.831	105.5	2.513	2.572	50.0
	WAYPOINT 8											
4:41	54.00 N	20.00 W	90.00	.5747	.5585	4.9036	.935	.867	105.5	2.559	2.604	50.0
4:45	54.00 N	19.21 W	90.00	.5838	.5613	5.0267	.984	.946	105.5	2.626	2.818	50.0
4:50	54.00 N	18.00 W	90.00	.6063	.5737	5.2146	1.072	1.090	105.5	2.691	2.934	50.0
		OMEGA MEAS.:		.5740	.5640	4.6709	.881	.764	105.5	2.362	2.311	50.0
4:55	54.00 N	16.79 W	90.00	.5766	.5637	4.8572	.931	.845	105.5	2.516	2.601	50.0
5: 0	54.00 N	15.56 W	90.00	.5878	.5671	5.0464	1.001	.960	105.5	2.631	2.849	50.0
	WAYPOINT 9											
5: 2	54.00 N	15.00 W	109.67	.5966	.5718	5.1369	1.030	1.036	105.5	2.656	2.954	50.0
5: 5	53.88 N	14.41 W	109.67	.6105	.5790	5.2362	1.078	1.116	105.5	2.672	3.046	50.0
		OMEGA MEAS.:		.5795	.5669	4.6956	.905	.781	105.5	2.392	2.335	50.0
5:10	53.64 N	13.26 W	109.67	.5845	.5658	4.8633	.961	.861	105.5	2.529	2.636	50.0
5:15	53.40 N	12.10 W	109.67	.5969	.5689	5.0677	1.032	.979	105.5	2.620	2.900	50.0
5:20	53.16 N	11.04 W	109.67	.6172	.5815	5.2438	1.115	1.129	105.5	2.664	3.093	50.0
		OMEGA MEAS.:		.5888	.5696	4.7007	.954	.766	105.5	2.422	2.306	50.0
5:25	52.92 N	9.94 W	109.67	.5912	.5686	4.8717	1.085	.868	105.5	2.556	2.665	50.0
	WAYPOINT 10											
5:29	52.70 N	6.92 W	109.67	.5996	.5723	5.0231	1.065	.977	105.5	2.643	2.902	50.0

THIS RUN IS PLOTTED

Figure 22. (Continued).

*** OPTIMUM UPDATE GAINS FOR THIS RUN***

```
*** T =  35.000 OMEGA #1 *** -.1180521E-05 -.6973333E-05 -.1063729E-03 -.6682307E-05  .5193185E-05 -.6620043E-06  .3473532E-06
 0.            0.            -.2894681E-07 -.6018725E-07 -.1319376E-06 -.1161752E+00  .1303874E-01  0.           -.5038975E-06
-.4439465E-05  .2235833E-06  .3353227E-02  .3168831E-02  0.           -.3888010E-06  0.            0.            0.
 0.            .2852935E-01  .6440701E+00  0.            0.            0.            0.            0.            0.

*** T =  35.000 OMEGA #2 *** -.3446171E-06  .1093223E-05  .1472305E-04  .1236029E-05  .2267048E-05  .9279486E-07  .1600083E-06
 0.            0.            -.1807829E-07 -.2218816E-07  .1603524E-07 -.3995714E-01  .1675331E-01  0.           -.3546499E-06
-.1629093E-05 -.2778233E-07 -.5294739E-03  .1316838E-02  0.           -.1693228E-06  0.            0.            0.
 0.            .3197771E-03  .7219192E-02  .1021074E-01  .9220580E+00  0.            0.            0.            0.

*** T =  50.000 OMEGA #1 ***  .4098966E-06 -.5016165E-05 -.1766833E-03 -.2563866E-04  .9839287E-05 -.1673447E-05  .4764786E-06
 0.            0.            -.4820625E-07 -.7217063E-07 -.2956743E-06 -.1342469E+00  .1583620E-01  0.           -.6931923E-06
-.6559144E-05  .5195223E-06  .1078162E-02  .9931146E-03  0.           -.2992773E-06  0.            0.            0.
 0.           -.3097351E-02  .1195635E+00  .2413742E-04  .1322034E-02  0.            0.            0.            0.

*** T =  50.000 OMEGA #2 ***  .2353186E-05  .1534208E-05  .4328031E-04  .8065005E-05  .1220523E-04  .4507364E-06  .6442589E-06
 0.            0.            -.3425260E-07 -.7127880E-07  .6704189E-07 -.1126402E+00  .5349127E-01  0.           -.1754234E-05
-.6207141E-05 -.1233064E-06 -.2967210E-03  .9260914E-03  0.           -.4179568E-06  0.            0.            0.
 0.            .1790069E-03  .9255359E-02  .3863636E-02  .6246214E+00  0.            0.            0.            0.

*** T =  65.000 OMEGA #1 *** -.1130489E-05  .9578525E-07 -.1387620E-03 -.2956479E-04  .7280277E-05 -.1414167E-05  .4469604E-06
 0.            0.            -.4414971E-07 -.5112350E-07 -.4573472E-06 -.1161385E+00  .3231716E-02  0.           -.7195196E-06
-.5225745E-05  .7728200E-06  .9778899E-03  .8558480E-03  0.            .5019905E-06  0.            0.            0.
 0.           -.2084000E-02  .7874991E-01  .7534283E-03  .5328375E-01  0.            0.            0.            0.

*** T =  65.000 OMEGA #2 ***  .5045042E-05 -.8382688E-06  .3429660E-04  .1235187E-04  .1894834E-04  .3916789E-06  .6131742E-06
 0.            0.             .4256182E-07 -.7679920E-07  .6653283E-07 -.1166531E+00  .6550772E-01  0.           -.2814390E-05
-.7564949E-05 -.1657910E-06 -.1808774E-03  .6901910E-03  0.            .1282570E-06  0.            0.            0.
 0.            .9228116E-03  .2671169E-01  .1471558E-02  .4188080E+00  0.            0.            0.            0.

*** T =  80.000 OMEGA #1 *** -.4766980E-06  .1972011E-05 -.1194007E-03 -.2718567E-04  .9526728E-05 -.1230683E-05  .7680584E-06
 0.            0.            -.4074157E-07 -.4995070E-07 -.6561933E-06 -.1341280E+00 -.6128204E-02  0.           -.9854857E-06
-.3542339E-05  .1071479E-05  .1047710E-02  .9849077E-03  0.            .5507645E-06  0.            0.            0.
 0.            .1672960E-02  .1373045E+00  .1219905E-02  .7775113E-01  0.            0.            0.            0.

*** T =  80.000 OMEGA #2 ***  .5196283E-05 -.1540454E-05  .2204409E-04  .1176958E-04  .1892157E-04  .2843216E-06  .5267651E-06
 0.            0.            -.4943607E-07 -.6470420E-07  .1266663E-06 -.1040966E+00  .8245640E-01  0.           -.4254791E-05
-.6437737E-05 -.2390464E-06 -.2468761E-03  .6806450E-03  0.            .4369499E-06  0.            0.            0.
 0.            .1122278E-02  .2277465E-01  .1572533E-02  .4206359E+00  0.            0.            0.            0.

*** T =  95.000 OMEGA #1 ***  .1263335E-05  .1895250E-05 -.1159531E-03 -.2615504E-04  .1167415E-04 -.1152093E-05  .8616759E-06
 0.            0.            -.3069316E-07 -.5235503E-07 -.7601657E-06 -.1435941E+00 -.2113694E-01  0.           -.1381512E-05
-.3204421E-06  .1268407E-05  .1030637E-02  .8607363E-03  0.           -.3555802E-07  0.            0.            0.
 0.            .1768050E-02  .1606029E+00  .1393778E-02  .8386833E-01  0.            0.            0.            0.

*** T =  95.000 OMEGA #2 ***  .4903507E-05 -.1872604E-05  .9712904E-05  .9787647E-05  .1763466E-04  .2455660E-06  .5528622E-06
 0.            0.            -.6141957E-07 -.4909913E-07  .1615467E-06 -.5691242E-01  .1033255E+00  0.           -.5900579E-05
-.3822006E-05 -.2967863E-06 -.2816183E-03  .6496100E-03  0.            .2254516E-06  0.            0.            0.
 0.            .4057815E-03  .6702531E-02  .2227473E-02  .4733255E+00  0.            0.            0.            0.

*** T = 110.000 OMEGA #1 ***  .1920343E-05  .1443201E-05 -.1145035E-03 -.2602853E-04  .1436434E-04 -.1208259E-05  .8476115E-06
 0.            0.            -.2238542E-07 -.5769734E-07 -.8160222E-06 -.1480548E+00 -.2818745E-01  0.           -.2074487E-05
 .3090525E-06  .1348426E-05  .1031903E-02  .8240478E-03  0.            .4542647E-06  0.            0.            0.
 0.           -.5438960E-03  .1644527E+00  .7542518E-03  .5626134E-01  0.            0.            0.            0.
```

Figure 22. (Continued).

```
PROGRAM NATNAV: BOSTON-SHANNON WITH OMEGA UPDATES EVERY 15 MIN.                                        01/15/73    RUN NO.  35    PAGE   8

*** T = 110.000 OMEGA #2 ***  .4301096E-05 -.1641506E-05  .4961204E-05  .9264284E-05  .1809294E-04  .2415463E-06  .6381887E-06
 0.             0.           -.6986405E-07 -.4327526E-07  .1780946E-06 -.8523004E-01  .1125374E+00 0.           -.6363595E-05
 -.2578519E-05 -.3007666E-06 -.2933273E-03  .6440397E-03 0.           -.1555647E-06 0.           0.           0.
 -0.           -.3063646E-03 -.4110710E-02  .1841619E-02  .4725421E+00 0.           0.           0.           0.

*** T = 125.000 OMEGA #1 ***  .2582781E-05  .1837638E-05 -.1092404E-03 -.2670051E-04  .1944934E-04 -.1256645E-05  .7482489E-06
 0.             0.           -.1403043E-07 -.5813419E-07 -.7966638E-06 -.1437193E+00 -.3328330E-01 0.           -.2276905E-05
 -.1155729E-05  .1339639E-05  .1013413E-02  .7585793E-03 0.           -.3285544E-06 -0.          -0.           0.
 0.            -.2064251E-02  .1617424E+00  .1829606E-04  .3595690E-01 0.           0.           0.           0.

*** T = 125.000 OMEGA #2 ***  .3945775E-05 -.1205791E-05  .4364886E-05  .9969993E-05  .2085990E-04  .2678881E-06  .8254947E-06
 0.             0.           -.6517896E-07 -.4475626E-07  .1380057E-06 -.7979539E-01  .1023084E+00 0.           -.5120948E-05
 -.3135677E-05 -.2348308E-06 -.2602540E-03  .5867060E-03 0.           -.2673298E-06 0.           0.           0.
 0.             .1137291E-02  .1064624E-01  .3883942E-03  .4095471E+00 0.           0.           0.           0.

*** T = 140.000 OMEGA #1 ***  .2431300E-05  .2275853E-05 -.1066533E-03 -.2723911E-04  .1548327E-04 -.1290868E-05  .6476473E-06
 0.             0.           -.1032814E-07 -.5766243E-07 -.7906563E-06 -.1457552E+00 -.3475537E-01 0.           -.2452980E-05
 -.2823294E-05  .1332609E-05  .1044980E-02  .7126217E-03 0.            .3653219E-07 0.           0.           0.
 0.            -.1379251E-02  .1733846E+00 -.4436892E-03  .2009077E-01 0.           0.           0.           0.

*** T = 140.000 OMEGA #2 ***  .4574264E-05 -.1176240E-05  .5271177E-05  .1059266E-04  .2378108E-04  .2633795E-06  .9066018E-06
 0.             0.           -.5342629E-07 -.4545680E-07  .1211649E-06 -.7251381E-01  .8752843E-01 0.           -.3560772E-05
 -.3980161E-05 -.2075193E-06 -.2287131E-03  .5517543E-03 0.           -.8452306E-07 0.           0.           0.
 0.             .1892804E-02  .1841671E-01 -.7542221E-03  .3467867E+00 0.           0.           0.           0.

*** T = 155.000 OMEGA #1 ***  .2170299E-05  .2622162E-05 -.1076290E-03 -.2637782E-04  .1398034E-04 -.1335286E-05  .5572522E-06
 0.             0.           -.1120859E-07 -.5725739E-07 -.7887662E-06 -.1490327E+00 -.3217907E-01 0.           -.2645144E-05
 -.2555198E-05  .1317845E-05  .1058019E-02  .6607286E-03 0.           -.2022922E-06 0.           -0.          0.
 0.            -.4088788E-04  .1832028E+00 -.2618112E-03  .2609138E-01 0.           0.           0.           0.

*** T = 155.000 OMEGA #2 ***  .4940492E-05 -.1045244E-05  .5097920E-05  .1013775E-04  .2490517E-04  .2457185E-06  .9055695E-06
 0.             0.           -.5095201E-07 -.4384831E-07  .1280393E-06 -.6978820E-01  .8650516E-01 0.           -.3607668E-05
 -.3857288E-05 -.2413499E-06 -.2078240E-03  .5588673E-03 0.            .1065085E-06 0.           0.           0.
 0.             .1721115E-02  .2187771E-01 -.8269086E-03  .3376478E+00 0.           0.           0.           0.

*** T = 170.000 OMEGA #1 ***  .2079456E-05  .2956195E-05 -.1096159E-03 -.2968500E-04  .1286596E-04 -.1368289E-05  .4621188E-06
 0.             0.           -.1520749E-07 -.5620443E-07 -.7629845E-06 -.1498874E+00 -.2717815E-01 0.           -.3001582E-05
 -.9324861E-06  .1292042E-05  .1064343E-02  .5992895E-03 0.            .9912154E-07 0.           -0.          0.
 0.             .6487354E-03  .1878639E+00  .6151044E-04  .3944436E-01 0.           0.           0.           0.

*** T = 170.000 OMEGA #2 ***  .5054902E-05 -.9173081E-06  .2955308E-05  .9211368E-05  .2520062E-04  .2321472E-06  .9331360E-06
 0.             0.           -.5676602E-07 -.3982551E-07  .1416388E-06 -.6845020E-01  .9297913E-01 0.           -.4852404E-05
 -.2805770E-05 -.2897083E-06 -.1691778E-03  .5702368E-03 0.            .1233810E-06 0.           0.           0.
 0.             .1049138E-02  .2319932E-01 -.3007738E-03  .3522789E+00 0.           0.           0.           0.

*** T = 185.000 OMEGA #1 ***  .1871509E-05  .3298479E-05 -.1103449E-03 -.3060640E-04  .1094604E-04 -.1388022E-05  .3864016E-06
 0.             0.           -.1834565E-07 -.5557195E-07 -.7755776E-06 -.1503074E+00 -.2340685E-01 0.           -.3293340E-05
  .1633652E-06  .1265153E-05  .1077935E-02  .6438189E-03 0.           -.6677407E-07 0.           0.           0.
 0.             .7124203E-03  .1942892E+00 -.3774611E-06  .4255927E-01 0.           0.           0.           0.

*** T = 185.000 OMEGA #2 ***  .5207893E-05 -.8046050E-06  .5928411E-06  .8428255E-05  .2568817E-04  .2112945E-06  .9607295E-06
 0.             0.           -.6169153E-07 -.3544194E-07  .1489507E-06 -.6565063E-01  .9764220E-01 0.           -.5648529E-05
 -.1764166E-05 -.3073605E-06 -.1746416E-03  .5774041E-03 0.            .1042960E-07 0.           0.           0.
 0.             .7572271E-03  .2606206E-01  .6363290E-06  .3614966E+00 0.           0.           0.           0.
```

Figure 22. (Continued).

```
PROGRAM NATNAV: BOSTON-SHANNON WITH OMEGA UPDATES EVERY 15 MIN.                         01/15/73    RUN NO.  35    PAGE   9

*** T = 200.000 OMEGA #1 ***  .1712790E-05  .3569228E-05 -.1104639E-03 -.3137985E-04  .1022577E-04 -.1403162E-05  .3347547E-06
 0.            0.            -.1919600E-07 -.5461066E-07 -.7737737E-06 -.1500303E+00 -.2130564E-01  0.           -.3237712E-05
 .3891336E-06  .1252293E-05  .1085592E-02  .4862821E-03  0.           -.1117418E-06  0.            0.            0.
 0.            .6450559E-03  .2001615E+00 -.2967697E-03  .4246833E-01  0.            0.            0.            0.

*** T = 200.000 OMEGA #2 ***  .5235765E-05 -.6691165E-06 -.1620854E-05  .7714421E-05  .2641500E-04  .1827622E-06  .9616030E-06
 0.            0.            -.6293306E-07 -.3202215E-07  .1397591E-06 -.6151331E-01  .1003463E+00  0.           -.5494832E-05
-.1255861E-05 -.2752831E-06 -.1630462E-03  .5811757E-03  0.           -.7546444E-07  0.            0.            0.
 0.            .1035777E-02  .2613982E-01 -.2025844E-03  .3655656E+00  0.            0.            0.            0.

*** T = 215.000 OMEGA #1 ***  .1929463E-05  .3759199E-05 -.1107904E-03 -.3224958E-04  .9113256E-05 -.1427412E-05  .2299894E-06
 0.            0.            -.1664629E-07 -.5279146E-07 -.7791358E-06 -.1478269E+00 -.2014160E-01  0.           -.2999953E-05
 .2068775E-06  .1254223E-05  .1085758E-02  .4204590E-03  0.           -.3223990E-07  0.            0.            0.
 0.            .6076364E-03  .2030367E+00 -.5065244E-03  .4323387E-01  0.            0.            0.            0.

*** T = 215.000 OMEGA #2 ***  .5234597E-05 -.5146035E-06 -.3575922E-05  .6559205E-05  .2713637E-04  .1514755E-06  .9928588E-06
 0.            0.            -.6188753E-07 -.2974657E-07  .1275556E-06 -.5721377E-01  .1019195E+00  0.           -.4922044E-05
-.1164893E-05 -.2334256E-06 -.1486124E-03  .5624809E-03  0.           -.7166656E-07  0.            0.            0.
 0.            .1435995E-02  .2750064E-01 -.5803671E-03  .3696673E+00  0.            0.            0.            0.

*** T = 230.000 OMEGA #1 ***  .1746612E-05  .4028546E-05 -.1102651E-03 -.3304428E-04  .7584790E-05 -.1446333E-05  .1033033E-06
 0.            0.            -.1904263E-07 -.5146031E-07 -.7794249E-06 -.1469788E+00 -.1872500E-01  0.           -.2931982E-05
-.8462650E-07  .1241548E-05  .1092592E-02  .3600240E-03  0.            .5604627E-07  0.            0.            0.
 0.            .1139375E-02  .2866736E+00 -.5463541E-03  .4056337E-01  0.            0.            0.            0.

*** T = 230.000 OMEGA #2 ***  .5279523E-05 -.2765356E-06 -.3616537E-05  .6505602E-05  .2766852E-04  .1290392E-06  .1008374E-05
 0.            0.            -.6089122E-07 -.2880391E-07  .1261113E-06 -.5450073E-01  .1029976E+00  0.           -.4588395E-05
-.1217306E-05 -.2252030E-06 -.1310090E-03  .5663691E-03  0.           -.6768519E-08  0.            0.            0.
 0.            .1575142E-02  .3176743E-01 -.6701204E-03  .3765339E+00  0.            0.            0.            0.

*** T = 245.000 OMEGA #1 ***  .1538333E-05  .4275832E-05 -.1098582E-03 -.3382345E-04  .5791846E-05 -.1459165E-05  .6084013E-09
 0.            0.            -.2046055E-07 -.5073142E-07 -.7791602E-06 -.1469737E+00 -.1661329E-01  0.           -.3096103E-05
 .2174685E-06  .1220516E-05  .1095155E-02  .2989125E-03  0.            .7206573E-07  0.            0.            0.
 0.            .1355098E-02  .2139601E+00 -.3375427E-03  .4265366E-01  0.            0.            0.            0.

*** T = 245.000 OMEGA #2 ***  .5342884E-05 -.5909726E-07 -.4536647E-05  .5619121E-05  .2817146E-04  .1065998E-06  .1015707E-05
 0.            0.            -.6202750E-07 -.2690273E-07  .1221208E-06 -.5147854E-01  .1048732E+00  0.           -.4924275E-05
-.9213670E-06 -.2287946E-06 -.1139008E-03  .5665956E-03  0.            .3770250E-07  0.            0.            0.
 0.            .1396613E-02  .3552961E-01 -.4474075E-03  .3639626E+00  0.            0.            0.            0.

*** T = 260.000 OMEGA #1 ***  .1512576E-05  .4473218E-05 -.1101542E-03 -.3464630E-04  .3790589E-05 -.1475147E-05 -.1264926E-06
 0.            0.            -.2223464E-07 -.4690800E-07 -.7636631E-06 -.1453029E+00 -.1431553E-01  0.           -.3354436E-05
 .8360436E-06  .1210352E-05  .1090693E-02  .2342123E-03  0.            .1904940E-07  0.            0.            0.
 0.            .1308414E-02  .2167233E+00 -.1162943E-03  .4634573E-01  0.            0.            0.            0.

*** T = 260.000 OMEGA #2 ***  .5308555E-05  .1417462E-06 -.5568520E-05  .4901924E-05  .2847079E-04  .8436938E-07  .1013913E-05
 0.            0.            -.6375602E-07 -.2410365E-07  .1216423E-06 -.4769259E-01  .1064358E+00  0.           -.5444566E-05
-.4532751E-06 -.2343573E-06 -.9713069E-04  .5662644E-03  0.            .2609764E-07  0.            0.            0.
 0.            .1226634E-02  .3954224E-01 -.1480486E-03  .3950863E+00  0.            0.            0.            0.

*** T = 275.000 OMEGA #1 ***  .1177263E-05  .4692221E-05 -.1093272E-03 -.3533148E-04  .1637306E-05 -.1481706E-05 -.2435275E-06
 0.            0.            -.2311765E-07 -.4765540E-07 -.7629312E-06 -.1443624E+00 -.1225797E-01  0.           -.3395976E-05
 .9786226E-06  .1203507E-05  .1088627E-02  .1734314E-03  0.           -.3070656E-07  0.            0.            0.
-0.            .1237317E-02  .2213561E+00 -.1084570E-03  .4765932E-01  0.            0.            0.            0.
```

Figure 22. (Continued).

```
PROGRAM NATNAV: BOSTON-SHANNON WITH OMEGA UPDATES EVERY 15 MIN.                            01/15/73    RUN NO.  35    PAGE  10

*** T = 275.000 OMEGA #2 ***   .5357415E-05   .3799582E-06 -.5400228E-05   .4282056E-05   .2869295E-04   .6679336E-07   .1015411E-05
 0.             0.            -.6425383E-07  -.2180830E-07  .1273779E-06 -.4397450E-01   .1072073E+00  0.            -.5542583E-05
 -.1506882E-06 -.2380745E-06 -.8123603E-04   .5838602E-03  0.                          -.7783169E-08  0.             0.             0.
 0.                            .1303409E-02   .4476307E-01   .4069935E-04   .4082177E+00  0.             0.             0.             0.

*** T = 290.000 OMEGA #1 ***   .7571770E-06 -.4833737E-05 -.1064472E-03 -.3594304E-04   .6447222E-07 -.1486219E-05 -.3289646E-06
 0.             0.            -.2370806E-07 -.4695072E-07 -.7843559E-06 -.1438970E+00 -.9726792E-02  0.            -.3226601E-05
 .9905952E-06   .1203081E-05  .1084098E-02   .1151845E-03  0.                          -.3056342E-07  0.             0.             0.
 0.                            .1276737E-02   .2262226E+00 -.1787441E-03   .5113743E-01  0.             0.             0.             0.

*** T = 290.000 OMEGA #2 ***   .5416732E-05   .5712425E-06 -.5703317E-05   .3669531E-05   .2884126E-04   .5007467E-07   .9978502E-06
 0.             0.            -.6462722E-07  -.1884563E-07  .1254978E-06 -.3916770E-01   .1086127E+00  0.            -.5441001E-05
 .4685132E-07  -.2246553E-06 -.6904787E-04   .5820299E-03  0.                          -.2307891E-07  0.             0.             0.
 0.                            .1558713E-02   .4927824E-01   .8965651E-04   .4245268E+00  0.             0.             0.             0.

*** T = 305.000 OMEGA #1 ***   .6523944E-06   .4950073E-05 -.1086376E-03 -.3658544E-04 -.1303410E-05 -.1500892E-05 -.3831768E-06
 0.             0.            -.2460636E-07 -.4554067E-07 -.7891811E-06 -.1421956E+00 -.6799335E-02  0.            -.3127753E-05
 .1279486E-05   .1207123E-05  .1077280E-02   .5803652E-04  0.                           .5435545E-08  0.             0.             0.
 0.                            .1365750E-02   .2289657E+00 -.1820290E-03   .5528341E-01  0.             0.             0.             0.

*** T = 305.000 ONEGA #2 ***   .5407740E-05   .6722407E-06 -.6845865E-05   .3034107E-05   .2887257E-04   .3141313E-07   .9763064E-06
 0.             0.            -.6534522E-07  -.1462809E-07  .1162616E-06 -.3267364E-01   .1104719E+00  0.            -.5465461E-05
 .2441979E-06  -.2036842E-06 -.6137828E-04   .5602695E-03  0.                          -.1235960E-07  0.             0.             0.
 0.                            .1771388E-02   .5239735E-01   .1409987E-03   .4450167E+00  0.             0.             0.             0.

*** T = 320.000 OMEGA #1 ***   .1326075E-05   .5353178E-05 -.1091205E-03 -.3732949E-04 -.3811621E-05 -.1508039E-05 -.5230584E-06
 0.             0.            -.2434496E-07 -.4234623E-07 -.7953462E-06 -.1379699E+00 -.5776145E-02  0.            -.3153402E-05
 .1429197E-05   .1209325E-05  .1061838E-02  -.7234520E-06  0.                           .2938916E-07  0.             0.             0.
 0.                            .1302317E-02   .2276083E+00 -.3153764E-04   .5889393E-01  0.             0.             0.             0.

*** T = 320.000 UMEGA #2 ***   .5275129E-05   .8119177E-06 -.5971201E-05   .2514279E-05   .2845907E-04   .2250575E-07   .9283565E-06
 0.             0.            -.6487636E-07  -.1154380E-07  .1242266E-06 -.2790869E-01   .1098692E+00  0.            -.5442643E-05
 .3404550E-06  -.2066031E-06 -.5190231E-04   .5718838E-03  0.                          -.2776064E-09  0.             0.             0.
 0.                            .1857685E-02   .5973923E-01   .3244828E-03  -.4735315E+00  0.             0.             0.             0.

   [CP TIME = 85.664]
```

Figure 22. (Continued).

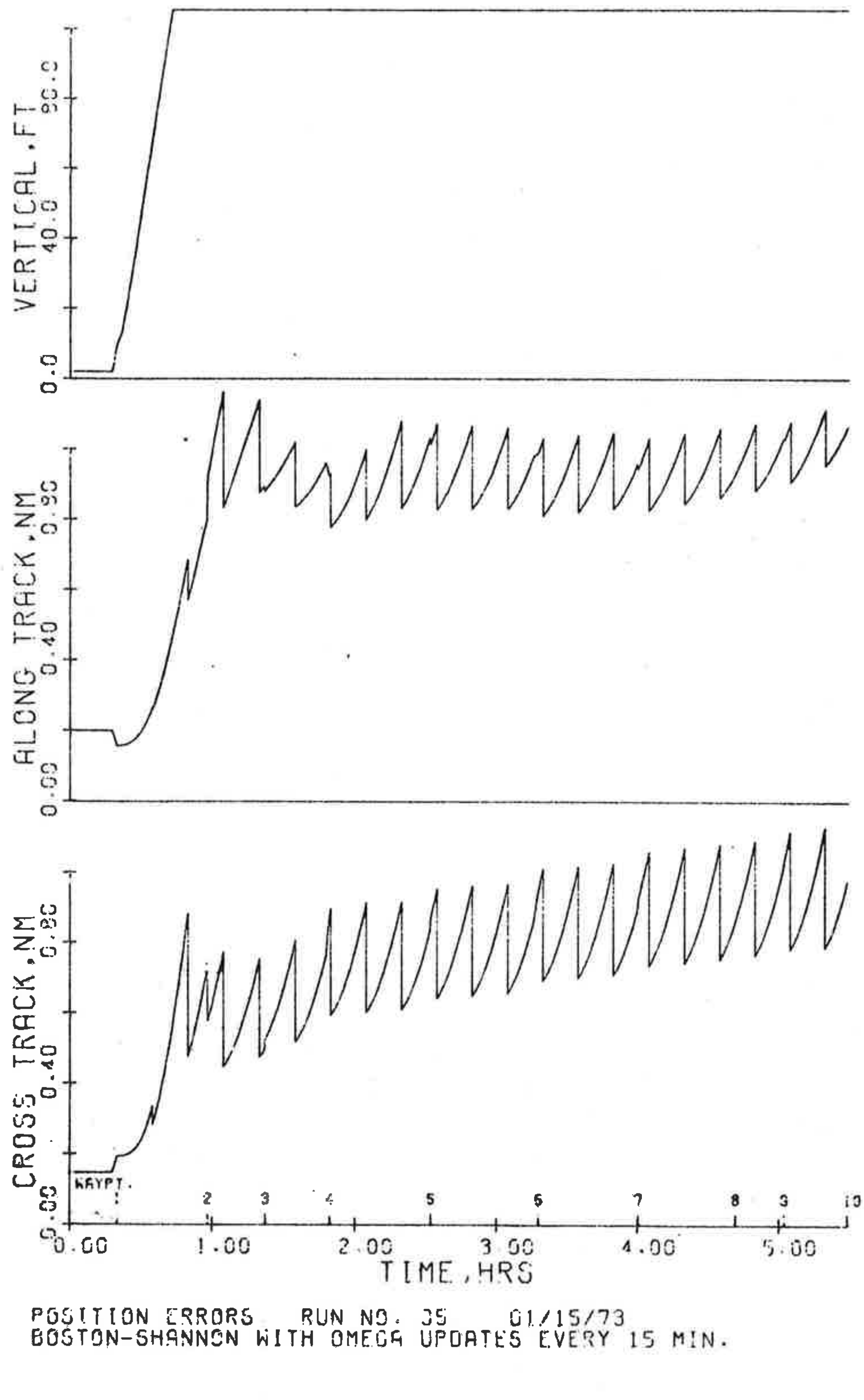

Figure 23. Plotted Output for NATNAV Sample Case.

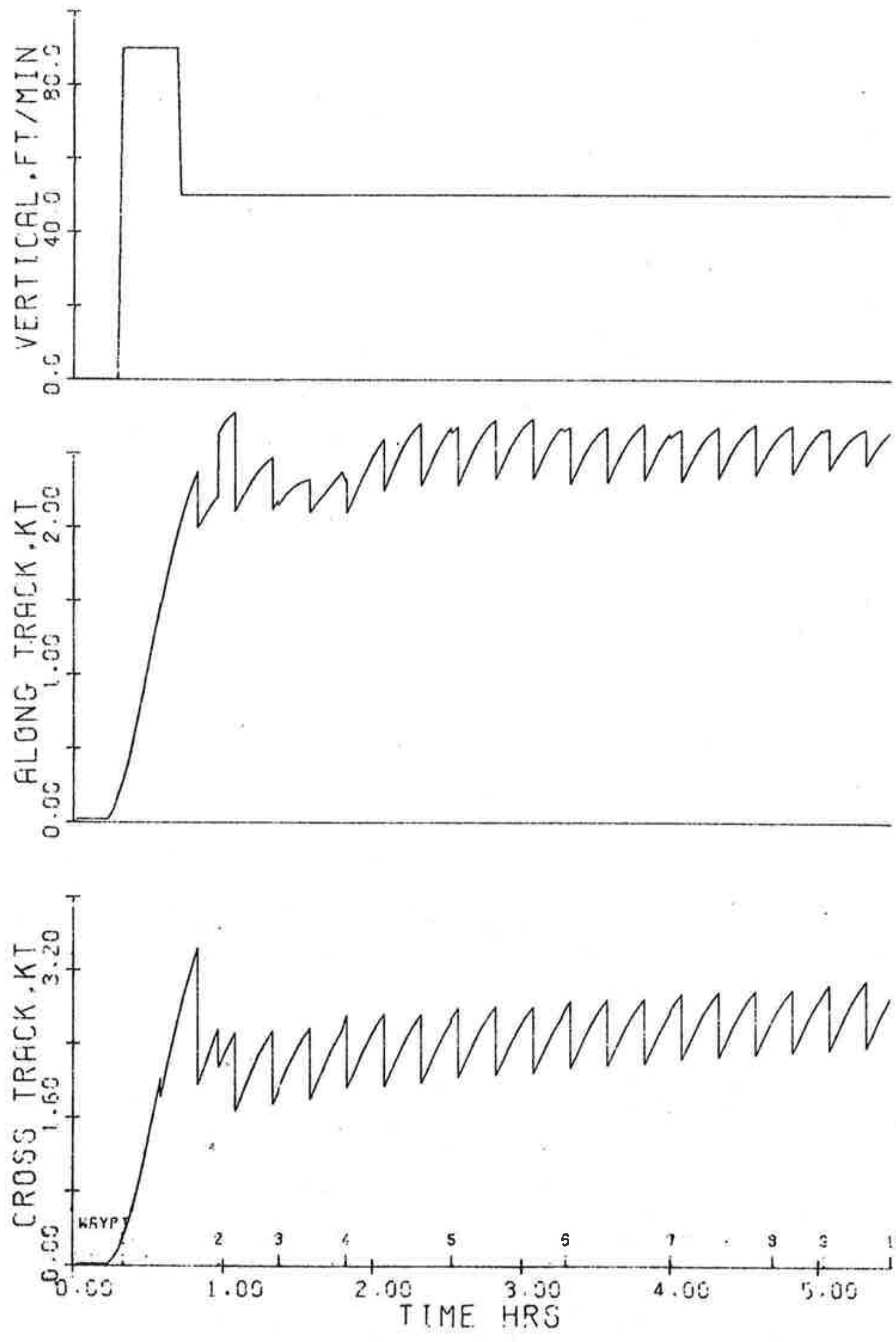

Figure 23. (Continued).

SECTION 9

PROGRAM OPERATION

Program NATNAV is run as any standard Fortran program; using either source or object code decks. The normal deck structure is depicted in Figure 24. The format of the input data deck has been presented in Section 7; the selection of the various options is summarized below.

9.1 PROGRAM OPTIONS

- OUTPUTS

If DTPLOT = 0., no plots will be generated; otherwise the standard deviations of the position and velocity errors will be plotted as functions of time in an along-track, cross-track and vertical coordinate system.

If DTOUT is input as a negative value, the optimum update gains calculated by the program for each measurement will be printed at the end of the run. The standard printout history will be generated using the absolute value of DTOUT.

- INS MODEL

The accuracy (and corresponding complexity) of the INS error model is specified by the following logical input parameters:

GYROS =	1 (TRUE)	Random and exponentially-correlated gyro drift errors are included.
	0 (FALSE)	Gyro drift errors are neglected.

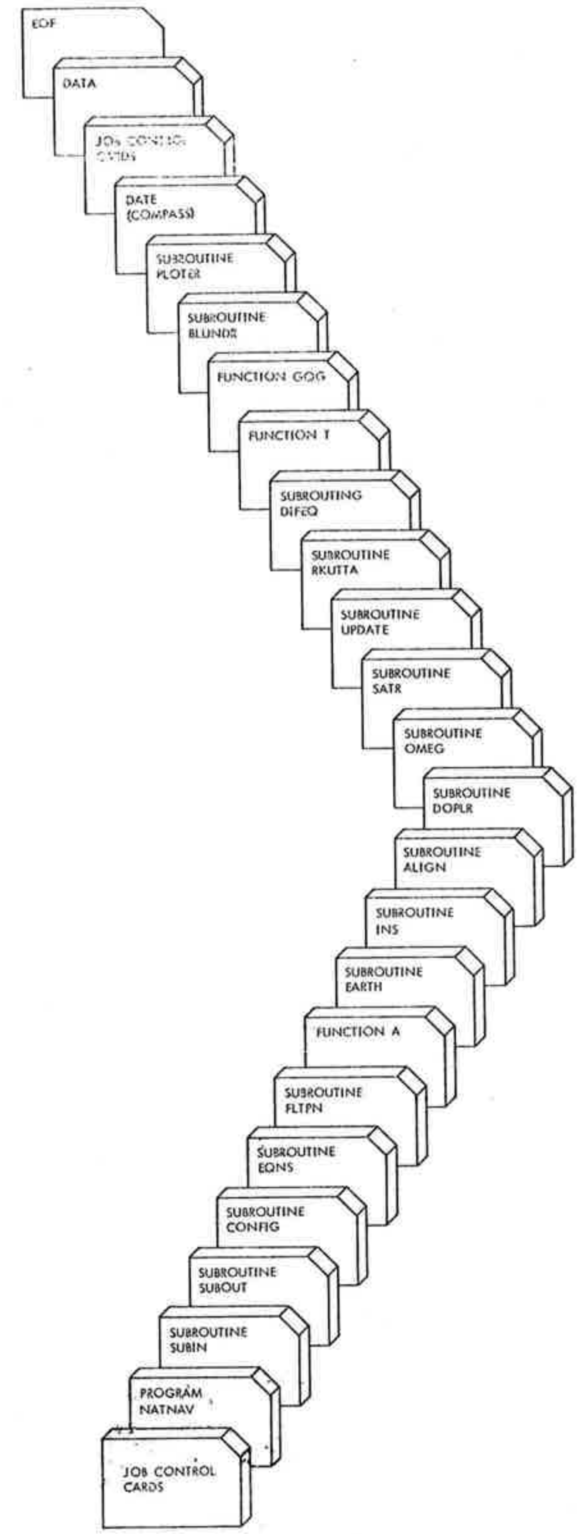

Figure 24. Program NATNAV Deck Structure.

ACC =	1 (TRUE)	Random and exponentially-correlated accelerometer measurement uncertainties are included.
	0 (FALSE)	Accelerometer measurement uncertainties are neglected.
TORQ =	1 (TRUE)	Gyro torquer scale factor errors are included.
	0 (FALSE)	Gyro torquer scale factor errors are neglected.
GRAVD =	1 (TRUE)	Exponentially-correlated geodetic uncertainties are included.
	0 (FALSE)	Geodetic uncertainties are neglected.
ALTSF =	1 (TRUE)	Random and scale factor errors in the altimeter and vertical speed indicator are included.
	0 (FALSE)	Altimeter and vertical speed indicator errors are ignored.

The configuration of the INS being modeled is determined by the input values of ISYS and TWOACC. The type of inertial system is selected from the following options:

ISYS =	1	Space stabilized
	2	Local level
	3	Free azimuth
	4	Strapdown
	5	Rotating azimuth
	6	Unipolar
	7	Wander azimuth

TWOACC =	1 (TRUE)	2-accelerometer INS
	0 (FALSE)	3-accelerometer INS

If ISYS = 1 or 4, TWOACC will automatically be set to FALSE.

- DEAD-RECKONING OPTION

If DREKON = 1 (TRUE), the dead-reckoning navigation mode is simulated. In lieu of an INS, the pilot uses airspeed, gyroscopic heading information and predicted winds to estimate his groundspeed and position.

- NAVIGATION UPDATES

One or more types of external measurements can be selected for improving the navigation system position and velocity estimates:

DOPLER =	1 (TRUE)	Doppler radar measurements are included.
	0 (FALSE)	No Doppler radar measurements.
OMEGA =	1 (TRUE)	Two Omega line-of-position measurements are included.
	0 (FALSE)	No Omega measurements.
SATRNG =	1 (TRUE)	Two satellite-ranging measurements are included.
	0 (FALSE)	No satellite-ranging measurements.

- SUBOPTIMUM FILTERING

If SUBOPT = 1 (TRUE), a set of input filter gain histories is used to update the position and velocity estimates; otherwise the optimum gains calculated by NATNAV are used to incorporate the measurement information. The input filter gains are assumed to be piecewise linear functions of time.

- BLUNDER/MALFUNCTION OPTION

The effects of a specified blunder or malfunction can be examined by using the Suboptimum Filtering Option. If SUBOPT = 1 (TRUE) and TBLUND > 0., the optimum filtering gains are used until time = TBLUND. Appropriate changes in the error estimates, system noises, measurement accuracies, etc. are made (via the user-supplied subroutine BLUNDR) at time = TBLUND; the simulation then continues using the input gain histories. These will have been generated by a previous NATNAV run without the blunder/malfunction (using the optimum gain printout option).

9.2 EXECUTION TIME

The execution time of the simulation will vary considerably depending upon the length of the simulated flight, the integration step size, the number of errors included, the types and frequency of the measurements being made, and the output options selected. To provide an indication of the running time, the sample case presented in Section VIII required 4.1 minutes to simulate a five hour flight, plot the results and print the optimum filter gains. This is about a 75 to 1 ratio of simulation time to execution time. For comparison, the CDC-6600 version of the program requires less than 20 percent as much time for execution.

9.3 DIAGNOSTICS

Program NATNAV has been made as self-sufficient as possible. No diagnostics will be produced other than the standard CDC-3800 execution error messages.

SECTION 10

PROGRAM RESTRICTIONS AND MODIFICATIONS

In developing Program NATNAV it was endeavored to achieve a reasonable compromise among conflicting factors, such as simulation realism, program simplicity, flexibility, ease of operation, and computer requirements. However, as experience with the program is gained, as objectives shift, and as new applications emerge, various modifications to NATNAV will undoubtedly be required. Several possible restrictions and potential modifications are discussed below.

- BLUNDER/MALFUNCTION STUDIES

As mentioned earlier, the analysis of most specific blunder or malfunction situations will require modification of Subroutine BLUNDR. The example implemented in the existing BLUNDR is a sudden 24 nm lane shift in the first Omega line-of-position measurement. Other situations would be simulated by replacing cards NAT20700 through NAT20740 (see Program Listing) with the appropriate statements. For example, a gradual doubling in the correlated drift rate of the INS azimuth gyro would be simulated by inserting the following statement:

```
QVGZ = 4.0 * QVGZ                                NAT20700
```

- SUBOPTIMUM GAINS

The present version of NATNAV permits the user to input a set of suboptimum filter gains, which are defined at up to twenty instants of time. To model filter gain histories in greater detail, the user could increase the dimensions of the variables TSUBK, KSUBDF, KSUBDS, KSUBØ1, KSUBØ2, KSUBS1, and KSUBS2 in Common

Block BSUBOP. Those programs requiring these changes can then be determined by reference to Table 4. In addition, the first dimension of XK in Subroutine UPDATE would also need to be increased appropriately.

- PLOTTING EXTENSIONS

Subroutine PLOTER is presently dimensioned to plot up to 400 data points in each error history, which should be sufficient for most North Atlantic simulations. However, to plot a simulated five-hour flight with updates every minute (600^{+} data points) the dimensions of X and Y in PLOTER would have to be increased (Card NAT20900). Also, the limit size on card NAT21350 would require a corresponding change.

In addition to the position and velocity error histories, PLOTER will plot the INS platform misalignment angles by merely changing the upper range of the DO loop beginning at card NAT21360 from 6 to 9.

Additional quantities can be plotted with somewhat more effort. First, the appropriate data must be saved by appending it to the WRITE statement on card NAT6590 in subroutine SUBOUT. In PLOTER, the dimension of DUM (card NAT20900) and the upper range of the DO loop (card NAT21420) must also be increased. Other additions would be required in PLOTER as appropriate to define the size and labelling of the new plots.

- FLIGHT PLAN ALTERNATIVES

Program NATNAV accepts flight plans consisting of position and wind data at a series of up to 20 waypoints. To accommodate additional waypoints, the dimensions of all arrays in Common Block BFLTPN could be increased appropriately.

Following normal operational procedures, the nominal route between pairs of waypoints maintains a constant track over the earth's surface. Great circle routes can be approximated by selecting appropriate waypoints along the precalculated great circle path. Alternatively, subroutine FLTPLN could be altered to calculate the actual great circle route between waypoints. (See References 5 and 6 for available great circle route subroutines.) A constant, average wind is used for groundspeed and heading calculations between waypoints. Although this is quite reasonable considering the accuracy of winds aloft forecasts, the nominal wind data could be generalized in space and time at the cost of added input complexity and additional calculations in Subroutine FLTPLN. The cruise altitude, now assumed constant, could be made variable by specifying a desired altitude at each waypoint, and beginning a climb as necessary to reach the new altitude at the waypoint.

The aircraft characteristics are defined simply in terms of constant climb speed, rate of climb, and cruise Mach number. No dynamics or attitude motions are included since they occur so rapidly relative to the time frame of interest in most navigation analyses. However, in certain cases, e.g. a detailed simulation of a strapdown I.N.S., a more accurate representation of the aircraft/pilot response characteristics might be necessary. For those situations, more realistic error models, such as those in Reference 7, could be included in Subroutine FLTPLN.

- ERROR MODELS

Detailed descriptions of the error models implemented in NATNAV are presented in Volume 1 (Ref. 1). However, the modular design of the program will permit the analysis of alternate or additional error models without great difficulty. For example, the simulation of an I.N.S. updated with VOR/DME information could be achieved either by replacing an existing system, such as satellite ranging, or by adding the VOR/DME model to the existing ones. Since the VOR/DME errors can be modelled as two biases and two exponentially-correlated noises (Ref. 7), this model could be easily implemented by replacing the calculations in Subroutine SATR with those for the VOR/DME errors. The location of the VOR/DME stations could be input via the arrays SATLAT, SATLON and HSAT in Common Block BSATR, and the logical variable SATRNG would be used to indicate VOR/DME measurements. To prevent confusion, the printouts referring to satellite-ranging measurements in SUBIN and SUBOUT should also be changed.

To add VOR/DME measurements, or others, to the existing program, a logical variable would be added to Common Block BLOGIC to indicate these measurements, and another common block would be inserted to transfer all pertinent data. SUBIN would be modified to read the appropriate inputs. A new subroutine would be required to calculate the optimum filter gains for the VOR/DME measurements. NATNAV would test the new logical variable, and call this subroutine to update the covariance matrix if necessary. The dimensions of the covariance matrix in Common Block BCOVAR, and the arrays in Common Blocks BINDEX and BINTEG would be increased to accommodate the additional error state variables. The data statements in Subroutine EQNS for the index arrays II and JJ would be changed, and appropriate additions would be required in Subroutine CONFIG to set up the differential equations for the covariance matrix. Functions T and GQG would need simple additions to calculate the new derivatives, and minor changes would be necessary elsewhere in the program to accommodate the increased dimension of the covariance matrix.

- TIME-SHARING VERSION

A time-sharing version of NATNAV would involve primarily modification of the input/output portions of the program. Most input data would presumably be kept on a separate file rather than being typed in for each run. Subroutine PLOTER might be run as a separate program to generate off-line plots. A number of other efficiencies could be made in a time-sharing version to minimize core-storage, execution time and remote terminal connect time. For example, it might be specialized to simulate only local-level type INS's, thereby eliminating four error state variables; or the secondary I.N.S. component errors (gyro torquer scale factor errors and geodetic uncertainties) might be deleted, to save six state variables; or the 4th-order Runge-Kutta integration routine might be replaced by a faster, but less accurate technique. All such changes would depend upon the applications anticipated for the time-sharing version.

SECTION 11

PROGRAM LISTING

The following pages present a complete FORTRAN IV listing of the NATNAV simulation program for the Naval Research Laboratory's CDC 3800 computer facility. For the user's convenience, a Table of Contents for this listing is given below:

```
      PROGRAM NATNAV
C
C     CDC-3800 VERSION  (NRL)     2/13/73
C
      COMMON /BALIGN/ SALIN1,SALIN2, RALIN1,RALIN2
      COMMON/BALT/TAUH,SALT,TAUHD,SALTD
      COMMON /BCONST/RADPDG,DEGPRD,FTPNM,NMPFT, MINPRD, OMIE
      COMMON /BCOVAR/ P(34,34)
      COMMON /BDOPLR/ TDF,TDS,SNDF,SNDS, SBDF,SBDS, SRDF,SRDS,
     1              DTDOP, QDF, QDS, RDF, RDS
      COMMON / BFLTPN/ DTA,DTT, H0, VCL,RC,MCR,HCR,NWPTS, LAT(20),
     1                LON(20), THETAW(20), VW(20), TCR, TM(20), VN(20),
     2                VE(20)
      COMMON /BINDEX/ II(585), JJ(585), KK(585)
      COMMON /BINIT/ INIT
      COMMON / BINS1/ISYS,EE0, EN0,ED0,DLA0,DL00,RDLA0,RDL00,DH0,
     1              RDH0,AKAP, PHIDOT, OMS2,FN,FE, FD
      COMMON /BINS2/TGX,TGY,TGZ,QWGX,QWGY,QWGZ,SGX,SGY,SGZ,
     1              QVGX,QVGY,QVGZ,TAX,TAY,TAZ,QWAX,QWAY,QWAZ,
     2              SAX,SAY,SAZ,QVAX,QVAY,QVAZ,TAUX,TAUY,TAUZ,
     3              DX,DY,DZ,SVX,SVY,SVZ,QVX,QVY,QVZ,QWH
      COMMON /BINS3/ C11,C12,C13,C21,C22,C23,C31,C32,C33,
     1               F12,F13,F17,F21,F23,F31,F32,F37,F62,F63,F64,F66,
     2               F67,F68,F69,F71,F73,F74,F76,F77,F78,F79,F91,F92,
     3              F94,F96,F97,F98,WX,WY,WZ
      COMMON /BINTEG/ S(585),SD(585), DT,DT05,NEQ
      COMMON /BLOGIC/ GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,
     1              DOPLER,OMEGA,SATRNG,SUBOPT,DREKON
      COMMON /BNOM/ NPHASE,H,HDOT,ALATR,ALAT,ALON,ALONR, ALB,
     1              ALBDOT, VG, VA, VELN, VELE, VELW, TRK, HDG, CRB,
     2              THW, R, RI, RI2, G, SL, CL, TL, SL2, CL2, CLI,
     3              RICLI, CTRK,STRK, ALAT2, CHDG, SHDG,RCL
      COMMON /BOMEGA/ IOM1, IOM2, IOM3, IOM4, TOM1, TOM2, SNOM1, SNOM2,
     1              SBOM1, SBOM2, SROM1,SROM2,DTOM,QOM1,QOM2,
     2              ROM1,ROM2
      COMMON /BDRKN/SVWN,SVWE,DVWN,DVWE
      COMMON /BPLOT/ DTPLOT,NPLOT,NTAPE
      COMMON /BSATR/ SATLAT(2),SATLON(2),HSAT(2),TSAT1,TSAT2,
     1              SNSAT1,SNSAT2,SBSAT1,SBSAT2,SRSAT1,SRSAT2,
     2              DTSAT,QSAT1,QSAT2,RSAT1,RSAT2
      COMMON /BSUBOP/NK,TSUBK(20),KSUBDF(20,34), KSUBDS(20,34),
     1              KSUB01(20,34), KSUB02(20,34), KSUBS1(20,34),
     2              KSUBS2(20,34),PGAINS,TBLUND
      COMMON /BLU/NN,MM
      COMMON /BTIME/ TIME
      COMMON /BTITLE/TITLE(10), NRUN, NPAGE,DTOUT, LINE,MO,IDAY,IYEAR
      COMMON /BUPDAT/ ALFA,KOPT(34), MTYPE
C
      DIMENSION XTYPE(6)
      REAL LAT,LON,MCR,NMPFT,MINPRD, KOPT,KSUBDF,KSUBDS,KSUB01,KSUB02,
     1              KSUBS1,KSUBS2
      LOGICAL GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,DOPLER,OMEGA,
     1           SATRNG,QUIT,INIT,SUBOPT,DREKON
      DATA (RADPDG=0.01745329),(DEGPRD=57.29578),(FTPNM=6076.12),
     1    (NMPFT=1.64579E-4),(MINPRD=3437.747)
      DATA (XTYPE=7HDOP FWD,8HDOP SIDE,8HOMEGA ~1,8HOMEGA ~2,
```

```
      1   6HSAT =1, 6HSAT =2 )
      DATA (NN=60), (MM=61) , (NTAPE=49)
C
      MPLOT=0
      CALL DATE(MO,IDAY,IYEAR,JDAY)
C
C                        READ INPUT DATA
   10 QUIT=.FALSE.
      CALL SUBIN(QUIT)
      IF(QUIT)  GO TO 900
C
C INITIALIZATION
      IF (PGAINS.GT.0.0) REWIND 7
      NPLOT=0
      IF (DTPLOT.EQ.0.0) GO TO 25
      MPLOT=MPLOT+1
      NPLOT=1
      REWIND NTAPE
   25 TOUT=0.
      LINE=51
      DT1=DT
      IWPTS=1
C
      DO 30 I=1,34
      DO 30 J=1,34
   30 P(I,J)=0.0
C
C INITIAL CONDITIONS
      TIME=0.
      INIT=.TRUE.
      CALL FLTPLN (TIME)
      TF=TM(NWPTS)
      TDOP=TOMEG=TSAT=1.0E10
      IF ( TBLUND.LE.0.0) TBLUND=1.0E10
      CALL INS
      CALL ALIGN
      IF (.NOT.DOPLER) GO TO 34
      TDOP=TM(1)+DTDOP
      CALL DOPLR
   34 IF (.NOT.OMEGA) GO TO 36
      TOMEG=TM(1)+DTOM
      CALL OMEG
   36 IF (.NOT.SATRNG) GO TO 38
      TSAT=TM(1)+DTSAT
      CALL SATR
   38 INIT=.FALSE.
      CALL CONFIG
      CPTIME=TIMEF(DUMY)
      WRITE(MM,40) CPTIME
   40 FORMAT (//5X,*[C.P. TIME =*,E14.6,*]*)
      CALL SUBOUT(0)
      TOUT=TOUT+DTOUT
C
C                        INTEGRATE COVARIANCE MATRIX
  100 T1=TIME+DT1
      DT=AMIN1(T1,TOUT,TF,TDOP,TOMEG,TSAT,TM(IWPTS),TBLUND)-TIME
```

```
      DT05=0.5*DT
      CALL RKUTTA
C                                 NOMINAL PATH VARIABLES
C
      CALL FLTPLN(TIME)
      CALL INS
C                    CHECK BLUNDER/MALFUNCTION
      IF (TIME.EQ.TBLUND) GO TO 300
C
C                    ALIGNMENT MODE
      IF (NPHASE.EQ.1.AND.DREKON) NPHASE=0
      IF (NPHASE.EQ.0.AND..NOT.DREKON) CALL ALIGN
C                    PRINT OUT AT EACH WAYPOINT
      MEAS=0
      IF (TIME.NE.TM(IWPTS)) GO TO 205
      IF (TM(IWPTS)-TCR) 120,130,140
  120 WRITE(MM,125)IWPTS
  125 FORMAT(1H ,6X,9HWAYPOINT ,I2)
      GO TO 150
  130 WRITE(MM,135)
  135 FORMAT(1H ,6X,12HBEGIN CRUISE)
      GO TO 150
  140 JWPTS=IWPTS-1
      WRITE(MM,125)JWPTS
  150 IWPTS=IWPTS+1
      LINE=LINE+1
      MEAS=-1
      CALL SUBOUT(MEAS)
C                    CLIMB/CRUISE MODE - MEASUREMENTS
  205 GO TO (250,250,210,210,800),NPHASE+1
  210 IF(.NOT.DOPLER) GO TO 220
      IF (TIME.LT.TDOP) GO TO 220
      IF (MEAS.EQ.0) CALL SUBOUT(MEAS)
      MEAS=1
      CALL DOPLR
      CALL SUBOUT(MEAS)
      TDOP=TDOP+DTDOP
  220 IF(.NOT.OMEGA) GO TO 230
      IF (TIME.LT.TOMEG) GO TO 230
      IF (MEAS.EQ.0) CALL SUBOUT(MEAS)
      MEAS=2
      CALL OMEG
      CALL SUBOUT(MEAS)
      TOMEG=TOMEG+DTOM
  230 IF(.NOT.SATRNG) GO TO 250
      IF(TIME.LT.TSAT) GO TO 250
      IF (MEAS.EQ.0) CALL SUBOUT(MEAS)
      MEAS=3
      CALL SATR
      CALL SUBOUT(MEAS)
      TSAT=TSAT+DTSAT
C
  250 IF (TIME.LT.TOUT) GO TO 100
      IF (MEAS.EQ.0) CALL SUBOUT(MEAS)
      TOUT=TOUT+DTOUT
      GO TO 100
```

```
C                    BLUNDER/MALFUNCTION CASE
  300 CALL SUBOUT (-1)
      WRITE (MM,310)
  310 FORMAT (1H0,5X,3H***,*BLUNDER/MALFUNCTION AT THIS TIME*,3H***)
      LINE=LINE+1
      CALL BLUNDR
      TBLUND=1.0E10
      SUBOPT=.TRUE.
      MEAS=0
      GO TO 250
C                     END OF RUN
  800 IF (NPLOT.EQ.0) GO TO 820
      NPLOT=NPLOT-1
      REWIND NTAPE
      CALL PLOTER (MPLOT)
      WRITE (MM,810)
  810 FORMAT (1H0,5X,19HTHIS RUN IS PLOTTED/)
  820 IF (PGAINS.EQ.0.0) GO TO 850
C
C                    PRINT OUT AND PUNCH OPTIMUM UPDATE GAINS
      ENDFILE 7
      REWIND 7
      CALL SUBOUT(-2)
      WRITE(MM,500)
  500 FORMAT(1H0,50X,4H*** ,*OPTIMUM UPDATE GAINS FOR THIS RUN*,4H ***,
     1    /)
      WRITE (62,505) NRUN
  505 FORMAT (*OPTIMUM UPDATE GAINS FOR RUN NO.*,I4)
      J=1
      LINE=3
  510 READ(7) T,MTYPE,(KOPT(I),I=1,34)
      IF (EOF,7) 550,520
  520 IF (LINE.GE.54) CALL SUBOUT(-2)
      N=MTYPE-2
      WRITE(MM,530) T,XTYPE(N),(KOPT(I),I=1,34)
  530 FORMAT (9H0*** T = ,F7.3,1X,A8,4H ***,7E14.6/
     1    (1X,9E14.6))
      TSUBK(J)=T
      J=J+1
      WRITE (62,540) (KOPT(I),I=1,34)
  540 FORMAT (8E10.3)
      LINE=LINE+5
      GO TO 510
  550 WRITE (62,560) (TSUBK(I),I=1,J)
  560 FORMAT (*TSUBK ARRAY*/(8E10.3))
C
  850 CPTIME=TIMEF(DUMY)
      WRITE (MM,40) CPTIME
      GO TO 10
C                     END OF JOB
  900 IF (MPLOT.GT.0) CALL PLOTER(-1)
      STOP
      END
```

```
      SUBROUTINE SUBIN (QUIT)
C
C                   THIS SUBROUTINE READS AND PRINTS INPUT DATA.
C
      COMMON /BALIGN/ SALIN1,SALIN2, RALIN1,RALIN2
      COMMON/BALT/TAUH,SALT,TAUHD,SALTD
      COMMON /BDOPLR/ TDF,TDS,SNDF,SNDS, SBDF,SBDS, SRDF,SRDS,
     1               DTDOP, GDF, GDS, RDF, RDS
      COMMON /BDRKN/SVWN,SVWE,DVWN,DVWE
      COMMON / BFLTPN/DTA,DTT,HO, VCL,RC,MCR,HCR,NWPTS, LAT(20),
     1                LON(20), THETAW(20), VW(20), TCR, TM(20), VN(20),
     2                VE(20)
      COMMON / BINS1/ISYS,EEO, ENO,EDD,DLAO,DLOO,RDLAO,RDLOO,DHO,
     1               RDHO,AKAP, PHIDOT, OMS2,FN,FE, FD
      COMMON /BINS2/TGX,TGY,TGZ,QWGX,QWGY,QWGZ,SGX,SGY,SGZ,
     1               QVGX,QVGY,QVGZ,TAX,TAY,TAZ,QWAX,QWAY,QWAZ,
     2               SAX,SAY,SAZ,QVAX,QVAY,QVAZ,TAUX,TAUY,TAUZ,
     3               DX,DY,DZ,SVX,SVY,SVZ,QVX,QVY,QVZ,QWH
      COMMON /BINTEG/ S(585),SD(585), DT,DT05,NEQ
      COMMON /BLOGIC/ GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,
     1               DOPLER,OMEGA,SATRNG,SUBOPT,DREKON
      COMMON /BLU/NN,MM
      COMMON /BOMEGA/ IOM1, IOM2, IOM3, IOM4, TOM1, TOM2, SNOM1, SNOM2,
     1               SBOM1, SBOM2, SROM1,SROM2,DTOM,QOM1,QOM2,
     2               ROM1,ROM2
      COMMON /BPLOT/ DTPLOT,NPLOT,NTAPE
      COMMON /BSATR/ SATLAT(2),SATLON(2),HSAT(2),TSAT1,TSAT2,
     1               SNSAT1,SNSAT2,SBSAT1,SBSAT2,SRSAT1,SRSAT2,
     2               DTSAT,QSAT1,QSAT2,RSAT1,RSAT2
      COMMON /BSUBOP/NK,TSUBK(20),KSUBDF(20,34), KSUBDS(20,34),
     1               KSUBQ1(20,34), KSUBQ2(20,34), KSUBS1(20,34),
     2               KSUBS2(20,34),PGAINS,TBLUND
      COMMON /BTITLE/TITLE(10), NRUN, NPAGE,DTOUT, LINE,MO,IDAY,IYEAR
C
      LOGICAL TWOACC,GYROS,ACCEL,TORQ,GRAVD,ALTSF,INS9,QUIT,SUBOPT
      LOGICAL        DOPLER,OMEGA,SATRNG,DREKON
      DIMENSION TOS(2,7),STAT(2,8)
      REAL MCR,LAT,LON,KSUBDF,KSUBDS,KSUBQ1,KSUBQ2,KSUBS1,KSUBS2
C
C
      DATA (STAT=6HNORWAY,1H ,8HTRINIDAD,1H ,6HHAWAII,1H ,8HN DAKOTA,
     1   1H ,8HREUNION ,1H ,8HARGENTIN,1HA,8HN TASMAN,2HIA,5HJAPAN,
     2   1H )
      DATA (TOS=8HSPACE ST,8HABILIZED,8HLOCAL LE,3HVEL,8HFREE AZI,
     1   4HMUTH,7HSTRAPDO,2HWN,8HROTATING,8H AZIMUTH,8HUNIPOLAR,1H ,
     2   8HWANDER A,6HZIMUTH)
      DATA (NORTH=2H N),(SOUTH=2H S),(EAST=2H E),(WEST=2H W)
C
      READ (NN,11) TITLE
   11 FORMAT (10A8)
      IF (EOF,NN) 1,2
    1 QUIT=.TRUE.
      RETURN
    2 NPAGE=1
      NRUN=NRUN+1
      READ (NN,5) DT,DTOUT,DTPLOT,NRUN
```

```
  5   FORMAT(10X,3E10.1,I2)
C
      PGAINS=0.0
      IF (DTOUT.GT.0.0) GO TO 1000
      DTOUT=-DTOUT
      PGAINS=1.0
 1000 CALL SUBOUT(-2)
      WRITE (MM,1005)
 1005 FORMAT (1H0,61X, *NATNAV INPUTS*/ 40X,55(1H-))
      WRITE (MM,1010) DT,DTOUT
 1010 FORMAT (1H0,44X,*INTEGRATION STEP-SIZE  = *,F6.2,6X,*MINUTES*//
     1        49X,*PRINTOUT INTERVAL   = *,F6.2,6X,*MINUTES*/)
      IF (DTPLOT.NE.0.) WRITE (MM,1015)  DTOUT
      IF (DTPLOT.EQ.0.) WRITE (MM,1020)
 1015 FORMAT (1H ,45X,*PLOT OUTPUT INTERVAL   = *,F6.2,6X,*MINUTES*///)
 1020 FORMAT (1H ,64X,*NO PLOT*/// )
C
      READ (NN,10) NWPTS,DTA,DTT,HO,VCL,RC,MCR,HCR
   10 FORMAT (I2,8X,7E10.2)
      READ (NN,20) (LAT(I),LON(I),VW(I),THETAW(I),I=1,NWPTS)
   20 FORMAT (4E10.2)
      WRITE (MM,1025)
 1025 FORMAT (1H0,59X,*FLIGHT PLAN DATA*/ 58X,10(2H- ))
      WRITE (MM,1030)DTA,DTT,HO,VCL,RC,MCR,HCR
 1030 FORMAT (1H0,46X,*INS ALIGNMENT TIME    =*,F8.2,4X,*MINUTES*//47X,
     1          *TAXI TIME*,13X,*=*,F8.2,4X,*MINUTES*//47X,
     2          *AIRPORT ELEVATION*,5X,*=*,F8.0,4X,*FEET*//47X,
     3         *A/C CLIMB SPEED*,7X,*=*,F8.0,4X,*KNOTS*//47X,
     4          *A/C RATE OF CLIMB*,5X,*=*,F8.0,4X,*FT/MIN*//47X,
     5          *CRUISE MACH NUMBER*,4X,*=*,F8.3//47X,*CRUISE ALTITUDE*,
     6          7X,*=*,F8.0,4X,*FEET*//
     7          /61X,*ROUTE OF FLIGHT *//20X,*WAYPOINT *,14X,*LATITUDE*,
     8          14X,*LONGITUDE*,14X,*WIND DIRECTION*,14X,*WIND SPEED*/
     9        44X,*(DEG)*,18X,*(DEG)*,21X,*(DEG)*,20X,*(KTS)*//)
      DO 100 I=1,NWPTS
      XLAT=ABS(LAT(I))
      XLON=ABS(LON(I))
      NORS=NORTH
      EORW=WEST
      IF (LAT(I).LT.0.0) NORS=SOUTH
      IF (LON(I).GT.0.0) EORW=EAST
  100 WRITE (MM,105) I,XLAT,NORS,XLON,EORW,THETAW(I),VW(I)
  105 FORMAT (23X,I2,16X,F7.2,A2,14X,F7.2,A2,2(20X,F5.1))
      CALL SUBOUT(-2)
C
      READ (NN,35) GYROS,ACCEL,TORQ,GRAVD,ALTSF,SUBOPT,DOPLER,
     1   OMEGA,SATRNG,DREKON
   35 FORMAT (10L5)
      IF (.NOT.DREKON) GO TO 1034
C
      READ (NN,1031) SVWN,SVWE,DVWN,DVWE
 1031 FORMAT (4E10.3)
      WRITE (MM,1032) DVWN,DVWE,SVWN,SVWE
 1032 FORMAT (1H0,50X,*DEAD-RECKONING OPTION*/50X,12(2H- )//3X,
     1   *WIND STATISTICS*,32X,*CORRELATION DISTANCES (NM)*,37X,
     2   *NORTH =*,6X,F7.2/96X,*EAST =*,7X,F7.2//50X,
```

```
     3    *STANDARD DEVIATIONS (KT)*,20X,*NORTH -*,6X,F7,2/95X,
     4    *EAST -*,7X,F7,2//)
      ACCEL=.FALSE.
      GRAVD=.FALSE.
      INS9=,FALSE.
      TWOACC=.TRUE.
      ISYS=2
      GO TO 1047
 1034 WRITE (MM,1035)
 1035 FORMAT (1H0,61X,*I.N.S. DATA*/61X,7(2H- ))
C
      READ (NN,25) ISYS,TWOACC,PHIDOT,AKAP
   25 FORMAT (I1,9X,L10,2E10.3)
      IF (ISYS.EQ.1.OR.ISYS.EQ.4) TWOACC=.FALSE.
      IF (TWOACC) N=2
      IF (.NOT.TWOACC) N=3
      IF (TWOACC) INS9=.FALSE.
      IF (.NOT.TWOACC) INS9=.TRUE.
      IF (INS9) M=9
      IF (.NOT.INS9) M=7
      WRITE (MM,1040)N,ISYS,(TOS(I,ISYS),I=1,2), M
 1040 FORMAT (1H0,15X,I2,*- ACCELEROMETER CASE*,13X,*TYPE*,I2,
     1           * SYSTEM*,7X,2A8,    8X,I2,* - STATE VARIABLE I.N.S. *,
     2           *MODEL*)
      IF (ISYS.NE,5) GO TO 1047
      WRITE (MM,1045) PHIDOT
 1045 FORMAT (1H ,48X,*AZIMUTH ROTATION RATE -*, F8.3,* RAD/SEC*)
C
 1047 READ(NN,30) ENO,EEO,EDO,DLAO,DLOO,DHO,RDLAO,RDLOO,RDHO
   30 FORMAT (8E10.2)
      WRITE (MM,1050)ENO,EEO,EDO,DLAO,DLOO,DHO,RDLAO,RDLOO,RDHO
 1050 FORMAT (1H0,3X,*INITIAL CONDITIONS*,29X,*PLATFORM TILT ANGLES*,
     1           25X,*NORTH -*,6X,F7.2,* (ARC-MIN)*/9X,*(1-SIGMA)*,78X,
     2           *EAST  -*,6X,F7.2,* (ARC-MIN)*/96X,*DOWN  -*,6X,F7.2,
     3          * (ARC-MIN)*//51X,*POSITION ERRORS*,30X,*LATITUDE  -*,2X,
     4         F7,2,* (ARC-MIN)* /96X,*LONGITUDE -  *,F7,2* (ARC-MIN)*,/
     5           96X,*ALTITUDE  -  *,F7,2,* (FEET)*//51X,*RATE ERRORS*,
     6     34X,*LATITUDE  -  *,F7,2,* (ARC-MIN/MIN)*/96X,*LONGITUDE -  *,
     7     F7,2,* (ARC-MIN/MIN)*/96X,*ALTITUDE  -  *,F7.2,* (FEET/MIN)*//)
      IF (GYROS,OR.ACCEL.OR,TORQ.OR,GRAVD.OR.ALTSF) WRITE (MM,1055)
 1055 FORMAT (1H ,97X,*X*,12X,*Y*,12X,*Z*)
C
      IF (.NOT.GYROS) GO TO 1065
C
      READ (NN,40) TGX,TGY,TGZ,SGX,SGY,SGZ,QWGX,QWGY,QWGZ
   40 FORMAT (8E10.2)
      WRITE (MM,1060)TGX,TGY,TGZ,SGX,SGY,SGZ,QWGX,QWGY,QWGZ
 1060 FORMAT (1H0,3X,*GYRO DRIFT UNCERTAINTIES*,11X,*CORRELATION TIMES*,
     1     * OF CORRELATED NOISE (MIN)*,6X,3F13,2/39X,
     2     *S,D. OF CORRELATED NOISE (ARC-MIN)*,15X,3F13,3/39X,
     3     *STRENGTH OF RANDOM NOISES (ARC-MIN2/HR)*,14X,3E13,4)
 1065 IF (.NOT.ACCEL) GO TO 1075
   45 FORMAT (8E10.2)
      READ (NN,45) TAX,TAY,TAZ,SAX,SAY,SAZ,QWAX,QWAY,QWAZ
C
      WRITE (MM,1070)TAX,TAY,TAZ,SAX,SAY,SAZ,QWAX,QWAY,QWAZ
```

```
1070 FORMAT (1H0,3X,*ACCELEROMETER MEASUREMENT*,10X,*CORRELATION*,
    1     * TIMES OF CORRELATED NOISE (MIN)*,12X,2(F7.2,6X),F7.2/ 9X,
    2    *UNCERTAINTIES*,17X,*S.D. OF CORRELATED NOISE (G)*,25X,
    3     3E13.4              / 39X,*STRENGTH OF RANDOM NOISE (FT2/SEC3)*,
    4    18X,3E13.4)
1075 IF (.NOT.TORQ) GO TO 1085
C
     READ (NN,50) TAUX,TAUY,TAUZ
  50 FORMAT (3E10.4)
     WRITE (MM,1080)TAUX,TAUY,TAUZ
1080 FORMAT (1H0,3X,*GYRO TORQUER SCALE*,17X,*STANDARD DEVIATION (PER*,
    1     *CENT)*,27X,2(F7.4,6X),F7.4/9X,*FACTOR ERRORS*)
1085 IF (.NOT.GRAVD) GO TO 1100
C
     READ (NN,55) SVX,SVY,SVZ,DX,DY,DZ
  55 FORMAT (6E10.2)
     WRITE (MM,1090)SVX,SVY,SVZ,DX,DY,DZ
1090 FORMAT (1H0,3X,*GEODETIC UNCERTAINTIES*,13X,
    1     *STANDARD DEVIATION (G)*,31X,3E13.4/39X,
    2    *CORRELATION DISTANCES (NM)*,28X,
    4     2(F8.2,5X),F8.2)
C
1100 IF (DTA.EQ.0.0.OR.DREKON) GO TO 1200
C
     READ (NN,65) SALIN1,SALIN2
  65 FORMAT (2E10.2)
     WRITE (MM,1217)SALIN1,SALIN2
1217 FORMAT(1H0,3X,*ALIGNMENT RANDOM ERRORS*,12X,*STANDARD *,
    1    *DEVIATION (KNOTS)*,23X,2F13.4)
1200 IF (.NOT.ALTSF) GO TO 1210
C
     READ (NN,60) TAUH,SALT,TAUHD,SALTD
  60 FORMAT (4E10.2)
     WRITE (MM,1205)TAUH,SALT,TAUHD,SALTD
1205 FORMAT (1H0,3X,*ALTIMETER SCALE FACTOR ERROR*,7X,*STANDARD *,
    1     *DEVIATION -*,F7.3,* PERCENT*/ 4X,*ALTIMETER RANDOM ERROR*,
    2     13X,*STANDARD DEVIATION -*,F7.3,* FT*//
    3    4X,*V.S.I. SCALE FACTOR ERROR*,10X,*STANDARD *,
    4    *DEVIATION -*,F7.3,* PERCENT*/4X,*V.S.I. RANDOM ERROR*,
    5    16X,*STANDARD DEVIATION -*,F7.3,* FT/MIN*)
C
1210 IF (INS9) WRITE (MM,1215) AKAP
1215 FORMAT (1H0,3X,*INERTIAL ALTITUDE WEIGHTING FACTOR -*,F8.3)
C
C
     IF (DOPLER.OR.OMEGA.OR.SATRNG) 1218,1260
1218 CALL SUBOUT(-2)
     IF (.NOT.DOPLER) GO TO 1230
     WRITE (MM,1220)
1220 FORMAT (1H0,55X,*DOPPLER MEASUREMENT DATA*/55X,14(2H= )//72X,
    1     *FORWARD*,18X,*SIDEWISE*)
C
     READ (NN,70) TDF,TDS,SNDF,SNDS,SBDF,SBDS,SRDF,SRDS,DTDOP
  70 FORMAT (8E10.3)
     WRITE (MM,1225) TDF,TDS,SNDF,SNDS,SBDF,SBDS,SRDF,SRDS,DTDOP
1225 FORMAT (1H0,3X,*CORRELATION TIMES OF CORRELATED NOISE (MIN)*,24X,
```

```
     1     F7.3,19X,F7.3//4X,*S.D. OF CORRELATED NOISE (KTS)*,37X,F7.3,
     2      19X,F7.3//4X,*S.D. OF SCALE FACTOR ERRORS (()*,36X,F7.3,
     3     19X,F7.3,//4X,*S.D. OF MEASUREMENT ERRORS (KTS)*,35X,F7.3,
     4     19X,F7.3//4X, *INTERVAL BETWEEN MEASUREMENTS -*,F8.3,
     5     * MINUTES*)
1230 IF (.NOT. OMEGA) GO TO 1245
     WRITE (MM,1235)
1235 FORMAT (1H0,56X,*OMEGA MEASUREMENT DATA*/56X,13(2H- )//70X,
     1      *FIRST L.O.P.*,12X,*SECOND L.O.P.*)
C
     READ (NN,75) IOM1,IOM2,IOM3,IOM4,TOM1,TOM2,SNOM1,SNOM2,SBOM1,
     2     SBOM2,SROM1,SROM2,DTOM
  75 FORMAT (4(I1,4X),6E10.3/8E10.3)
     WRITE (MM,1240) (STAT(I,IOM1),I=1,2),(STAT(I,IOM3),I=1,2),
     1                   (STAT(I,IOM2),I=1,2),(STAT(I,IOM4),I=1,2),TOM1,
     2      TOM2,SNOM1,SNOM2,SROM1,SBOM2,SROM1,SROM2,DTOM
1240 FORMAT (1H0,3X,*OMEGA STATIONS*,54X,A8,A2,14X,A8,A2/ 72X,A8,A2,
     1     14X,A8,A2//
     1      4X,*CORRELATION TIMES (MIN)*,45X,F7.3,17X,F7.3//4X,*S.D. OF*,
     2      * CORRELATED NOISE (MICRO-SEC)*,32X,F7.3,17X,F7.3//4X,*S.D.*,
     3      * OF BIAS ERRORS (MICRO-SEC)*,37X,F7.3,17X,F7.3//4X,*S.D.*,
     4      * OF RANDOM ERRORS (MICRO-SEC)*,35X,F7.3,17X,F7.3//4X,
     5      *INTERVAL BETWEEN MEASUREMENTS  -*,F8.3,* MINUTES*)
1245 IF (.NOT. SATRNG) GO TO 1260
     WRITE (MM,1250)
1250 FORMAT (1H0,56X,*SATELLITE RANGING DATA*/56X,13(2H- )//72X,
     1      *SATELLITE 1*,14X,*SATELLITE 2*)
C
     READ (NN,80)SATLON,TSAT1,TSAT2,SNSAT1,SNSAT2,SBSAT1,SBSAT2,
     1     SRSAT1,SRSAT2,DTSAT
  80 FORMAT (8E10.2)
     WRITE (MM,1255)SATLON,SNSAT1,SNSAT2,TSAT1,TSAT2,SBSAT1,
     1      SBSAT2,SRSAT1,SRSAT2,DTSAT
1255 FORMAT (1H0,3X,*LONGITUDE (DEG)*,54X,F7.2,18X,F7.2//4X,
     1      *CORRELATION TIMES (MIN)*,46X,F7.2,18X,F7.2,
     2     //4X,*S.D. OF CORRELATED NOISE (MICRO-SEC)*,33X,F7.2,18X,
     3     F7.2//4X,*S.D. OF BIAS ERRORS (MICRO-SEC)*,38X,F7.2,18X,F7.2/
     5     /4X,*S.D. OF RANDOM ERRORS (MICRO-SEC)*,36X,F7.2,18X,F7.2/4X,
     6     *INTERVAL BETWEEN MEASUREMENTS  -*,F8.3,* MINUTES*)
C
1260 IF (.NOT.SUBOPT) GO TO 1400
     READ (NN,85) NK,TBLUND
  85 FORMAT (I2,8X,E10.2)
     READ (NN,90) (TSUBK(I),I=1,NK)
  90 FORMAT (8E10.2)
     CALL SUBOUT(-2)
     IF (TBLUND.LE.0.0) GO TO 1264
     WRITE (MM,1261)TBLUND
1261 FORMAT (1H0,50X,*BLUNDER/MALFUNCTION AT T = *,F7.2)
     SUBOPT=.FALSE.
1264 WRITE (MM,1265)
1265 FORMAT (1H0,56X,*SUBOPTIMUM GAINS USED*/56X,13(2H- )//)
     LINE=4
     IF (.NOT.DOPLER) GO TO 1310
     DO 1268 I=1,NK
     READ (NN,90)  (KSUBDF(I,J),J=1,34)
```

```
1260 READ (NN,90)  (KSUBDS(I,J),J=1,34)
     WRITE(MM,1270)
1270 FORMAT(1H0,5X,*FORWARD DOPPLER MEASUREMENT GAINS :*)
     LINE=LINE+2
     DO 1280 I=1,NK
     IF (LINE.GE.54) CALL SUBOUT(-2)
     WRITE (MM,1285) TSUBK(I),(KSUBDF(I,J),J=1,34)
1280 LINE=LINE+4
1285 FORMAT(9H0*** T = ,F5.1,8H MIN ***,1X,10E11.3/(1X,12E11.4))
     WRITE (MM,1290)
1290 FORMAT (1H0,5X,*SIDEWISE DOPPLER MEASUREMENT GAINS :*)
     LINE=LINE+2
     DO 1300 I=1,NK
     IF (LINE.GE.54) CALL SUBOUT(-2)
     WRITE (MM,1285) TSUBK(I),(KSUBDS(I,J),J=1,34)
1300 LINE=LINE+4
1310 IF (.NOT.OMEGA) GO TO 1350
     DO 1315 I=1,NK
     READ (NN,90)  (KSUBO1(I,J),J=1,34)
1315 READ (NN,90)  (KSUBO2(I,J),J=1,34)
     WRITE (MM,1320)
1320 FORMAT (1H0,5X,*FIRST OMEGA L.O.P. GAINS :*)
     LINE=LINE+2
     DO 1330 I=1,NK
     IF (LINE.GE.54) CALL SUBOUT(-2)
     WRITE (MM,1285) TSUBK(I),(KSUBO1(I,J),J=1,34)
1330 LINE=LINE+4
     WRITE (MM,1335)
1335 FORMAT (1H0,5X,*SECOND OMEGA L.O.P. GAINS :*)
     LINE=LINE+2
     DO 1340 I=1,NK
     IF (LINE.GE.54) CALL SUBOUT(-2)
     WRITE (MM,1285) TSUBK(I),(KSUBO2(I,J),J=1,34)
1340 LINE=LINE+4
1350 IF (.NOT.SATRNG) GO TO 1400
     DO 1355 I=1,NK
     READ (NN,90)  (KSUBS1(I,J),J=1,34)
1355 READ (NN,90)  (KSUBS2(I,J),J=1,34)
     WRITE (MM,1360)
1360 FORMAT (1H0,5X,*FIRST SATELLITE RANGING GAINS :*)
     LINE=LINE+2
     DO 1370 I=1,NK
     IF (LINE.GE.54) CALL SUBOUT(-2)
     WRITE (MM,1285) TSUBK(I),(KSUBS1(I,J),J=1,34)
1370 LINE=LINE+4
     WRITE (MM,1380)
1380 FORMAT (1H0,5X,*SECOND SATELLITE RANGING GAINS :*)
     LINE=LINE+2
     DO 1390 I=1,NK
     IF (LINE.GE.54) CALL SUBOUT(-2)
     WRITE (MM,1285) TSUBK(I),(KSUBS2(I,J),J=1,34)
1390 LINE=LINE+4
1400 CONTINUE
C
     RETURN
     END
```

```
      SUBROUTINE SUBOUT(MEAS)
C
C
C                THIS SUBROUTINE PRINTS THE STD.DEV. OF THE ERRORS
C                IN A TRACK-BASED COORDINATE SYSTEM, AND SETS THE PLO
C                DATA IF REQUIRED.
C
      COMMON/BALT/TAUH,SALT,TAUHD,SALTD
      COMMON /BCONST/RADPDG,DEGPRD,FTPNM,NMPFT, MINPRD, OMIE
      COMMON /BCOVAR/ P(34,34)
      COMMON / BINS1/ISYS,EE0, EN0,ED0,DLA0,DLO0,RDLA0,RDLO0,DH0,
     1           RDH0,AKAP, PHIDOT, OMS2,FN,FE, FD
      COMMON /BINS2/TGX,TGY,TGZ,QWGX,QWGY,QWGZ,SGX,SGY,SGZ,
     1           QVGX,QVGY,QVGZ,TAX,TAY,TAZ,QWAX,QWAY,QWAZ,
     2           SAX,SAY,SAZ,QVAX,QVAY,QVAZ,TAUX,TAUY,TAUZ,
     3           DX,DY,DZ,SVX,SVY,SVZ,QVX,QVY,QVZ,QWH
      COMMON /BLOGIC/ GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,
     1           DOPLER,OMEGA,SATRNG,SUBOPT,DREKON
      COMMON /BLU/NN,MM
      COMMON /BNOM/ NPHASE,H,HDOT,ALATR,ALAT,ALON,ALONR, ALB,
     1           ALBDOT, VG, VA, VELN, VELE, VELW, TRK, HDG, CRB,
     2           THW, R, RI, RI2, G, SL, CL, TL, SL2, CL2, CLI,
     3           RICLI, CTRK,STRK, ALAT2, CHDG, SHDG,RCL
      COMMON /BPLOT/ DTPLOT,NPLOT,NTAPE
      COMMON /BTIME/ TIME
      COMMON /BTITLE/ TITLE(10), NRUN,NPAGE,DTOUT,LINE,MO,IDAY,IYEAR
      DIMENSION TYPE(3)
      REAL  NMPFT,MINPRD
      INTEGER TIMEH,TIMEM
      LOGICAL  GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC, DOPLER,OMEGA,
     1   SATRNG,SUBOPT,DREKON
      DATA (TYPE=8H  DOPLER,8H   OMEGA,8HSAT.RNG.)
      DATA (NORTH=2H N),(SOUTH=2H S),(EAST=2H E),(WEST=2H W)
C
      IF (MEAS.EQ.-2) GO TO 110
      IF (LINE.LT.50) GO TO 140
C                               OUTPUT HEADING
  110 LINE=0
      WRITE(MM,1011) TITLE,MO,IDAY,IYEAR,NRUN,NPAGE
 1011 FORMAT (*1PROGRAM NATNAV: *,10A8,2X,I2,*/*,I2,*/*,I2,3X,
     1   *RUN NO.*,I4,3X,*PAGE*,I4)
      NPAGE=NPAGE+1
      IF (MEAS.EQ.-2) RETURN
      WRITE (MM,130)
  130 FORMAT (1H0,1X,*TIME*,5X,*LAT*,6X,*LON*,5X,*TRK*,6X,*EPSN*,
     1   5X,*EPSE*,5X,*EPSD*,7X,*DX*,7X,*DY*,7X,*DH*,
     2   6X,*DXDOT*,4X,*DYDOT*,5X,*DHDOT*/2X,*(HR)*,
     3   4X,*(DEG)*,4X,*(DEG)*,3X,*(DEG)*,5X,*(MIN)*,4X,*(MIN)*,
     4   4X,*(MIN)*,5X,*(NM)*,5X,*(NM)*,5X,*(FT)*,
     5   5X,*(KTS)*,4X,*(KTS)*,3X,*(FT/MIN)*/)
C
C                  CONVERT UNITS FOR PRINTOUT
  140 TIMEH=INT(TIME/59.9999)
      TIMEM=TIME-TIMEH*60
      RNM=R*NMPFT
      ALATD=ABS(ALAT)*DEGPRD
```

```
      ALOND=ABS(ALON)*DEGPRD
      NORS=NORTH
      IF (ALAT.LT.0.0) NORS=SOUTH
      EORW=WEST
      IF (ALON.GT.0.0) EORW=EAST
      TRKD=TRK*DEGPRD
      EN=SQRT(ABS(P(1,1)))*MINPRD
      EE=SQRT(ABS(P(2,2)))*MINPRD
      ED=SQRT(ABS(P(3,3)))*MINPRD
      CH2=CTRK*CTRK
      SH2=STRK*STRK
      CLL=CL*CL
      DLA2=ABS(P(4,4))
      DL02=ABS(P(5,5))
      TEMP=2.0*P(4,5)*STRK*CTRK*CL
      XX=RNM*SQRT(ABS(DLA2*CH2+DL02*SH2*CLL+TEMP))
      YY=RNM*SQRT(ABS(DLA2*SH2+DL02*CH2*CLL-TEMP))
      DVN2=ABS(P(6,6))
      DVE2=ABS(P(7,7))
      TEMP=2.0*P(6,7)*STRK*CTRK*CL
      DXDOT=RNM*60.*SQRT(ABS(DVN2*CH2+DVE2*SH2*CLL+TEMP))
      DYDOT=RNM*60.*SQRT(ABS(DVN2*SH2+DVE2*CH2*CLL-TEMP))
C                      VERTICAL ESTIMATES
      IF (NPHASE.GT.1) GO TO 200
      DVD=RDHO
      DALT=DHO
      GO TO 220
  200 DVD=SQRT((HDOT*TAUHD*0.01)**2+SALTD*SALTD)
      DALT=SQRT(H*H*ABS(P(22,22))+QWH)
  220 IF (INS9) DVD=SQRT(ABS( P(9,9)))/60.0
C
      IF (MEAS.GT.0) GO TO 300
      WRITE (MM,150) TIMEH,TIMEM,ALATD,NORS,ALOND,EORW,TRKD,
     1       EN,EE,ED,XX,YY,DALT,DXDOT,DYDOT,DVD
  150 FORMAT (1H ,I2,1H:,I2,1X,2(F7.2,A2),F7.2,1X,3F9.4,1X,2F9.3,F9.1,
     1     1X,2F9.3,F9.1)
      GO TO 500
      LINE=LINE+1
      GO TO 500
C
  300 WRITE (MM,350) TYPE(MEAS),EN,EE,ED,XX,YY,DALT,DXDOT,DYDOT,DVD
  350 FORMAT(17X,A8,7H MEAS.-,1X,3F9.4,1X,2F9.3,F9.1,1X,2F9.3,F9.1/)
      LINE=LINE+2
C                                SET PLOT OUTPUT
  500 IF (NPLOT.EQ.0) RETURN
      TEMP=TIME/60.
      WRITE (NTAPE) TEMP,EN,EE,ED,DALT,XX,YY,DVD,DXDOT,DYDOT
      NPLOT=NPLOT+1
      RETURN
      END
```

```
      SUBROUTINE CONFIG
C
C                    THIS SUBROUTINE SETS THE INDICES KK OF THE NEQ
C                    DIFFERENTIAL EQUATIONS FOR THE COVARIANCE MATRIX
C                    OF THE SPECIFIED AIDED I.N.S. CONFIGURATION.
C             THE CORRESPONDENCE BETWEEN THE STATE VECTOR S AND THE
C             COVARIANCE MATRIX P IS
C
C                           S(K) = P(I,J)
C
C             THE ELEMENTS OF THE I.N.S. STATE ARE SELECTED FOR THE
C             DESIRED MODEL BY MEANS OF THE LOGICAL PARAMETERS  GYROS,
C             ACCEL, TORQ, ALTSF, GRAVD, INS9, DOPLER,OMEGA,SATRNG.
C
C             THE 28 EQNS OF A  7-STATE I.N.S. ARE ALWAYS INCLUDED IN S
C
      COMMON /BINDEX/ II(585), JJ(585), KK(585)
      COMMON /BINTEG/ S(585),SD(585), DT,DT05,NEQ
      COMMON /BLOGIC/ GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,
     1                DOPLER,OMEGA,SATRNG,SUBOPT,DREKON
      LOGICAL GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,DOPLER,OMEGA,
     1                 SUBOPT,SATRNG,DREKON
C
C                    7-STATE I.N.S.
      NEQ=0
      CALL EQNS(1,28)
C                    THREE GYRO DRIFT STATES
      IF (GYROS) CALL EQNS (29,55)
C                    TWO ACCELEROMETER UNCERTAINTIES
  120 IF(.NOT.ACCEL) GO TO 130
      L2=72
      IF (GYROS) L2=78
      CALL EQNS (56,L2)
C                    THREE GYRO TORQUER ERRORS
      L2=102
  130 IF (.NOT.TORQ) GO TO 140
      IF (GYROS) L2=111
      CALL EQNS (79,L2)
      IF (ACCEL) CALL EQNS (112,117)
C                    ALTIMETER SCALE FACTOR ERROR
  140 IF (.NOT.ALTSF) GO TO 150
      L2=124
      IF (GYROS) L2=127
      CALL EQNS (118,L2)
      IF (ACCEL) CALL EQNS (128,129)
      IF (TORQ) CALL EQNS (130,132)
C                    TWO GRAVITATIONAL DEFLECTIONS
  150 IF (.NOT.GRAVD) GO TO 160
      L2=149
      IF (GYROS) L2=155
      CALL EQNS (133,L2)
      IF (ACCEL) CALL EQNS (156,159)
      IF (TORQ) CALL EQNS (160,165)
      IF (ALTSF) CALL EQNS (166,167)
C                    DOPPLER MEASUREMENT ERRORS
  160 IF (.NOT.DOPLER) GO TO 170
```

```
      L2=203
      IF (GYROS) L2=215
      CALL EQNS (168,L2)
      IF (ACCEL) CALL EQNS (216,223)
      IF (TORQ) CALL EQNS (224,235)
      IF (ALTSF) CALL EQNS(236,239)
      IF (GRAVD) CALL EQNS (240,247)
C                         OMEGA MEASUREMENT ERRORS
  170 IF (.NOT.OMEGA) GO TO 180
      L2=283
      IF (GYROS) L2=295
      CALL EQNS (248,L2)
      IF (ACCEL) CALL EQNS (296,303)
      IF (TORQ) CALL EQNS (304,315)
      IF (ALTSF) CALL EQNS (316,319)
      IF (GRAVD) CALL EQNS (320,327)
      IF (DOPLER) CALL EQNS (328,343)
C                         SATTELITE RANGING ERRORS
  180 IF (.NOT.SATRNG) GO TO 190
      L2=379
      IF (GYROS) L2=391
      CALL EQNS (344,L2)
      IF (ACCEL) CALL EQNS (392,399)
      IF (TORQ) CALL EQNS (400,411)
      IF (ALTSF) CALL EQNS (412,415)
      IF (GRAVD) CALL EQNS (416,423)
      IF (DOPLER) CALL EQNS (424,439)
      IF (OMEGA) CALL EQNS (440,455)
C                         9-STATE I.N.S.
  190 IF (.NOT.INS9) GO TO 300
      L2=472
      IF (GYROS) L2=478
      CALL EQNS (456,L2)
      IF (.NOT.ACCEL) GO TO 200
      L2=494
      IF (GYROS) L2=497
      CALL EQNS (479,L2)
  200 IF (.NOT.TORQ) GO TO 210
      L2=503
      IF (ACCEL) L2=506
      CALL EQNS (498,L2)
  210 IF (.NOT.ALTSF) GO TO 220
      L2=508
      IF (ACCEL) L2=509
      CALL EQNS (507,L2)
  220 IF (.NOT.GRAVD) GO TO 230
      L2=525
      IF (GYROS) L2=528
      CALL EQNS (510,L2)
      IF (ACCEL) CALL EQNS (529,533)
      IF (TORQ) CALL EQNS (534,536)
      IF (ALTSF) CALL EQNS (537,537)
  230 IF (.NOT.DOPLER) GO TO 240
      L2=545
      IF (ACCEL) L2=549
      CALL EQNS (538,L2)
```

```
      IF (GRAVD) CALL EQNS (550,553)
 240  IF (.NOT.OMEGA) GO TO 250
      L2=561
      IF (ACCEL) L2=565
      CALL EQNS (554,L2)
      IF (GRAVD) CALL EQNS(566,569)
 250  IF (.NOT.SATRNG) GO TO 300
      L2=577
      IF (ACCEL) L2=581
      CALL EQNS (570,L2)
      IF (GRAVD) CALL EQNS (582,585)
C
 300  CONTINUE
      RETURN
      END
```

```
      SUBROUTINE EQNS (L1,L2)
C
C                    THIS SUBROUTINE SETS THE INDICES FOR THOSE EQNS TO
C                    BE INTEGRATED IN THE ARRAY KK.  NEQ IS THE TOTAL
C                    NO. OF EQNS TO BE INTEGRATED.  IT ALSO INITIALIZES
C                    THE ARRAY TO BE INTEGRATED, S(L).
C
      COMMON /BCOVAR/ P(34,34)
      COMMON /BINDEX/ II(585), JJ(585), KK(585)
      COMMON /BINTEG/ S(585),SD(585), DT,DT05,NEQ
C
C                    INDICES FOR COVARIANCE MATRIX
      DATA ((II(I),I=1,347) =
     1    7(1),6(2),5(3),4(4),3(5),2(6),7,3(1),3(2),3(3),3(4),3(5),3(6),
     2    3(7),3(10),2(11),12,2(1),2(2),2(3),2(4),2(5),2(6),2(7),2(13),
     2    14,2(10),2(11),2(12),3(1),3(2),3(3),3(4),3(5),3(6),3(7),2(16),
     3    17,3(10),3(11),3(12),3(13),3(14),1,2,3,4,5,6,7,10,11,12,13,14,
     4    16,17,18,2(1),2(2),2(3),2(4),2(5),2(6),2(7),2(19),20,2(10),
     5    2(11),2(12),2(13),2(14),2(16),2(17),2(18),19,20,4(1),
     6    4(2),4(3),4(4),4(5),4(6),4(7),3(23),3(24),25,26,4(10),4(11),
     7    4(12),4(13),4(14),4(16),4(17),4(18),4(22),4(19),4(20),4(1),
     8    4(2),4(3),4(4),4(5),4(6),4(7),3(27),3(28),29,30,4(10),4(11),
     9    4(12),4(13),4(14),4(16),4(17),4(18),4(22),4(19),4(20),4(23),
     1    4(24),4(25),4(26),4(1))
      DATA ((II(I),I=348,585) =
     1    4(2),4(3),4(4),4(5),4(6),4(7),3(31),3(32),33,34,4(10),4(11),
     2    4(12),4(13),4(14),4(16),4(17),4(18),4(22),4(19),4(20),4(23),
     3    4(24),4(25),4(26),4(27),4(28),4(29),4(30),2(1),2(2),2(3),2(4),
     4    2(5),2(6),2(7),2(8),9,3(8),3(9),1,2,3,4,5,6,7,3(8),3(9),3(15),
     5    8,9,15,1,2,3,4,5,6,7,3(8),3(9),19,20,21,10,11,12,13,14,3(15),
     6    16,17,18,21,4(8),4(9),4(15),4(21),4(8),4(9),4(15),4(21),4(8),
     7    4(9),4(15),4(21))
      DATA (JJ=1,2,3,4,5,6,7,2,3,4,5,6,7,3,4,5,6,7,4,5,6,7,5,6,7,6,7,7,
     1    8(10,11,12),11,2(12),8(13,14),14,3(13,14),7(16,17,18),
     2    17,2(18),5(16,17,18),15(22),8(19,20),20,8(19,20),2(22),
     3    7(23,24,25,26),2(24,25,26),2(26),11(23,24,25,26),
     4    7(27,28,29,30),2(28,29,30),2(30),15(27,28,29,30),
     5    7(31,32,33,34),2(32,33,34),2(34), 19(31,32,33,34),
     6    8(8,9),9,2(10,11,12),7(15),2(13,14,15),6(15),3(16,17,18),
     7    3(22),7(21),2(19,20,21),8(21),19,20,4(21),22,4(23,24,25,26),
     8    4(27,28,29,30),4(31,32,33,34))
C
      DO 100 L=L1,L2
      I=II(L)
      J=JJ(L)
      NEQ=NEQ+1
      KK(NEQ)=L
  100 S(NEQ)=P(I,J)
C
      RETURN
      END
```

```
      SUBROUTINE FLTPLN(T)
C
C                 THIS SUBROUTINE CALCULATES THE NOMINAL POSISION,
C                 VELOCITY, ETC, OF THE AIRCRAFT AS FUCTIONS OF
C                 TIME,  A NEW WAYPOINT IS DEFINED AT THE BEGINNING OF
C                 THE PHASES OF THE FLIGHT ARE
C           NPHASE = 0          INS ALIGNMENT
C           NPHASE = 1          TAXI
C           NPHASE = 2          CLIMBOUT
C           NPHASE = 3          CRUISE
C           NPHASE = 4          END OF FLIGHT
C
      COMMON /BCONST/RADPDG,DEGPRD,FTPNM,NMPFT, MINPRD, OMIE
      COMMON / BFLTPN/ DTA,DTT, H0, VCL,RC,MCR,HCR,NWPTS, LAT(20),
     1                 LON(20), THETAW(20), VW(20), TCR, TM(20), VN(20),
     2                 VE(20)
      COMMON /BINIT/ INIT
      COMMON /BNOM/ NPHASE,H,HDOT,ALATR,ALAT,ALON,ALONR, ALB,
     1               ALBDOT, VG, VA, VELN, VELE, VELW, TRK, HDG, CRB,
     2               THW, R, RI, RI2, G, SL, CL, TL, SL2, CL2, CLI,
     3               RICLI, CTRK,STRK, ALAT2, CHDG, SHDG,RCL
C
      REAL MCR,LAT,LON,NMPFT,MINPRD
      LOGICAL INIT
      DATA (OMIE=4.37527E-3)
      RADIUS(X)=20925732.-70173.396*SIN(X)**2
C
      ALNF(X1,X2)=ALOG(COS(X1)*(1.+SIN(X2))/(COS(X2)*(1.+SIN(X1))))
      IF (.NOT.INIT) GO TO 120
C
C     INITIALIZATION
      NPHASE=0
      CONV=FTPNM/60.
      DO 15 I=1,NWPTS
      LAT(I)=LAT(I)*RADPDG
      LON(I)=LON(I)*RADPDG
      VW(I)=VW(I)*CONV
   15 THETAW(I)=THETAW(I)*RADPDG
      VCR=MCR*A(HCR)*CONV
      VCL=VCL*CONV
      TM(1)=DTA+DTT
      TCR=(HCR-H0)/RC+TM(1)
C
C     CALCULATE TIMES AT WAYPOINTS
      I=2
C
C     AVERAGE WIND
   10 J=I-1
      THETAW(J)=.5*(THETAW(J)+THETAW(I))
      VW(J)=.5*(VW(J)+VW(I))
      IF (TM(J).GE.TCR) 30,20
C
C     CLIMB PHASE
   20 VA=VCL
      H=H0+RC*(TM(J)-TM(1))
      MU=1
```

```
      GO TO 40
C
C     CRUISE PHASE
  30  VA=VCR
      H=HCR
      MU=0
C
  40  DLON=LON(I)-LON(J)
      DLAT=LAT(I)-LAT(J)
      R= RADIUS(.5*(LAT(I)+LAT(J)))+H
      IF (DLAT.EQ.0.) TRK    = SIGN(1.570796,DLON)
      IF (DLAT.NE.0.) TRK    =ATAN2( DLON,ALNF(LAT(J),LAT(I)))
      ALPHA=THETAW(J)-TRK
      CRB    =+ASIN(VW(J)*SIN(ALPHA)/VA)
      HDG    =TRK    +CRB
      VG=VA*COS(CRB    )-VW(J)*COS(ALPHA)
      VN(J)=VG*COS(TRK    )
      VE(J)=VG*SIN(TRK    )
      IF (DLAT.EQ.0.) TM(I)=TM(J)     +DLON*R*COS(LAT(I))/VE(J)
      IF (DLAT.NE.0.) TM(I)=TM(J)     +R*DLAT/VN(J)
  70  IF (MU.EQ.0) GO TO 115
      IF (TM(I)-TCR) 110,110,80
C
C     NEW WAYPOINTS AT END OF CLIMB
  80  DO 90 JJ=I,NWPTS
      K=NWPTS+I-JJ
      KK=K+1
      LAT(KK)=LAT(K)
      LON(KK)=LON(K)
      THETAW(KK)=THETAW(K)
  90  VW(KK)=VW(K)
      NWPTS=NWPTS+1
      LAT(I)=LAT(J)+VN(J)*(TCR-TM(J))/R
      TM(I)=TCR
      THETAW(I)=2.*THETAW(J)-THETAW(I)
      VW(I)=2.*VW(J)-VW(I)
      IF (DLAT.EQ.0.) GO TO 100
      LON(I)=LON(J)+(VE(J)/VN(J))*ALNF(LAT(J),LAT(I))
      GO TO 110
 100  LON(I)=LON(J)+VE(J)/(R*COS(LAT(J)))*(TM(I)-TM(J))
 110  MU=0
 115  IF (I.EQ.NWPTS) GO TO 120
      I=I+1
      GO TO 10
C                     CHECK END OF FLIGHT
 120  IF (T.LT.TM(NWPTS)) GO TO 122
      T=TM(NWPTS)
      NPHASE=4
      I=NWPTS
      GO TO 180
C
 122  IF (T.GE.TM(1)) GO TO 140
      NPHASE=0
      IF (T.GE.DTA) NPHASE=1
      IF (.NOT.INIT) GO TO 130
C
```

```
      H=H0
      ALAT=LAT(1)
      ALON=LON(1)
      ALATR=0.0
      ALONR=0.0
      HDOT=0.0
      ALBDOT=OMIE
      VELW=VW(1)
      THW=THETAW(1)
      VA=0.0
      VG=0.0
      HDG=0,0
      TRK=0,0
      CRB=0,0
      VELN=0.0
      VELE=0.0
  130 ALB=LON(1)+OMIE*T
      GO TO 190
  140 IF (T,LT.TCR) GO TO 150
C
C     CRUISE MODE
      NPHASE=3
      HDOT=0.
      H=HCR
      M=MCR
      VA=VCR
      GO TO 160
C
C     CLIMBOUT MODE
  150 NPHASE=2
      HDOT=RC
      DT=T-TM(1)
      H=H0+HDOT*DT
      M=VCL/(A(H)*CONV)
      VA=VCL
C
  160 I=2
  170 IF (T,LT.TM(I)) GO TO 180
      I=I+1
      GO TO 170
C
  180 J=I-1
      DT=T-TM(J)
      VELN=VN(J)
      VELE=VE(J)
      VG=SQRT(VELN**2+VELE**2)
      IF (VELN.EQ.0.) TRK    =SIGN(1,570796,VELE)
      IF (VELN.NE.0.) TRK    =ATAN2(VELE,VELN)
      THW=THETAW(J)
      VELW=VW(J)
      CRB=ASIN(VELW*SIN(THW-TRK)/VA)
      HDG    =TRK    +CRB
      R= RADIUS(.5*(LAT(J)+LAT(I)))+H
      ALATR=VELN/R
      ALAT=LAT(J)+ALATR*DT
      ALONR=  VELE/(R*COS(ALAT))
```

```
      IF (VELN.EQ.0.) ALON=LON(J)+ALONR*DT
      IF (VELN.NE.0.)ALON=LON(J)+(VELE/VELN)*ALNF(LAT(J),ALAT)
      ALODOT=ALONR+OMIE
      ALR=ALON+OMIE*T
C
 190  CALL EARTH (ALAT,H)
C
      RETURN
      END
```

```
      FUNCTION A(H)
C
C     SPEED OF SOUND FUNCTION  -  A IN KNOTS
C
      DATA (A1=437847.),(A2=3,009)
      IF (H,LE.36089.) A=SQRT(A1-A2*H)
      IF (H,GT.36089.) A=573.8
      END
```

```
      SUBROUTINE EARTH(LAT,ALT)
C
C                    THIS ROUTINE CALCULATES THE APPROXIMATE GEOCENTRIC R
C                    VECTOR AND GRAVITATIONAL ACCELERATION AS FUNCTIONS O
C                    LATTITUDE AND ALTITUDE FOR A REFERENCE ELLIPSOID.
C
C
C                     LAT = LATTITUDE (RADIANS)
C                     ALT = ALTITUDE (FEET)
C                       R = RADIUS (FEET)
C                       G = GRAVITY (FEET/MINUTE/MINUTE)
C
      COMMON /BNOM/ NPHASE,H,HDOT,ALATR,ALAT,ALON,ALONR, ALB,
     1              ALBDOT, VG, VA, VELN, VELE, VELW, TRK, HDG, CRB,
     2              THW, R, RI, RI2, G, SL, CL, TL, SL2, CL2, CLI,
     3              RICLI, CTRK,STRK, ALAT2, CHDG, SHDG,PCL
      REAL LAT
      DATA (RE=20925732.),(F=0.00335345),(GE=32.0881),
     1    (C=0.00529)
C
      SLT2=SIN(LAT)**2
      R=RE*(1.0-F*SLT2)+ALT
C
      G=3600.*GE*(1.0+C*SLT2)*(1.0-1.E-7*ALT)
C
      RETURN
      END
```

```
      SUBROUTINE INS
C
C                 THIS SUBROUTINE INITIALIZES THE I.N.S. VARIABLES,
C                 CALCULATES THE SYSTEM MATRIX ELEMENTS FOR THE
C                 I.N.S., AND SETS THE PROPER TRANSFORMATION
C                 MATRIX AND NOISE VALUES.
C
      COMMON/BALT/TAUH,SALT,TAUHD,SALTD
      COMMON /BCONST/RADPDG,DEGPRD,FTPNM,NMPFT, MINPRD, OMIE
      COMMON /BCOVAR/ P(34,34)
      COMMON /BDRKN/SVWN,SVWE,DVWN,DVWE
      COMMON /BINIT/ INIT
      COMMON / BINS1/ISYS,EEO, ENO,EDO,DLAO,DLOO,RDLAO,RDLOO,DHO,
     1           RDHO,AKAP, PHIDOT, OMS2,FN,FE, FD
      COMMON /BINS2/TGX,TGY,TGZ,QWGX,QWGY,QWGZ,SGX,SGY,SGZ,
     1           QVGX,QVGY,QVGZ,TAX,TAY,TAZ,QWAX,QWAY,QWAZ,
     2           SAX,SAY,SAZ,QVAX,QVAY,QVAZ,TAUX,TAUY,TAUZ,
     3           DX,DY,DZ,SVX,SVY,SVZ,QVX,QVY,QVZ,QWH
      COMMON /BINS3/ C11,C12,C13,C21,C22,C23,C31,C32,C33,
     1            F12,F13,F17,F21,F23,F31,F32,F37,F62,F63,F64,F66,
     2            F67,F68,F69,F71,F73,F74,F76,F77,F78,F79,F91,F92,
     3           F94,F96,F97,F98,WX,WY,WZ
      COMMON /BLOGIC/ GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,
     1           DOPLER,OMEGA,SATRNG,SUBOPT,DREKON
      COMMON /BNOM/ NPHASE,H,HDOT,ALATR,ALAT,ALON,ALONR, ALB,
     1           ALBDOT, VG, VA, VELN, VELE, VELW, TRK, HDG, CRB,
     2           THW, R, RI, RI2, G, SL, CL, TL, SL2, CL2, CLI,
     3           RICLI, CTRK,STRK, ALAT2, CHDG, SHDG,RCL
      COMMON/BTIME/TIME
      REAL NMPFT,MINPRD
      LOGICAL INIT,GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,DOPLER,
     1           OMEGA,SATRNG,SUBOPT,DREKON
C
      SL=SIN(ALAT)
      CL=COS(ALAT)
      TL=SL/CL
      ALAT2=2.*ALAT
      SL2=SIN(ALAT2)
      CL2=COS(ALAT2)
      CLI=1./CL
      RCL=R*CL
      RI=1.0/R
      RI2=RI*RI
      RICLI=RI*CLI
      CLB=COS(ALB)
      SLB=SIN(ALB)
      STRK=SIN(TRK)
      CTRK=COS(TRK)
      SHDG=SIN(HDG)
      CHDG=COS(HDG)
      AL1=ALONR*(ALBDOT+OMIE)
      OMS2=G*RI
      IF (.NOT.INIT) GO TO 100
C
      OMIPNX=0.0
      OMIPNY=0.0
```

```
      OMIPNZ=0.0
C
      PHIDOT=PHIDOT*6.2832
      IF (ISYS.NE.5)  PHIDOT=0.0
C                     TRANSFORMATION MATRIX
      C11=1.
      C12=0.
      C13=0.
      C21=0.
      C22=1.
      C23=0.
      C31=0.
      C32=0.
      C33=1.
C
      F62=F63=F64=F66=F67=F68=F69=0.0
      F71=F73=F74=F76=F77=F78=F79=0.0
      F91=F92=F94=F96=F97=F98=0.0
C
C                     INITIALIZE COVARIANCE MATRIX AND SET NOISE STRENGTHS
C
C
C                     CONVERT ARC-MIN TO RAD
      CONV=1.0/MINPRD
      P(1,1)=(EN0*CONV)**2
      P(2,2)=(EE0*CONV)**2
      P(3,3)=(ED0*CONV)**2
      P(4,4)=(DLA0*CONV)**2
      P(5,5)=(DLO0*CONV)**2
C                     CONVERT ARC-MIN/HR TO RAD/MIN
      CONV=CONV/60.
      P(6,6)=(RDLA0*CONV)**2
      P(7,7)=(RDLA0*CONV)**2
C
      IF (.NOT.INS9) GO TO 20
      P(8,8)=DH0**2
      P(9,9)=(RDH0*60.)**2
C
   20 IF (.NOT.GYROS) 22,25
   22 QWGX=QWGY=QWGZ=0.0
      GO TO 30
C                     CONVERT ARC-MIN2/HR  TO RAD2/MIN
   25 CONV=1.410266E-9
      QWGX=QWGX*CONV
      QWGY=QWGY*CONV
      QWGZ=QWGZ*CONV
C
      TGX=1./TGX
      TGY=1./TGY
      TGZ=1./TGZ
C                     CONVERT ARC-MIN/HR TO RAD/MIN
      CONV=4.848137E-6
      QVGX=2.*TGX*(SGX*CONV)**2
      QVGY=2.*TGY*(SGY*CONV)**2
      QVGZ=2.*TGZ*(SGZ*CONV)**2
C
```

```
      P(10,10)=(SGX*CONV)**2
      P(11,11)=(SGY*CONV)**2
      P(12,12)=(SGZ*CONV)**2
C
   30 IF (.NOT.ACCEL) 32,35
   32 QWAX=QWAY=QWAZ=0.0
      GO TO 40
C                       CONVERT FT2/SEC3 TO FT2/MIN3
   35 CONV=216000.
      QWAX=QWAX*CONV
      P(15,15)=(SAZ*G)**2
      QWAY=QWAY*CONV
      QWAZ=QWAZ*CONV
C
      TAX=1./TAX
      TAY=1./TAY
      TAZ=1./TAZ
C                       CONVERT G TO FT/MIN2
      QVAX=2.*TAX*(SAX*G)**2
      QVAY=2.*TAY*(SAY*G)**2
      QVAZ=2.*TAZ*(SAZ*G)**2
C
      P(13,13)=(SAX*G)**2
      P(14,14)=(SAY*G)**2

      P(14,14)=(SAY*G)**2
      P(15,15)=(SAZ*G)**2
C
   40 IF (.NOT.TORQ) GO TO 50
      P(16,16)=(TAUX*0.01)**2
      P(17,17)=(TAUY*0.01)**2
      P(18,18)=(TAUZ*0.01)**2
C
   50 IF (.NOT.GRAVD) GO TO 60
C
      DX=DX*FTPNM
      DY=DY*FTPNM
      DZ=DZ*FTPNM
      DX=1./DX
      DY=1./DY
      DZ=1./DZ
C
      QVX=2.*DX*(SVX*G)**2
      QVY=2.*DY*(SVY*G)**2
      QVZ=2.*DZ*(SVZ*G)**2
C
      P(19,19)=(SVX*G)**2
      P(20,20)=(SVY*G)**2
      P(21,21)=(SVZ*G)**2
C
C
   60 IF (.NOT.ALTSF) GO TO 70
      P(22,22)=(TAUH*0.01)**2
      QWH=SALT*SALT
C
   70 IF (.NOT.DREKON) GO TO 100
```

```
      DVWN=FTPNM*DVWN
      DVWE=FTPNM*DVWE
      DVWN=1./DVWN
      DVWE=1./DVWE
C                    CONVERT KTS TO FT/MIN
      CONV=FTPNM/60.
      QWX =2.*DVWN*(SVWN*CONV)**2
      QWY =2.*DVWE*(SVWE*CONV)**2
C
      P(6,6)=(SVWN*CONV*RI)**2
      P(7,7)=(SVWE*CONV*RICLI)**2
C
C                    SPECIFIC FORCE  (NEGLECTING LAT, LONG, VERT  ACC)
  100 FN=2.*HDOT*ALATR+0.5*AL1*SL2*R
      FE=2.*ALBDOT*(-R*ALATR*SL+HDOT*CL)
      FD=R *(AL1*CL*CL+ALATR*ALATR)-G
C
C     ELEMENTS OF SYSTEM MATRIX
C
      F12=-ALBDOT*SL
      F13=ALATR
      F14=F12
      F17=CL
      F21=-F12
      F23=ALBDOT*CL
      F31=-F13
      F32=-F23
      F37=-SL
C
      IF (.NOT.DREKON) GO TO 105
      F66=-VG*DVWN-HDOT*RI
      F77=-VG*DVWE-HDOT*RI+ALATR*TL
      QWAX=QWX*VG
      QWAY=QWY*VG
      GO TO 120
C
  105 F62=-FD*RI
      F63=FE*RI
      F64=-AL1*CL2
      F66=-2.*HDOT*RI
      F67=-ALBDOT*SL2
      F68=-0.5*RI*AL1*SL2
      F69=-2.*ALATR*RI
      F71=FD*RICLI
      F73=-FN*RICLI
      F74=2.*ALBDOT*(ALATR*HDOT*RI*TL)
      F76=2.*ALBDOT*TL
      F77=2.*(ALATR*TL-HDOT*RI)
      F78=RI*ALATR*F76
      F79=-2.*RI*ALBDOT
C
      IF (TWOACC) GO TO 110
      F91=FE
      F92=-FN
      F94=R*AL1*SL2
      F96=2.*R*ALATR
```

```
      F97=2.*R*ALBDOT*CL*CL
      F98=-(AKAP-2.)*OMS2*RI*(FD+G)
C
  110 IF (ISYS.GT.1) GO TO 120
C                      SPACE STABILIZED (ISYS = 1)
      C11=-SL*CLB
      C12=-SL*SLB
      C13=CL
      C21=-SLB
      C22=CLB
      C31=-CL*CLB
      C32=-CL*SLB
      C33=-SL
      GO TO 200
C                    LOCAL LEVEL (ISYS = 2)
 120  OMIPNX=ALBDOT*CL
      OMIPNY=-ALATR
      OMIPNZ=-ALBDOT*SL
      GO TO (200,200,130,140,150,160,170),ISYS
C                      FREE AZIMUTH (ISYS = 3)
 130  OMIPNZ=0.0
      PSIDOT=ALBDOT*SL
 135  PSI=PSI+PSIDOT*(TIME-TPSI)
      TPSI=TIME
      C11=COS(PSI)
      C12=-SIN(PSI)
 137  C21=-C12
      C22=C11
      GO TO 200
C                      STRAPDOWN (ISYS = 4)
 140  C11=CHDG
      C12=-SHDG
      GO TO 137
C                      ROTATING AZIMUTH (ISYS = 5)
 150  PSIDOT=PHIDOT
      GO TO 135
C                      UNIPOLAR (ISYS = 6)
 160  PHIDOT=ALONR
      C11=COS(ALON)
      C12=-SIN(ALON)
      GO TO 137
C                      WANDER AZIMUTH (ISYS = 7)
 170  PSIDOT=ALONR*SL
      PHIDOT=PSIDOT
      GO TO 135
C                      TORQUING RATES
 200  WX    =C11*OMIPNX+C21*OMIPNY+C31*OMIPNZ
      WY    =C12*OMIPNX+C22*OMIPNY+C32*OMIPNZ
      WZ    =C13*OMIPNX+C23*OMIPNY+C33*OMIPNZ+PHIDOT
C
      RETURN
      END
```

```
      SUBROUTINE ALIGN
C
C                   THIS SUBROUTINE CALCULATES THE MEASUREMENT VECTORS,
C                   AND UPDATES THE COVARIANCE MATRIX FOR THE ASSUMED
C                   VELOCITY MEASUREMENTS DURING THE ALIGNMENT PHASE.
C
      COMMON /BALIGN/ SALIN1,SALIN2, RALIN1,RALIN2
      COMMON /BCONST/RADPDG,DEGPRD,FTPNM,NMPFT, MINPRD, OMIE
      COMMON /BCOVAR/ P(34,34)
      COMMON /BINIT/ INIT
      COMMON /BNOM/ NPHASE,H,HDOT,ALATR,ALAT,ALON,ALONR, ALB,
     1              ALBDOT, VG, VA, VELN, VELE, VELW, TRK, HDG, CRB,
     2              THW, R, RI, RI2, G, SL, CL, TL, SL2, CL2, CLI,
     3              RICLI, CTRK,STRK, ALAT2, CHDG, SHDG,RCL
      COMMON /BUPDAT/ ALFA,KOPT(34), MTYPE
      REAL KOPT
      LOGICAL INIT
C
      IF (.NOT.INIT) GO TO 100
C
C                   CONVERT KNOTS TO FT/MIN
      CONV=FTPNM/60.
      RALIN1=(SALIN1*CONV)**2
      RALIN2=(SALIN2*CONV)**2
      RETURN
C
C                   NORTHERLY
  100 ALFA=P(6,6)*R*R+RALIN1
      DO 110 I=1,34
  110 KOPT(I)=P(I,6)*R/ALFA
      MTYPE=1
      CALL UPDATE
C                   EASTERLY
      ALFA=P(7,7)*RCL*RCL+RALIN2
      DO 120 I=1,34
  120 KOPT(I)=P(I,7)*RCL/ALFA
      MTYPE=2
      CALL UPDATE
C
      RETURN
      END
```

```
      SUBROUTINE DOPLR
C
C                      THIS SUBROUTINE CALCULATES THE MEASUREMENT VECTORS,
C                      AND OPTIMUM FILTER GAINS, AND UPDATES THE
C                      COVARIANCE MATRIX FOR BOTH FORWARD AND SIDEWISE
C
      COMMON /BCONST/RADPDG,DEGPRD,FTPNM,NMPFT, MINPRD, OMIE
      COMMON /BCOVAR/ P(34,34)
      COMMON /BDOPLR/ TDF,TDS,SNDF,SNDS, SBDF,SBDS, SRDF,SRDS,
     1                DTDOP,QDF,QDS, RDF, RDS
      COMMON /BINIT/ INIT
      COMMON /BLOGIC/ GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,
     1                DOPLER,OMEGA,SATRNG,SUBOPT,DREKON
      COMMON /BNOM/ NPHASE,H,HDOT,ALATR,ALAT,ALON,ALONR, ALB,
     1                ALBDOT, VG, VA, VELN, VELE, VELW, TRK, HDG, CRB,
     2                THW, R, RI, RI2, G, SL, CL, TL, SL2, CL2, CLI,
     3                RICLI, CTRK,STRK, ALAT2, CHDG, SHDG,RCL
      COMMON /BUPDAT/ ALFA,KOPT(34), MTYPE
      REAL KOPT,NMPFT,MINPRD
      LOGICAL GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,DOPLER,OMEGA,
     1              SATRNG,INIT,SUBOPT,DREKON
C
C                      DOPPLER VELOCITY MEASUREMENTS
      IF(.NOT.INIT) GO TO 100
      TDF=1.0/TDF
      TDS=1.0/TDS
      CONV=FTPNM/60.
      QDF=2.0*TDF*(SNDF*CONV)**2
      QDS=2.0*TDS*(SNDS*CONV)**2
      P(23,23)=(SBDF*0.01)**2
      P(25,25)=(SBDS*0.01)**2
      RDF=(SRDF*CONV)**2
      RDS=(SRDS*CONV)**2
      RETURN
C
 100  VSIDE=VG*SIN(CRB)
      VFWD=VG*COS(CRB)
C
C                      FORWARD DOPPLER VELOCITY MEASUREMENT VECTOR
      H3=-VSIDE
      H4=-R*ALONR*SL*SHDG
      H6=R*CHDG
      H7=R*CL*SHDG
      H8=0.0
      H22=0.0
      TEMP=ALATR*CHDG+ALONR*CL*SHDG
      IF (.NOT.TWOACC) H8=TEMP
      IF(TWOACC)H22=H  *TEMP
      H23=VFWD
      H24=1.0
      H25=0.0
      H26=0.0
      MTYPE=3
      GO TO 300
C                      SIDEWISE DOPPLER VELOCITY MEASUREMENT VECTOR
 200  H3=VFWD
```

```
      H4=-R*ALONR*SL*CHDG
      H6=-R*SHDG
      H7=R*CHDG*CL
      TEMP=ALONR*CL*CHDG-ALATR*SHDG
      IF (.NOT.TWOACC) H8=TEMP
      IF (TWOACC) H22=H*TEMP
      H23=0.0
      H24=0.0
      H25=VSIDE
      H26=1.0
      MTYPE=4
C                       CALCULATE OPTIMUM GAINS
  300 DO 310 I=1,34
  310 KOPT(I)=H3*P(I,3)+H4*P(I,4)+H6*P(I,6)+H7*P(I,7)+H8*P(I,8)
     1        +H22*P(I,22)+H23*P(I,23)+H24*P(I,24)+H25*P(I,25)
     2        +H26*P(I,26)
      ALFA=H3*KOPT(3)+H4*KOPT(4)+H6*KOPT(6)+H7*KOPT(7)+H8*KOPT(8)
     1        +H22*KOPT(22)+H23*KOPT(23)+H24*(KOPT(24)+RDF)
     2        +H25*KOPT(25)+H26*(KOPT(26)+RDS)
      DO 320 I=1,34
  320 KOPT(I)=KOPT(I)/ALFA
C
      CALL UPDATE
      IF (MTYPE.EQ.3) GO TO 200
C
      RETURN
      END
```

```
      SUBROUTINE OMEG
C
C                   THIS SUBROUTINE CALCULATES THE MEASUREMENT VECTORS
C                   AND OPTIMUM FILTER GAINS, AND UPDATES THE COVARIANCE
C                   MATRIX FOR TWO LINE-OF-POSITION MEASUREMENTS.  THE F
C                   L.O.P. USES STATIONS IOM1 AND IOM2, WHILE THE SECOND
C                   L.O.P.USES STATIONS IOM3 AND IOM4.  THE INDICES ARE
C                         1     NORWAY
C                         2     TRINIDAD
C                         3     HAWAII
C                         4     NORTH DAKOTA
C                         5     REUNION
C                         6     ARGENTINA
C                         7     TASMANIA
C                         8     JAPAN
C
      COMMON /BCONST/RADPDG,DEGPRD,FTPNM,NMPFT, MINPRD, OMIE
      COMMON /BCOVAR/ P(34,34)
      COMMON /BINIT/ INIT
      COMMON /BNOM/ NPHASE,H,HDOT,ALATR,ALAT,ALON,ALONR, ALB,
     1              ALBDOT, VG, VA, VELN, VELE, VELW, TRK, HDG, CRB,
     2              THW, R, RI, RI2, G, SL, CL, TL, SL2, CL2, CLI,
     3              RICLI, CTRK,STRK, ALAT2, CHDG, SHDG,RCL
      COMMON /BOMEGA/ IOM1, IOM2, IOM3, IOM4, TOM1, TOM2, SNOM1, SNOM2,
     1              SBOM1, SBOM2, SROM1,SROM2,DTOM,QOM1,QOM2,
     2              ROM1,ROM2
      COMMON /BUPDAT/ ALFA,KOPT(34), MTYPE
      DIMENSION OMLAT(8),OMLON(8),CLOM(8),SLOM(8)
      REAL KOPT,NMPFT,MINPRD
      LOGICAL INIT
C
C                   OMEGA STATION COORDINATES(RADIANS)
      DATA (PHVEL=986.123)
      DATA (OMLAT= 1.15926,0.186780,0.373600, 0.809213, -0.375246,
     1          -0.753982, -.733038, 0.605629 )
      DATA (OMLON=0.229560,-1.07580,-2.75465,-1.71627,0.968658,
     1     -1.13970,2.56563,2.26020    )
C
C                   OMEGA AZIMUTH FUNCTION
      AZF(I)=ATAN2(CLOM(I)*SIN(OMLON(I)-ALON),
     1              SLOM(I)*CL-CLOM(I)*COS(OMLON(I)-ALON)*SL)
C
C                   INITIAL OMEGA SET-UP
      IF (INIT) 10,60
   10 TOM1=1.0/TOM1
      TOM2=1.0/TOM2
      QOM1=2.0*TOM1*SNOM1**2
      QOM2=2.0*TOM2*SNOM2**2
      P(27,27)=SBOM1**2
      P(29,29)=SBOM2**2
      ROM1=SROM1**2
      ROM2=SROM2**2
      DO 20 I=1,8
      CLOM(I)=COS(OMLAT(I))
   20 SLOM(I)=SIN(OMLAT(I))
      RETURN
```

```
C                          OMEGA LINE-OF-POSITION MEASUREMENT VECTORS
C                                 FIRST MEASUREMENT
   60   AZA=AZF(IOM1)
        AZB=AZF(IOM2)
        H27=1,0
        H28=1,0
        H29=0,0
        H30=0,0
        MTYPE=5
        GO TO 100
C                                 SECOND MEASUREMENT
   70   AZA=AZF(IOM3)
        AZB=AZF(IOM4)
        H27=0,0
        H28=0,0
        MTYPE=6
        H29=1,0
        H30=1,0
C
  100 H4   =R *(COS(AZA)-COS(AZB))/PHVEL
      H5   =R *(SIN(AZA)-SIN(AZB))*CL/PHVEL
C
C                          CALCULATE OPTIMUM GAINS
        DO 120 I=1,34
  120   KOPT(I)=H4*P(I,4)+H5*P(I,5)+H27*P(I,27)+H28*P(I,28)+H29
       1          *P(I,29)+H30*P(I,30)
        ALFA=H4*KOPT(4)+H5*KOPT(5)+H27*KOPT(27)+
       1      H28*(KOPT(28)+ROM1)+H29*KOPT(29)+H30*(KOPT(30)+ROM2)
        DO 140 I=1,34
  140   KOPT(I)=KOPT(I)/ALFA
        CALL UPDATE
        IF (MTYPE.EQ.5) GO TO 70
C
        RETURN
        END
```

```
      SUBROUTINE SATR
C
C                        THIS SUBROUTINE CALCULATES THE MEASUREMENT VECTORS
C                        AND OPTIMUM FILTER GAINS, AND UPDATES THE COVARIANCE
C                        FOR TWO SATELLITE RANGING MEASUREMENTS,  THE
C                        LATTITUDE, LONGITUDE AND ALTITUDE OF EACH SATELLITE
C                        ARE INPUT PARAMETERS, AND ARE ASSUMED TO BE CONSTANT
C
      COMMON /BCONST/RADPDG,DEGPRD,FTPNM,NMPFT, MINPRD, OMIE
      COMMON /BCOVAR/ P(34,34)
      COMMON /BINIT/ INIT
      COMMON /BLOGIC/ GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,
     1                DOPLER,OMEGA,SATRNG,SUBOPT,DREKON
      COMMON /BNOM/ NPHASE,H,HDOT,ALATR,ALAT,ALON,ALONR, ALB,
     1              ALBDOT, VG, VA, VELN, VELE, VELW, TRK, HDG, CRB,
     2              THW, R, RI, RI2, G, SL, CL, TL, SL2, CL2, CLI,
     3              RICLI, CTRK,STRK, ALAT2, CHDG, SHDG,RCL
      COMMON /BSATR/ SATLAT(2),SATLON(2),HSAT(2),TSAT1,TSAT2,
     1              SNSAT1,SNSAT2,SBSAT1,SBSAT2,SRSAT1,SRSAT2,
     2              DTSAT,QSAT1,QSAT2,RSAT1,RSAT2
      COMMON /BUPDAT/ ALFA,KOPT(34), MTYPE
      DIMENSION       RPSN(3), CRSAT(2), SRSAT(2)
      REAL KOPT,NMPFT,MINPRD
      LOGICAL GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,DOPLER,OMEGA,
     1        SATRNG,SUBOPT,DREKON
      LOGICAL INIT
      DATA (RSYNCH=138337348.),(HSYNCH=117411616.),(FTPMS=983.567)
C
      IF (INIT) 10,60
 10   TSAT1=1.0/TSAT1
      TSAT2=1.0/TSAT2
      QSAT1=2.0*TSAT1*(SNSAT1*FTPMS)**2
      QSAT2=2.0*TSAT2*(SNSAT2*FTPMS)**2
      P(31,31)=(SBSAT1*FTPMS)**2
      P(33,33)=(SBSAT2*FTPMS)**2
      RSAT1=(SRSAT1*FTPMS)**2
      RSAT2=(SRSAT2*FTPMS)**2
      SATLON(1)=SATLON(1)*RADPDG
      SATLON(2)=SATLON(2)*RADPDG
C
C                        INITIAL SATELLITE CALCULATIONS
C                        FOR SYNCHRONOUS,EQUITORIAL ORBITS
      SATLAT(1)=0.0
      SATLAT(2)=0.0
      HSAT(1)=HSYNCH
      HSAT(2)=HSYNCH
      RSAT=RSYNCH
      CRSAT(1)=RSAT
      SRSAT(1)=0.0
      CRSAT(2)=RSAT
      SRSAT(2)=0.0
      H8=0.0
      H22=0.0
      RETURN
C
C                        SATELLITE RANGING MEASUREMENT VECTORS
```

```
C                    FIRST SATELLITE
   60 H31=1.0
      H32=1.0
      H33=0.0
      H34=0.0
      MTYPE=7
      GØ TØ 100
C                    SECØND SATELLITE
   70 H31=0.0
      H32=0.0
      H33=1.0
      H34=1.0
      MTYPE=8
C                    LINE-ØF-SIGHT VECTØR
  100 MEAS=MTYPE-6
      DLØN=SATLØN(MEAS)-ALØN
      CLØN=CØS(DLØN)
      RPSN(1)=SRSAT(MEAS)*CL-CRSAT(MEAS)*SL*CLØN
      RPSN(2)=CRSAT(MEAS)*SIN(DLØN)
      RPSN(3)=-(SRSAT(MEAS)*SL+CRSAT(MEAS)*CL*CLØN)+R
      TEMP=1.0/SQRT(RPSN(1)**2+RPSN(2)**2+RPSN(3)**2)
C
      H4  =R*RPSN(1)*TEMP
      H5  =RCL*RPSN(2)*TEMP
      IF (.NØT.TWØACC) H8  =RPSN(3)*TEMP
      IF (TWØACC) H22  =H  *RPSN(3)*TEMP
C                    CALCULATE ØPTIMUM GAINS
      DØ 120 I=1,34
  120 KØPT(I)=H4*P(I,4)+H5*P(I,5)+H8*P(I,8)+H22*P(I,22)+
     1        H31*P(I,31)+H32*P(I,32)+H33*P(I,33)+H34*P(I,34)
      ALFA=H4*KØPT(4)+H5*KØPT(5)+H8*KØPT(8)+H22*KØPT(22)+
     1     H31*KØPT(31)+H32*(KØPT(32)+RSAT1)+H33*KØPT(33)+
     2     H34*(KØPT(34)+RSAT2)
      DØ 140 I=1,34
  140 KØPT(I)=KØPT(I)/ALFA
      CALL UPDATE
      IF (MTYPE.EQ.7) GØ TØ 70
C
      RETURN
      END
```

```
      SUBROUTINE UPDATE
C
C                 THIS SUBROUTINE UPDATES THE COVARIANCE MATRIX FOR
C                 OPTIMUM OR SUBOPTIMUM MEASUREMENTS.   IF A SUBOPTIMUM
C                 GAIN HISTORY IS SPECIFIED, THE SUBOPTIMUM GAINS ARE
C                 FOUND BY LINEAR INTERPOLATION.
C
      COMMON /BCOVAR/ P(34,34)
      COMMON /BINDEX/ II(585), JJ(585), KK(585)
      COMMON /BINTEG/ S(585),SD(585), DT,DT05,NEQ
      COMMON /BLOGIC/ GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,
     1                DOPLER,OMEGA,SATRNG,SUBOPT,DREKON
      COMMON /BSUBOP/NK,TSUBK(20),KSUBDF(20,34), KSUBDS(20,34),
     1                KSUB01(20,34), KSUB02(20,34), KSUBS1(20,34),
     2                KSUBS2(20,34),PGAINS
      COMMON/BTIME/TIME
      COMMON /BUPDAT/ ALFA,KOPT(34), MTYPE
      REAL KOPT,KSUB,         KSUBDF,KSUBDS,KSUB01,KSUB02,KSUBS1,KSUBS2
      DIMENSION XK(20,34,6),KSUB(34)
      EQUIVALENCE (XK(1),KSUBDF(1)),(TIME,T)
      LOGICAL GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,DOPLER,OMEGA,
     1        SATRNG,SUBOPT,DREKON
C
      IF (MTYPE.LE.2) GO TO 10
C
      IF (SUBOPT) GO TO 100
C
C                 OPTIMUM FILTER GAINS
C
   10 DO 50 I=1,34
      DO 50 J=I,34
      P(I,J)=P(I,J)-ALFA*KOPT(I)*KOPT(J)
   50 P(J,I)=P(I,J)
C                 WRITE OUT OPTIMUM GAINS
      IF (PGAINS.EQ.0..OR.MTYPE.LE.2) GO TO 300
      WRITE (7) TIME,MTYPE,(KOPT(I),I=1,34)
      GO TO 300
C
C                 SUBOPTIMUM FILTER GAINS
C
C                 INTERPOLATE FOR SUBOPTIMUM GAINS
C
  100 IF (T.GT.TSUBK(1)) GO TO 110
      IJ=1
  102 DO 105 M=1,34
  105 KSUB(M)=XK(IJ,M,MTYPE-2)
      GO TO 145
  110 DO 120 I=2,NK
      J=I-1
      IF (T.LT.TSUBK(I)) GO TO 130
  120 CONTINUE
      IJ=NK
      GO TO 102
  130 D1=(T-TSUBK(J))/(TSUBK(I)-TSUBK(J))
      D2=1.0-D1
      DO 140 M=1,34
```

```
  140 KSUB(M)=D1*XK(I,M,MTYPE-2)+D2*XK(J,M,MTYPE-2)
  145   DO 150 I=1,34
        DO 150 J=I,34
        P(I,J)=P(I,J)-ALFA*(KSUB(I)*KOPT(J)+(KOPT(I)-KSUB(I))*KSUB(J))
  150 P(J,I)=P(I,J)
C
C
C                     SET S ARRAY
  300   GO TO (310,350,310,350,310,350,310,350,310),MTYPE+1
  310   DO 320 L=1,NEQ
        K=KK(L)
        I=II(K)
        J=JJ(K)
  320   S(L)=P(I,J)
C
  350   RETURN
        END
```

```
      SUBROUTINE RKUTTA
C
C     RUNGE-KUTTA INTEGRATION ROUTINE - FOURTH ORDER
C
      COMMON /BCOVAR/ P(34,34)
      COMMON /BINDEX/ II(585), JJ(585), KK(585)
      COMMON /BINTEG/ S(585),SD(585), DT,DT05,NEQ
      COMMON/BTIME/TIME
      DIMENSION B1(585),B2(585),B3(585),SI(585)
      EQUIVALENCE (TIME,T)
C
      CALL DIFEQ(T)
      IF (DT.EQ.0.0) RETURN
      DO 2 N=1,NEQ
      SI(N)=S(N)
      B1(N)=DT*SD(N)
    2 S(N)=SI(N)+.5*B1(N)
      TT=T+DT05
      CALL DIFEQ(TT)
      DO 4 N=1,NEQ
      B2(N)=DT*SD(N)
    4 S(N)=SI(N)+.5*B2(N)
      CALL DIFEQ(TT)
      DO 6  N=1,NEQ
      B3(N)=DT*SD(N)
      TT=T+DT
    6 S(N)=SI(N)+B3(N)
      CALL DIFEQ(TT)
      DO 8 N=1,NEQ
      S(N)=SI(N)+(B1(N)+2.*B2(N)+2.*B3(N)+DT*SD(N))*0.16666667
      K=KK(N)
      I=II(K)
      J=JJ(K)
      P(J,I)=S(N)
    8 P(I,J)=S(N)
      T=TT
C
      RETURN
      END
```

```
      SUBROUTINE DIFEQ(TIME)
C
C                    SETS THE PROPER ELEMENTS OF THE COVARIANCE MATRIX
C                    AND CALCULATES THE NEQ DERIVATIVES TO BE INTEGRATED
C
      COMMON /BCOVAR/ P(34,34)
      COMMON /BINDEX/ II(585), JJ(585), KK(585)
      COMMON /BINTEG/ S(585),SD(585), DT,DT05,NEQ
C
C                    SET P*MATRIX VALUES
      DO 100 L=1,NEQ
      K=KK(L)
      I=II(K)
      J=JJ(K)
      P(I,J)=S(L)
  100 P(J,I)=P(I,J)
C                    CALCULATE DERIVATIVES
      DO 200 L=1,NEQ
      K=KK(L)
      I=II(K)
      J=JJ(K)
  200 SD(L)=T(I,J)+T(J,I)+GQG(I,J)
C
      RETURN
      END
```

```
      FUNCTION T(I,J)
C
C     COMPUTE ELEMENTS OF FP MATRIX
C
      COMMON /BCOVAR/ P(34,34)
      COMMON /BDOPLR/ TDF,TDS,SNDF,SNDS, SBDF,SBDS, SRDF,SRDS,
     1                DTDOP,ODF,ODS, RDF, RDS
      COMMON / BINS1/ISYS,FE0, EN0,ED0,DLA0,DL00,RDLA0,RDL00,DH0,
     1                RDH0,AKAP, PHIDOT, OMS2,FN,FE, FD
      COMMON /BINS2/TGX,TGY,TGZ,QWGX,QWGY,QWGZ,SGX,SGY,SGZ,
     1                QVGX,QVGY,QVGZ,TAX,TAY,TAZ,QWAX,QWAY,QWAZ,
     2                SAX,SAY,SAZ,QVAX,QVAY,QVAZ,TAUX,TAUY,TAUZ,
     3                DX,DY,DZ,SVX,SVY,SVZ,QVX,QVY,QVZ,QWH
      COMMON /BINS3/ C11,C12,C13,C21,C22,C23,C31,C32,C33,
     1                 F12,F13,F17,F21,F23,F31,F32,F37,F62,F63,F64,F66,
     2                 F67,F68,F69,F71,F73,F74,F76,F77,F78,F79,F91,F92,
     3                F94,F96,F97,F98,WX,WY,WZ
      COMMON /BLOGIC/ GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,
     1                DOPLER,OMEGA,SATRNG,SUBOPT,DREKON
      COMMON /BNOM/ NPHASE,H,HDOT,ALATR,ALAT,ALON,ALONR, ALB,
     1                ALBDOT, VG, VA, VELN, VELE, VELW, TRK, HDG, CRB,
     2                THW, R, RI, RI2, G, SL, CL, TL, SL2, CL2, CLI,
     3                RICLI, CTRK,STRK, ALAT2, CHDG, SHDG,RCL
      COMMON /BOMEGA/ IOM1, IOM2, IOM3, IOM4, TOM1, TOM2, SNOM1, SNOM2,
     1                SBOM1, SBOM2, SROM1,SROM2,DTOM,QOM1,QOM2,
     2                ROM1,ROM2
      COMMON /BSATR/ SATLAT(2),SATLON(2),HSAT(2),TSAT1,TSAT2,
     1                SNSAT1,SNSAT2,SBSAT1,SBSAT2,SRSAT1,SRSAT2,
     2                DTSAT,QSAT1,QSAT2,RSAT1,RSAT2
      LOGICAL GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,DOPLER,OMEGA,
     1           SATRNG,SUBOPT,DREKON
C
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,16,16,19,20,21,16,
     116,24,16,26,16,28,16,30,16,32,16,34),I
    1 T=F12*P(2,J)+F13*P(3,J)+F12*P(4,J)+F17*P(7,J)+C11*P(10,J)+C12*
     1  P(11,J)+C13*P(12,J)+WX*C11*P(16,J)+WY*C12*P(17,J)+WZ*C13*
     2  P(18,J)
      RETURN
    2 T=F21*P(1,J)+F23*P(3,J)-P(6,J)+C21*P(10,J)+C22*P(11,J)+C23*P(12,J)
     1    +WX*C21*P(16,J)+WY*C22*P(17,J)+WZ*C23*P(18,J)
      RETURN
    3 T=F31*P(1,J)+F32*P(2,J)+F32*P(4,J)+F37*P(7,J)+C31*P(10,J)
     1    +C32*P(11,J)+C33*P(12,J)+WX*C31*P(16,J)+WY*C32*P(17,J)
     2    +WZ*C33*P(18,J)
      RETURN
    4 T=P(6,J)
      IF (NPHASE.EQ.0) T = 0.0
      RETURN
    5 T=P(7,J)
      IF (NPHASE.EQ.0) T = 0.0
      RETURN
    6 T=F62*P(2,J)+F63*P(3,J)+F64*P(4,J)+F66*P(6,J)+F67*P(7,J)+F68
     1    *P(8,J)+F69*P(9,J)+RI*(C11*P(13,J)+C12*P(14,J)+C13*P(15,J)
     2    +P(19,J))
      IF (.NOT.TWOACC) RETURN
      T=T+(F68*H+F69*HDOT)*P(22,J)
```

```
      RETURN
 7    T=F71*P(1,J)+F73*P(3,J)+F74*P(4,J)+F76*P(6,J)+F77*P(7,J)+F78
     1     *P(8,J)+F79*P(9,J)+RICLI*(C21*P(13,J)+C22*P(14,J)+C23
     2     *P(15,J)+P(20,J))
      IF (.NOT,TWOACC) RETURN
      T=T+(F78*H+F79*HDGT)*P(22,J)
      RETURN
 8    T=P(9,J)
      RETURN
 9    T=F91*P(1,J)+F92*P(2,J)+F94*P(4,J)+F96*P(6,J)+F97*P(7,J)+F98
     1     *P(8,J)-(C31*P(13,J)+C32*P(14,J)+C33*P(15,J))+P(21,J)
     2    +AKAP*OMS2*H*P(22,J)
      RETURN
 10   T=-TGX*P(10,J)
      RETURN
 11   T=-TGY*P(11,J)
      RETURN
 12   T=-TGZ*P(12,J)
      RETURN
 13   T=-TAX*P(13,J)
      RETURN
 14   T=-TAY*P(14,J)
      RETURN
 15   T=-TAZ*P(15,J)
      RETURN
 16   T=0.
      RETURN
   19 T=-DX*P(19,J)*VG
      RETURN
   20 T=-DY*P(20,J)*VG
      RETURN
   21 T=-DZ*P(21,J)*VG
      RETURN
   24 T=-TDF*P(24,J)
      RETURN
   26 T=-TDS*P(26,J)
      RETURN
   28 T=-TOM1*P(28,J)
      RETURN
   30 T=-TOM2*P(30,J)
      RETURN
   32 T=-TSAT1*P(32,J)
      RETURN
   34 T=-TSAT2*P(34,J)
C
      RETURN
      END
```

```
      FUNCTION GQG(I,J)
C
C             COMPUTE ELEMENTS OF DRIVING NOISE MATRIX - G Q GT
C
      COMMON /BDOPLR/ TDF,TDS,SNDF,SNDS, SBDF,SBDS, SRDF,SRDS,
     1                DTDOP,QDF,QDS, RDF, RDS
      COMMON / BINS1/ISYS,EE0, EN0,ED0,DLA0,DL00,RDLA0,RDL00,DH0,
     1                RDH0,AKAP, PHIDOT, OMS2,FN,FE, FD
      COMMON /BINS2/TGX,TGY,TGZ,QWGX,QWGY,QWGZ,SGX,SGY,SGZ,
     1                QVGX,QVGY,QVGZ,TAX,TAY,TAZ,QWAX,QWAY,QWAZ,
     2                SAX,SAY,SAZ,QVAX,QVAY,QVAZ,TAUX,TAUY,TAUZ,
     3                DX,DY,DZ,SVX,SVY,SVZ,QVX,QVY,QVZ,QWH
      COMMON /BINS3/ C11,C12,C13,C21,C22,C23,C31,C32,C33,
     1                 F12,F13,F17,F21,F23,F31,F32,F37,F62,F63,F64,F66,
     2                 F67,F68,F69,F71,F73,F74,F76,F77,F78,F79,F91,F92,
     3                F94,F96,F97,F98,WX,WY,WZ
      COMMON /BNOM/ NPHASE,H,HDOT,ALATR,ALAT,ALON,ALONR, ALB,
     1                ALBDOT, VG, VA, VELN, VELE, VELW, TRK, HDG, CRB,
     2                THW, R, RI, RI2, G, SL, CL, TL, SL2, CL2, CLI,
     3                RICLI,CTRK,STRK,ALAT2,CHDG,SHDG,RCL
      COMMON /BOMEGA/ IOM1, IOM2, IOM3, IOM4, TOM1, TOM2, SNOM1, SNOM2,
     1                SBOM1, SBOM2, SROM1,SROM2,DTOM,QOM1,QOM2,
     2                ROM1,ROM2
      COMMON /BSATR/ SATLAT(2),SATLON(2),HSAT(2),TSAT1,TSAT2,
     1                SNSAT1,SNSAT2,SBSAT1,SRSAT2,SRSAT1,SRSAT2,
     2                DTSAT,QSAT1,QSAT2,RSAT1,RSAT2
C
      IF (I.LE.J) GO TO 5
      II=I
      I=J
      J=II
    5 GO TO (10,20,30,14,14,60,70,14,90,100,110,120,130,140,150,14,14,
     1    14,190,200,210,14,14,240,14,260,14,280,14,300,14,320,14,340),I
C                I=1
   10 IF (J.GT.4) GO TO 14
      GO TO (11,12,13,14),J
   11 GQG=C11*C11*QWGX+C12*C12*QWGY+C13*C13*QWGZ
      RETURN
   12 GQG=C11*C21*QWGX+C12*C22*QWGY+C13*C23*QWGZ
      RETURN
   13 GQG=C11*C31*QWGX+C12*C32*QWGY+C13*C33*QWGZ
      RETURN
   14 GQG=0.0
      RETURN
C                I=2
   20 IF (J.GT.4) GO TO 14
      GO TO (21,22,14),J-1
   21 GQG=C21*C21*QWGX+C22*C22*QWGY+C23*C23*QWGZ
      RETURN
   22 GQG=C21*C31*QWGX+C22*C32*QWGY+C23*C33*QWGZ
      RETURN
C                I=3
   30 IF (J.GT.4) GO TO 14
      GO TO (31,14),J_2
   31 GQG=C31*C31*QWGX+C32*C32*QWGY+C33*C33*QWGZ
      RETURN
```

```
C                    I=6
  60   IF (J,GT.10) GO TO 14
       GO TO (61,62,14,63,14),J-5
  61   GQG=RI2*(C11*C11*QWAX+C12*C12*QWAY+C13*C13*QWAZ)
       RETURN
  62   GQG=RI*RICLI*(C11*C21*QWAX+C12*C22*QWAY+C13*C23*QWAZ)
       RETURN
  63   GQG=-RI*(C11*C31*QWAX+C12*C22*QWAY+C13*C33*QWAZ)
       RETURN
C                    I=7
  70   IF (J,GT.10) GO TO 14
       GO TO (71,14,72,14),J-6
  71   GQG=RICLI*RICLI*(C21*C21*QWAX+C22*C22*QWAY+C23*C23*QWAZ)
       RETURN
  72   GQG=-RICLI*(C21*C31*QWAX+C22*C32*QWAY+C23*C33*QWAZ)
       RETURN
C                    I=9
  90   IF (J,GT.10) GO TO 14
       GO TO (91,14),J-8
  91   GQG=C31*C31*QWAX+C32*C32*QWAY+C33*C33*QWAZ+(AKAP*OMS2)**2*QWH
       RETURN
C                    I=10
 100   IF (J,GT.11) GO TO 14
       GO TO (101,14),J-9
 101   GQG=QVGX
        RETURN
C                    I=11
 110   IF (J,GT.12) GO TO 14
       GO TO (111,14),J-10
 111   GQG=QVGY
       RETURN
C                    I=12
 120   IF (J,GT.13) GO TO 14
       GO TO (121,14),J-11
 121   GQG=QVGZ
       RETURN
C                    I=13
 130   IF (J,GT.14) GO TO 14
       GO TO (131,14),J-12
 131   GQG=QVAX
       RETURN
C                    I=14
 140   IF (J,GT.15) GO TO 14
       GO TO (141,14),J-13
 141   GQG=QVAY
       RETURN
C                    I=15
 150   IF (J,GT.16) GO TO 14
       GO TO (151,14),J-14
 151   GQG=QVAZ
       RETURN
C                    I=19
 190   IF (J,GT.20) GO TO 14
       GO TO (191,14),J-18
 191   GQG=QVX*VG
       RETURN
```

```
C                    I=20
 200  IF (J,GT.21) GO TO 14
      GO TO (201,14),J-19
 201  GQG=QVY*VG
      RETURN
C                    I=21
 210  IF (J,GT.22) GO TO 14
      GO TO (211,14),J-20
 211  GQG=QVZ*VG
      RETURN
C                    I=24
 240  IF (J,GT.25) GO TO 14
      GO TO (241,14), J-23
 241  GQG=QDF
      RETURN
C                    I=25
 260  IF (J,GT.27) GO TO 14
      GO TO (261,14), J-25
 261  GQG=QDS
      RETURN
C                    I=28
 280  IF (J,GT.29) GO TO 14
      GO TO (281,14), J-27
 281  GQG=QOM1
      RETURN
C                    I=30
 300  IF (J,GT.31) GO TO 14
      GO TO (301,14), J-29
 301  GQG=QOM2
      RETURN
C                    I=32
 320  IF (J,GT.33) GO TO 14
      GO TO (321,14), J-31
 321  GQG=QSAT1
      RETURN
C                    I=34
 340  IF (J,GT.35) GO TO 14
      GO TO (341,14), J-33
 341  GQG=QSAT2
      RETURN
      END
```

```
      SUBROUTINE BLUNDR
C
C                   THIS SUBROUTINE FURNISHES THE ERROR STATISTICS
C                   EXISTING IMMEDIATELY AFTER THE OCCURANCE OF A
C                   BLUNDER OR MALFUNCTION AT TIME = TBLUNC.
C                   IT MUST SET THE APPROPRIATE PARAMETERS IN INTERNAL
C                   UNITS (FEET, RADIANS, MINUTES) FOR THE SPECIFIC
C                   SITUATION UNDER INVESTIGATION.
C
      COMMON /BALIGN/ SALIN1,SALIN2, RALIN1,RALIN2
      COMMON/BALT/TAUH,SALT,TAUHD,SALTD
      COMMON /BCONST/RADPDG,DEGPRD,FTPNM,NMPFT, MINPRD, OMIE
      COMMON /BCOVAR/ P(34,34)
      COMMON /BDOPLR/ TDF,TDS,SNDF,SNDS, SBDF,SBDS, SRDF,SRDS,
     1          DTDOP, QDF, QDS, RDF, RDS
      COMMON / BFLTPN/ DTA,DTT, H0, VCL,RC,MCR,HCR,NWPTS, LAT(20),
     1           LON(20), THETAW(20), VW(20), TCR, TM(20), VN(20),
     2           VE(20)
      COMMON / BINS1/ISYS,EE0, EN0,ED0,DLA0,DL00,RDLA0,RDL00,DH0,
     1          RDH0,AKAP, PHIDOT, OMS2,FN,FE, FD
      COMMON /BINS2/TGX,TGY,TGZ,QWGX,QWGY,QWGZ,SGX,SGY,SGZ,
     1          QVGX,QVGY,QVGZ,TAX,TAY,TAZ,QWAX,QWAY,QWAZ,
     2          SAX,SAY,SAZ,QVAX,QVAY,QVAZ,TAUX,TAUY,TAUZ,
     3          DX,DY,DZ,SVX,SVY,SVZ,QVX,QVY,QVZ,QWH
      COMMON /BINS3/ C11,C12,C13,C21,C22,C23,C31,C32,C33,
     1           F12,F13,F17,F21,F23,F31,F32,F37,F62,F63,F64,F66,
     2           F67,F68,F69,F71,F73,F74,F76,F77,F78,F79,F91,F92,
     3          F94,F96,F97,F98,WX,WY,WZ
      COMMON /BLOGIC/ GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,
     1          DOPLER,OMEGA,SATRNG,SUBOPT,DREKON
      COMMON /BOMEGA/ IOM1, IOM2, IOM3, IOM4, TOM1, TOM2, SNOM1, SNOM2,
     1          SBOM1, SBOM2, SROM1,SROM2,DTOM,QOM1,QOM2,
     2          ROM1,ROM2
      COMMON /BSATR/ SATLAT(2),SATLON(2),HSAT(2),TSAT1,TSAT2,
     1          SNSAT1,SNSAT2,SBSAT1,SBSAT2,SRSAT1,SRSAT2,
     2          DTSAT,QSAT1,QSAT2,RSAT1,RSAT2
      REAL LAT,LON,MCR,NMPFT,MINPRD
      LOGICAL GYROS,ACCEL,TORQ,ALTSF,GRAVD,INS9,TWOACC,DOPLER,OMEGA,
     1        SATRNG,QUIT,INIT,SUBOPT,DREKON
C
C      *   *   *   *  EXAMPLE BLUNDER IS OMEGA LANE SWITCH,
C      *   *   *   *  L. O. P.  =1 BIAS ERROR SUDDENLY JUMPS BY 24 NM.
C
      DATA (PHVEL=986,123)
      P(27,27)=(SQRT(P(27,27))+24,0*FTPNM/PHVEL)**2
C
      RETURN
      END
```

```
      AY=0.25
 485  CALL SYMBCL (AX,AY,0.07,6HWAYPT.,0.0,6)
  49  CONTINUE
      IF (LL.EQ.5) LL=1
      IF (LL.EQ.7) LL=5
      JJ=JJ-1
C                    LABEL ORDINATE
  50  CALL SCALE (Y(1)   ,NPTS,AYLEN(J),YMIN,DY,1.DVY)
      CALL AXIS(0.0,0.0,YTIT(K),MM(L),AYLEN(J)-.5,90.,DVY,YMIN,DY,
     1     4HF6.2)
      IF (J.EQ.8) L=4
      IF (J.EQ.7) L=3
      IF (J.EQ.6) L=3
      IF (J.EQ.5) L=2
      IF (J.EQ.4) L=1
      IF (J.GT.4) K=K-2
      IF (J.LE.4) K=K-1
C                    PLOT CURVE
      CALL LINE (X,Y,NPTS,1,-1,0,0,0)
 100  CONTINUE
C                    RESET FOR NEXT RUN
      CALL PLOT (7.0,10.0,-3)
      CALL PLOT (0.0,0.0,-2)
C
 900  RETURN
      END
```

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