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A USER'S GUIDE TO THE FLEXIBLE SPACECRAFT DYNAMICS AND CONTROL PROGRAM-V

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FOREWARD FOR USER'S GUIDE-V

The Flexible Spacecraft Dynamics Program (FSD program) is a second generation computer program having evolved from the Radio Astronomy Explorer (RAE) Dynamics program which had its inception in 1965. The main FSD program was written and developed by the AVCO Corporation, Systems Division, Wilmington, Massachusetts and was delivered to NASA in 1970. Since that time many checkouts and numerous improvements have been made. The program has run on the IBM 360/91 and 360/95 machines at GSFC, requiring up to 600 bytes of storage with overlay capability. **More recently, the program has been running on the IBM 3081 machine which has no restrictions on storage requirements. Currently, the use of the program has been extended to the VAX 11/780 machine. The operation of the program is user** oriented. That is, the design of the program and input/output is such that, aside from initial job control language cards, a dynamicist or an analytical control engineer can set up and run problems without programming assistance; no programming skills are required.

It is beyond the scope of this Guide to go into the many applications of this program. Examination of the input control words and various options does give an indication of its versatility. The program can be used in dynamics and control analysis as well as in orbit support of deployment and control of spacecraft. This program has been used to simulate the dynamics of antenna deployment and in-orbit attitude performance of the RAE-A, B, IMP-I, J, ISEE-A, C, Langley HAWKEYE, Air Force SCATHA, Italy SAN MARCO-D, Japan EXOS-B, ISPM, Dynamic Explorer-A, B, ISTP and CRRES.

With current emphasis on active control of pointed instruments on flexible spacecraft, recent additions have been in the controls area. Some additions to the current FSD program are as follows:

1. A two axis gimble platform and digital control system (proportional, integral and derivative controller) to track the earth's magnetic field from a spinning or non-spinning spacecraft. The magnetic field can be sensed on the spacecraft hub or at the end of a flexible boom. The control system coding is contained in one subroutine so that other control laws can be implemented without requiring changes in the overall program.

2. A two axis platform magnetic tracking system using the program's rotation damper degree of freedom for the azimuth gimble. This permits simulation of flexible elements on the azimuth platform as well as on the spacecraft while tracking the magnetic field.

3. Proportional, integral and derivative controller has been added to each axis (roll, pitch and yaw of the earth pointing mode) to generate control torques from the respective momentum wheels. An arbitrarily oriented momentum wheel with control is also included. User formulated control laws are permitted.

4. Jet damping added to the thruster option to simulate launch vehicle dynamics.

5. Thermal expansion and contraction of flexible elements caused by changing sun angle, spacecraft or orbit shadowing.

In addition to being used in Goddard related flight programs, the FSD program is being modified and maintained by the Systems Division of the AVCO Corporation, Wilmington, Massachusetts.

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A USER'S GUIDE TO THE FLEXIBLE SPACECRAFT DYNAMICS AND CONTROL PROGRAM-V

INTRODUCTION

This computer program was initially developed to simulate the dynamics of the IMP and RAE class of satellites. Generality was retained in its development so that it is applicable to the simulation of the dynamics and control of a large class of flexible and rigid spacecraft.

The program is applicable to inertially oriented spinning, earth oriented or gravity gradient stabilized spacecraft. Internal and external environmental effects developed at orbital altitude are simulated. The effects include gravity gradient forces, solar pressure, magnetic torques and thermal bending due to solar heating. Body torquing devices in the computer program include momentum wheels, a viscous ring nutation damper, magnetic torquer coils and attitude control thrusters. For gravity gradient satellites, an option is available for simulating either a magnetic hysteresis or viscous libration damper.

The computer program has the capability of simulating up to ten flexible tubular elements arbitrarily oriented with respect to the body fixed coordinate frame. A finite series of shape function are used to describe the bending and twisting of the flexible elements. Higher order displacement terms are retained in order to achieve reasonable accuracy for large displacements.

The equations of motion are derived from variational principles, i.e., the principle of virtual work. The generalized coordinates include the three rotational and three translational degrees of freedom of the body fixed axes and the amplitudes of the shape functions for each flexible element. An additional generalized coordinate is necessary to describe the motions of the libration damper.

Generalized forces were derived and programmed for gravity gradient forces, solar pressure, bending stresses and structural damping. The induced temperature gradients and solar pressure generalized forces are derived from the instantaneous angle of incidence between the sun line vector and the deformed flexible elements. The effects of aerodynamic drag on the flexible motions of a spacecraft is also computed for low altitude orbits.

A special purpose computer program (Integral Evaluation Program) was also developed to compute input data for the dynamics computer program. This computer program evaluates definite integrals that evolve in the mathematical process of spatially integrating the internal and external forces acting on the flexible elements of a satellite. The integrals are normalized products of the shape functions and their derivatives evaluated over the flexible elements lengths. For a given shape function, selected to represent the deformed shape of a flexible element, the integrals have to be evaluated only once. The integrals are read into the dynamics program either on cards or compiled into block data. The dynamics simulations can then be made without further recourse to the integral evaluation program. The shape functions are specified by the coefficients of polynomials. For a flexible element with no tip mass, a set of typical shape function used would represent cantilever beam bending modes. Other more appropriate shape functions would be specified for simulating flexible elements with tip masses. The dynamics program can use up to three shape functions or modes in simulation of the deflectional motion of the flexible elements. At times it is necessary to have different types of flexible elements with different stiffness characteristics on the same spacecraft. The dynamics program has, therefore, the capability of utilizing two different sets of values as determined by the integral evaluation program for two different families of shape function. An example of the use of this capability would be a spinning spacecraft requiring interlocked closed cross-section elements on the spin axis and utilizing wire elements on the transverse axes.

The input to the Flexible Spacecraft Dynamics program consists of four main parts, i.e.:

1. Input which is necessary to construct the orbit of the spacecraft.

2. Control words to invoke or delete various options such as gravity gradient effects, control torques, starting integration interval, etc.

3. Input to describe mathematically the spacecraft, appendages and control system.

4. Desired state variable output which is controlled by INOPT 1 or 2 and by KPLOTS array addresses.

The input to these portions is on punched cards, punched in columns 2 through 72. The Fortran input symbol can be punched in any of these columns followed by its input value. Since the program utilizes a nameless read, more than one input symbol and associated value can be punched on a card provided the symbol value pairs are separated by at least one blank. Within each main portion, the order of input is immaterial. A heading card can be inserted within the input deck provided an H is punched in column one. Comment cards can be inserted in the input dat eck with an "$" or "*" punched in column one.

The input to the main parts will be described in detail.

PART 1

ORBIT GENERATION

There are two options for describing the orbit. They are:

1. Utilizing the internal orbit generator which generates a two-body (Keplerian) orbit at each time step in the program. Constant orbit drifting rates of longitude of ascending node and argument of perigee can also be input to the program providing better orbit simulation if long term study is required. For the majority of simulations, this simplified orbit is quite adequate. However, if a definitive orbit is desired, or the program is used during operational support of a mission, the second orbit option should be used.

2. An orbit tape can be read by the program via control words and Fortran I/O unit. The orbit tape is generated by GTDS (Goddard Trajectory Determination System) of Code 582 at GSFC for the satellite and time span in question.

   The orbit option is set by two input control words, IORB and ITAPE. For internal orbit generation, set

   IORB = 0, ITAPE = 0 (preset values)

   For reading orbit tape option, set

   IORB = 1, ITAPE = NM

   where NM is the Fortran I/O unit number corresponding to the following JCL to be inserted for this option

```
//GO. FTNMF001 DD UNIT=2400,DSN=FSD.EPHEM,
   //VOL=SER=XXXXXX,LABEL=1,BLP),DCB=
      (RECFM=VS,BLKSIZE=2808,BUFNO=1)
```

In either case the following orbital input parameters are input: the parameters for which the earth is the central body are pre-set internally, so it is not really necessary to read in these values unless it is desired to change them. The user can also specify a central body other than the earth by reading in the appropriate parameters.

The orbital input parameters are as follows:

EARTH PROPERTIES

Fortran Symbol	Math Symbol	Description	Units
AEARTH	a_E	Semi-major axis of Earth. Internally set to 6378.165	km
ZMU	μ_E	Gravitational constant of Earth. Internally set to 3.986032D + 05	km^3/sec^2
ZJ20		Oblate Earth coefficient. Internally set to 1.082D-06	N.D.
FLAT	$\frac{a}{a-b}$	a = Semi-major axis of Earth b = Semi-minor axis of Earth Flat is internally set to 298.3	N.D.
WWO		GHA of Aries at instant vernal equinox occurs in the year of simulation. Used for the (2, 2) term in the expansion of Earth's gravitational model (preset = 55.0)	
WE	ω_E	Earth's mean angular velocity about the sun. Internally set to 1.1407D-05 Deg/sec.	deg/sec
TVER		Time in seconds from Jan. 1st at 00:00 to time of Vernal Equinox in the year of simulation. Internally set to 6873720.0 seconds.	sec
ECLPTC		Obliquity of the ecliptic. Internally set to 23.444 deg.	
J2 J3 J4 J22		Oblate Earth coefficients. Internally set as follows: J2 = 1082.3D-06, J3 = 2.3D-06, J4 = 1.8D-06, J22 = 5.35D-06 Non-dimensional values.	

Classical Orbit Parameter Option

Fortran Symbol	Math Symbol	Description	Units
IKPLR	N. A.	Control word for Keplerian orbit parameter input IKPLR = 0, input $\{\chi_i\}$ and $\{\dot{\chi}_i\}$ IKPLR = 1, (preset) input Keplerian orbit parameters	N. D.

Fortran Symbol	Math Symbol	Description	Preset Value	Units
AS	a	Semi-major axis	8000.0	km
E	e	Eccentricity	0.0	N.D.
EI	i	Inclination angle	0.0	deg
F	f	True anomaly	0.0	deg
BW	Ω	Longitude of ascending node	0.0	deg
W	ω	Argument of perigee	0.0	deg
BWDOT	$\dot{\Omega}$	Rate of change of longitude of ascending node	0.0	deg/day
WDOT	$\dot{\omega}$	Rate of change of argument of perigee	0.0	deg/day

The following cards are input only if IKPLR = 0, otherwise they are omitted.

XSAT (1-3)	$\{\chi_i\}$	Components of initial position vector in the Aries (Equatorial) Inertial Frame. (preset = 8000.0, 0.0, 0.0)	km
XSATDT (1-3)	$\{\dot{\chi}_i\}$	Components of initial velocity vector in the Aries (Equatorial) Inertial Frame. (preset = 0.0, 7.0587, 0.0)	km/sec

PART 2

CONTROL WORDS

TIME CONTROL WORDS

Fortran Symbol	Description	Units
IDATE	Year, Month, Day YYMMDD (This number should fall within the orbit described in Part 1). (i.e. it should be the same year as the value of TVER specified. preset = 760101)	Integers
TIME	Time in seconds from start of day. This is also the problem start time (preset = 0.0)	Seconds
TSTOP	Problem stop time. Specified as incremental time from TIME (preset = 3600.0)	Seconds
FREQ	Output data print frequency (preset = 60.0)	Seconds

GENERAL CONTROL WORDS

Fortran Symbol	Description	Units
IDATA	Control word for printing of input data by subroutine ECHO (preset = 1)	

If IDATA = 0 prints out original set of input parameters, implies MLAST = 1.

If IDATA = 1 prints out set of input parameters which were the end conditions of the previous case in the stack. Implies MLAST = 0.

IDATA, unlike MLAST, is used in the case within the stack to which it applies.

Fortran Symbol	Description	Units
MLAST	Control word associated with stacking of cases. If a card MLAST = 0 is inserted within a case, the terminal conditions of this case are used as initial conditions for the next case which follows.	Integer, N.D.

Fortran Symbol	Description	Units
MLAST (con't)	If a card MLAST = 1 is inserted in each case, the first set of data for spacecraft description is used in each case which follows the first except for those cards which override the originals in the first case. (Preset = 0).	N.D.

NOTE

Stacking Procedure

The capability is provided to stack computer runs in order to simplify and speed the parametric analysis of spacecraft dynamics problems. Two types of problems can be processed: (1) Parallel stacking capability — series of simulations are being made with similar initial conditions and it is desired to change one or more parameters in each case, or (2) Series stacking capability — a continuous (in time) simulation is run where at specified times, changes in parameters are made but the dependent variables are carried over from the last time of one sequence to the beginning of the next sequence.

To run a stacked case, it is only necessary to insert a "1" card, i.e., a "1" punched in column one, after each set of input data. The simulation will continue until the TSTOP of a sequence is reached. The new data will be read in after the "1" card and the simulation will restart with the modified input data. An indefinite number of stacked cases can be processed providing there is sufficient computer time available.

. deployment run is also considered to be a stacked case. The first sequences should have either MDPLY = 1 or DDPLY = 1 or both. Deployment is either initiated or terminated in a particular sequence by setting ZL1(k) equal to the desired deployment rate or equal to zero, respectively.

Note that it is important to specify an appropriate value of DELTAT for each sequence in order to start the Runge Kutta-Adams Moulton integration scheme. If no new DELTAT is specified in the new stack, the DELTAT value of the previous stack will be used for the new stack.

If it is desired to rerun the deployment sequence with a change in a parameter, set MLAST = 1 in the last sequence. This will restore the input set of initial conditions.

OPTION CONTROL WORDS

Fortran Symbol	Description	Units
INOPT	Control word for type of satellite being studied. (Preset value = 1) INOPT = 1 Spin Stabilized Satellite INOPT = 2 Gravity-Gradient or earth-pointing Sat' llite	Integer, N.D.
IHAMLT	Control word to call Relative Hamiltonian subroutine. (Preset value = 0) IHAMLT = 0 By-passes subroutine IHAMLT = 1 Employs subroutine	Integer, N.D.
IGRAV	Control word to incorporate or exclude gravity effects. (Preset value = 1) IGRAV = 0 Gravity excluded IGRAV = 1 Gravity included	Integer, N.D.
MDPLY	Control word for boom deployment subroutine. (Preset value = 0) MDPLY = 0 Not a deployment case MDPLY = 1 Deployment of booms required	Integer, N.D.
DDPLY	Control word for libration damper boom deployment. (Preset value = 0) DDPLY = 0 Not a deployment case DDPLY = 1 Deployment of libration damper boom required	Integer, N.D.
ISDPLY	Control word to begin boom deployment from a "see sun" pulse. (Preset value = 0) ISDPLY = 0 By-passes subroutine ISDPLY = 1 Employs subroutine	Integer, N.D.

Fortran Symbol	Description	Units
IDAMP	Control word to exclude or allow libration damper motion. (Preset value = 0) IDAMP = 0 No damper motion IDAMP = 1 Damper motion	Integer, N.D.
IVISCS	Control word to employ viscous ring nutation damper into program. (Preset value = 0) IVISCS = 0 By-passes subroutine IVISCS = 1 Employs subroutine	Integer, N.D.
ISPIN3	Control word to call spin axis moment subroutine. (Preset value = 0) ISPIN3 = 0 Bypass subroutine ISPIN3 = 1 Employs subroutine	Integer, N.D.
IATTDE	Control word to call the attitude control subroutines. (Preset value = 0) IATTDE = 0 Bypasses subroutine IATTDE = 1 Employs subroutine	Integer, N.D.
IWHEEL	Control word to call momentum wheel subroutine. (Preset value = 0) IWHEEL = 0 Bypasses subroutine IWHEEL = 1 Employs subroutine	Integer, N.D.
IMGMTS	Control word to exclude or allow magnetic moments. (Preset value = 0) IMGMTS = 0 magnetic moments excluded IMGMTS = 1 magnetic moments allowed	Integer, N.D.
ITORK	Control word to apply torque about body axes. (Preset value = 0) ITORK = 0 No torque applied ITORK = 1 Torque applied	Integer, N.D.

Fortran Symbol	Description	Units
IBENDM	Control word to calculate and print out flexible element root bending moments. (Preset value = 0) IBENDM = 0 No calculation IBENDM = 1 Calculate and print	Integer, N.D.
ITENSE	Control word to calculate and print out element root tensions. (Preset value = 0) ITENSE = 0 No calculation ITENSE = 1 Calculate and print	Integer, N.D.
IPLANS	Control word to invoke a thermal lag effect on appendages due to planet and satellite shadowing. (Preset value = 0) IPLANS = 0 No lag invoked IPLANS = 1 Lag invoked	Integer, N.D.
ISATSH	Control word to invoke thermal lag effect of appendages due to satellite shadowing (Preset value = 0) ISATSH = 0 No shadowing ISATSH = 1 Shadowing and lag	Integer, N.D.
IWRTTF	Control word to print out thermal forces before and after computation of thermal lag. (Preset value = 0) IWRTTF = 0 No print out IWRTTF = 1 Print	Integer, N.D.
IAFM(1)	Control word to print out unit sun vector in body frame. (Preset value = 0) IAFM(1) = 0 No sun vector printout IAFM(1) = 1 Prints out sun vector	Integer, N. D.
IAFM(2)	Control word for punch cards restart. (Preset value = 0)	Integer, N. D.

Fortran Symbol	Description	Units
	IAFM(2) = 0 No cards punched	
	IAFM(2) = 1 Cards punched	
IAFM(3)	Control word for printing of output data. (Preset value = 0)	Integer, N. D.
	IAFM(3) = 1 No printout, printer plots only	
	IAFM(3) = 0 Printout and plots	
IAFM(4)	Control word to activate the data records and autocorrelation function plots for fast fourier transform analysis. (Preset value = 0)	Integer, N. D.
	IAFM(4) = 0 No data record and autocorrelation function plots	
	IAFM(4) = 1 Data record and autocorrelation function plots	
IAFM(5)	Control word to activate Adams-Moultion integrator message table. (Preset value = 0)	Integer, N. D.
	IAFM(5) = 0 No integrator message	
	IAFM(5) = 1 Integrator message printed	
IACOMP	Control word to activate the acceleration computation for both hub and element tip accelerations. (Preset value = 0)	Integer, N. D.
	IACOMP = 0 Bypasses computation	
	IACOMP = 1 Computes accelerations	
IHUBAC	Control word to activate acceleration computation and printout for the hub. (Preset value = 0)	Integer, N. D.
	IHUBAC = 0 No computation	
	IHUBAC = 1 Computes hub accelerations	
ITIPAC	Control word to activate acceleration computation and printout for the element tip. (Preset value = 0)	Integer, N. D.
	ITIPAC = 0 No computation	
	ITIPAC = 1 Computes tip accelerations	

Fortran Symbol	Description	Units
IPULSE	Control word to activate thrust subroutine. (Preset value = 0) IPULSE = 0 Bypasses subroutine IPULSE ⩾ 1 Employs subroutine	Integer, N. D.
ISPLSE	Control word to activate sun crossing time to start thrusting. (Preset value = 0) ISPLSE = 0 Sun crossing not used ISPLSE = 1 Sun crossing used	Integer, N. D.
IPLPRP	Control word for number of thrust pulses per spin period. IPLPRP = 1 One pulse (Preset) IPLPRP = 2 Two pulses	Integer. N.D.
ISPNP	Control word to print out orbit update message (only if ISPLSE = 1, IPULSE > 1). i.e., if ISPNP = 5, (preset) the orbit update message will be printed at every 5th pulse.	Integer, N. D.
IHCALC	Control word to calculate and print out the angular momentum vector of the system and system moments of inertia (preset value = 0) IHCALC = 0 No calculation IHCALC = 1 Calculates and prints	Integer, N. D.
IHREF	Control word to compute reference direction for EPSERR from the initial system angular momentum vector (Preset value = 0) IHREF = 0 No calculation IHREF = 1 Determines reference direction from initial angular momentum vector	Integer, N. D.
IKPLR	Control word for Keplerian orbit parameter input (Preset value = 1) IKPLR = 0 Input position an velocity IKPLR = 1 Input Keplerian orbit parameters	Integer, N. D.

Fortran Symbol	Description	Units
ICSD	Control word to activate the Fast Fourier Transform analysis and plot. See p. 18 for KPLOTS control also (Preset value = 0)	Integer, N.D.
	ICSD = 0 By-passes subroutine	
	ICSD = 1 Employs subroutine	
IPRY	Control word to print and plot pitch, roll and yaw rates instead of OMBC values when INOPT = 2	
	IPRY = 0 No print out and plot	
	IPRY = 1 Print out and plots (preset = 0)	
ISCP	Control word to activate the spacecraft configuration plot option. (Not available in current program)	Integer, N.D.
	ISCP = 0 By-passes subroutine	
	ISCP = 1 Employs plot subroutine	
IPUNCH	Control word for punched card output under normal case end. Set MLAST = 1 and IPUNCH = 1 (preset = 0)	Integer, N.D.
KNTRL(10)	Vector of control integers (10) for DE-B control system simulation	Integer, N.D.
I2BDY	Control word to add secondary body to simulation	Integer, N.D.
	I2BDY = 0 No secondary body	
	I2BDY = 1 Secondary body present	
IRAST	Control word to invoke prescribed rastering motions for secondary body.	Integer, N.D.
	IRAST = 0 No rastering	
	IRAST = 1 Rastering Prescribed	
IARST(3)	Control word to specify type of rastering cycle to be invoked on each axis.	Integer, N.D.
	IARST (I) = 0 No motion	
	IARST (I) = 1 Motion of Type 1	
	IARST (I) = 2 Motion of Type 2	
	I = 1 to 3	
	I = 1 motion about the 3 axis	

Fortran Symbol	Description	Units
	I = 2 motion about the 1 axis	
	I = 3 motion about the 2 axis	
IACFLT(20)	Control integers for filtered sensor signal to actuate momentum wheel cycling or pulsed thrusting.	Integer, N.D.
IDPHLD	Control word for simulation of constant angular velocity of libration damper.	Integer, N.D.
	IDPHLD = 0 No simulation	
	IDPHLD = 1 Constant angular velocity for damper	
IPLOT	Control word for plotting of output data.	Integer, N.D.
	IPLOT = 0 No plots	
	IPLOT = 1 Printer plots or FFT analysis. (Preset = 0)	Integer, N.D.
IGMBL	Control word for two axis gimble simulation.	Integer, N.D.
	IGMBL 0 No gimble simulated (preset)	
	IGMBL 1 Gimble simulated	
IPCTCS (20)	20 Control words for gimble platform con rol system simulation (preset = 0)	Integer, N.D.
IJTOMP	Control word to invoke jet damping.	Integer, N.D.
	IJTDMP 0 No jet damping (preset)	
	IJTDMP 1 Jet damping	
IGMBLD	Control word for two axis gimble (damper simulation)	Integer, N.D.
	IGMBLD 0 No gimble simulated (preset)	
	IGMBLD 1 Gimble simulated	
IPLDCS (20)	20 Control words for gimble platform (damper) simulation (preset = 0)	Integer, N.D.
ITHRM (20)	20 Control words for element thermal expansion – contraction simulation	
IAMPRM (1)	Control word for arbitrary oriented momentum wheel simulation (preset = 0)	Integer, N.D.

Fortran Symbol	Description	Units
IAMWH (10)	10 Control words for axis momentum wheel simulation (preset = 0)	Integer, N.D.
IOMKDM (1)	Control word to invoke use of reference frequency for damping coefficient (preset = 0)	Integer, N.D.

INTEGRATION CONTROL WORDS

Fortran Symbol	Description	Units
DELTAT	Starting integration interval for Runge Kutta. (preset value = 0.01)	Seconds
DELMIT	Minimum value for time integration interval for predictor-corrector. If integration step size becomes less than DELMIT, simulation stops. (Preset = 1.0 D-7)	Seconds
FACTOR	Percentage by which Δt is varied in the Adams-Moulton integrator. If the difference between extrapolated and interpolated values of the integrands is greater than the upper bound (on the difference) Δt is decreased; if the difference is greater than the lower bound, Δt is increased. (predictor-corrector) FACTOR is presently set to 0.3). i.e., $\Delta t_{n+1} = \Delta t_n (1 * \text{FACTOR})$	N.D.

Fortran Symbol	Description	Units
UP(i)	The upper bound on the absolute difference between the extrapolated and interpolated values used in the predictor-corrector of the integration routine.	Corresponds to specific variables
DN(i)	The lower bound on the absolute difference between the extrapolated and interpolated values.	Corresponds to specific variables

NOTE

UP and DN are bounds on the difference between the extrapolated and interpolated values of the components of the state vector. They are set internally and are not required to be input. Unless the user fully understands their use, it is recommended that they be left undisturbed. The same applies to the integration bounds control words which follow.

INTEGRATION BOUNDS

Fortran Symbol	Description	Units
CONSA	This is the upper bound on the absolute difference between the extrapolated and interpolated values used in the predictor-corrector for the integration of the elements in the first two rows of direction cosine matrix. The lower bound is automatically set two orders of magnitude below the upper bound. (Preset value = 1.0 D-5)	N. D.
COMEG	This is the upper bound allowed for the error in the predictor-corrector of the integration of the body components of inertial angular velocity. The lower bound is automatically set two orders of magnitude below the upper bound. (Preset value = 1.0 D-7)	rad/sec
DUC	This is the upper bound on the error for the predictor-corrector integration for the libration damper angle of gravity-gradient satellites. For the simulation of spin stabilized satellites with nutation damping, this represents the upper bound on the error for predictor-corrector integration for the viscous torque of the damper. (Preset value = 1.0 D-2)	rad

Fortran Symbol	Description	Units
DUC1	This is a lower bound for DUC. (Preset value = 1.0 D-4)	rad
DUCD	This is the upper bound on the error for the predictor-corrector integration for the angular velocity of the libration damper for gravity-gradient satellites. For the simulation of spin-stabilized satellites with viscous damping, this is the upper bound on the error for the predictor-corrector integration for the angular momentum of the viscous liquid. (Preset value = 1.0 D-3)	rad/sec
DUCD1	This is the lower bound for DUCD. (Preset value = 1.0 D-5)	rad/sec
DOOP	This is the upper bound on the error for predictor-corrector integration for the 2 axis components of damper element deflections. (Preset value = 1.0 D-1)	feet
DOOP1	This is the lower bound for DOOP. (Preset value = 1.0 D-3)	feet
DOOPV	This is the upper bound on the error for predictor-corrector integration for the 2 axis components of damper element velocity. (Preset value = 5.0 D-5)	ft/sec
DOOPV1	This is the lower bound for DOOPV. (Preset value = 5.0 D-7)	ft/sec
DIP	This is the upper bound on the error for predictor-corrector integration for the 3 axis components of damper element deflections. (Preset value = 1.0 D-1)	feet
DIP1	This is the lower bound for DIP. (Preset value = 1.0 D-3)	feet

Fortran Symbol	Description	Units
DIPV	This is the upper bound on the error for predictor-corrector integration for the 3 axis components of damper element velocities. (Preset value = 5.0 D-7)	ft/sec
DIPV1	This is the lower bound for DIPV.	ft/sec
AOOP	This is the upper bound on the error for the predictor-corrector integration for the 2 axis element frame component of antenna tip displacement. (Preset value = 1.0 D-1)	feet
AOOP1	This is the lower bound for AOOP. (Preset value = 1.0 D-3)	feet
AOOPV	This is the upper bound on the error for the predictor-corrector integration for the 2 axis element frame component of tip velocities. (Preset value = 5.0 D-5)	ft/sec
AOOPV1	This is the lower bound for AOOPV. (Preset value = 5.0 D-7)	ft/sec
AIP	This is the upper bound on the error for the predictor-corrector integration for the 3 axis element frame component of tip displacement. (Preset value = 1.0 D-1)	feet
AIP1	This is the lower bound for AIP. (Preset value = 1.0 D-3)	feet
AIPV	This is the upper bound on the error for the predictor-corrector integration for the 3 axis element frame component of tip velocity. (Preset value = 5.0 D-5)	
AIPV1	This is the lower bound for AIPV. (Preset value = 5.0 D-7)	ft/sec
TWIUP	Upper integration bound for twist angle. (Preset value = 1.0 D-4)	deg

Fortran Symbol	Description	Units
TWIDN	Lower integration bound for twist angle. (Preset value = 1.0 D-6)	deg
TWDUP	Upper integration bound for twist velocity. (Preset value = 1.0 D-5)	deg/sec
TWDDN	Lower integration bound for twist velocity (Preset value = 1.0 D-7)	deg/sec
CSUP(20)	Upper bound on difference between predicted and corrected control system state vector. Location in CSUP corresponds to the location of the variable in the state vector initial condition array SVCS. (Preset value = 1.0 D-02)	
CSDN(20)	Lower bound on difference between predicted and corrected control system state vector. Location in CSDN corresponds to location of the variable in the state vector initial condition array SVCS. (Preset value = 1.0 D-04)	
SBUP(2)	Integration upper bounds for secondary body angles and angular rates. (Preset = 1.0 D-3)	rad rad/sec
SBDN(2)	Integration lower bounds for secondary body angles and angular rates. (Preset = 1.0 D-5)	rad rad/sec
ACPARM(19)	Upper bound for filter integrater.	
ACPARM(20)	Lower bound for filter integrater.	

Fortran Symbol	Description	Units
PCSPRM(30)	Integration upper bound for magnetometer first order lag transfer function (preset = 0)	gauss
PCSPRM(31)	Integration lower bound for magnetometer first order lag transfer function (preset = 0)	gauss
GMUP(1)	Integration upper bound for gimble angles (preset = 1.0 D–3)	rad
GMUP(2)	Integration upper bound for gimble angular rates (preset = 1.0 D–3)	rad/sec
GMDN(1)	Integration lower bound for gimble angles (preset = 1.0 D–5)	rad
GMDN(2)	Integration lower bound for gimble angular rates (preset = 1.0 D–5)	rad/sec
DMUP(1)	Integration upper bound for damper gimble angles (preset = 1.0 D–3)	rad
DMUP(2)	Integration upper bound for damper gimble angular rates (preset = 1.0 D–3)	rad/sec
DMDN(1)	Integration lower bound for damper gimble angles (preset = 1.0 D–5)	rad
DMDN(2)	Integration lower bound for damper gimble angular rates (preset = 1.0 D–5)	rad/sec
DCSPRM(30)	Integration upper bound for damper related magnetometer first order lag transfer function (preset = 0)	gauss
DCSPRM(31)	Integration lower bound for damper related magnetometer first order lag transfer function (preset = 0)	gauss
THRMPR(2)	Integration upper bound for thermal expansion – contraction simulation (preset = 0)	°R
THRMPR (3)	Integration lower bound for thermal expansion-contraction simulation (preset = 0)	°R
AMPARM (101)	Integration upper bound for filtered error angle of the arbitrarily oriented momentum wheel (preset = 0)	deg
AMPARM (102)	Integration lower bound for filtered error angle of the arbitrarily oriented momentum wheel (preset = 0)	deg
AMPARM (103)	Integration upper bound for arbitrarily oriented momentum wheel speed (preset = 0)	deg/sec
AMPARM (104)	Integration lower bound for arbitrarily oriented momentum wheel speed (preset = 0)	deg/sec
AMWHPR (101)	Integration upper bound for filtered angle error of the axis momentum wheel simulation (preset = 0)	deg

AMWHPR (102)	Integration lower bound for filtered angle error of the axis momentum wheel simulation (preset = 0)	[illegible]
AMWHPR (103)	Integration upper bound for axis momentum wheel speed (preset = 0)	deg/sec
AMWHPR (104)	Integration lower bound for axis momentum wheel speed (preset = 0)	deg/sec

PLOT CONTROL WORDS

Fortran Symbol	Description	Units
IPLOT	Control word for plotting of output data.	Integer, N.D.
	IPLOT = 0 No plots.	
	IPLOT = 1 Printer plots or FFT analysis. (Preset = 0).	Integer, N.D.

Fortran Symbol	Description	Preset Value	Units
IPLMOD	Control word for individual modal analysis plot IPLMOD = 0, No individual modal analysis plot IPLMOD = 1, Store individual modal variables for plotting	0	Integer N.D.
IKMOD	Control word to activate the flexible element requiring independent higher mode plots. E.g., if NELMTS = 7, NDAMPR = 0, Set IPLMOD = 1 and IKMOD = 5 in order to activate higher modal displacement plots for 5th elements NOTE Value of MODES for IKMODth element must be greater or equal to one and less or equal to 3.	1	Integer N.D.

The variables to be plotted by printer plot are controlled by KPLOTS array values. The dimensions of KPLOTS array is 253. The control of plotting is as follows

KPLOTS(I) = 0	do not plot Ith variable (preset value)
KPLOTS(I) = 1	plot Ith variable
KPLOTS(I) = 2	for plot and FFT analysis
KPLOTS(I) = 3	for FFT analysis only

All KPLOTS array addresses are integer variables with value of either 0 or 1. For the first ten KPLOTS array addresses, (i.e., I = 1 to 10), the variables plotted are functions of INOPT. For I ⩾ 11, the plotting variables are independent of the INOPT value. The KPLOTS array addresses are given in the following table.

For I $\leqslant$ 10

KPLOTS Array Address	Fortran Variable Plotted vs. Time INOPT 1	INOPT 2	Units
1	PSI1	ALFAE	deg
2	THET1	BETAE	deg
3	PHI1	GAMAE	deg
4	OMEG1	OMBC1	deg/sec
5	OMEG2	OMBC2	deg/sec
6	OMEG3	OMBC3	deg/sec
7	PHILD	PHILD	deg
8	NUT ANG (deg)	PRAT	deg/sec
9	EPSERR (deg)	RRAT	deg/sec
10	--	YRAT	deg/sec

The definition of the Fortran variables are given in Part 4 of this document.

For I $\geqslant$ 11

KPLOTS Array Address I	Description	Fortran Symbol	Units	Note
11	1st flexible element 1-2 plane tip displacement	U21	feet	
12	1st flexible element 1-2 plane tip velocity	U2DOT1	ft/sec	
13	1st flexible element 1-3 plane tip displacement	U31	feet	

KPLOTS Array Address I	Description	Fortran Symbol	Units	Note
14	1st flexible element 1-3 plane tip velocity	U3DOT1	ft/sec	
15	1st flexible element twist* displacement	no symbol	deg	
16	1st flexible element twist* velocity	no symbol	deg/sec	
17	2nd flexible element 1-2 plane tip displacement	U22	feet	
18	2nd flexible element 1-2 plane tip velocity	U2DOT2	ft/sec	
19	2nd flexible element 1-3 plane tip displacement	U32	feet	
20	2nd flexible element 1-3 plane tip velocity	U3DOT2	ft/sec	
⋮	etc.			
65	10th flexible element 1-2 plane tip displacement	U210	feet	
66	10th flexible element 1-2 plane tip velocity	U2DOT10	ft/sec	
67	10th flexible element 1-3 plane tip displacement	U310	feet	
68	10th flexible element 1-3 plane tip velocity	U3DOT10	ft/sec	
69	10th flexible element* twist displacement	no symbol	deg	

*Individual twist modes are printed out and the sum of the modes is plotted. See p. 106 for output print symbols

KPLOTS Array Address I	Description	Fortran Symbol	Units	Note
70	10th flexible element* twist velocity	no symbol	deg/sec	
71	1st damper flexible element 1-2 plane tip displacement	UD21	feet	
72	1st damper flexible element 1-2 plane tip velocity	UD2DT1	ft/sec	
73	1st damper flexible element 1-3 plane tip displacement	UD31	feet	
74	1st damper flexible element 1-3 plane tip velocity	UD3DT1	ft/sec	
75	1st damper element* twist displacement	no symbol	deg	
76	1st damper element* twist velocity	no symbol	deg/sec	
77	2nd damper flexible element 1-2 plane tip displacement	UD22	feet	
⋮	etc.			
128	10th damper flexible element 1-3 plane tip velocity	UD3DT10	ft/sec	
129	10th damper element* twist displacement	no symbol	deg	
130	10th damper element* twist velocity	no symbol	deg/sec	
131	Mode 1 1-2 plane tip displacement for element IKMOD	AK1	feet	$1 \leqslant MODES \leqslant 3$ IPLMOD = 1

*Individual twist modes are printed out and the sum of the modes is plotted. See p. 106 for output print symbols.

KPLOTS Array Address I	Description	Fortran Symbol	Units	Note
132	Mode 1 1-3 plane tip displacement for element IKMOD	BK1	feet	$1 \leq$ MODES ≤ 3 IPLMOD = 1
133	Mode 2 1-2 plane tip displacement for element IKMOD	AK2	feet	$1 \leq$ MODES ≤ 3 IPLMOD = 1
134	Mode 2 1-3 plane tip displacement for element IKMOD	BK2	feet	$1 \leq$ MODES ≤ 3 IPLMOD = 1
135	Mode 3 1-2 plane tip displacement for element IKMOD	AK3	feet	$1 \leq$ MODES ≤ 3 IPLMOD = 1
136	Mode 3 1-3 plane tip displacement for element IKMOD	BK3	feet	$1 \leq$ MODES ≤ 3 IPLMOD = 1
137	Mode 1 twist displacement for element IKMOD		deg	
137	Mode 1 twist displacement for element IKMOD	CWK1	deg	
138	Mode 2 twist displacement for element IKMOD	CWK2	deg	
139	Mode 3 twist displacement for element IKMOD	CWK3	deg	
140	Mode 1 1-2 plane tip displacement for damper element IKMOD		feet	
141	Mode 1 1-3 plane tip displacement for damper element IKMOD	DINK2	feet	
142	Mode 2 1-2 plane tip displacement for damper element IKMOD	DINK2	feet	

KPLOTS Array Address I	Description	Fortran Symbol	Units	Note
143	Mode 2 1-3 plane tip displacement for damper element IKMOD	DINK2	feet	
144	Mode 3 1-2 plane tip displacement for damper element IKMOD	DOUTK3	feet	
145	Mode 3 1-3 plane tip displacement for damper element IKMOD	DINK3	feet	
146	Mode 1 twist displacement for damper element ZKMOD	CWK1	deg	
147	Mode 2 twist displacement for damper element ZKMOD	CWK2	deg	
148	Mode 3 twist displacement for damper element ZKMOD	CWK3	deg	
149 ↓ 154	Accelerometer reading value from 1 to 6 respectively	ACCRED1 ACCRED2 ⋮ ACCRED6	ft/sec^2 ft/sec^2 ⋮ ft/sec^2	IACOMP = 1 IHUBAC = 1 The Max. No. of plot is NUMHUB
155	Instantaneous body moment of inertia about 1-axis	BIXX	slug-ft^2	IHCALC = 1
156	Instantaneous body moment of inertia about 2-axis	BIYY	slug-ft^2	IHCALC = 1
157	Instantaneous body moment of inertia about 3-axis	BIZZ	slug-ft^2	IHCALC = 1
158	Right ascension angle of angular momentum vector in Aries inertial frame	None	deg	IHCALC = 1 PLOTTED ONLY

KPLOTS Array Address I	Description	Fortran Symbol		Note
159	Declination angle of angular momentum vector in Aries inertial frame	None	deg	IHCALC = 1 PLOTTED ONLY
160	Magnitude of angular momentum vector	HMAG	ft-lb-sec	IHCALC = 1
161 ↓ 170	Root tension history for element 1 to 10 respectively	TENSN1 TENSN2 ⋮ TENSN10	lb lb ⋮	ITENSE = 1 plotting quantities ≤ (NELMTS+NDAMPR)
171	1-2 plane root bending moment for element 1	BNMTA1	lb-ft	IBENDM = 1
172	1-3 plane root bending moment for element 1	BNMTB1	lb-ft	IBENDM = 1
173	1-2 plane root bending moment for element 2	BNMTA2	lb-ft	IBENDM = 1
174	1-3 plane root bending moment for element 2	BNMTB2	lb-ft	IBENDM = 1
⋮	etc.			
189	1-2 plane root bending moment for element 10	BNMTA10	lb-ft	IBENDM = 1
190	1-3 plane root bending moment for element 10	BNMTB10	lb-ft	IBENDM = 1
191	Right ascension angle of the unit sun line vector in body reference frame	None	deg	IAFM(1) = 1 PLOTTED ONLY
192	Declination angle of the unit sun line vector in body reference frame	None	deg	IAFM(1) = 1 PLOTTED ONLY

KPLOTS Array Address I	Description	Fortran Symbol	Units	Note
193 → 195	Magnetic field vector components in 1, 2, 3, body axis respectively	SMAGB1 SMAGB2 SMAGB3	GAUSS GAUSS GAUSS	IMGMTS = 1
196	Relative Hamiltonian of the system	HAMILT	ft-lb	IHAMLT = 1
197	Magnitude of root bending moment for 1st flexible element	None	ft-lb	PLOTTED ONLY
↓	etc.			
206	Magnitude of root bending moment for 10th flexible element	None	ft-lb	PLOTTED ONLY
207	Momentum wheel speed 1-axis	WHL SPD1	deg/sec	
208	Momentum wheel speed 2-axis	WHL SPD2	deg/sec	
209	Momentum wheel speed 3-axis	WHL SPD3	deg/sec	
210	External moment about 1 body axis	MOMENT 1	ft-lbs	
211	External moment about 2 body axis	MOMENT 2	ft-lbs	
212	External moment about 3 body axis	MOMENT 3	ft-lbs	

KPLOTS Array Address I	Description	Fortran Symbol	Units	Note
213	Component of angular momentum on 1 body axis	HBODY 1	ft-lb-sec	IHCALC 1
214	Component of angular momentum on 2 body axis	HBODY 2	ft-lb-sec	IHCALC 1
215	Component of angular momentum of 3 body axis	HBODY 3	ft-lb-sec	IHCALC 1
216	Pitch sensor output		volts	IWHEEL 1 and
217-219	Pitch sensor dynamics			KNTRL(1) 1 or 2
220	Not used			
221	Roll sensor output		volts	
222-224	Roll sensor dynamics		volts/sec, etc	
225	Not used			
226	Output of pitch compensation amplifier		volts	
227	Not used			
228	Tachometer output		volts	
229	Not used			
230	Momentum wheel speed			
231-233	Not used			
234	Nutation damper phase shift dynamics			
235	Nutation damper phase shift output			

KPLOTS Array Address I	Description	Fortran Symbol	Units	Note
236	Rotation of secondary body about 3 axis	GAMSB	deg	
237	Rotation of secondary body about the carried 1 axis	ALPSB	deg	
238	Rotation of secondary body about the carried 2 axis	BETSB	deg	
239	Relative angular rate of secondary body about 3 axis	GAMMAD	deg/sec	
240	Relative angular rates of secondary body about the carried 1 axis	ALPHAD	deg/sec	
241	Relative angular rates of secondary body about the carried 2 axis	BETAD	deg/sec	
242	Component of secondary body relative angular velocity on 1 axis of secondary body	OM1SB	deg/sec	
243	Component of secondary body relative angular velocity on 2 axis of secondary body	OM2SB	deg/sec	
244	Component of secondary body relative angular velocity on 3 axis of secondary body	OM3SB	deg/sec	
245	State variable sensor output		varies	
246	State variable filter output		varies	
247	State variable filter first integrater output		varies	

KPLOTS Array Address I	Description	Fortran Symbol	Units	Note
248	Product of inertia	IXY	slug ft^2	
249	Product of inertia	IXZ	slug ft^2	
250	Product of inertia	IXY	slug ft^2	
251	1st damper element 1-2 plane slope		rad	
252	1st damper element 1-3 plane slope		rad	
253	2nd damper element 1-2 plane slope		rad	
• • • •	etc.		rad	
269	10th damper element 1-2 plane slope		rad	
270	10th damper element 1-3 plane slope		rad	
271	1st flexible element 1-2 plane slope	U2P 1	rad	
272	1st flexible element 1-3 plane slope	U3P 2	rad	
273	2nd flexible element 1-2 plane slope	U2P 2	rad	
	etc.			
289	10th flexible element 1-2 plane slope	U2P 10	rad	
290	10th flexible element 1-3 plane slope	U3P 10	rad	
291	1st mode 1-2 plane slope		rad	Mode output is for the element specified by input IKMOD
292	1st mode 1-3 plane slope		rad	

KPLOTS Array Address I	Description	Fortran Symbol	Units	Note
293	2nd mode 1-2 plane slope		rad	
294	2nd mode 1-3 plane slope		rad	
295	3rd mode 1-2 plane slope		rad	
296	3rd mode 1-3 plane slope		rad	
297	Azimuth angle for the gimble azimuth platform		deg	
298	Azimuth angular rate for the gimble azimuth platform		deg/sec	
299	Elevation angle for the gimble elevation platform		deg	
300	Elevation angular rate for the gimble elevation platform		deg/sec	
301	Output of first order lag transfer function for magnetometer one axis		Gauss	
302	Output of first order lag transfer function for magnetometer two axis		Gauss	
303	Output of first order lag transfer function for magnetometer three axis		Gauss	
304	Azimuth error output		deg	IPLTCS 1
305	Elevation error output		deg	IPLTCS 1
306	Azimuth PID digital controller output			Units depend on PID gain constant units
307	Elevation PID digital controller output			

KPLOTS Array Address I	Description	Fortran Symbol	Units	Not
308	Azimuth platform drive motor torque		ft-lbs	IPLTCS 1
309	Elevation platform drive motor torque		ft-lbs	
310	Azimuth angle for the gimble azimuth platform		deg	
311	Azimuth angular rate for the azimuth platform		deg/sec	IGMBLD 1
312	Elevation angle for the gimble elevation platform		deg	
313	Elevation angular rate for the gimble elevation platform		deg/sec	
314	Output of first order lag transfer function for magnetometer one axis		gauss	
315	Output of first order lag transfer function for magnetometer two axis.		gauss	
316	Output of first order lag transfer function for magnetometer three axis		gauss	
317	Azimuth error output		rad	
318	Elevation error output		rad	
319	Azimuth PID digital controller output			Units depend on PID gain constants
320	Elevation PID digital controller output			
321	Azimuth platform drive motor torque		ft-lbs	
322	Elevation platform drive motor torque		ft-lbs	IAMWH(1) = 1 and IAMWH(2) = 1

KPLOTS Array Address I	Description	Fortran Symbol	Units	Note
323	Roll axis filter output of error signal for momentum wheel control		rad	
324	Pitch axis filter output of error signal for momentum wheel control		rad	IAMWH(3) = 1
325	Yaw axis filter output of error signal for momentum wheel control		rad	IAMWH(4) = 1
326	Roll axis momentum wheel speed		deg/sec	
327	Pitch axis momentum wheel speed		deg/sec	
328	Yaw axis momentum wheel speed		deg/sec	
329	Arbitrarily oriented momentum wheel filter output of control system angular error			IAMPRM(1) = 1
330	Momentum wheel speed			
331	1st element temperature		°F	ITHRM(1) = 1 and ITHRM(11) = 1
⋮	etc			etc
340	10th element temperature		°F	ITHRM(20) = 1

Fortran Symbol	Description	Present Value
LCPU	CPU time in seconds allowed for print out, integer (Preset = 20).	

DIAGNOSTIC CONTROL WORDS

Fortran Symbol	Description	Preset Value
IOUT	Control word to print computations as performed in the Simulator. IOUT = 1 No print of computations. IOUT = 2 Print of computations at print frequency. IOUT = 3 Print of computations for each call of DEREQ1.	1
KLUGE	Control word to stop computing on this input set. If KLUGE = 1 and IOUT = 2, machine stops at time zero, before normal output is printed, and prints calculations.	0
ISWTCH	Control word to print energy related computations. If ISWITCH = 0 and IHAMLT = 1, energy computations are printed out. If ISWITCH $\neq$ 0, no print of energy computations are made.	8
NOPT	A control word to give the number of times subroutine DEREQ1 was entered. NOPT = 0 No printout of number of times. NOPT = 1 Prints out number of times.	0

PART 3

SPACECRAFT DESCRIPTION & SIMULATION OPTIONS

CORE PROPERTIES

Fortran Symbol		Description	Units
BDYMI (i, j)	I_{ij}	Moments of inertia of satellite core about Y body axes. i = 1, 2, 3 j = 1, 2, 3	slug ft^2
SCO	S_0	Projected area of central core of satellite Used for aerodynamics <u>and</u> solar pressure. (preset = 14.6)	ft^2
ZMS	M_s	Mass of entire satellite (preset = 25.0)	slugs
HUBCDA (3)		C_DA values for spacecraft hub along three body axes. (preset = 1.0, 1.0, 1.0)	ft^2
HUBCP (3)		Body frame position vector of hub center of pressure. (preset = 0.0, 0.0, 0.0)	ft^2

ELEMENT GEOMETRY AND PHYSICAL PROPERTIES

Fortran Symbol	Math Symbol	Description	Units
NELMTS		The number of elements rigidly attached to satellite core. (preset = 6, do not set to 0).	Integer, N.D.
ZL0 (k)	ℓ_{0k}	Length of the k^{th} element at start of problem time. (preset = 1.0, do not set to 0)	feet
ZL1 (k)	$\dot{\ell}_k$	Velocity of deployment of k^{th} element. (preset = 0.0)	ft/sec
ZLA (k)	$\ddot{\ell}_k$	Acceleration of deployment of k^{th} element. (preset = 0.0)	ft/sec^2
ZBZ (1, k) 2 ZBZ (2, k) 2 ZBZ (3, k) 2	z_{m1k} z_{m2k} z_{m3k}	Coordinates of the origin of the k element frames as defined in the reference Y body frame or nuration damper Z frame. (preset = 0.0)	feet

Fortran Symbol	Math Symbol	Description	Units
ALFAEK(k)	α_k	Euler angle relating orientation of k^{th} element frame as defined in the reference Y body frame or libration damper Z frame. (Around 1 axis, 2nd angle in 2 - 1 - 3) rotation. (preset = 0.0)	deg
BETAEK(k)	β_k	Euler angle relating orientation of k^{th} element frame as defined in the reference Y body frame or libration damper Z frame. (Around 2 axis, 1st angle in 2 - 1 - 3 rotation.) (preset = 0.0)	deg
GAMAEK(k)	γ_k	Euler angle relating orientation of the k^{th} element frame as defined in the reference Y body frame or libration damper Z frame. (Around 3 axis, 3rd angle in 2 - 1 - 3 rotation.) (preset = 0.0)	deg
MODES(k)		Designation of bending modes for element 0 = Rigid body 1 = Bending mode 1 2 = Bending mode 2 3 = Bending mode 3 (includes 3 modes)	Integers
A (k, j) 1	A_{ij}	Component of the k^{th} core element tip deflection in the j^{th} bending mode as measured along the 2 axis of the element frame. (preset = 0.0)	feet
ADOT (k, j) 1	A_{ij}	Component of the k^{th} core element tip velocity in the j^{th} bending mode as measured in the element frame along the 2 axis of the frame. (preset = 0.0)	ft/sec
B (k, j) 1	B_{ij}	Component of the k^{th} core element tip deflection in the j^{th} bending mode as measured in the element frame along the 3 axis of the frame. (preset = 0.0)	feet

Fortran Symbol	Math Symbol	Description	Units
BDOT (k, j) 1	B_{ij}	Component of the k^{th} core element tip velocity in the j^{th} bending mode as measured in the element frame along the 3 axis of the frame. (preset = 0.0)	ft/sec

NOTE

In the above arrays, the "1" following the parentheses indicates that the first integer in the parentheses varies as numbers are read off across the input card. For example, the card:

A (k, 1) 1   2.0   4.0   5.0

would be interpreted by the program as:

A (1, 1) = 2.0

A (2, 1) = 4.0

A (3, 1) = 5.0 etc.

The arrays A, ADOT, B, BDOT are both input and output of the program. Thus if the user wished to start a problem on case with initial tip deflections and on velocities of the rigidly attached elements, these quantities would be input. Otherwise, they are internally set to zero at the start of the problem and are output only.

Fortran Symbol	Description
LK (k)	This is a control word for the selection of one of two preset (Block 2) data sets for the k^{th} element. Each data set contains normalized mass integrals and normalized effective areas integrals for flexible elements. The first data set is generated using cantilever beam modes. The second data set utilizes spinning string modes with a tip mass. LK (k) = 1 uses data set 1 LK (k) = 2 uses data set 2 (preset to 1)

Fortran Symbol	Description
	A data set can be generated for a specific antenna configuration by using the Integral Evaluation Program.
LLK (k)	This is a control word for the selection of one of two preset data sets for the k^{th} element. Each data set contains normalized internal force integrals and normalized thermal force integrals for flexible elements.

LLK (k) = 1 uses data set 1

LLK (k) = 2 uses data set 2
(preset to 1)

A data set can be generated for a specific flexible configuration by using the Integral Evaluation Program.

Fortran Symbol	Math Symbol	Description	Units
EMODLS (k)	E	Young modulus for k^{th} element (preset = 2.0 D7)	lb-in.$^{-2}$
RTUBE (k)	r	Mean radius of k^{th} element (preset = 2.935 D-1)	inches
HTUBE (k)	h	Wall thickness of k^{th} element (preset = 2.0 D-3)	inches
THERMC (k)	α_T	Thermal coefficient of expansion for k^{th} element. (preset = 8.85 D-6)	in./in./°F
TIPMS (k)	M_T	Tip mass attached to k^{th} element	slugs
SAO (k)	S_{co}	The projected area of a one foot length of element corrected for flow around a cylinder. Used in computing aerodynamic and solar pressure. (preset = 0.0)	ft^2
STMK (k)	S_{Tk}	The projected area of a tip mass corrected for flow around a spherical body. Used in computing aerodynamic and solar pressure.	ft^2

Fortran Symbol	Math Symbol	Description	Units
RHOK(k)	ρ_k	Mass per unit length of the k^{th} element. (preset = 4.36 D-4)	slugs/ft
POO	p_o	Solar pressure on a flatplate at normal incidence. (preset = 0.0)	lb/ft^2
DTOO	ΔT_o	Temperature differential across antenna at normal incidence of sunlight. (preset = 0.0)	°F
CDAMP(n, k)2	C_{cr}	Damping ratio in n^{th} bending mode for k^{th} element. (preset = 0.0)	N.D.
SKOA(k, n)2	A_{kno}	The 2 axis component in the k^{th} element frame of the offset zero stress position corresponding to the n^{th} mode shape. (preset = 0.0)	feet
SKOB(k, n)2	B_{kno}	The 3 axis component in the k^{th} element frame of the offset zero stress position corresponding to the n^{th} mode shape. (preset = 0.0)	feet
AERO	C_D	Aerodynamic drag coefficients for the elements. (preset = 2.0)	N.D.
TDIS(k)		Factor to account for variations in temperature distributions for k^{th} element. (preset = 2.0)	N.D.

Computation of Flexible Element Root Bending Moments

Fortran Symbol	Math Symbol	Description	Units
IBENDM		Control word to calculate and print out flexible element root bending moments. (Preset value = 0) IBENDM = 0 No calculation IBENDM = 1 Calculate and print	Integer, N.D.

Fortran Symbol	Math Symbol	Description	Units
ZKBM(6)	$X_n''(0)$	Root curvatures of normalized shape function for first three modes. Two sets are permissible corresponding to data sets controlled by LLK(K) (internal forces). LLK(K) = 1 ZKBM(1-3) (preset = 3.5, -22.0, 61.7) LLK(K) = 2 ZKBM(4-6) (preset = 3.5, -22.0, 61.7)	N.D.

Computation of Element Root Tensions

Fortran Symbol	Description	Units
ITENSE	Control word to calculate and print out element root tensions. (Preset value = 0) ITENSE = 0 No calculation ITENSE = 1 Calculate and print	Integer, N.D.

Thermal Lag-Element Bending

Fortran Symbol	Math Symbol	Description	Units
IPLANS		Control word to invoke a thermal lag effect on appendages due to planet and satellite shadowing. (Preset value = 0) IPLANS = 0 No lag invoked IPLANS = 1 Lag invoked	Integer, N.D.
TAUPL	τ_p	Characteristic delay time for computing planet shadowing switching times. (preset = 1.0)	sec
OCCRIT	O_{CR}	Threshold for invoking thermal lag for planet shadowing	N.D.

Fortran Symbol	Math Symbol	Description	Units
ISATSH		Control word for invoking satellite shadowing and thermal lag for satellite shadowing. (Preset value = 0) ISATSH = 0 No shadowing ISATSH = 1 Shadowing and lag	Integer, N. D.
RADSH	R_s	Radius of shading disk for satellite shadowing. (preset = 10.0)	feet
TAUK(10)	τ_k	Characteristic delay time for each element. (preset = 1.0)	sec
OCULTK(10)	O_k	Threshold for invoking thermal lag switching for each element (satellite shadowing)	N.D.
IWRTTF		Control word to write out thermal forces before and after computation of thermal lag. (Preset value = 0)	Integer, N.D.

Thermal Expansion and Contraction of Element

Fortran Symbol	Math Symbol	Description	Preset Value	Units
ITHRM(20)		Control words for element thermal expansion simulation	0	Integer, N.D.
ITHRM(1)		Basic control word for thermal expansion simulation ITHRM(1) 0 No thermal expansion ITHRM(1) Thermal expansion simulated		
ITHRM(2)		Internal. Not input		
ITHRM(3-10)		Not used		
ITHRM(11-20)		Control words for individual elements according to internal numbering system		

Fortran Symbol	Math Symbol	Description	Preset Value	Units
		ITHRM(K + 10) 0 No thermal expansion for KTH element		
		ITHRM(K + 10) 1 Thermal expansion for the KTH element		
THRMPR(100)		Physical constants for thermal expansion simulation	0.0 D0	
THRMPR(1)		Solar radiation constant at the satellite		$\frac{\text{Btu}}{\text{sec-ft}^2\,{}^\circ\text{R}}$ ${}^\circ$R
THRMPR(2-3)		Upper and lower integration bounds		ft/sec
THRMPR (4)		Acceleration due to gravity at sea level		
THRMPR(5)		Stefan Boltzmann Radiation constant		$\frac{\text{Btu}}{\text{sec-ft}^2\,{}^\circ\text{R}^4}$
THRMPR(6-10)		Not used		
THRMPR(11-20)		Specific heat for individual element material according to internal numbering system		$\frac{\text{Btu}}{\text{lb}\,{}^\circ\text{R}}$
THRMPR(21-30)		Emissivity of individual element surface material according to internal numbering system		N.D.
THRMPR(31-40)		Absorbtivity of individual element surface material according to internal numbering system		N.D.
THRMPR(41-50)		Area of individual element surface for thermal absorbtion according to internal numbering system	0.0 D0	ft^2
THRMPR(51-60)		Area of individual element surface for thermal emission according to internal numbering system		ft^2

Thermal Expansion and Contraction of Element (Cont)

Fortran Symbol	Math Symbol	Description	Preset Value	Units
THRMPR(61-80)		Used internally		
THRMPR(81-90)		Element reference temperature for length calculation		°R
THRMPR(91-100)		Initial condition for element temperature simulation		°R

```
      TYPICAL INPUT FOR THERMAL EXPANSION SIMULATION
ITHRM(1) 1
      THERMAL COEFFICIENT OF EXPANSION PER DEG R
THERMC(1-4) 1.OD-3
      ELEMENTS IN SIMULATION
ITHRM(11) 1 0 1 0
      SOLAR RADIATION BTU / SEC. - FOOT**2
THRMPR(1) 0.12278
      GRAVITATIONAL ACCELERATION FOR CONVERSION ONLY
THRMPR(4) 32.174
      STEPHAN BOLTZMANN CONSTANT BTU/SEC. - FOOT**2 - DEG R**4
THRMPR(5) 0.476D-12
      SPECIFIC HEAT FOR ELEMENT MATERIAL BTU / POUND - DEG R
THRMPR(11-14) 0.21
      EMISSIVITY FOR ELEMENT SURFACE
THRMPR(21-24) 0.2
      ABSORPTIVITY FOR ELEMENT SURFACE
THRMPR(31-34) 0.2
      AREA ASSOCIATED WITH ABSORPTIVITY FOOT**2
THRMPR(41-44) 0.05
      AREA ASSOCIATED WITH EMISSIVITY FOOT**2
THRMPR(51-54) 0.15
      REFERENCE TEMPERATURE FOR STANDARD LENGTH ZLO DEG R
THRMPR(81-84) 500.0
      INITIAL TEMPERATURE OF ELEMENT
THRMPR(91-94) 500.0
      INTEGRATION BOUNDS
THRMPR(2) 1.0D-8 1.0D-10
```

Plotting Locations for Element Temperatures

KPLOTS(331-340)	Element average temperature

ELEMENT DAMPING COEFFICIENT

Fortran Symbol	Type	Preset Value	Descriptior
IOMKDM(1-10)	I*4	0	Control word to invoke use of reference frequency IOMKDM(K) 0 Reference Frequency not used IOMKDM(K) 1 Reference Frequency used
OMKDMP(3,10)	R*4	0.0 D0	Reference frequency (rad/sec) for calculation of model damping coefficient

Element Twist (Torsion) Option

Fortran Symbol	Math Symbol	Description	Units
ITWIST		Control word to include or exclude twist motion for flexible element. ITWIST = 0, twist motion excluded ITWIST = 1, twist motion included (preset = 0)	N.D.
NKT(10)		Set to the number of twist modes desired for a particular flexible element; i.e., NK(K) = 0, 1, 2 or 3 for the k^{th} element.	N.D.
ZA(10)		Cross-sectional area for the k^{th} flexible element. (preset = 3.757 D-2)	in^2

Fortran Symbol	Math Symbol	Description	Units
I2OVI3(10)	I_2/I_3	Ratio of cross-section moments of inertia. $I_2/I_3 = \dfrac{\int Z_3^2 dA}{\int Z_2^2 dA}$ (Preset = 1.0)	
ZDQ(10)	D_{ϕ}	$\int \phi_w^2\, dA$ for the cross section. ϕ_w is warping function. (preset = 7.463 D-8, elliptic cross section)	in^6
ZJ(10)	J	Torsional constant. $J = \int \left[\left(Z_2 + \dfrac{\partial\phi_w}{\partial Z_3}\right)^2 + \left(-Z_3 + \dfrac{\partial\phi_w}{\partial Z_2}\right)^2\right] dA$ (preset = 2.118 D-4, elliptic cross section)	in^4
D2(10)	D_2	$\int Z_2 \phi_w\, dA$ for cross section. (preset = 0.0DO)	in^5
D3(10)	D_3	$\int Z_3 \phi_w\, dA$ for cross section. (preset = 0.0DO)	in^5
CW(3, 10)		Twist angle. (preset = 0.0DO)	deg
CDW(3, 10)		Twist velocity. (preset = 0.0DO)	deg/sec
CDTW(3, 10)		Twist damping coefficient. (preset = 0.0DO)	$\dfrac{\text{ft-lbs}}{\text{rad/sec}}$

TIP MASS ROTARY INERTIA OPTION

Fortran Symbol	Math Symbol	Description	Units
ITPROT		Control word to include or exclude tip mass rotary inertia. ITPROT = 0, rotary inertia excluded ITPROT = 1, rotary inertia included (preset = 0)	N.D.

Fortran Symbol	Math Symbol	Description	Units
NUMTIP(10)		Set to 1 for tip mass rotatory inertia simulation for the k^{th} element. (preset = 0)	N.D.
TIPINR(3, 10)		Principal rotatory inertias of tip mass about undeformed element axis. TIPINR(I, K) is inertia about I^{th} element axis for the k^{th} element tip mass.	slug ft^2

LIBRATION DAMPER OPTION

Fortran Symbol	Math Symbol	Description	Units
IDAMP		Control word to exclude or allow libration damper motion. (Preset value = 0) IDAMP = 0 No damper motion IDAMP = 1 Damper motion	Integer, N.D.
IDPHLD		Control word for simulation of constant relative angular velocity of libration damper mass or system of booms. IDPHLD = 0 No simulation (preset) IDPHLD = 1 Constant angular velocity for damper	
NDAMPR		The number of damper boom elements composing the libration damper.	Integer, N.D.
PHIS	ϕ_s	Stop angle for libration damper. (preset = 35.0)	deg
PHILD	ϕ_{LD}	The angular deflection of the libration damper boom relative to its equilibrium position. Also Euler angle in definition of libration damper frame (Z) with respect to body Y frame. (preset = 0.0)	deg
DPHILD	ϕ_{LD}	Angular velocity of libration damper boom relative to the body. (preset = 0.0)	deg/sec

Fortran Symbol	Math Symbol	Description	Units
BETLD	β_{LD}	Euler angle of libration damper Z frame with respect to the body Y frame. (preset = 0.0)	deg
GAMLD	γ_{LD}	Euler angle of libration damper Z with respect to body Y frame. (preset = 0.0)	deg
YIZM(1, n)2	$\{y_{em}\}$	Coordinates of the origin of the libration damper Z frames as defined in the body Y frame. (preset = 0.0)	feet

NOTE

YIZM locates the point of rotation of damper in the main body frame.

ZBZ locates the root of the elements with respect to the point where rotation takes place (which is specified by the YIZM array) for those elements composing the damper. In short, the ZBZ array locates the element roots with respect to whatever frame you are in.

For non damper elements use ZBZ array only.

For damper elements use ZBZ + YIZM
(one vector for each boom)

NOTE

The 2 after the parentheses indicates that it is the second coordinate which varies. Also, since ZL0, ZL1, ZLA, and the ZBZ's are input for both fixed elements and damper booms, the order in which their values are punched on an input card is important. The order is: data for element booms first, followed by data for damper booms. For example, if the user were to set NELMTS 1, NDAMPR 2, (implying the spacecraft has a total of three appendages) and the following card is also input; ZBZ(1,1)2 5.0 7.0 8.0 the program would interpret this as the "1" axis of the one rigidly attached element is located 5 feet from the origin of the body frame, the "1" axis of the 1st libration damper frame is located 7 feet from the origin of the body frame, and the "1" axis of the 2nd libration damper frame is located 8 feet from the origin of the body frame.

Fortran Symbol	Description	Units
DIN(k, j)1	Component of the k^{th} element (libration damper) tip displacement in the j^{th} bending mode as measured in the element frame (Z) along the 3 axis of the element frame. (preset = 0.0)	feet
DINDOT(k, j)1	Component of the k^{th} element (libration damper) tip velocity in j^{th} bending mode as measured in the element frame (Z) along the 3 axis of the frame. (preset = 0.0)	ft/sec
DOUT(k, j)1	Component of the k^{th} element (libration damper) tip displacement in the j^{th} bending mode as measured in the element frame (Z) along the 2 axis of the frame. (preset = 0.0)	feet
DOUTDT(k, j)1	Component of the k^{th} element (libration damper) tip velocity in the j^{th} bending mode as measured in the element frame (Z) along the 2 axis of the frame. (preset = 0.0)	ft/sec

NOTE

In the above arrays, the "1" following the parentheses indicates that the first integer in the parenthesis varies as the numbers are read off across the card. For example, the card:

DIN(k, 2)1 1.0 3.0 4.5 2.0

would be interpreted by the program as:

DIN(1, 2) = 1.0
DIN(2, 2) = 3.0
DIN(3, 2) = 4.5
DIN(4, 2) = 2.0 etc.

The arrays DIN, DINDOT, DOUT, and DOUTDT are both input and output of the program. Thus if the user wished to start a problem with initial tip deflections and velocities for the libration damper elements, these quantities would be input. Otherwise they are internally set to zero at the start of the problem and are output only.

Fortran Symbol	Math Symbol	Description	Preset Value	Units
ZK1D	k_{1D}	Torsional spring constant for libration damper.		ft-lb/rad
ZK2D	k_{2D}	Stop spring constant for libration damper.	2.0	ft-lb/rad
ZMDO	M_{ko}	Saturation moment for magnetic hysteresis libration damper.	1.02 D-3	ft-lb
ZMDBO		Initial moment for magnetic hysteresis libration damper.	0.0	ft-lb
DECAY	σ	Exponential decay factor for magnetic hysteresis libration damper.	20.0	N.D.
DPRMI(i, j)2		Moments of inertia of the hub of the libration damper about the Z frame axes of the damper.	0.0	slug ft^2
CNV	C_{nv}	Damping coefficient for viscous damping by libration damper.	0.0	ft-lb/ rad/sec

EARTH ORIENTED SATELLITE OPTION - ATTITUDE AND BODY RATES

Fortran Symbol	Math Symbol	Description	Preset Value	Units
ALFAE	α	Roll Angle. The intermediate Euler angle in a 2-1-3 rotation of the local vertical to body frame.	0.0	deg
BETAE	β	Pitch Angle. The first Euler angle in a 2-1-3 rotation of the local vertical to body frame.	0.0	deg
GAMAE	γ	Yaw Angle. The last Euler angle in a 2-1-3 rotation of the local vertical to body frame.	0.0	deg

Fortran Symbol	Math Symbol	Description	Preset Value	Units
OMBC (i) (i) = 1, 2, 3	$\omega_{i_{B/C}}$	Components of satellite angular velocity with respect to the local vertical frame, with components expressed in the body frame.	0.0	deg/sec
IBTEST		Terminates case (within stack) when BETAE goes from - to +. Used in boom deployment. (Preset value = 0) IBTEST = 0 By-passes option IBTEST = 1 Employs option	0	N.D.

BOOM DEPLOYMENT FROM SUN PULSE OPTION

Fortran Symbol	Description	Preset Value
ISDPLY	ISDPLY = 0 By-passes subroutine ISDPLY = 1 Employs subroutine	0
ISAXIS	Axis of rotation of spacecraft. (Should be either 1, 2, or 3)	3
NCROSS	Number of sun crossings before deployment begins.	5
STANG	Delay angle. (deg)	
ANGTOL	Angle tolerance. (deg)	
NPRINT	Number of print-outs from (NCROSS-1) crossings to NCROSS (the last) crossing.	2
IRAXIS	Spacecraft body axis upon which sun sensor is located.	3

SPINNING BODY OPTION ATTITUDE AND BODY RATES

Fortran Symbol	Math Symbol	Description	Units
PSI1	ψ	First Euler angle in a 3-1-3 rotation from local inertial to body frame. (preset = 0.0)	deg
THET1	θ	Intermediate Euler angle in a 3-1-3 rotation from local inertial to body frame. (preset = 0.0)	deg
PHI1	ϕ	Final Euler angle in a 3-1-3 rotation from local inertial to body frame. (preset = 0.0)	deg
OMEG(i) (i) = 1, 2, 3	ω_{iB}	Components of satellite angular velocity with respect to inertial space, with components expressed in body frame. Spin axis is the third body axis. (preset = 0.0)	deg/sec
ETTA ZETTA	η (2nd angle) ζ (1st angle)	Angles which specify a preferred inertial direction of the body spin axis with respect to inertial space. This is a 3-2 rotation from the local inertial frame. (preset = 0.0)	deg deg

NUTATION VISCOUS RING DAMPER OPTION

Fortran Symbol	Math Symbol	Description	Units
IVISCS		Control word to employ viscous ring nutation damper into program. (Preset value = 0) IVISCS = 1 Employs subroutine IVISCS = 0 By-passes subroutine	Integer, N.D.
VISCTY	γ	Kinematic viscosity of liquid in nutation damper. (preset = 3.0)	Centistokes
RADTBE	a	Radius of nutation damper tube.	inches

Fortran Symbol	Math Symbol	Description	Units
RADRNG	b	Ra .s of nutation damper ring. (preset = 10.0)	inches
DENSTY	ρ	Density of fluid in nutation damper. (preset = 56.16)	lb/ft^3
ETTAD ZETTAD	η_D (2nd angle) ζ_D (1st angle)	Angles which specify the axis of the ring damper with respect to the body. This is a 3-2 rotation from the body frame to the damper axis. The Y_3 body axis initially coincides with the damper axis. (preset = 90.0)	deg deg
YARRAY	Y_1, Y_2, Y_3	Components of torque exerted by the liquid upon the satellite, directed along the damper ring axis. (preset = 0.0)	ft-lb
OMEGL	ω_L	Initial spatial average angular velocity of the liquid relative to the ring. (preset = 0.0)	deg/sec

ATTITUDE CONTROL MOMENT OPTION

Fortran Symbol	Math Symbol	Description	Units
IATTDE		Control word to call the attitude control subroutines. IATTDE = 0 By-passes subroutine IATTDE = 1 Employs subroutine (Preset = 0)	Integer, N.D.
DTMXA		Time increment from initial problem time to when the attitude control system is activated (time reference at beginning of stack for stacked cases) (preset = 1.0)	seconds

Fortran Symbol	Math Symbol	Description	Units
PX1	B	Fraction of spin period after sun line reference point established when control torque is applied to Y_1 body axis. Absolute value should be greater than one print interval. (preset = 0.4)	N.D.
PXO	C	Fraction of spin period after sun line reference point established when control torque is removed from Y_1 body axis. (preset = 0.5)	N.D.
CMX	M_{iy}	Control moment along Y_1 body axis. Input as a positive number means moment applied about positive Y_1 body axis. Input as a negative number means moment applied about negative Y_1 body axis. (preset = 0.0)	ft-lb
NPULSE		The number of sequential moment pulses applied to the body once the control system is activated. The application rate is one pulse per spin period. (preset = 4)	Integer, N.D.

Constant Torque Levels About Body Axes

Fortran Symbol	Math Symbol	Description	Units
ITORK		Control word to apply torque about body axes. (Preset value = 0) ITORK = 0 No torque applied ITORK = 1 Torque applied	Integer, N.D.
CMTORK(3)		Torque magnitude applied to body axes. (preset = 0.0)	ft-lb

SPIN AXIS MOMENT OPTION

Fortran Symbol	Description	Units
ISPIN3	Control word to call spin axis moment subroutine. (Preset value = 0) ISPIN3 = 0 By-pass subroutine ISPIN3 = 1 Employ subroutine	Integer, N.D.
DTZMA	Time increment from initial problem time to leading edge of spin moment.	seconds
PZDT	Duration of spin moment.	seconds
CMZO	Magnitude of moment about the spin axis. Input as a positive number means moment applied about the positive Y_3 body axis.	ft-lb

THRUST LOADING OPTION

Fortran Symbol	Math Symbol	Description	Units
IPULSE	N. A.	Control word to act..^te thrust application IPULSE = 0 No thrusting IPULSE = 1 Apply thrust once IPULSE $>$ 1 Apply thrust IPULSE times (only if ISPLSE $\neq$ 0.)	N. D.
ISPLSE	N. A.	Control word to activate sun crossing time to start the thrusting ISPLSE = 0 Sun crossing not used ISPLSE = 1 Sun crossing used	N. D.
ISPNP	N. A.	Control word to print out the orbit update message (only if ISPLSE = 1, IPULSE $>$1) i.e., if ISPNP = 5, the orbit update message will be printed at every 5th pulse.	N. D.
IPLPRI	N.A.	Control word for number of thrust pulses per spin record	N.D.

Fortran Symbol	Math Symbol	Description	Units
		IPLPRP = 1 One pulse	
		IPLPRP = 2 Two pulses	
		Only one or two pulses are allowed. (Preset = 1)	
TVECTR(3,2)	$\{D_v\}$	Unit vector defining the direction of the force applied to the body due to thrusting. This vector is defined in the body frame. (preset = 0.0, 0.0, 1.0)	N.D.
TLOCAT(3,2)	$\{\ell_T\}$	Location in the body frame of the point application of the force due to thrusting. (preset = 0.0)	feet
TTIMES(4,2)		Times to define thrust variation measured from the problem starting time (see page A-16).	sec
	t_1	TTIMES (1,I) Start of pulse	
	t_2	TTIMES (2,I) End of exponential rise	
	t_3	TTIMES (3,I) End of linear thrust	
	t_4	TTIMES (4,I) End of pulse I=1 or 2	
TPARAM(4,2)		Parameters to define thrust variation	
	A	TPARAM (1,I) Coefficient during exponential rise	lb
	B	TPARAM (2,I) Exponential decay constant during exponential rise	sec^{-1}
	C	TPARAM (3,I) Coefficient for linear slope	lb/sec
	D	TPARAM (4,I) Exponential decay constant during exponential decay	sec^{-1}
REFANG(2)	A_R	Angular delay from the Y_1 axis crossing the sun line to the initiation of the pulse.	deg

JET DAMPING OPTION

Fortran Symbol	Math Symbol	Description	Preset Value	Units
IJTDMP		Control word to invoke jet damping option IJTDMP 0 No jet damping IJTDMP 1 Jet damping NOTE: Jet damping implies thrusting and therefore IPULSE>0	0	Integer, N.D.
TANKCG(3)		Position vector to center of mass of fuel to be expended during thrusting.	0.0 D0	ft
FUELPP(2)		Fuel to be expended during one thrust pulse		slugs
FUELM		Total mass of fuel. (SLUGS)		slugs
RGYFL(3)		Square of the radius of gyration of the fuel mass about its own center of mass		ft^2

ANGULAR MOMENTUM OPTION

Fortran Symbol	Math Symbol	Description	Units
IHCALC	N. A.	Control word to calculate and print the angular momentum of the system.	N. D.

Fortran Symbol	Math Symbol	Description	Units
IHCALC (cont'd)		IHCALC = 0 No calculation IHCALC = 1 Calculate and print	
IHREF	N.A.	Control word to compute reference direction for the EPSERR from the system initial angular momentum. IHREF = 0 No calculation IHREF = 1 Determining reference direction from angular momentum.	N.D.

MOMENTUM WHEEL OPTION

Fortran Symbol	Math Symbol	Description	Units
IWHEEL		Control word to call momentum wheel subroutine. (Preset value = 0) IWHEEL = 0 By-passes subroutine IWHEEL = 1 Employs subroutine	Integer, N.D.
XMOMIN(i) (i) = 1, 2, 3	I_{wi}	Inertia of wheel about its spin axis. For i = 1, wheel is located on Y_1 body axis, i = 2 wheel is located on Y_2 body axis and i = 3, wheel is located on the Y_3 body axis. (preset = 1.0, 1.0, 1.0)	slug ft^2
VMOM(i) (i) = 1, 2, 3	Ω_i	Angular velocity of the i wheel with respect to the body. Input as a positive number signifies that the angular velocity vector points in the direction of the positive body axis. Input as a negative number signifies that the angular velocity vector points in the direction of the negative body axis. (preset = 0.0, 0.0, 0.0)	deg/sec

Fortran Symbol	Math Symbol	Description	Units
DVMOM(I)	$\{\dot{\omega}_w\}$	Momentum wheel acceleration (negative for deceleration). I = 1, 2, 3 (preset = 0. 0, 0. 0, 0. 0)	deg/sec^2
VSUR(I)	$\{\omega_w\}_{UP}$	Upper limit of momentum wheel speed. I = 1, 2, 3 (preset = 1. 0D6, 1. 0D6, 1. 0D6)	deg/sec
VSDR(I)	$\{\omega_w\}_{LO}$	Lower limit of momentum wheel speed. I = 1, 2, 3 (preset = -1. 0D6, -1. 0D6, -1. 0D6)	deg/sec

MAGNETIC MOMENT OPTION

Fortran Symbol	Math Symbol	Description	Preset Value	Units
IMGMTS		Control word to exclude or allow magnetic moments. IMGMTS 1 uses constant spacecraft dipole defined by DPMAG; IMGMTS 2 provides proportional magnetic coil spin up; IMGMTS 3 provides constant level magnetic coil spin up.	0	Integer, N.D.
MAGFLD		Number of harmonics included in the representation of the earth's magnetic field (preset = 7).		Integer, N.D.
G(I, J) H(I, J)		Coefficients of earth's magnetic field.		
COILS(3)		Peak coil dipole strength along body axes. For example, for spin up COILS(1) -1500. 0 COILS(2) 1500. 0 for spin down COILS(1) 1500. 0 COILS(2) -1500. 0		pole-cm

Fortran Symbol	Math Symbol	Description	Preset Value	Units
DPMAG(i) (i) = 1, 2, 3		Body frame components of the dipole moment of the satellite. Positive input means that the north poie of the dipole points in the direction of the positive body axis. For negative inputs, the north pole points in the direction of the negative body axis.	0.0	pole-cm

NOTE

An IGRF 1965 Geomagnetic Field model includes 80 spherical harmonic coefficients is used (REF6).

SPACECRAFT ACCELERATION OPTION

Fortran Symbol	Math Symbol	Description	Preset Value	Units
IACOMP		Control word to activate the acceleration computation for both hub and element tip accelerations (=1).	0	N.D.
IHUBAC		Control word to activate the acceleration computation and printout for the hub (=1).	0	N.D.
ITIPAC		Control word to activate the acceleration computation and printout for the element tip (=1).	0	N.D.

Accelerometer Location Variables

Fortran Symbol	Math Symbol	Description	Preset Value	Units
NUMHUB	N	Number of accelerometers and points within the hub where acceleration vectors are to be computed.	6	N.D.
YHUB(I, J)1	$\{y_{hub}\}$	Coordinates of the jth accelerometer in the Y body frame: I = coordinate number (i = 1, 2, 3) J = accelerometer number (j = 1 to N)	0.0	feet
ALFAEA(J)	α_a	Second Euler angle defining the orientation of the No. 1 axis (sensitive axis) of the jth accelerometer to the y body frame (rotation about y_1).	0.0	deg
BETAEA(J)	β_a	First Euler angle defining the orientation of the accelerometer relative to the y body frame (rotation about y_2).	0.0	deg
GAMAEA(J)	γ_a	Third Euler angle defining the orientation of the accelerometer relative to the y body frame (rotation about y_3). β-α-γ or 2-1-3 rotation.	0.0	deg
ZXI*(k,n)	$X_n(1.0)$	Shape function evaluated at $z_1 = 1.0$ for kth element and nth mode. n = 1, 2, 3. Normalized cantilever beam eigenfunction is used for the preset value.	1.0D0 for n = 1, 2, 3	

Fortran Symbol	Math Symbol	Description	Preset Value	Units
ZXIP*(k,n)	$X_n'(1.0)$	Derivatives of shape function evaluated at $\bar{z}_1 = 1.0$ for kth element and nth mode. n = 1, 2, 3. Normalized cantilever beam eigenfunction is used for preset value.	1.33D0 for n = 1 4.53D0 for n = 2 7.24D0 for n = 3	
ZXIPP*(k,n)	$X_n''(1.0)$	Second derivative of shape function evaluated at $\bar{z}_1$ = 1.0 for kth element and nth mode. n = 1, 2, 3. Normalized cantilever eigenfunction is used for the preset value.	0.0D0 for n = 1, 2, 3	
ZZNP*(k,I,n)	$[z_{np}]$	Axial displacement shape function evaluated at $\bar{z}_1$ = 1.0 for kth element. I = 1 to n; J = 1 to n. ZZNP should always be input as a square matrix.		

FAST FOURIER TRANSFORM (FFT) ANALYSIS

Fortran Symbol	Math Symbol	Description	Units
ICSD		Control word to activate the FFT analyses subroutine. ICSD = 0 No FFT analysis ICSD = N FFT analysis activated (preset = 0) The integer N requests that N frequencies be extracted from the selected KPLOTS data sets. Also, the following must be input for FFT analysis: KPLOTS(253) set to 2 for plot and FFT analysis set to 3 for FFT analysis only.	

*When other than a normalized cantilevel beam shape function is desired, the user should input the appropriate values of ZXI, ZXIP, ZXIPP and ZZNP.

NOTE

The value of N should not exceed the number of frequencies that can reasonably be expected to exist in the data. The range of permissible values for N are from 1 to 10. $1 \leq N \leq 10$.

There are two precautions the user should take when employing the Fast Fourier Transform analysis option. First, the data points to be analyzed in the Fast Fourier Transform are controlled by the values of TSTOP and FREQ, i.e.,

$$N = \text{Sample size} = \frac{\text{TSTOP}}{\text{FREQ}} + 1$$

In other words, the data set input to the FFT subroutines is exactly the same as that appearing in the normal printout. Therefore, the input TSTOP value should at least cover more than the two longest vibrational periods of the data set to be analyzed. The value of FREQ should not be too coarse in order that the higher harmonics can be picked up by the analysis. Furthermore, it is preferred that the data set to be analyzed is in steady state condition. Therefore, it is recommended that the user first run the program without using the FFT analysis option to obtain a general idea about the periodic behavior of the data sets to be analyzed, and then run the program with the FFT option inputting the appropriate TSTOP and FREQ values. Second, because the data sets generated by FSD program are all deterministic, the autocorrelation function analysis may not be necessary; hence, IAFM(4) should be set equal to 0.

ATMOSPHERIC DENSITY MODEL OPTION

Fortran Symbol	Math Symbol	Description	Units
IDRAG		Control word to include or exclude atmosphere models. Set to 1 for 1962 standard atmosphere. Set to 2, 3 or 4 for Jacchia-Roberts atmospheric model (see below). Preset = 1	
IJACCT		Modified Julian date of first data on Jacchia-Roberts file (10300 corresponds to March 19, 1969). Note: input value is used only for IDRAG3.	

Fortran Symbol	Math Symbol	Description	Units
KP(21, 8)		Three hour magnetic activity indices for 21 day period. Note: input values are used only for IDRAG 2 or 3.	
TC(20)		Exospheric temperatures. Note: input values used only for IDRAG 2 or 3.	
ER(3)		Earth's rotation rate for rotating atmosphere calculation. (preset = 0.0D0 0.0D0 7.29211D-5 rad/sec)	

NOTE

For IDRAG 2 the modified Julian date for the Jacchia-Roberts data file is internally set to the simulation date defined by IDATE. For IDRAG 3 the input modified Julian date defined by IJACCT is used. For IDRAG 4 the Jacchia-Roberts data is to be read from unit 15 (360/95).

Linear Varying Drag Loading (for tethered mass)

XLTEST		Linear varying drag loading is calculated for any element whose length is greater than XLTEST. (preset = 1.0D + 06)	feet

NOTE

The arrays for pressure calculations can be input but are preset to appropriate values in BLOCK data.

GROUND SIMULATION OPTION

Fortran Symbol	Math Symbol	Description	Units
IGRUND		Control word to activate the ground simulation environment. IGRUND = 1 Activates option IGRUND = 0 Does not activate option (preset = 0)	NA

Fortran Symbol	Math Symbol	Description	Units
IGASBR		Control word to activate the air bearing ground simulation. If IGRUND = 1 and IGASBR = 0, the spin platform (single axis) capability is used. If IGRUND = 1 and IGASBR = 1, air bearing (3 axis) capability is used. (preset = 0)	NA
IALTUD		Control word to activate the computation of the local verticle direction of the gravitational acceleration at the ground testing site altitude. If IALTUD = 0, gravitational acceleration input is necessary; if IALTUD = 1, the altitude input is necessary.	NA
ALFAEG	α_G	First rotation angle of 3-1 rotation from local geographical frame to the body frame (or the right ascention angle), see page A-19. (Preset = 0.0D0)	deg
DELTAG	δ_G	Second rotation angle of a 3-1 rotation from local geographical frame to the body frame (or the declination angle of spin or number 3 body axes in local geographical frame). (Preset = 0.0D0)	deg
ALTUDE	h_G	The altitude of the ground test site. Used to compute the gravitational acceleration at the altitude when IALTUD = 1. (Preset = 0.0D0)	km
OMGY(1-3)	$\{w_G\}$	Angular velocity vector of body axes expressed in the local geographical frame. (Preset = 0.0D0)	deg/sec
GACC(1-3)	$\{A_G\}$	Three components of acceleration vector input along the three axes of the local geographical frame. A_{G1} is along the east local horizontal, A_{G2} is along the north local horizontal and A_{G3} is along the local vertical direction. (Preset = 0.0D0 0.0D0 32.145(552D0)	ft/sec^2

SECONDARY BODY SIMULATION

The effect of a rigid secondary body connected to the primary body through a three degree of freedom rotary (universal) joint can be simulated. The connecting joint has either one, two, or three degree of freedom selected by input. The suspension simulation for the secondary body includes a bilinear spring, viscous damping, and angular stops (limits) for each axis.

A rastering capability of the secondary body is included so that the azimuth angle can be swept through at a specified rate; and at the angular stop an incremental step change in elevation may be made. The secondary body then moves in the opposite azimuth direction to the opposite stop, etc. Rastering stops when the number of input elevation steps have been completed.

Fortran Symbol	Type	Preset Value	Description
I2BDY	I*4	0	Control word to add secondary body to simulation I2BDY 0 No secondary body I2BDY 1 Secondary body present
NDOF2	I*4	0	Number of degrees of freedom of secondary body NDOF2 1 Rotation about the 2 axis of secondary body. NDOF2 2 Rotation about the 3 & 2 axes of secondary body. NDOF2 3 Rotation about the 3, 1 & 2 axes of secondary body.
SECM	R*8	0.0D0	Mass of secondary body. (slugs). NOTE: The mass of the secondary body must be included in the system mass ZMS.
SECI(3,3)	R*8	0.0D0	Mass moments of inertia of secondary body about its own center of mass. (slugs-ft^2).
ZBAR2(3)	R*8	0.0D0	Location of the secondary body center of mass measured from the pivot point which is the secondary body fixed reference frame origin (ft.).

SECONDARY BODY SIMULATIONS (Cont.)

Fortran Symbol	Type	Preset Value	Description
YI02(3)	R*8	0.0D0	Location of the pivot point for the secondary body measured in the main body reference frame. (ft.).
SBK1(3)	R*8	0.0D0	Spring constant for secondary body suspension. Applies to angles less than the stop angle. (ft-lb/rad).
SBK2(3)	R*8	0.0D0	Spring constant for secondary body suspension. Applies to angles greater than the stop angle. (ft-lb/rad).
SBSTA(3)	R*8	0.0D0	Stop angle for secondary body suspension. (rad).
SBDM(3)	R*8	0.0D0	Damping coefficients for secondary body motions. (ft-lb-sec/rad).
GAM20	R*8	0.0D0	Rotation about the three axis in a 3-1-2 angle set from the main body frame to the secondary body equilibrium frame. (deg). NOTE: The secondary body equilibrium frame is that orientation at which spring have zero restoring torque.
ALP20	R*8	0.0D0	Rotation about the one axis in a 3-1-2 angle set from the main body frame to the secondary body equilibrium frame. (deg).
BET20	R*8	0.0D0	Rotation about the two axis in a 3-1-2 angle set from the main body frame to the secondary body equilibrium frame. (deg).
GAM2I	R*8	0.0D0	Initial condition for rotation about the three axis of the secondary body. Measured from the equilibrium frame to the secondary body fixed frame. (deg).
ALP2I	R*8	0.0D0	Initial condition for rotation about the one axis of the secondary body. Measured from the equilibrium frame to the secondary body fixed frame. (deg).

SECONDARY BODY SIMULATION (Cont.)

Fortran Symbol	Type	Preset Value	Description
BET21	R*8	0.0D0	Initial condition for rotation about the two axis of the secondary body. Measured from the equilibrium frame to the secondary body fixed frame. **(deg).** NOTE: The motion of the secondary body is simulated in terms of a 3-1-2 set of angles from the equilibrium frame to a secondary body fixed frame. If only two degrees of freedom are specified, the simulation uses a 3-2 set of angles. If one degree of freedom is specified the simulation uses a rotation about the 2 axis.
OM21(3)	R*8	0.0D0	Initial conditions for angular rates of the secondary body about the secondary body fixed axes. **(deg/sec).**
SBUP(2)	R*8	2*1.0D-3	Integration upper bounds for secondary body angles and angular rates.
SBDN(2)	R*8	2*1.0D-5	Integration lower bounds for secondary body angles and angular rates.

Plotting locations for secondary body variables

Fortran Symbol	Description
KPLOTS (236)	Rotation of secondary body about 3 axis γ_{SB}
KPLOTS (237)	Rotation of secondary body about the carried 1 axis α_{SB}
KPLOTS (238)	Rotation of secondary body about the carried 2 axis β_{SB}

Plotting locations for secondary body variables (Cont.)

Fortran Symbol	Description
KPLOTS (239)	Relative angular rate of secondary body about 3 axis $\dot{\gamma}_{SB}$
KPLOTS (240)	Relative angular rates of secondary body about the carried 1 axis of secondary body $\dot{\alpha}_{SB}$
KPLOTS (241)	Relative angular rates of secondary body about the carried 2 axis $\dot{\beta}_{SB}$
KPLOTS (242)	Component of secondary body relative angular velocity on 1 axis of secondary body ω_{1SB}
KPLOTS (243)	Component of secondary body relative angular velocity on 2 axis of secondary body ω_{2SB}
KPLOTS (244)	Component of secondary body relative angular velocity on 3 axis of secondary body ω_{3SB}

Secondary Body Rastering Input

Fortran Symbol	Type	Preset Value	Description
IRAST	I*4	0	Control word to invoke prescribed rastering motions for secondary body. IRAST = 0 No rastering IRAST = 1 Rastering prescribed
IARST(3)	I*4	0	Control word to specify type of rastering cycle to be invoked on each axis. IARST(I) = 0 No motion IARST(I) = 1 Motion of Type 1

Fortran Symbol	Type	Preset Value	Description
			IARST(I) = 2 Motion of Type 2
			I = 1 to 3
			I = 1 motion about the 3 axis
			I = 2 motion about the 1 axis
			I = 3 motion about the 2 axis
			NOTE: The types of motion cycles are shown in Figure 20 and 21 on pages A-20, 21.
IRSCY(3)	I*4	0	Number of cycles of rastering motion to be performed on each axis.
DELA(3)	R*8	0.0D0	Angular motion to be performed during a single cycle of rastering motion for each axis. (deg).
TAUA(4,3)	R*8	0.0D0	Time increments to define rastering cycle for each axis. See Figure 20 and 21.
			TAUA (1, I) = T_1
			TAUA (2, I) = T_2
			TAUA (3, I) = T_3
			TAUA (4, I) = T_4
ANG20(3)	R*8	0.0D0	Initial angle for the start of the rastering cycle. (deg).

ACTUATOR INITIATION FROM ZERO CROSSING OF FILTERED STATE VARIABLES

Thrusters and momentum wheels can be activated from either positive or negative going zero crossings of spacecraft state variables such as accelerometer readings, body components of spin vector, body components of earth's magnetic field, and body components of the sun vector. A fixed time delay is permitted by input starting from the time zero crossing of the state variable. Also, a simple filter of the form:

$$\frac{K\tau s}{(1 + \tau s)^2}$$

where K = gain factor, input
s = Laplace operator
τ = time constant, input

is included to take out any d.c. bias that may be present in the state variable. The momentum wheel speed is driven in a triangular wave form between limits (VSUR and VSDR) at the frequency specified by input.

Fortran Symbol	Type	Preset Value	Description
IACFLT(20)	R*8	0	Control integers for filtered sensor signal to actuate momentum wheel cycling or pulsed thrusting.
IACFLS(1) = 0			No filtered sensor simulation.
IACFLT(1) = 1			Filtered sensor simulation.
IACFLT(2) = 1			Pulsed thrusting to be simulated.
IACFLT(2) = 2			Momentum wheel cycling to be simulated.
IACFLT(3) = 1			Sensor measures magnetic field.
IACFLT(3) = 2			Sensor measures an acceleration component.
IACFLT(3) = 3			Sensor measures body angular velocity.
IACFLT(3) = 4			Sensor measures solar intensity.
IACFLT(4) = 0			Use natural initial conditions for filter integraters.
IACFLT(4) = 1			Use input initial conditions for filter integrater.
ACPARM(20)	R*8	0.0D0	Numerical data required for filtered sensor signal simulation.
ACPARM(1)			Filter gain.
ACPARM(2)			Filter time constant.
ACPARM(3-5)			Unit vector defining sensor direction in the body frame.
ACPARM(6-8)			Sensor position in the body frame. (for acceleration sensor).
ACPARM(9)			Cycle half period for momentum wheel cycling.

Actuator Initiation from Zero Crossing of Filtered State Variables (Cont.)

Fortran Symbol	Type	Preset Value	Description
ACPARM(10)			Time delay for initiation of actuator after zero crossing.
ACPARM(17)			Initial condition for filter integrater.
ACPARM(18)			Initial condition for filter integrater.
ACPARM(19)			Upper bound for filter integrater.
ACPARM(20)			Lower bound for filter integrater.

Plotting locations for filter state variables

Fortran Symbol	Description
KPLOTS(245)	Sensor output
KPLOTS(246)	Filter output
KPLOTS(247)	Filter first integrater output

DUAL-SPIN SPACECRAFT CONTROL SYSTEM (DE-B)

The input Fortran symbols for the DE-B control and active nutation damper system are given below. A block diagram of the control system is given in Appendix A, page A-22 along with some mathematical description of the formulation.

Fortran Symbol	Type	Preset Value	Description
KNTRL(10)	I*4	0	Vector of control integers for DE-B control system simulation
KNTRL (1)			KNTRL(1) = 0 No control system KNTRL(1) = 1 Control system with second order sensors KNTRL(1) = 2 Control system with fourth order sensors
(2)			KNTRL(2) = 0 No nutation damper KNTRL(2) = 1 Primary damper circuit

Fortran Symbol	Type	Preset Value	Description
(2)			KNTRL(2) = 2 Offset pointing damper circuit
(3)			KNTRL(3) = 0 No KNTRL(3) = 1 First order tachometer
(4) – (8)			Not used
(9)			KNTRL(9) = I, I is starting integer for noise generator. I *must be odd* and should have 6 or 7 digits.
(10)			KNTRL(10) = 0 No noise channels KNTRL(10) = 3 Noise generated for sensors & bial voltage. Use only 0 or 3.
CPARM(43)	R*8	(1-30) 0.000 (31-40)1.000 (41-43)0.000	Control system parameters for DE-B control system simulation

CPARM	Math Symbol	Units	Description
(1)	τ_s	sec.	Sensor time constant
(2)	τ_1	sec.	Lead term in pitch compensation
(3)	τ_2	sec.	Lag term in pitch compensation
(4)	τ_F	sec.	Tachometer time constant
(5)	K_s	volts/rad.	sensor gain
(6)	K_c	volts/volt	Pitch amplifier gain
(7)	K_a	volts/volt	Power amplifier gain
(8)	K_f	volts/(rad/sec)	Tachometer gain
(9)	K_b	volts/(rad/sec)	Motor back EMF constant
(10)	K_t	ft.lbs/volt	Motor torque constant
(11)			Not used for input

CPARM	Math Symbol	Units	Description
(12)	V_{lim}	volts	Voltage limit in compensation amplifier
(13)	$K_{\mu 1}$	volts/volt	Gain in primary damper circuit
(14)	$\tau_{\mu 1}$	sec.	Time constant in primary damper circuit
(15)	V_b	volts	Bias voltage
(16)	τ_{co}	ft-lbs	Coulomb friction torque
(17)	Ω_{min}	rad/sec	Test relative wheel speed to avoid coulomb friction torque discontinuity at zero speed
	$\tau_c = \tau_{c0} \dfrac{\Omega_\omega}{\Omega_{min} + \lvert\Omega_\omega\rvert}$		
(18)	ρ_s	volts/volts	In fourth order sensor. See p. A-22.
(19)	$K_{\mu 2}$	sec.	Gain in offset pointing damper circuit
(20)	$\tau_{\mu 2}$	N.D.	Time constant in offset pointing damper circuit
(21)		N.D.	Sign of damper circuit output set 1.0 or -1.0
(22)		volts	Roll sensor output limit
(23)		ft.-lbs.	Motor torque output upper limit
(24)		ft.-lbs.	Motor torque output lower limit
(25-30)			Not used
(31-33)			Noise model SIGMA for pitch, roll and voltage bias respectively
(34-35)			Not used
(36-38)			Noise model LAG for pitch, roll and voltage bias respectively
(39-40)			Not used

CPARM	Math Symbol	Units	Description
(41)		rad.	Pitch sensor bias
(42)		rad.	Roll sensor bias
(43)			Not used

Fortran Symbol	Type	Preset Value	Description
SVCS(20)	R*8	0.000	Initial conditions for control system state vector

SVCS		Units	Description
(1)		volts	Pitch sensor output
(2-4)		volts	Pitch sensor dynamics
(5)			Not used
(6)		volts	Roll sensor output
(7-9)		volts	Roll sensor dynamics
(10)			Not used
(11)		volts	State variable for pitch compensation amplifier
(12)			Not used
(13)		volts	Tachometer output
(14)			Not used
(15)		rad/sec	Wheel speed
(16-18)			Not used
(19)		volts	Nutation damper
(20)		volts	Nutation damper

Fortran Symbol	Type	Preset Value	Description
GNIC(10)	R*8	0.0D0	Initial conditions for noise model channels. GNIC(1) Pitch channel GNIC(2) Roll channel GNIC(3) Bias voltage channel GNIC(4-10) Not used
CSUP(20)	R*8	1.0D-2	Upper bound on difference between predicted and corrected control system state vector. Location in CSUP corresponds to the location of the variable in the state vector initial condition array SVCS
CSDN(20)	R*8	1.0D-4	Lower bound on difference between predicted and corrected control system state vector. Location in CSDN corresponds to the location of the variable in the state vector initial condition array SVCS

In addition to the input described above, the following must be given:

IWHEEL	1	Makes call to momentum wheel subroutine (WHEELS)
XMOMIN(2)	—	Inertia of momentum wheel (slug-ft^2)

It is recommended that integration control bounds be given for critical control variables to prevent integration time step from exceeding the time constants of the closed-loop system. For example, if fastest component in the control system has a time constant of .1 sec., it is unreasonable to expect accurate simulation results with a larger time step. Setting the integration bounds to some reasonable (small) fraction of the nominal value (eg 10^{-2} to 10^{-4}) will ensure that the integration errors are of the same order (e.g. 2 to 4 place accuracy). The time stop corresponding to this level of accuracy will be determined internally.

The output for the DE-B control system simulation includes both printed data and plots. The printed output is as follows:

Fortran Symbol	Description	Units
PTCH Out	Pitch channel sensor output	volts
ROLL Out	Roll channel sensor output	volts

Fortran Symbol	Description	Units
COMP Out	Output of compensation amplifier	volts
TACH Out	Output of tachometer	volts
TMOTOR	Torque output of momentum wheel motor	ft-lbs
WHL SPD	Momentum wheel speed	rad/sec
NUTD Out	Nutation damper phase shift circuit output	volts

The output available for plotting is the entire state vector for the control system. The locations and definitions of these variables are as follows.

KPLOTS Address	Description	Units
216	Pitch sensor output	volts
217-219	Pitch sensor dynamics	volts/sec, etc.
220	Not used	
221	Roll sensor output	volts
222-224	Roll sensor dynamics	volts/sec, etc.
225	Not used	
226	Output of pitch compensation amplifier	volts
227	Not used	
228	Tachometer output	volts

TWO AXIS GIMBLE SIMULATION (No Active Control)

Fortran Symbol	Type	Preset Value	Description
IGMBL	I*4	0	Control word for two axis gimble simulation IGMBL 0 No gimble simulated IGMBL 1 Gimble simulated
AZIN(3,3)	R*8	0.0D0	Moments of inertia of the azimuth platform about its own center of mass (slug-ft^2)
AZAX(3)	R*8	0.0D0	Position vector in the body frame to the origin of the gimble motion reference frame. This position is a point on the azimuth motion axis. (ft)
AZCG(3)	R*8	0.0D0	Position vector to the azimuth platform center of mass in the azimuth motion reference frame. (ft.)
AZMS	R*8	0.0D0	Mass of the azimuth platform (slugs)
ELIN(3,3)	R*8	0.0D0	Moments of inertia of the elevation platform about its own center of mass. (slug-ft^2)
ELAX(3)	R*8	0.0D0	Position vector in the azimuth motion reference frame. This position is a point on the elevation motion axis. (ft)
ELCG(3)	R*8	0.0D0	Position vector to the elevation platform center of mass in the elevation motion reference frame. (ft)
ELMS	R*8	0.0D0	Mass of the elevation platform (slugs)
GMK1(2)	R*8	0.0D0	Spring constant for two axis gimble suspension. Applies to angles less than the stop angle. (ft-lb/rad) GMK1(1) Azimuth Axis GMK1(2) Elevation Axis
GMK2(2)	R*8	0.0D0	Spring constant for two axis gimble suspension. Applies to angles greater than the stop angle. (ft-lb/rad) GMK2(1) Azimuth Axis GMK2(2) Elevation Axis
GMDMP(2)	R*8	0.0D0	Viscous damping constant for two axis gimble suspension. (ft-lb-sec/rad) GMDMP(1) Azimuth Axis GMDMP(2) Elevation Axis

TWO AXIS GIMBLE SIMULATION (No Active Control) CONT.

Fortran Symbol	Type	Preset Value	Description
GMSTP(2)	R*8	0.0D0	Stop angle for two axis gimble suspension. (rad) GMSTP(1) Azimuth Axis GMSTP(2) Elevation Axis
AZIMO	R*8	0.0D0	Rotation about the three axis in a 3-1-2 angle set from the main body frame to the gimble motion reference frame. (deg) NOTE: The gimble motion reference frame is a main body fixed frame
ROLLO	R*8	0.0D0	Rotation about the one axis in a 3-2-1 angle set from the main body frame to the gimble motion reference frame (deg)
ELEVO	R*8	0.0D0	Rotation about the two axis in a 3-1-2 angle set from the main body frame to the gimble motion reference frame (deg)
AZIMI	R*8	0.0D0	Initial azimuth angular position for the azimuth platform (deg)
AZIMID	R*8	0.0D0	Initial azimuth angular velocity for the azimuth platform (deg/sec)
ELEVI	R*8	0.0D0	Initial elevation angular position for the elevation platform (deg)
ELEVID	R*8	0.0D0	Initial elevation angular velocity for the elevation platform (deg/sec)
GMUP(2)	R*8	1.0D-3	Integration upper bounds for gimble angles and angular rates GMUP(1) (rad) GMUP(2) (rad/sec)
GMDN(2)	R*8	1.0D-5	Integration lower bounds for gimble angles and angular rates GMDN(1) (rad) GMDN(2) (rad/sec)

TWO AXIS GIMBLE SIMULATION (No Active Control) CONT.

Plotting locations for two axis gimble motion variables

Fortran Symbol	Description
KPLOTS(297)	Azimuth angle for the gimble azimuth platform
KPLOTS(298)	Azimuth angular rate for the gimble azimuth platform
KPLOTS(299)	Elevation angle for the gimble elevation platform
KPLOTS(300)	Elevation angular rate for the gimble elevation platform

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CONTROL SYSTEM FOR TWO AXIS PLATFORM MAGNETIC TRACKING

Fortran Symbol	Type	Preset Value	Description
IPLTCS(1-20)	I*4	0	Control words for gimble platform control system simulation
IPLTCS(1)			Control word to invoke the two axis platform control system option IPLTCS(1) 0 No control system IPLTCS(1) 1 Control system NOTE: If a control system is invoked the gimble simulation must also be invoked
IPLTCS(2)			Control word to specify magnetometer is mounted at the tip of an element IPLTCS(2) 0 Magnetometer in body IPLTCS(2) K Magnetometer on Kth element NOTE. K is defined in terms of the internal program element ordering system
IPLTCS(3)			Control word for guassian noise transfer function for the three axes of the magnetometer IPLTCS(3) 0 No transfer function IPLTCS(3) 1 Transfer function
IPLTCS(4)			Number of magnetometer samples to be averaged for smoothing of magnetometer output IPLTCS(4) N average N samples $N \geqslant 1$
IPLTCS(5-20)			Not used
PCSPRM(100)	R*8	0.0D0	Platform control system parameters
PCSPRM(1-9)			Not used
PCSPRM(10)			Sampling time for PID digital controller (sec)
PCSPRM(11)			Azimuth axis quantatisation level for platform position (rad)
PCSPRM(12)			Azimuth PID integrator upper saturation limit (rad)
PCSPRM(13)			Azimuth PID integrator lower saturation limit (rad)

CONTROL SYSTEM FOR TWO AXIS PLATFORM MAGNETIC TRACKING (CONT)

Fortran Symbol	Type	Preset Value	Description
PCSPRM(14)			Azimuth PID proportional gain K_P
PCSPRM(15)			Azimuth PID integrator gain K_I
PCSPRM(16)			Azimuth PID derivative gain K_D
PCSPRM(17-20)			Not used
PCSPRM(21)	R*8	0.0D0	Elevation axis quantatisation level for platform position (rad)
PCSPRM(22)			Elevation PID integrator upper saturation limit
PCSPRM(23)			Elevation PID integrator lower saturation limit
PCSPRM(24)			Elevation PID proportional gain K_P
PCSPRM(25)			Elevation PID integrator gain K_I
PCSPRM(26)			Elevation PID derivative gain K_D
PCSPRM(27-29)			Not used
PCSPRM(30)			Integration upper bound for magnetometer first order lag transfer function
PCSPRM(31)			Integration lower bound for magnetometer first order lag transfer function
PCSPRM(32)			Magnetometer one axis bandwidth
PCSPRM(33)	R*8	0.0D0	Magnetometer two axis bandwidth
PCSPRM(34)			Magnetometer three axis bandwidth
PCSPRM(35)			Magnetometer sampling rate (sec)
PCSPRM(36)			Computational delay (sec)
PCSPRM(37-40)			Not used
PCSPRM(41)			Azimuth platform amplifier gain K_A

CONTROL SYSTEM FOR TWO AXIS PLATFORM MAGNETIC TRACKING (CONT)

Fortran Symbol	Type	Preset Value	Description
PCSPRM(42)	R*8	0.0D0	Azimuth platform motor torque constant K_T
PCSPRM(43)			Azimuth platform back EMF constant K_B
PCSPRM(44)			Azimuth platform motor torque upper limit L_1 (ft-lbs)
PCSPRM(45)			Azimuth platform motor torque lower limit L_2 (ft-lbs)
PCSPRM(46)			Azimuth platform coulomb friction torque constant (ft-lbs)
PCSPRM(47)			Azimuth platform minimum angular rate for coulomb friction torque (rad/sec)
PCSPRM(48-50)			Not used
PCSPRM(51)			Elevation platform amplifier gain K_A
PCSPRM(52)			Elevation platform motor torque constant K_T
PCSPRM(53)			Elevation platform back EMF constant K_B
PCSPRM(54)			Elevation platform motor torque upper limit L_1 (ft-lbs)
PCSPRM(55)			Elevation platform motor torque lower limit L_2 (ft-lbs)
PCSPRM(56)			Elevation platform coulomb friction torque constant (ft-lbs)
PCSPRM(57)	R*8	0.0D0	Elevation platform minimum angular rate for coulomb friction torque (rad/sec)
PCSPRM(58-79)			Not used
PCSPRM(80)			Amplitude of sinusoidal noise added to one axis magnetometer measurement (gauss)
			Amplitude of sinusoidal noise for two axis (gauss)

CONTROL SYSTEM FOR TWO AXIS PLATFORM MAGNETIC TRACKING (CONT)

Fortran Symbol	Type	Preset Value	Description
PCSPRM(82)	R*8	0.0D0	Amplitude of sinusoidal noise for three axis (gauss)
PCSPRM(83)			Phase of sinusoidal noise added to one axis magnetometer measurement (deg)
PCSPRM(84)			Phase of sinusoidal noise for two axis (deg)
PCSPRM(85)			Phase of sinusoidal noise for three axis (deg)
PCSPRM(86)			Frequency of sinusoidal noise added to one axis magnetometer measurement (cps)
PCSPRM(87)			Frequency of sinusoidal noise for two axis (cps)
PCSPRM(88)			Frequency of sinusoidal noise for three axis (cps)
PCSPRM(89)			Not used
PCSPRM(90–95)			Used internally. Not input
PCSPRM(96–100)			Not used

Plotting locations for platform control system variables

Input Symbol	Description
KPLOTS(301)	Output of first order lag transfer function for magnetometer one axis
KPLOTS(302)	Output of first order lag transfer function for magnetometer two axis
KPLOTS(303)	Output of first order lag transfer function for magnetometer three axis
KPLOTS(304)	Azimuth error output
KPLOTS(305)	Elevation error output
KPLOTS(306)	Azimuth PID digital controller output

CONTROL SYSTEM FOR TWO AXIS PLATFORM MAGNETIC TRACKING (CONT)

Input Symbol	Description
KPLOTS(307)	Elevation PID digital controller output
KPLOTS(308)	Azimuth platform drive motor torque
KPLOTS(309)	Elevation platform drive motor torque

TWO AXIS DAMPER GIMBLE SIMULATION (No Active Control)

Fortran Symbol	Type	Preset Value	Description
IGMBLD	I*4	0	Control word for two axis damper gimble simulation IGMBLD 0 No gimble simulated IGMBLD 1 Gimble simulated
DELIN (3,3)	R*8	0.0D0	Moments of inertia of the elevation platform about its own center of mass (slug-ft^2)
DELAX(3)	R*8	0.0D0	Position vector in the azimuth motion reference frame. This position is a point on the elevation motion axis. (ft)
DELCG(3)	R*8	0.0D0	Position vector to the elevation platform center of mass in the elevation motion reference frame (ft)
DELMS	R*8	0.0D0	Mass of the elevation platform (slugs).
DMK1(2)	R*8	0.0D0	Spring constant for two axis gimble suspension. Applies to angles less than the stop angle (ft-lb/rad) DMK1(2) Elevation axis
DMK2(2)	R*8	0.0D0	Spring constant for two axis gimble suspension. Applies to angles greater than the stop angle. (ft-lb/rad) DMK2(2) Elevation Axis
DMDMP(2)	R*8	0.0D0	Viscous damping constant for two axis gimble suspension (ft-lb-sec/rad) GMDMP(2) Elevation axis
DMSTP(2)	R*8	0.0D0	Stop angle for two axis gimble suspension (rad) GMSTP(2) Elevation axis

TWO AXIS DAMPER GIMBLE SIMULATION (No Active Control) CONT

Fortran Symbol	Type	Preset Value	Description
DLEVI	R*8	0.0D0	Initial elevation angular position for the elevation platform (deg)
DLEVID	R*8	0.0D0	Initial elevation angular velocity for the elevation platform (deg/sec)
DMUP(2)	R*8	1.0D-3	Integration upper bounds for gimble angles and angular rates DMUP(1) (rad) DMUP(2) (rad/sec)
DMDN(2)	R*8	1.0D-5	Integration lower bounds for gimble angles and angular rates DMDN(1) (rad) DMDN(2) (rad/sec)

Plotting locations for two axis gimble motion variables

Input Symbol	Description
KPLOTS(310)	Azimuth angle for the gimble azimuth platform
KPLOTS(311)	Azimuth angular rate for the gimble azimuth platform
KPLOTS(312)	Elevation angle for the gimble elevation platform
KPLOTS(313)	Elevation angular rate for the gimble elevation platform

CONTROL SYSTEM FOR TWO AXIS PLATFORM (DAMPER) MAGNETIC TRACKING

Fortran Symbol	Type	Preset Value	Description
IPLDCS(1-20)	I*4	0	Control words for gimble damper platform control system simulation
IPLDCS(1)			Control word to invoke the two axis platform control system option IPLDCS(1) 0 No control system IPLDCS(1) 1 Control system NOTE: If a control system is invoked the gimble simulation must also be invoked
IPLDCS(2)			Control word to specify magnetometer is mounted at the tip of an element IPLDCS(2) 0 Magnetometer in body IPLDCS(2) K Magnetometer on Kth element NOTE: K is defined in terms of the internal program element ordering system
IPLDCS(3)			Control word for guassian noise transfer function for the three axes of the magnetometer IPLDCS(3) 0 No transfer function IPLDCS(3) 1 Transfer function
IPLDCS(4)			Number of magnetometer samples to be averaged for smoothing of magnetometer output IPLDCS(4) N average N samples $N \geq 1$
IPLDCS(5-20)			Not used
DCSPRM(100)	R*8	0.0D0	Platform control system parameters
DCSPRM(1-9)			Not used
DCSPRM(10)			Sampling time for PID digital controller (sec)
DCSPRM(11)			Azimuth axis quantatisation level for platform position (rad)
DCSPRM(12)			Azimuth PID integrator upper saturation limit

CONTROL SYSTEM FOR TWO AXIS PLATFORM (DAMPER) MAGNETIC TRACKING

Fortran Symbol	Type	Preset Value	Description
DCSPRM(13)	R*8	0.0D0	Azimuth PID integrator lower saturation limit
DCSPRM(14)			Azimuth PID proportional gain K_P
DCSPRM(15)			Azimuth PID integrator gain K_I
DCSPRM(16)			Azimuth PID derivative gain K_D
DCSPRM(17-20)			Not used
DCSPRM(21)			Elevation axis quantatisation level for platform position (rad)
DCSPRM(22)			Elevation PID integrator upper saturation limit
DCSPRM(23)			Elevation PID integrator lower saturation limit
DCSPRM(24)			Elevation PID proportional gain K_P
DCSPRM(25)			Elevation PID integrator gain K_I
DCSPRM(26)			Elevation PID derivative gain K_D
DCSPRM(27-29)			Not used
DCSPRM(30)			Integration upper bound for magnetometer first order lag transfer function
DCSPRM(31)			Integration lower bound for magnetometer first order lag transfer function
DCSPRM(32)			Magnetometer one axis bandwidth
DCSPRM(33)	R*8	0.0D0	Magnetometer two axis bandwidth
DCSPRM(34)			Magnetometer three axis bandwidth
DCSPRM(35)			Magnetometer sampling rate (sec)
DCSPRM(36)			Computational delay (sec)
DCSPRM(37-40)			Not used

CONTROL SYSTEM FOR TWO AXIS PLATFORM (DAMPER) MAGNETIC TRACKING (CONT)

Fortran Symbol	Type	Preset Value	Description
DCSPRM(41)	R*8	0.0D0	Azimuth platform amplifier gain K_A
DCSPRM(42)			Azimuth platform motor torque constant K_T
DCSPRM(43)			Azimuth platform back EMF constant K_B
DCSPRM(44)			Azimuth platform motor torque upper limit L_1 (ft-lbs)
DCSPRM(45)			Azimuth platform motor torque lower limit L_1 (ft-lbs)
DCSPRM(46)			Azimuth platform coulomb friction torque constant (ft-lbs)
DCSPRM(47)			Azimuth platform minimum angular rate for coulomb friction torque (rad/sec)
DCSPRM(48-50)			Not used
DCSPRM(51)			Elevation platform amplifier gain K_A
DCSPRM(52)			Elevation platform motor torque constant K_T
DCSPRM(53)			Elevation platform back EMF constant K_B
DCSPRM(54)			Elevation platform motor torque upper limit L_1 (ft-lbs)
DCSPRM(55)			Elevation platform motor torque lower limit L_1 (ft-lbs)
DCSPRM(56)			Elevation platform coulomb friction torque constant (ft-lbs)
DCSPRM(57)	R*8	0.0D0	Elevation platform minimum angular rate for coulomb friction torque (rad/sec)
DCSPRM(58-79)			Not used
DCSPRM(80)			Amplitude of sinusoidal noise added to one axis magnetometer measurement (gauss)
DCSPRM(81)			Amplitude of sinusoidal noise for two axis (gauss)

CONTROL SYSTEM FOR TWO AXIS PLATFORM (DAMPER) MAGNETIC TRACKING (CONT)

Fortran Symbol	Type	Preset Value	Description
DCSPRM(82)			Amplitude of sinusoidal noise for three axis (gauss)
DCSPRM(83)			Phase of sinusoidal noise added to one axis magnetometer measurement (deg)
DCSPRM(84)			Phase of sinusoidal noise for two axis (deg)
DCSPRM(85)			Phase of sinusoidal noise for three axis (deg)
DCSPRM(86)			Frequency of sinusoidal noise added to one axis magnetometer measurement (cps)
DCSPRM(87)			Frequency of sinusoidal noise for two axis (cps)
DCSPRM(88)			Frequency of sinusoidal noise for three axis (cps)
DCSPRM(89)			Not used
DCSPRM(90-95)			Used internally. Not input
DCSPRM(96-100)			Not used

Plotting locations for damper platform control system variables

Input Symbol	Description
KPLOTS(314)	Output of first order lag transfer function for magnetometer one axis
KPLOTS(315)	Output of first order lag transfer function for magnetometer two axis
KPLOTS(316)	Output of first order lag transfer function for magnetometer three axis
KPLOTS(317)	Azimuth error output
KPLOTS(318)	Elevation error output
KPLOTS(319)	Azimuth PID digital controller output
KPLOTS(320)	Elevation PID digital controller output
KPLOTS(321)	Azimuth platform drive motor torque

CONTROL SYSTEM FOR TWO AXIS PLATFORM (DAMPER) MAGNETIC TRACKING (CONT)

Input Symbol	Description
KPLOTS(322)	Elevation platform drive motor torque

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AXIS MOMENTUM WHEEL CONTROL

Fortran Symbol	Type	Preset Value	Description
IAMWH(1-10)	I*4	0	Control words for axis momentum wheel simulation
IAMWH(1)			Basic control word for axis momentum wheel simulation IAMWH(1) 0 No simulation IAMWH(1) 1 Simulation
IAMWH(2)			Control word for roll axis momentum wheel IAMWH(2) 0 No roll axis wheel IAMWH(2) 1 Roll axis wheel
IAMWH(3)			Control word for pitch axis momentum wheel IAMWH(3) 0 No pitch axis wheel IAMWH(3) 1 Pitch axis wheel
IAMWH(4)			Control word for Yaw axis momentum wheel IAMWH(4) 0 No Yaw axis wheel IAMWH(4) 1 Yaw axis wheel
AMWHPR (200)	R*8	0.0D0	Physical parameters for axis momentum wheel simulation
AMWHPR(1-4)			Not used
AMWHPR(5)			Expenential decay coefficient for integrator saturation simulation
AMWHPR(6-11)			Not used
AMWHPR(12)			Upper saturation limit for roll axis integrator
AMWHPR(13)			Lower saturation limit for roll axis integrator
AMWHPR(14)			Proportional gain in roll axis controller
AMWHPR(15)	R*8	0.0D0	Integrator gain in roll axis controller
AMWHPR(16)			Derivative gain in roll axis controller
AMWHPR(17)			Filter gain for roll angle error

AXIS MOMENTUM WHEEL CONTROL (CONT)

Fortran Symbol	Type	Preset Value	Description
AMWHPR(18)	R*8	0.0D0	Filter bandwidth for roll angle error
AMWHPR(19–21)			Not used
AMWHPR(22)			Upper saturation limit for pitch axis integrator
AMWHPR(23)			Lower saturation limit for pitch axis integrator
AMWHPR(24)			Proportional gain in pitch axis controller
AMWHPR(25)			Integrator gain in pitch axis controller
AMWHPR(26)			Derivative gain in pitch axis controller
AMWHPR(27)			Filter gain for pitch angle error
AMWHPR(28)			Filter bandwidth for pitch angle error
AMWHPR(29–31)			Not used
AMWHPR(32)			Upper saturation limit for yaw axis integrator
AMWHPR(33)			Lower saturation limit for yaw axis integrator
AMWHPR(34)			Proportional gain in yaw axis controller
AMWHPR(35)			Integrator gain in yaw axis controller
AMWHPR(36)			Derivative gain in yaw axis controller
AMWHPR(37)	R*8	0.0D0	Filter gain for yaw angle error
AMWHPR(38)			Filter bandwidth for yaw angle error
AMWHPR(39-40)			Not used
AMWHPR(41)			Roll axis amplifier gain for controller output
AMWHPR(42)			Roll axis momentum wheel motor torque constant
AMWHPR(43)			Roll axis momentum wheel motor back EMF constant

AXIS MOMENTUM WHEEL CONTROL (CONT)

Fortran Symbol	Type	Preset Value	Description
AMWHPR(44)	R*8	0.0D0	Roll axis momentum wheel torque upper limit
AMWHPR(45)			Roll axis momentum wheel motor torque lower limit
AMWHPR(46)			Roll axis momentum wheel coulomb friction torque constnat
AMWHPR(47)			Roll axis momentum wheel minimum angular rate for coulomb friction torque
AMWHPR(48)			Roll axis momentum whee' moment of inertia
AMWHPR(49-50)			Not used
AMWHPR(51)			Pitch axis amplifier gain for controller output
AMWHPR(52)			Pitch axis momentum wheel motor torque constant
AMWHPR(53)			Pitch axis momentum wheel motor back EMF constant
AMWHPR(54)			Pitch axis momentum wheel motor torque upper limit
AMWHPR(55)			Pitch axis momentum wheel motor torque lower limit
AMWHPR(56)	R*8	0.0D0	Pitch axis momentum wheel coulomb friction torque constant
AMWHPR(57)			Pitch axis momentum wheel minimum angular rate for coulomb friction torque
AMWHPR(58)			Pitch axis momentum wheel moment of inertia
AMWHPR(59-60)			Not used
AMWHPR(61)			Yaw axis amplifier gain for controller output
AMWHPR(62)			Yaw axis momentum wheel motor torque constant
AMWHPR(63)			Yaw axis momentum wheel motor back EMF constant

AXIS MOMENTUM WHEEL CONTROL (CONT)

Fortran Symbol	Type	Preset Value	Description
AMWHPR(64)	R*8	0.0D0	Yaw axis momentum wheel motor torque upper limit
AMWHPR(65)			Yaw axis momentum wheel motor torque lower limit
AMWHPR(66)			Yaw axis momentum wheel coulomb friction torque constant
AMWHPR(67)			Yaw axis momentum wheel minimum angular rate for coulomb friction torque
AMWHPR(68)			Yaw axis momentum wheel moment of inertia
AMWHPR(69-100)			Not used
AMWHPR(101)			Integration upper bound for filtered angle error
AMWHPR(102)			Integration lower bound for filtered angle error
AMWHPR(103)			Integration upper bound for momentum wheel speed
AMWHPR(104)			Integration lower bound for momentum wheel speed
AMWHPR(105-110)			Not used
AMWHPR(111)			Initial condition for roll axis momentum wheel speed
AMWHPR(112-120)			Not used
AMWHPR(121)			Initial condition for pitch axis momentum wheel speed
AMWHPR(122-130)			Not used
AMWHPR(131)			Initial condition for yaw axis momentum wheel speed
AMWHPR(132-200)			Not used

AXIS MOMENTUM WHEEL CONTROL (CONT)

Plotting locations for axis momentum wheel control

Input Symbol	Description
KPLOTS(323)	Roll axis filter output of error signal
KPLOTS(324)	Pitch axis filter output of error signal
KPLOTS(325)	Yaw axis filter output of error signal
KPLOTS(326)	Roll axis momentum wheel speed
KPLOTS(327)	Pitch axis momentum wheel speed
KPLOTS(328)	Yaw axis momentum wheel speed

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ARBITRARILY ORIENTED MOMENTUM WHEEL CONTROL

Fortran Symbol	Type	Preset Value	Description
IAMPRM(10)	I*4	0	Control words for arbitrarily oriented momentum wheel simulation
IAMPRM(1)			Control word to invoke simulation IAMPRM(1) 0 No simulation IAMPRM(1) 1 Simulation
AMPARM(200)	R*8	0.0D0	Physical constants for arbitrarily oriented momentum wheel simulation
AMPARM(1)			Not used
AMPARM(2–4)			Direction cosines of the momentum wheel axis in body frame
AMPARM(5–7)			Weighting factors for roll(5), Pitch(6) and YAW(7) angles input to filter
AMPARM(8)			Exponential decay coefficient for integrator saturation simulation
AMPARM(9–31)			Not used
AMPARM(32)			Upper saturation limit for integrator
AMPARM(33)			Lower saturation limit for integrator
AMPARM(34)			Proportional gain in controller
AMPARM(35)			Integrator gain in controller
AMPARM(36)			Derivative gain in controller
AMPARM(37)			Filter gain for angle error
AMPARM (38)			Filter bandwidth for angle error
AMPARM(39-60)			Not used
AMPARM(61)			Amplifier gain for controller output
AMPARM(62)			Momentum wheel motor torque constant

ARBITRARILY ORIENTED MOMENTUM WHEEL CONTROL (CONT)

Fortran Symbol	Type	Preset Value	Description
AMPARM(63)	R*8	0.0D0	Momentum wheel motor back EMF constant
AMPARM (64)			Momentum wheel motor torque upper limit
AMPARM(65)			Momentum wheel motor torque lower limit
AMPARM(66)			Momentum wheel coulomb friction torque constant
AMPARM(67)			Momentum wheel minimum angular rate for coulomb friction torque
AMPARM(68)			Momentum wheel moment of inertia
AMPARM(69-100)			Not used
AMPARM(101)			Integration upper bound for filtered angle error
AMPARM(102)			Integration lower bound for filtered angle error
AMPARM(103)			Integration upper bound for momentum wheel speed
AMPARM(104)			Integration lower bound for momentum wheel speed
AMPARM(105-130)			Not used
AMPARM(131)			Initial condition for momentum wheel speed
AMPARM(132-200)			Not used

Plotting locations for arbitrarily oriented momentum wheel

Input Symbol	Description
KPLOTS(329)	Filter output of control system angular error
KPLOTS(330)	Momentum wheel speed

END OF INPUT

The end of the input cards is indicated by two cards: the first one with a 1 punched in column one; the second one with the word END punched in columns one through three.

PART 4

DEFINITION OF PRINTED COMPUTER OUTPUT DATA

Fortran Symbol	Description	Units
DATE	Year, month, day	YY MM DD
TIME	Time, in hours, minutes, seconds from start of day.	HHMMSS.XX
XSAT1 XSAT2 XSAT3	Aries inertial components of satellite position vector.	km
XSATDT1 XSATDT2 XSATDT3	Aries inertial components of satellite velocity vector.	km/sec
DELTAT	Integration step size at the time of print out	sec
SA(i, j)	Transformation matrix from body frame to Aries frame.	N.D.
RMAG	Magnitude of satellite position vector.	km
LAT	Geodetic latitude	deg
LONG	Longitude, measured east from Greenwich Meridian	deg
ALFAE BETAE GAMAE	Euler angles; orientation of gravity gradient satellite body axes with respect to local vertical frame. Output only for earth-oriented satellite.	deg
PSI1 PHI1 THET1	Euler angles; orientation of spin stabilized satellite body axes with respect to local inertial frame. Output only for spin stabilized satellites.	deg

Fortran Symbol	Description	Units
W1BC W2BC W3BC	Body frame components of satellite angular velocity measured with respect to the local vertical frame. Output only for earth-oriented satellite.	deg/sec
RRATE PRATE YRATE	Roll, pitch, and yaw angle rates. Output only for earth-oriented satellite.	deg/sec
W1B W2B W3B	Body frame components of satellite angular velocity vector measured with respect to inertial space.	deg/sec
DOUT(k, j)	Component of the k^{th} element (libration damper) tip displacement in the j^{th} bending modes as measured in the element frame (Z^1) along the 2 axis of the frame. (INOPT = 2 only)	feet
DOUTDT(k, j)	Component of the k^{th} element (libration damper) tip velocity in the j^{th} bending mode as measured in the element frame (Z^1) along the 2 axis of the frame. (INOPT = 2 only)	ft/sec
DIN(k, j)	Component of the k^{th} element (libration damper) tip displacement in the j^{th} bending mode as measured in the element frame (Z^1) along the 3 axis of the frame. (INOPT = 2 only)	feet
DINDOT(k, j)	Component of the k^{th} element (libration damper) tip velocity in the j^{th} bending mode as measured in the element frame (Z^1) along the 3 axis of the frame. (INOPT = 2 only)	feet
A(k, j)	Component of the k^{th} primary element tip deflection in the j^{th} bending mode as measured along the 2 axis of the element frame.	feet

Fortran Symbol	Description	Units
ADOT(k, j)	Component of the k^{th} primary element tip velocity in the j^{th} bending mode as measured in the element frame along the $\underline{2}$ axis of the frame.	ft/sec
B(k, j)	Component of the k^{th} primary element tip deflection in the j^{th} bending mode as measured along the $\underline{3}$ axis of the element frame.	feet
BDOT(k, j)	Component of the k^{th} primary element tip velocity in the j^{th} bending mode as measured along the 3 axis of the element frame.	ft/sec
UD(i, k)	Total tip displacement, for the bending modes simulated, of the k^{th} libration damper element, measured along the i^{th} axis of the element frame. (INOPT = 2 only)	feet
UD(i)DT(k)	Total tip velocity, for the bending modes simulated, of the k^{th} libration damper element, measured along the i^{th} axis of the element frame. (INOPT = 2 only)	ft/sec
U(i, k)	Total tip displacement, for the bending modes simulated, of the k^{th} primary element, measured along the i^{th} axis of the element frame.	feet
U(i)DOT(k)	Total tip velocity, for the bending modes simulated, of the k^{th} primary element, measured along the i^{th} axis of the element frame.	ft/sec
ZLD(k)	Length of the k^{th} element, libration damper. (INOPT = 2 only)	feet
ZLK(k)	Length of the k^{th} primary element.	feet

Fortran Symbol	Description	Units
PHILD	The angular deflection of the libration damper boom relative to its equilibrium position. (INOPT = 2 only)	deg
DPHILD	Angular velocity of libration damper boom relative to the body. (INOPT = 2 only)	deg/sec
OMEGL	Spatial average angular velocity of the nutation damper fluid relative to the body. (INOPT = 1 only)	deg/sec
VSUBL	Average linear velocity of the nutation damper fluid relative to the damper tube wall. (INOPT = 1 only)	ft/sec
MSUBM1 MSUBM2 MSUBM3	Body frame components of torque exerted by the nutation damper fluid upon the satellite. (INOPT = 1 only)	ft-lb
CMX	Control moment along Y_1 body axis. (INOPT = 1 only)	ft-lb
SIMPX	A function related to total impulse for control moments applied along Y_1 body integral of the applied moment. (INOPT = 1 only)	ft-lb-sec
SUNVEC1 SUNVEC2 SUNVEC3	Components of sun to satellite unit vector, body frame.	N.D.
XMB1 XMB2 XMB3	Body frame components of magnetic torque acting on satellite.	ft-lb
SMAGI1 SMAGI2 SMAGI3	Components of Earth's magnetic field strength, Aries inertial frame.	Gauss

Fortran Symbol	Description	Units
SMAGB1 SMAGB2 SMAGB3	Components of the Earth's magnetic field strength, body frame.	Gauss
SOLILL	Solar illumination 0 = Occulted 1 = Full sunlight	N. D.
RWHEEL1 RWHEEL2 RWHEEL3	Body frame components of reaction torque exerted by the momentum wheels upon the satellite.	ft-lb
EPSERR	Angular error between desired and actual direction of spin axis. (INOPT = 1 only)	deg
SUNANG	Angle between sunline and orbit normal.	deg
SB(BODY)	Sun to satellite unit vector in body frame.	N. D.
SD(INERTIAL)	Sun to satellite unit vector in inertial coordinates - print out when boom deployment from sun pulse is used.	N. D.
FTAKIN(10, 3)	Thermal force in flexible element 1-2 plane direction before satellite shadowing and thermal lag.	lb
FTAKOT(10, 3)	Thermal force in flexible element 1-2 plane direction after satellite shadowing and thermal lag.	lb
FTBKIN(10, 3)	Thermal force in B direction before satellite shadowing or thermal lag.	lb
FTBKOT(10, 3)	Thermal force in flexible element 1-3 plane after satellite shadowing or thermal lag.	lb
TENSN(10)	Element root tension.	lb
YCEMS(i) i=1, 2, 3	Displacement components of center of mass with respect to original body axes due to flexible appendage motion	feet

Fortran Symbol	Math Symbol	Description	Unit
BNMTA(10)		Element root bending moment in flexible element 1-2 plane.	ft-ib
BNMTB(10)		Element root bending moment in flexible element 1-3 plane.	ft-lb
MOMENT1 MOMENT2 MOMENT3		Right hand side of Euler equations of motion applied to the spacecraft hub with gyroscopic terms also included. Used in check out.	ft-lb
HAMILT		Relative Hamiltonian of entire system.	ft-lb
HVECTR1 HVECTR2 HVECTR3	$\{h_i\}$	Angular momentum vector of the spacecraft in inertial frame	lb-ft-sec
HBODY1 HBODY2 HBODY3	$\{h_B\}$	Angular momentum vector expressed in spacecraft body reference frame	ft-lb-sec
HMAG		Magnitude of the angular momentum vector	lb-ft-sec
NUTANG	θ	Angle between the angular momentum vector and the spin axis (3 axis)	deg
EPSERH	N.A.	Angular error between the initial angular momentum vector direction and actual direction of spin axis (INOPT = 1 only)	deg
CW(k, j)		Twist angle of the k^{th} flexible element with the j^{th} twist mode	deg
CWD(k, j)		Time derivative of twist angle of k^{th} flexible element with the j^{th} twist mode	deg/sec
STAG PR		Stagnation pressure (IDRAG $\geqslant$ 1)	lbs/ft^2

Classical Orbital Parameters After Thrusting

The change in the orbit velocity vector at the time of thrusting will be reflected in the change of the values of classical orbital parameters. The standard printout will be interrupted and a set of new orbit information will be printed immediately after the impulsive thrusting. If the sun reference option is used (ISPLSE=1), the number of pulses together with the mean time (hour, minute, second) for the orbit update will always be printed. In this case, the orbit update message printout will be controlled by input word ISPNP. For instance, if the IPULSE is specified as 21 and ISPNP=5, the orbit update message will be printed at 5, 10, 15, 20, and 21st pulse.

Fortran Symbol	Math Symbol	Description	Units
ACCOB(I)	$\{\ddot{r}\}$	Acceleration vector of center of mass expressed in Aries inertial frame (I = 1, 2, 3)	ft/sec^2
ACCRED(J)	a_{h1}	Jth accelerometer reading (J = 1, NUMHUB)	ft/sec^2
HUBACC(I, J)	$\{x_h\}$	Acceleration vector expressed in Aries inertial frame of a point in the hub (I = 1, 2, 3; J = 1, NUMHUB)	ft/sec^2
TIPACC(I, K)	$\{a_T\}$	Acceleration vector of kth element tip expressed in Aries inertial frame (I = 1, 2, 3; K = 1, NELMTS)	ft/sec^2
BIXX	$\int_S \left(y^2_{2\,Lp} + y^2_{3\,Lp}\right)dm$	Instantaneous moment of inertia with respect to No. 1 body reference axis	$slug\text{-}ft^2$
BIYY	$\int_S \left(y^2_{1\,Lp} + y^2_{3\,Lp}\right)dm$	Instantaneous moment of inertia with respect to No. 2 body reference axis	$slug\text{-}ft^2$
BIZZ	$\int_S \left(y^2_{1\,Lp} + y^2_{2\,Lp}\right)dm$	Instantaneous moment of inertia with respect to No. 3 body reference axis	$slug\text{-}ft^2$

Fast Fourier Transform Analysis Output

The related printer plots for the Fast Fourier Transform are the power spectrum density function and the cross-correlation functions together with the results of harmonic analysis (frequencies, amplitude and phase angles). These are printed immediately following the regular printer plot of the FSD program. The data set to be analyzed and the autocorrelation function plot are also available. When the Fast Fourier Transform analysis option is used, increasing the I/O time estimate by a factor of 50 percent is recommended.

DE-B Control System Printed Output

Fortran Symbol	Description	Units
PTCH Out	Pitch channel sensor output	volts
ROLL Out	Roll channel sensor output	volts
COMP Out	Output of compensation amplifier	volts
TACH Out	Output of tachometer	volts
TMOTOR	Torque output of momentum wheel motor	ft.-lbs
WHL SPD	Momentum wheel speed	rad/sec
NUTD Out	Nutation damper phase shift circuit output	olts

Secondary Body Printed Output

GAMSB	Rotation of secondary body about 3 axis	deg
ALPSB	Rotation of secondary body about the carried 1 axis	deg
BETSB	Rotation of secondary body about the carried 2 axis	deg
OM1SB	Component of secondary body relative angular velocity on 1 axis of secondary body	deg/sec
OM2SB	Component of secondary body relative angular velocity on 2 axis of secondary body	deg/sec
OM3SB	Component of secondary body relative angular velocity on 3 axis of secondary body	deg/sec

Fortran Symbol	Description	Units
SEN OUTP	Sensor output (zero crossing of state variable)	depends on state variable
FIL OUTP	Filter output (zero crossing of state variable)	

TWO AXIS PLATFORM (and DAMPER) CONTROL SYSTEMS PRINTED OUTPUT

Fortran Symbol	Description	Units
SMAGF1 SMAGF2 SMAGF3	Filtered body frame components of earth's magnetic field	Gauss
GMBL AZ	Gimble platform azimuth angle	deg
GMBL AZD	Gimble platform azimuth angular velocity	deg/sec
GMBL EL	Gimble platform elevation angle	deg
GMBL ELD	Gimble platform elevation angular velocity	deg/sec
AZIM ERR	Gimble platform azimuth error angle	deg
ELEV ERR	Gimble platform elevation error angle	deg
AZIM PID	Gimble platform azimuth PID output	Depends on PID gain constants
ELEV PID	Gimble platform elevation PID output	
AZIM MOT	Gimble platform azimuth motor torque	ft–lbs
ELEV MOT	Gimble platform elevation motor torque	ft–lbs

AXIS MOMENTUM WHEEL PRINTED OUTPUT

Fortran Symbol	Description	Units
FTR ROLL	Roll filtered error output	deg
FTR PITCH	Pitch filtered error output	deg
FTR YAW	Yaw filtered error output	deg

ARBITRARILY ORIENTED MOMENTUM WHEEL PRINTED OUTPUT

Fortran Symbol	Description	Units
FTR ANG	Filtered error output	deg
ARB MWS	Momentum wheel speed	deg/sec
MOT TK	Motor torque	ft–lbs
CONT INT	Output of PID control system integrator	Depends on PID gain constants
CONT DER	Output of PID control system differentiator	

ELEMENT THERMAL EXPANSION PRINTED OUTPUT

Fortran Symbol	Description	Units
TEMP(1-10)	Average temperature of element	°R
ZLKP(1-10)	Axial velocity of element due to temperature effects	ft/sec
ZLKDP(1-10)	Axial acceleration of element due to temperature effects	ft/sec^2

Adams-Moulton Numerical Integration Control Message Output

The Adams-Moulton numerical integration control message is presented in a table format immediately following the nominal FSD printout and before the printer plot in each stacked case sequence. This table is the summary of the performance of numerical integration within a stacked case run. The definitions of the variables in the table are as follows:

Variable	Description
KCUT	Number of times the integration step size is reduced for a particular equation
UPPER	Upper integration bound for a particular equation
LOWER	Lower integration bound for a particular equation
DEPEND	Dependent array value of a state variable at the starting time of a stacked case sequence
DERIVE	Derivative array value of a state variable at the starting time of a stacked case sequence

GENERAL REFERENCES

1. Avco Corporation, AVSD-0191-71-CR, User's Manual for IMP Dynamics Computer Program, Volume I, E. A. Lawlor, L. Beltracchi, L. Turner, and M. Weinberger, March 1971.

2. Avco Corporation, AVSD-0191-71-CR, User's Manual for IMP Dynamics Computer Program, Volume II, Integral Evaluation Computer Program, E. A. Lawlor, March 1971.

3. Avco Corporation, Contract No. NAS 5-24008 Mod 15, Modification of the FSD Program for Linear Thrusting and Angular Momentum Computation User's Manual, K. Yong and E. A. Lawlor, November 1974.

4. Avco Corporation, Spacecraft Configuration Plot Program, A. Anderson, February 1973.

5. X-732-73-151, A User's Guide to the Flexible Spacecraft Dynamics Program-I, August 1973.

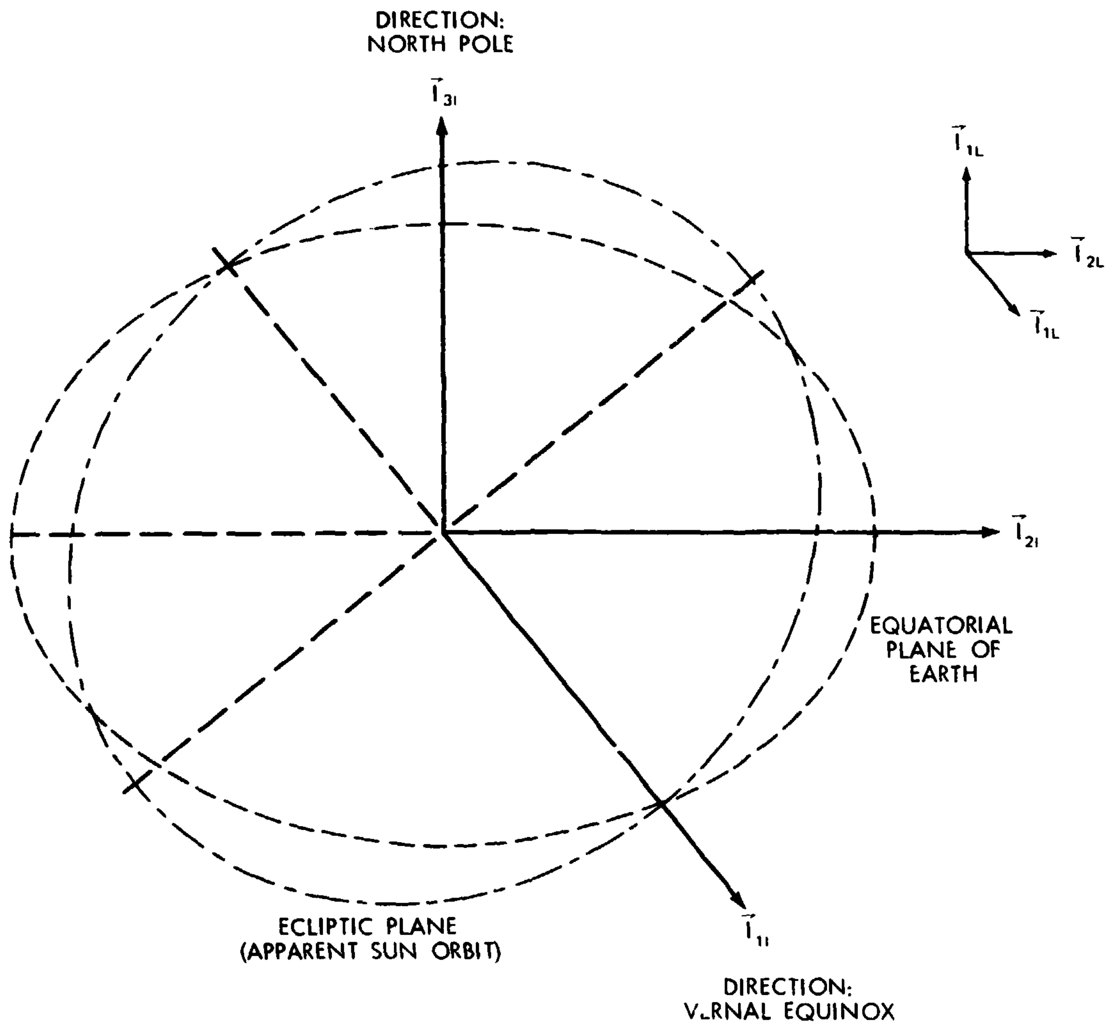
6. E. G. Stassinopolus, G. D. Mead, ALLMAG, GDALMG, LINTRA, Computer Programs For Geomagnetic Fields and Field Line Calculations, NSSDC-72-12 FEB 1972.

7. X-712-76-4, A User's Guide to the Flexible Spacecraft Dynamics Program-II, March 1976

8. Avco Corporation, Modification of the IMP Dynamics Computer Program for Limited Dual Spin Capability, E.A. Lawlor, February 1972.

APPENDIX A

COORDINATE SYSTEMS AND OTHER RELATED MATERIAL



ARIES FRAME:

RIGHT HANDED ORTHOGONAL REFERENCE FRAME
ORIGIN: CENTER OF EARTH

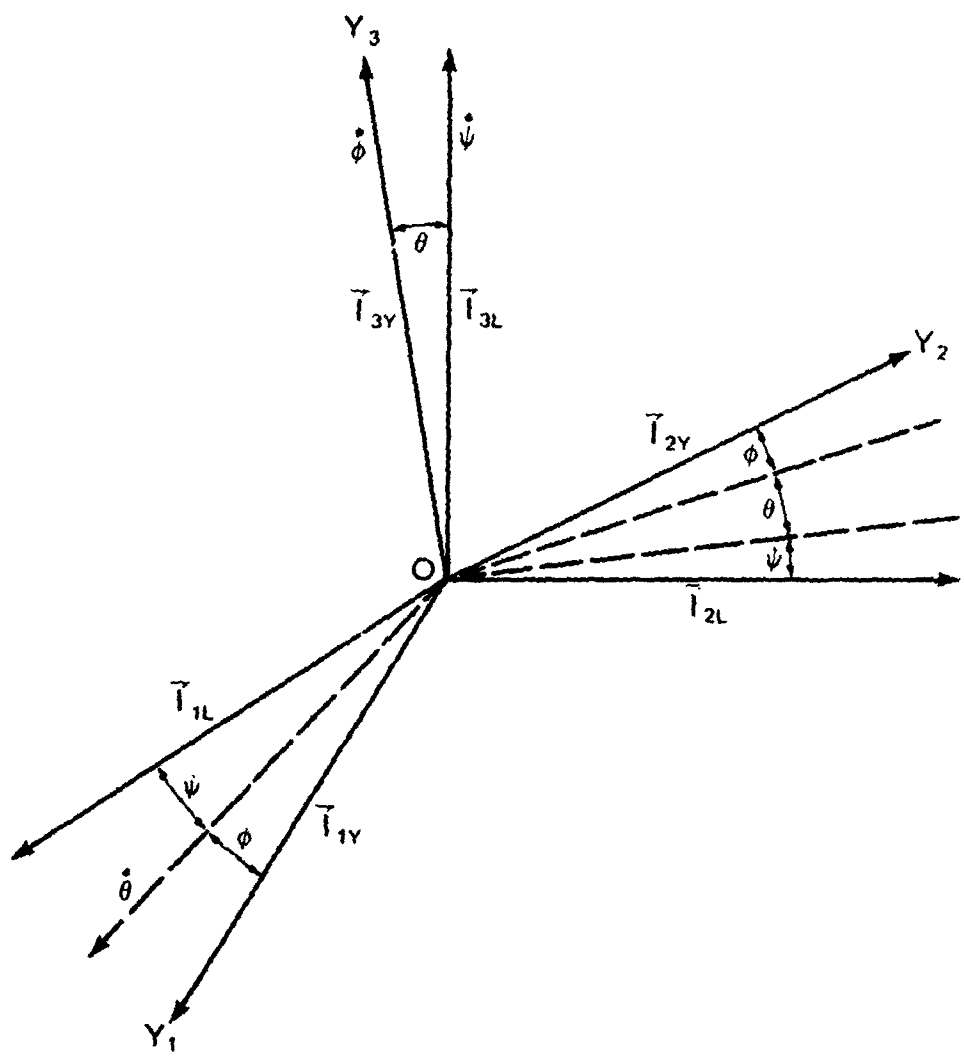
$\vec{1}_{1I}$ POINTS TOWARD VERNAL EQUINOX

$\vec{1}_{2I}$ EQUATORIAL PLANE, PERPENDICULAR TO $\vec{1}_{1L}$

$\vec{1}_{3I}$ POINTS TOWARD EARTH'S GEOMETRIC NORTH POLE

THE LOCAL INERTIAL (L-FRAME) IS OBTAINED BY A PARALLEL TRANSLATION OF THE ARIES FRAME FROM THE EARTH CENTER TO THE SATELLITE CENTER OF MASS.

Figure 1. Aries Coordinate System



L: LOCAL INERTIAL FRAME

Y: BODY FRAME

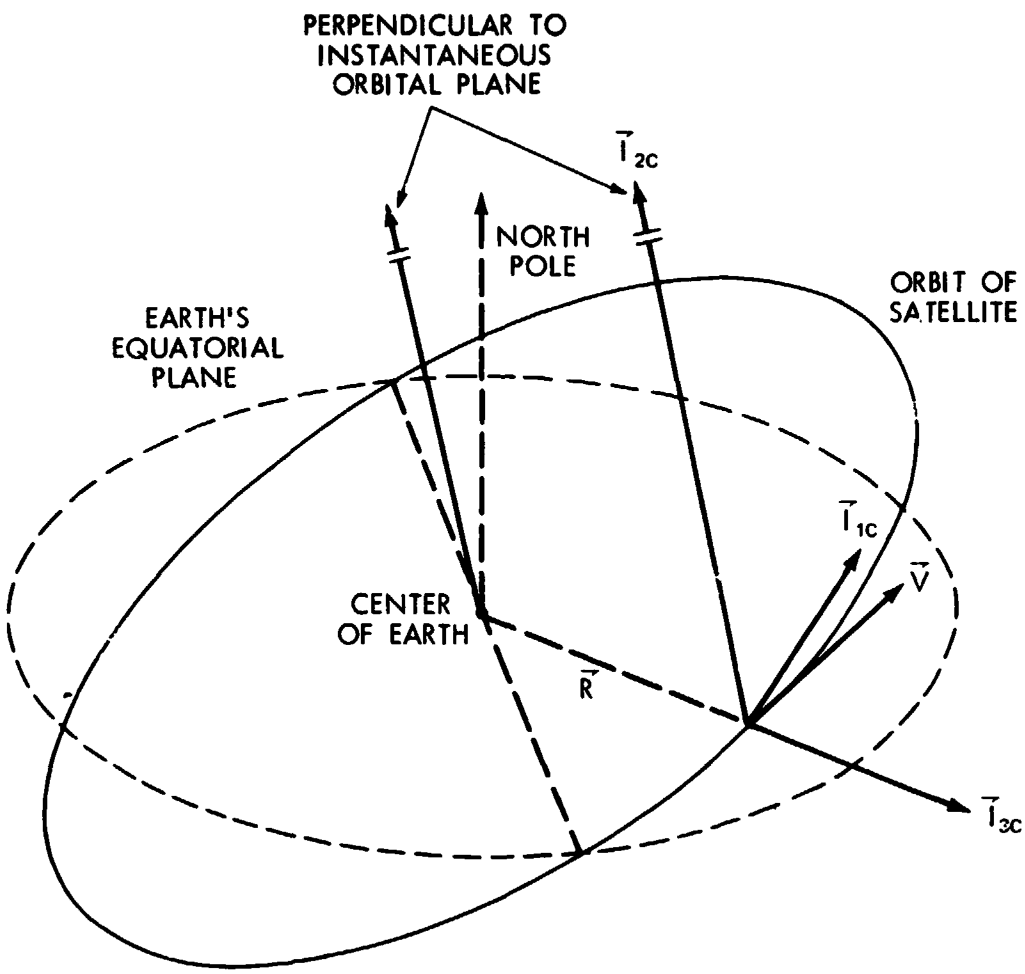
SEQUENCE OF ROTATIONS $\psi \rightarrow \theta \rightarrow \phi$

ALONG AXIS (3) (1) (3)

FOR SPINNING BODY: Y_3 TAKEN AS SPIN AXIS

θ = ANGLE BETWEEN SPIN AXIS AND THIRD INERTIAL DIRECTION

Figure 2. Euler Angles for a Spinning Body



$\vec{1}_{3C}$ POINTS FROM EARTH CENTER TO CENTER OF MASS OF SATELLITE, AND IS PARALLEL TO THE RADIUS VECTOR $\vec{R}$

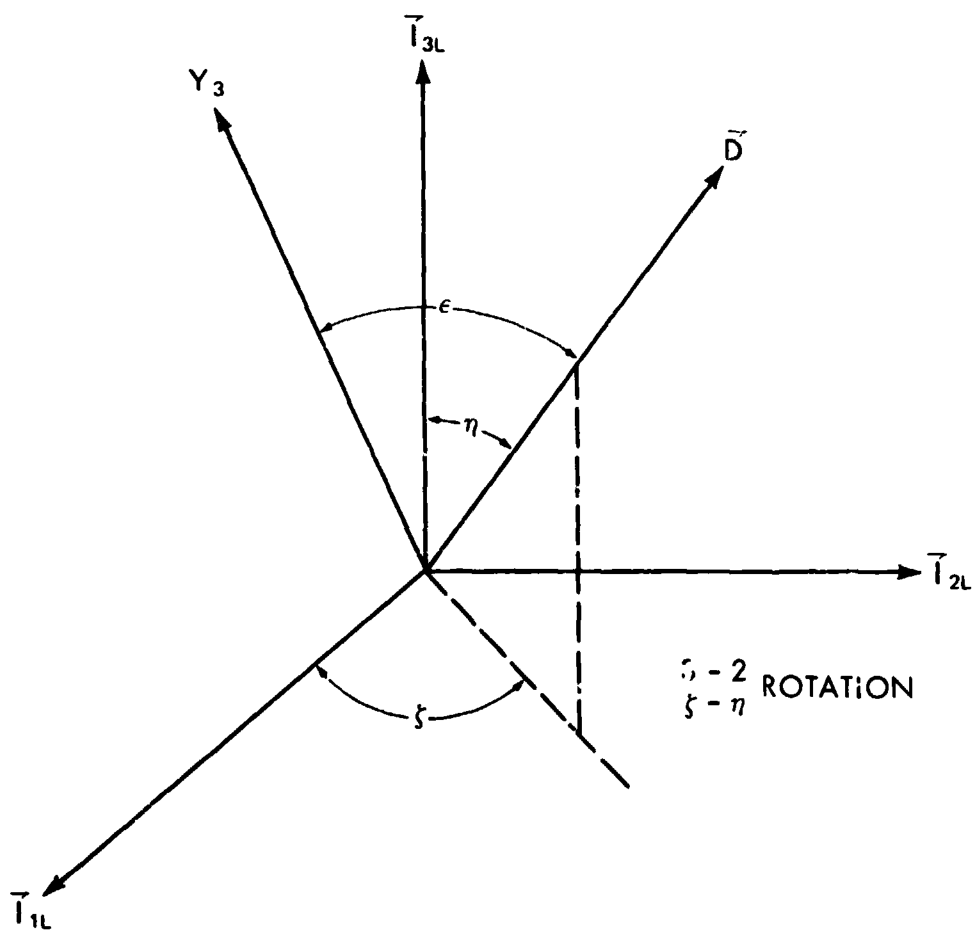
$\vec{1}_{2C}$ PERPENDICULAR TO INSTANTANEOUS ORBITAL PLANE
ITS DIRECTION IS DEFINED BY $\vec{R} \times \vec{V}$. $\vec{V}$ IS THE INERTIAL VELOCITY OF THE CENTER OF MASS OF THE SATELLITE.

$\vec{1}_{1C}$ COMPLETES RIGHTHANDED ORTHOGONAL FRAME
FOR A CIRCULAR ORBIT $\vec{1}_{1C}$ LIES ALONG $\vec{V}$
FOR AN ELLIPTIC ORBIT, $\vec{1}_{1C}$ LIES ALONG $\vec{V}$ ONLY AT APOGEE AND PERIGEE. $\vec{1}_{1C}$ ALWAYS LIES IN INSTANTANEOUS ORBITAL PLANE AND MAKES AN ACUTE ANGLE WITH $\vec{V}$

THE LOCAL "VERTICAL" FRAME (C) HAS UNIT VECTORS $\vec{1}_{1C}$, $\vec{1}_{2C}$, $\vec{1}_{3C}$ AND IS CENTERED AT CENTER OF MASS OF SATELLITE

THE "VERTICAL" USED HERE IS DIRECTION OF GRAVITY FORCE FOR A SPHERICAL EARTH.

Figure 3. Local Vertical Coordinate System



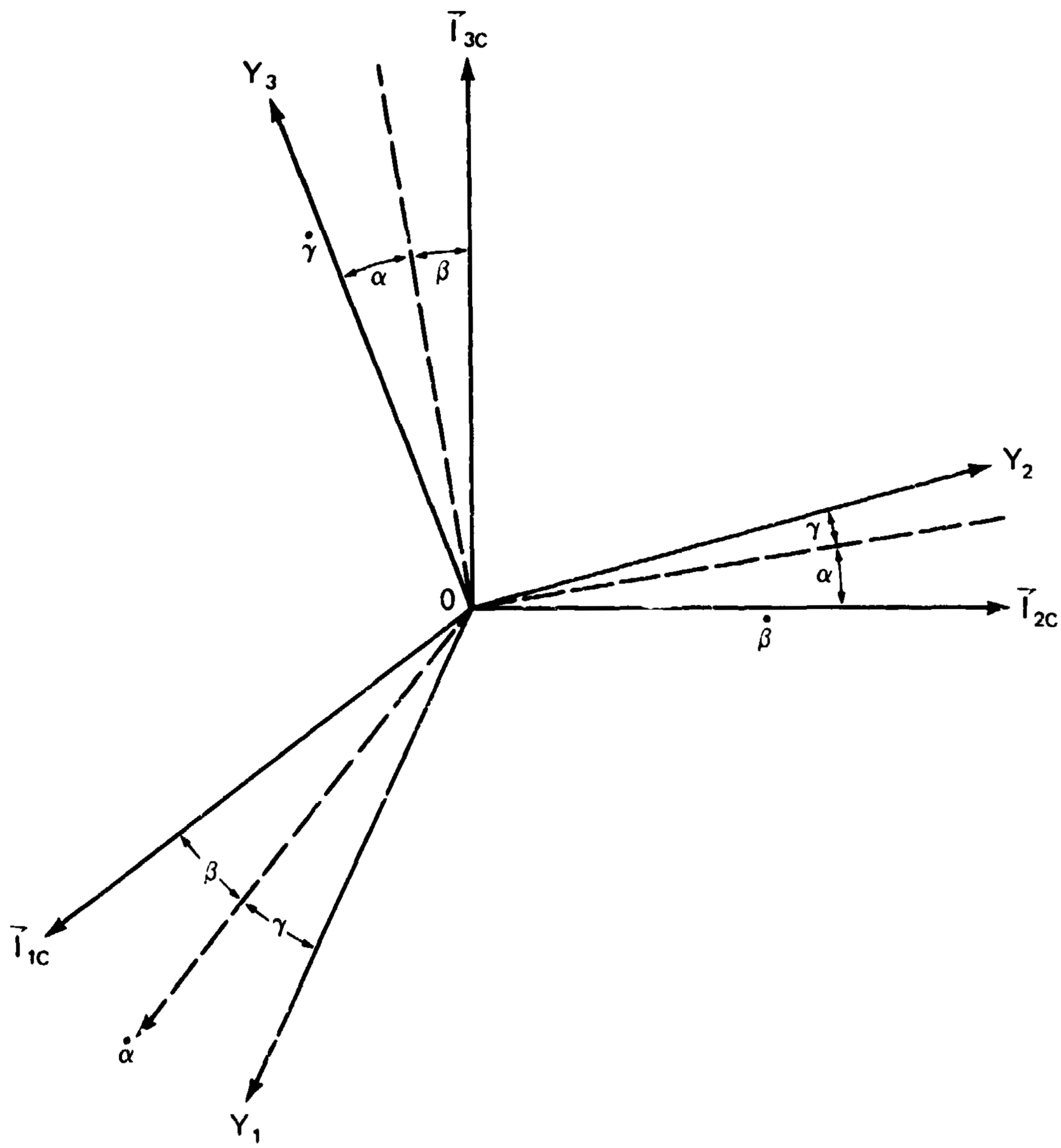
DIRECTION COSINES OF $\bar{D}$ WITH RESPECT TO LOCAL INERTIAL FRAME:

$\sin\eta \cos\zeta$

$\sin\eta \sin\zeta$

$\cos\eta$

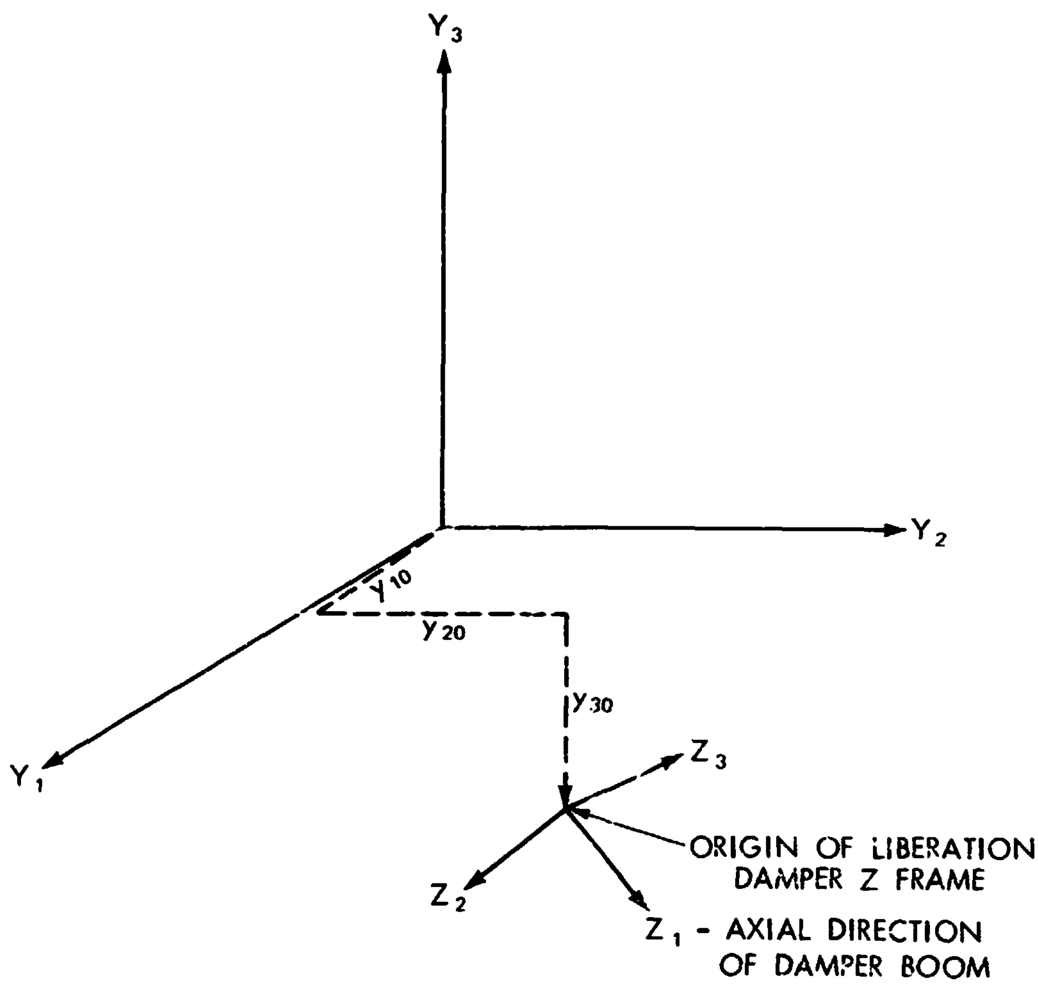
Figure 4. Error Angle for Spin Axis



C: LOCAL "VERTICAL" FRAME
Y: BODY FRAME

SEQUENCE OF ROTATIONS	β →	α →	γ
ALONG AXIS	(2)	(1)	(3)
	PITCH	ROLL	YAW

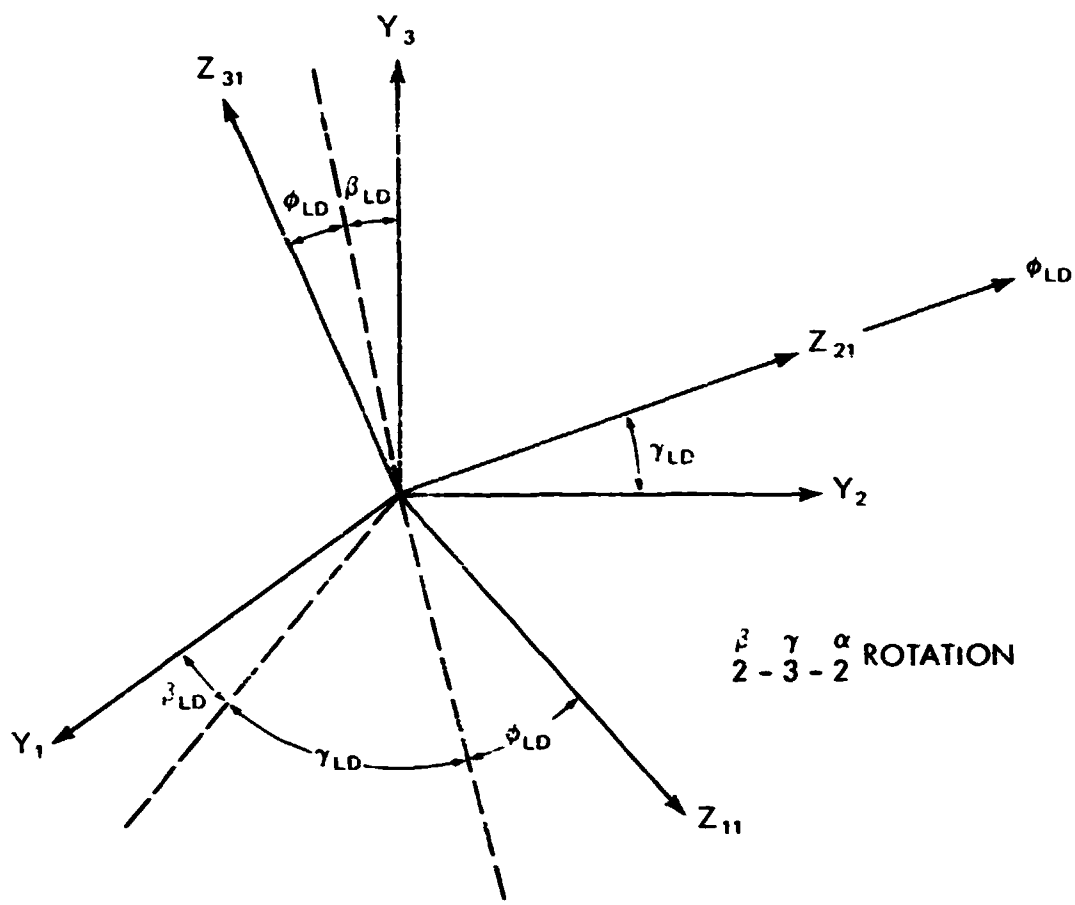
Figure 5. Euler Angles for Gravity Gradient Stabilized Vehicles



y_1, y_2, y_3 COMPONENTS OF AN ARBITRARY VECTOR, ON THE 1, 2, 3 AXES OF THE BODY Y FRAME

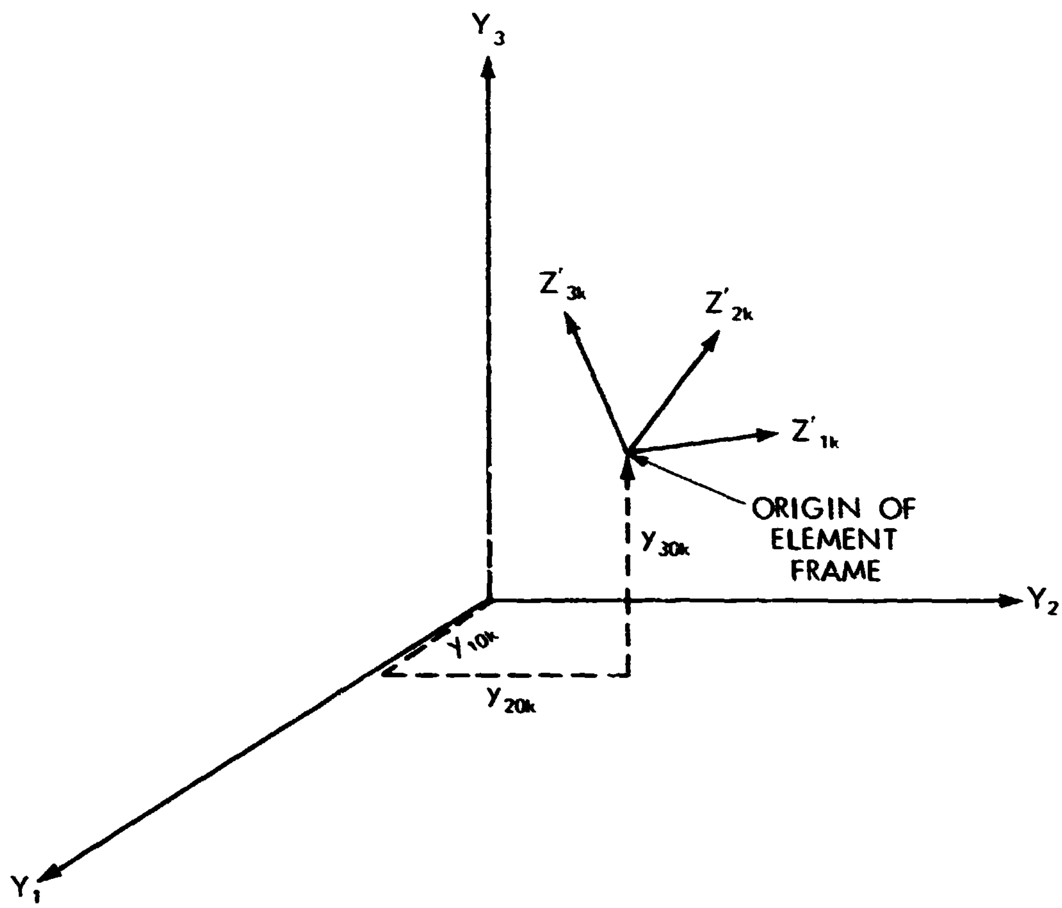
z_1, z_2, z_3 COMPONENTS OF AN ARBITRARY VECTOR, ON THE 1, 2, 3 AXES OF THE LIBRATION DAMPER Z FRAME

Figure 6. Origin of Libration Damper Z Frame



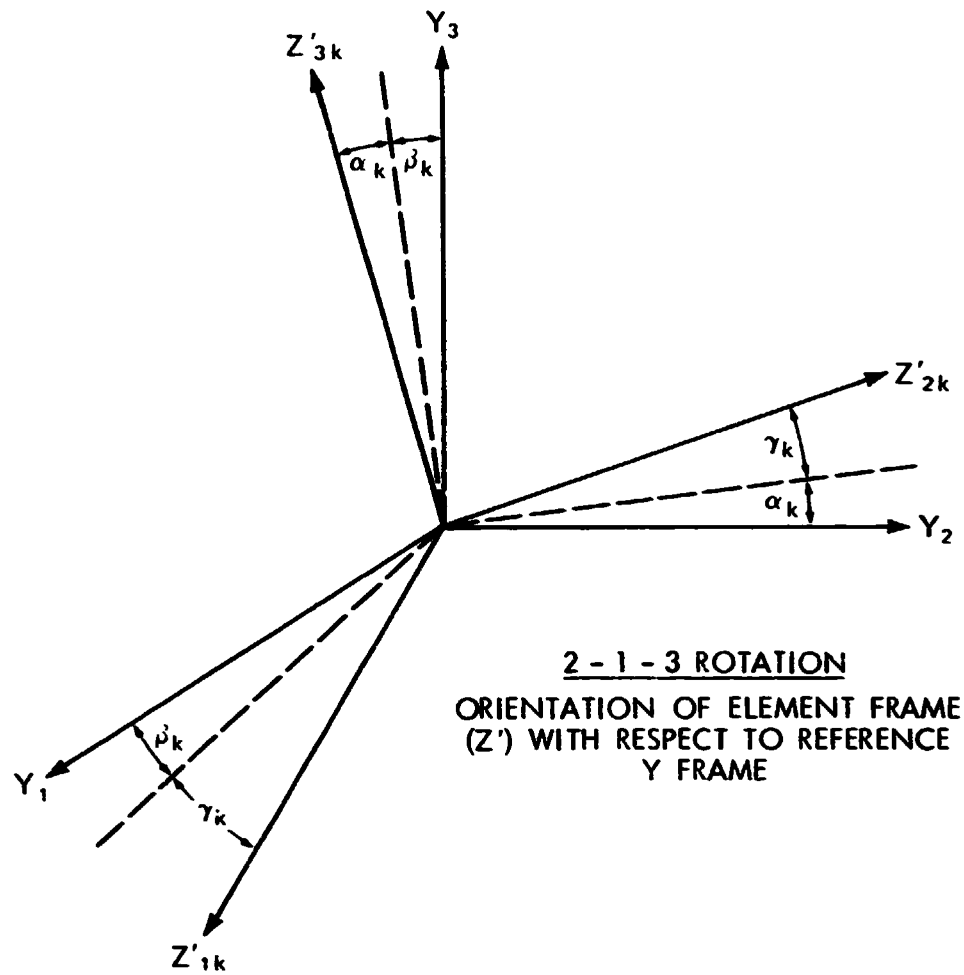
y_1, y_2, y_3	COMPONENTS OF AN ARBITRARY VECTOR, ON THE 1, 2, 3 AXES OF THE BODY Y FRAME
z_{11}, z_{21}, z_{31}	COMPONENTS OF AN ARBITRARY VECTOR, ON THE 1, 2, 3 AXES OF THE LIBRATION DAMPER Z FRAME. Z_{11} POINTS IN AXIAL DIRECTION OF DAMPER BOOM, OUTWARD FROM SATELLITE CORE
$\gamma_{LD}, \beta_{LD}, \phi_{LD}$	EULER ANGLES

Figure 7. Orientation of the Libration Damper Z Frame with Respect to Body Y Frame



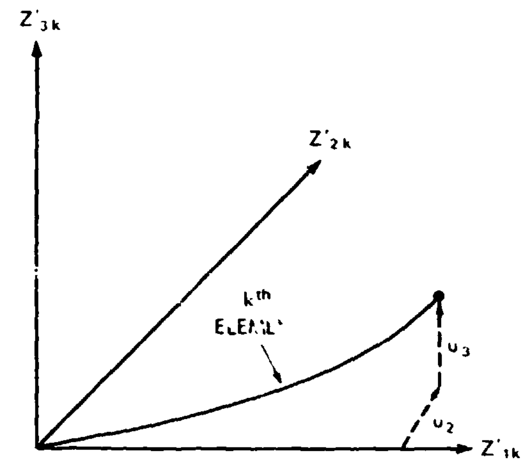
y_1, y_2, y_3	COMPONENTS OF AN ARBITRARY VECTOR, ON THE 1, 2, 3 AXES OF THE Y FRAME
$z'_{1K}, z'_{2K}, z'_{3K}$	COMPONENTS OF AN ARBITRARY VECTOR, ON THE 1, 2, 3 AXES OF THE Z'_k (k^{th} ELEMENT) FRAME. THE 1 AXIS OF THE ELEMENT FRAME POINTS ALONG UNDEFORMED ELEMENT, OUTWARD FROM SATELLITE CORE
$y_{10K}, y_{20K}, y_{30K}$	Y FRAME COMPONENTS OF Z ORIGIN

Figure 8. Origin of Boom Element Frame



y_1, y_2, y_3	COMPONENTS OF AN ARBITRARY VECTOR, ON THE 1, 2, 3 AXES OF THE REFERENCE Y FRAME
z'_{1k}, z'_{2k}, z'_{3k}	COMPONENTS OF AN ARBITRARY VECTOR. ON THE 1, 2, 3 AXES OF THE Z'_k (K^{th} ELEMENT) FRAME. THE 1 AXIS OF THE ELEMENT FRAME POINTS ALONG UNDEFORMED ELEMENT, OUTWARD FROM SATELLITE CORE
α_k, β_k, γ_k	EULER ANGLES

Figure 9. Orientation of Element Frame (Z') with Respect to Reference Y Frame



z'_{1k}, z'_{2k}, z'_{3k}	COMPONENTS OF AN ARBITRARY VECTOR, ON THE 1, 2, 3 AXES OF THE Z'_k (k^{th} ELEMENT) FRAME
u_2	ELEMENT TIP DEFLECTION, Z'_{2k} COMPONENT,
u_3	ELEMENT TIP DEFLECTION, Z'_{3k} COMPONENT

Figure 10. k^{th} Element Coordinate System

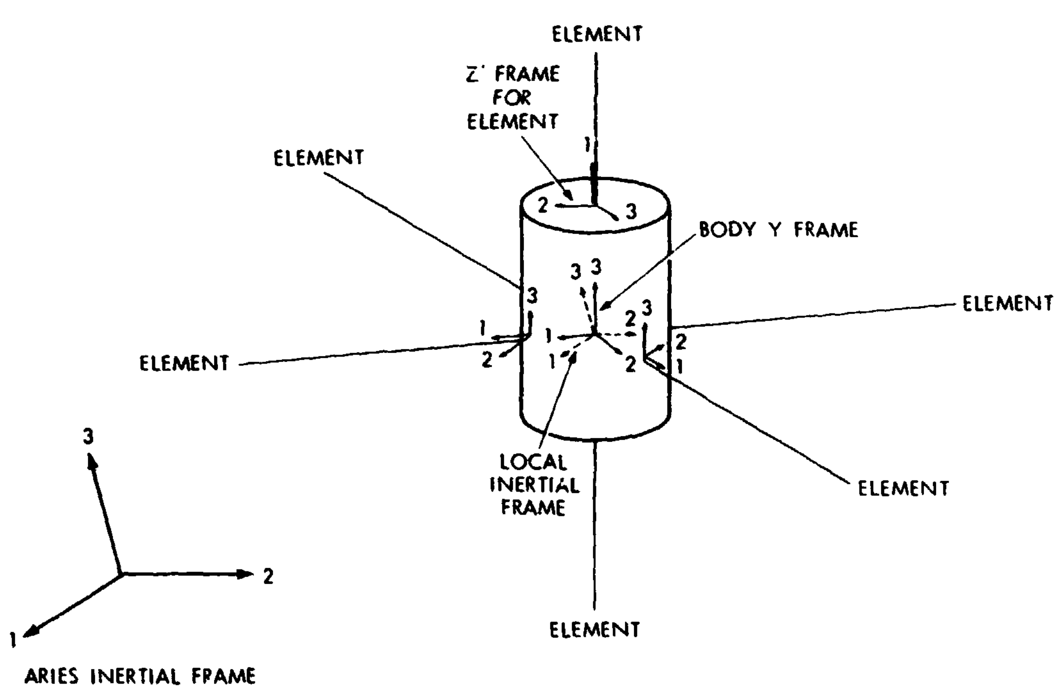
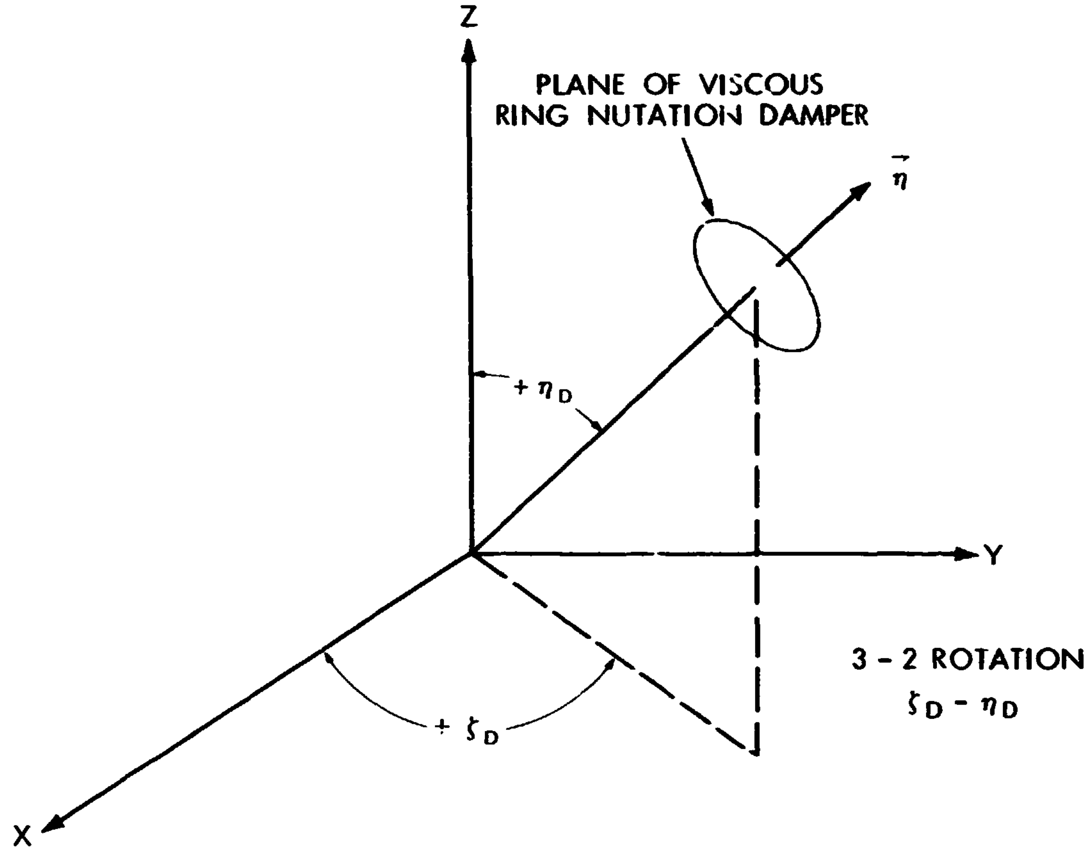


Figure 11



X, Y, Z SATELLITE BODY AXES

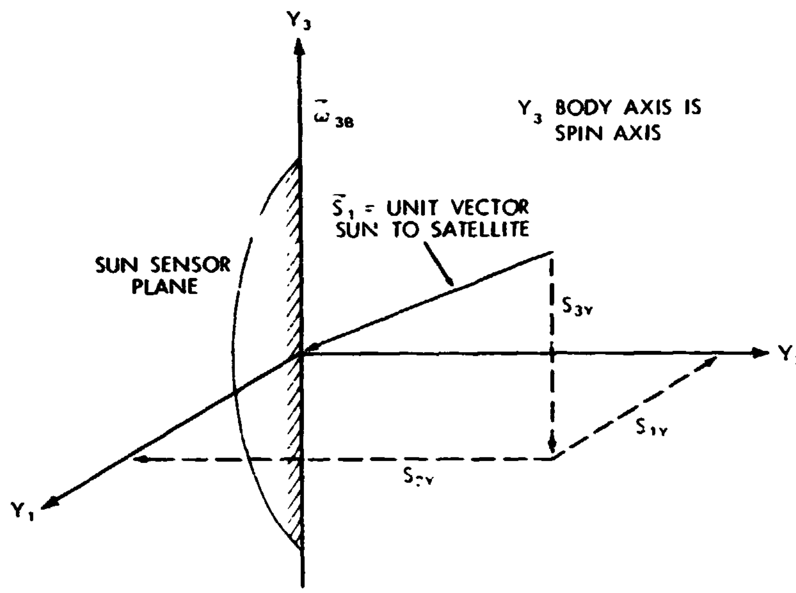
DIRECTION COSINES OF $\vec{\eta}$ WITH RESPECT TO BODY

$$\eta_x = \text{SIN}\ \eta_D\ \text{COS}\ \zeta_D$$

$$\eta_y = \text{SIN}\ \eta_D\ \text{SIN}\ \zeta_D$$

$$\eta_z = \text{COS}\ \eta_D$$

Figure 12. Axis of Ring Damper η Unity Vector Perpendicular to Plane of Ring Damper

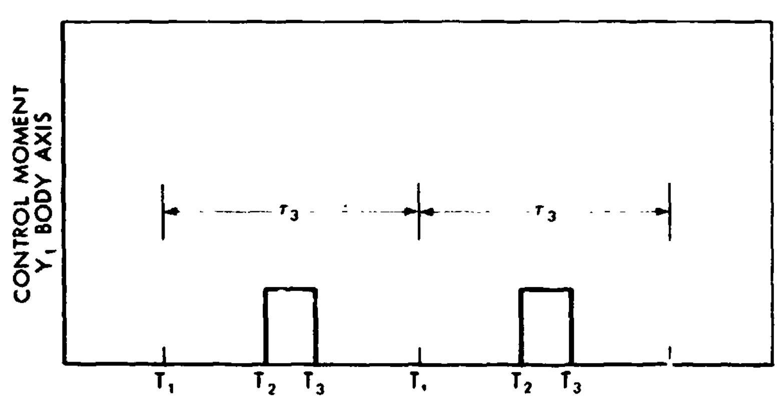


REFERENCE POINT IN SPIN PERIOD DEFINED WHEN:

$$S_{2V} = 0$$

$$S_{1V} < 0$$

Figure 13. Sun Sensor Reference Point in Spin Period



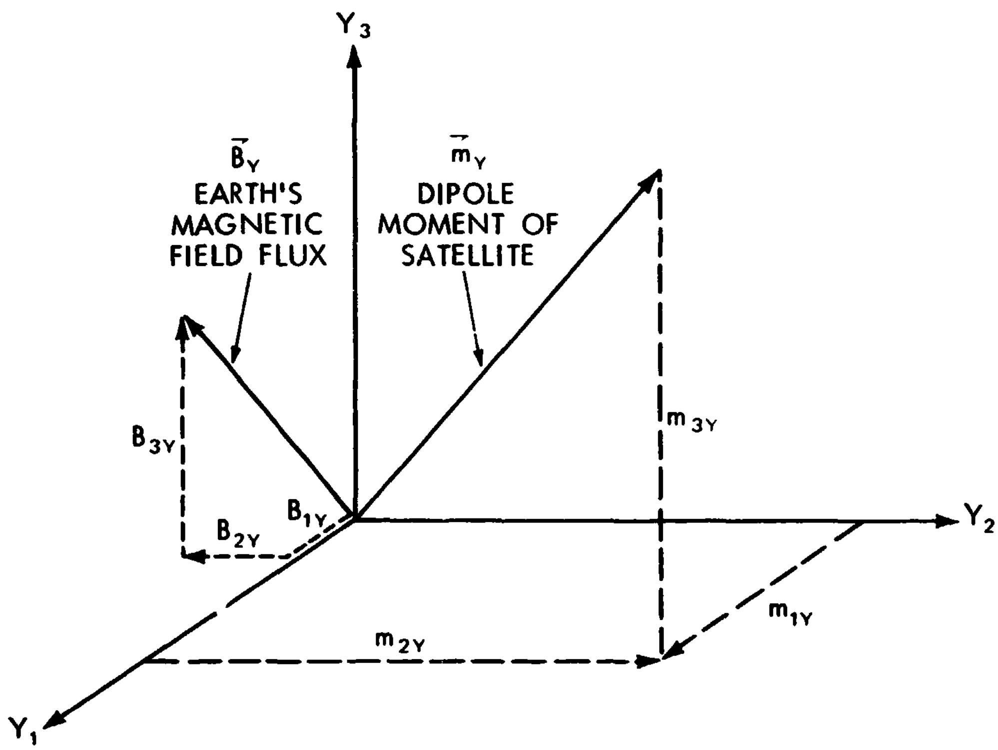
$T_2 = T_1 + B\ \tau_3$

$T_3 = T_1 + C\ \tau_3$

τ_3 = SPIN PERIOD = $\dfrac{2\pi}{|\omega_{3B}|}$

T_1 = REFERENCE TIME IN SPIN PERIOD

Figure 14. Time History of Control Moment about Y_1 Body Axis



Y_1, Y_2, Y_3	BODY AXES
B_{1Y}, B_{2Y}, B_{3Y}	COMPONENTS OF $\vec{B}_Y$ ON BODY AXES
m_{1Y}, m_{2Y}, m_{3Y}	COMPONENTS OF $\vec{m}_Y$ ON BODY AXES

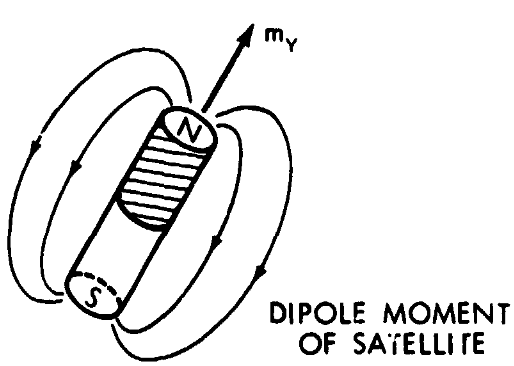
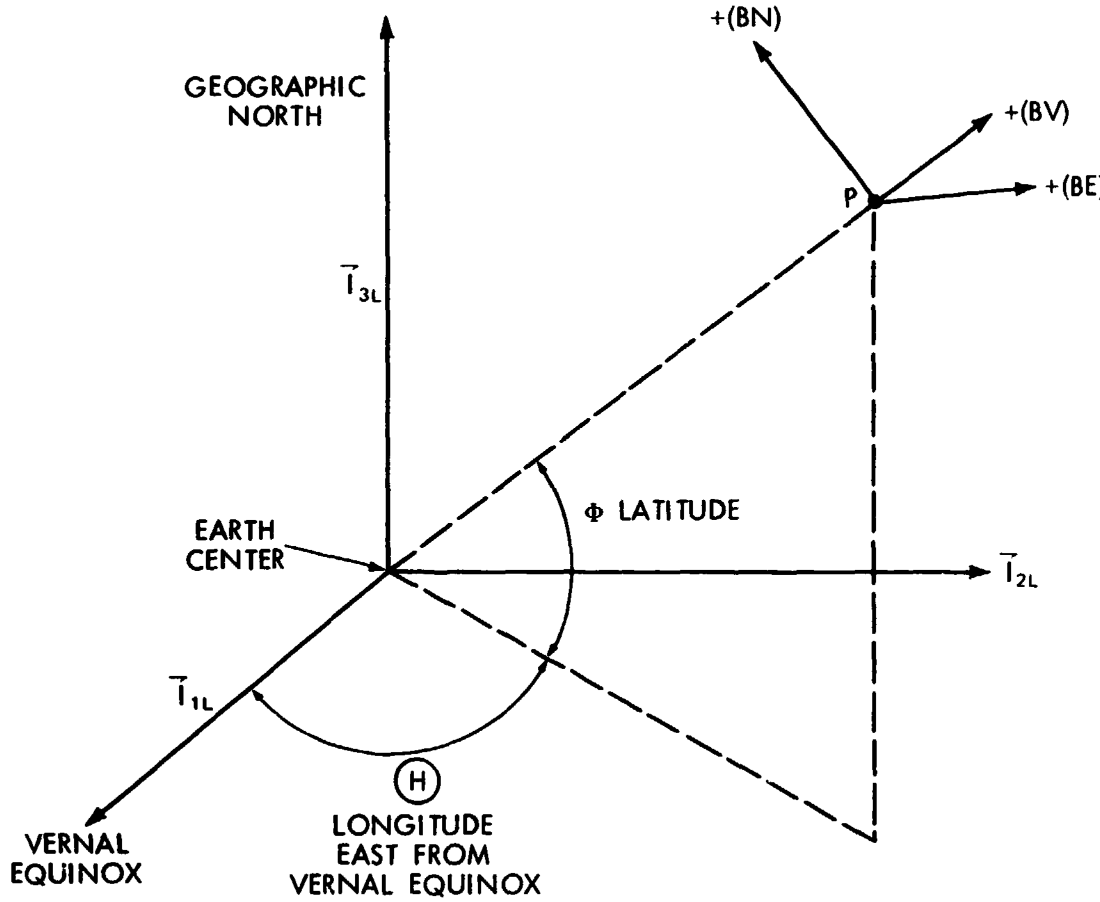
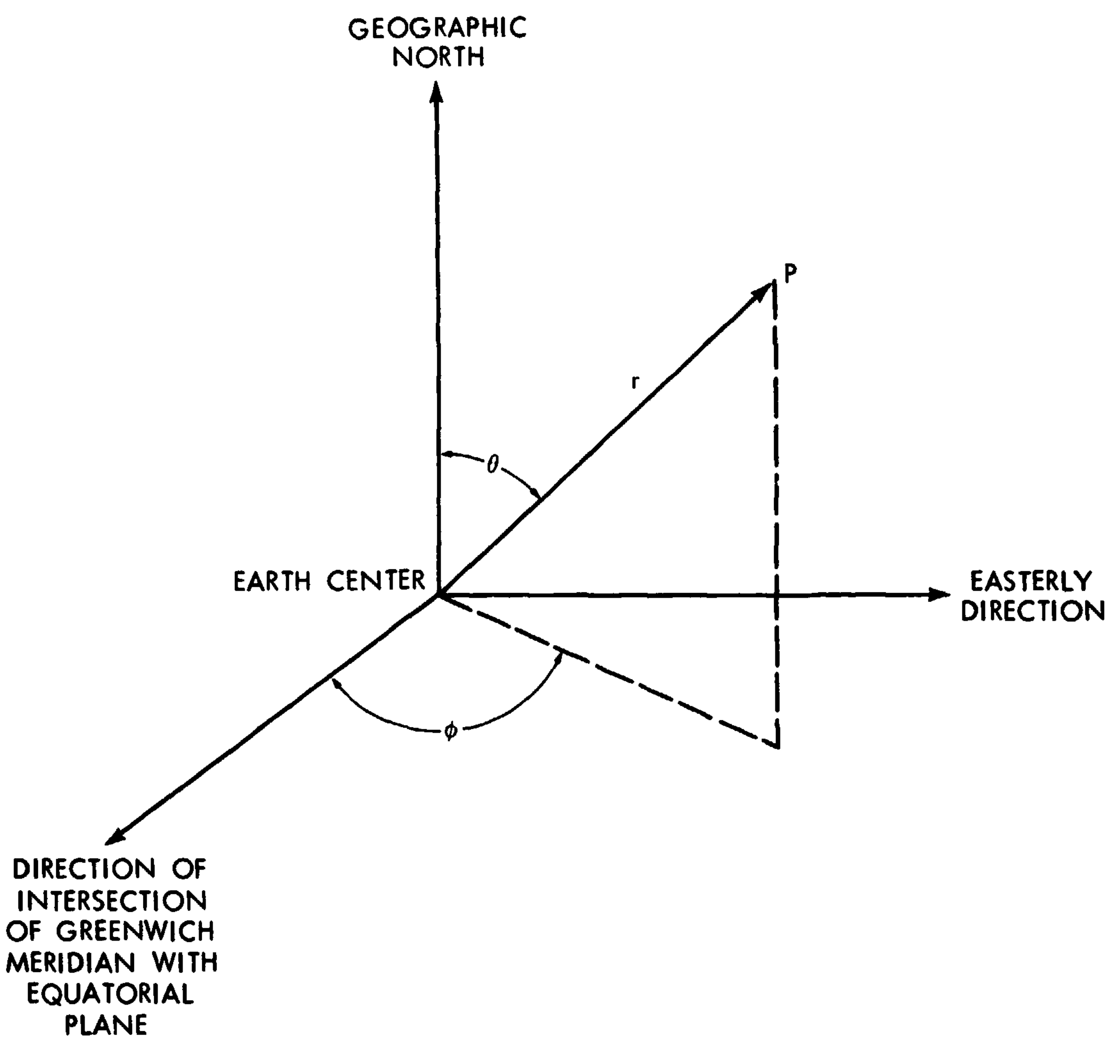


Figure 15. Dipole Moment of Satellite and Earth's Magnetic Field Flux in Body Frame



$\overline{I}_{1L}$, $\overline{I}_{2L}$, $\overline{I}_{3L}$	UNIT VECTORS, ARIES EQUATORIAL INERTIAL FRAME
BV:	VERTICAL COMPONENT OF FIELD, POSITIVE AWAY FROM CENTER OF EARTH
BE:	PARALLEL TO EQUATORIAL PLANE, TANGENT TO CONSTANT LATITUDE CIRCLE, POSITIVE IN EASTERLY DIRECTION
BN:	COMPLETES RIGHTHANDED ORTHOGONAL TRIAD, POSITIVE TOWARDS GEOGRAPHIC NORTH

Figure 16. Components of Magnetic Field



ϕ = GEOGRAPHIC LONGITUDE
θ = GEOGRAPHIC COLATITUDE = 90°-LATITUDE
r = RADIUS VECTOR

Figure 17. Coordinates for Spherical Harmonics

Thrust Loading

The time history of the thrust loading is as shown in Figure 18.

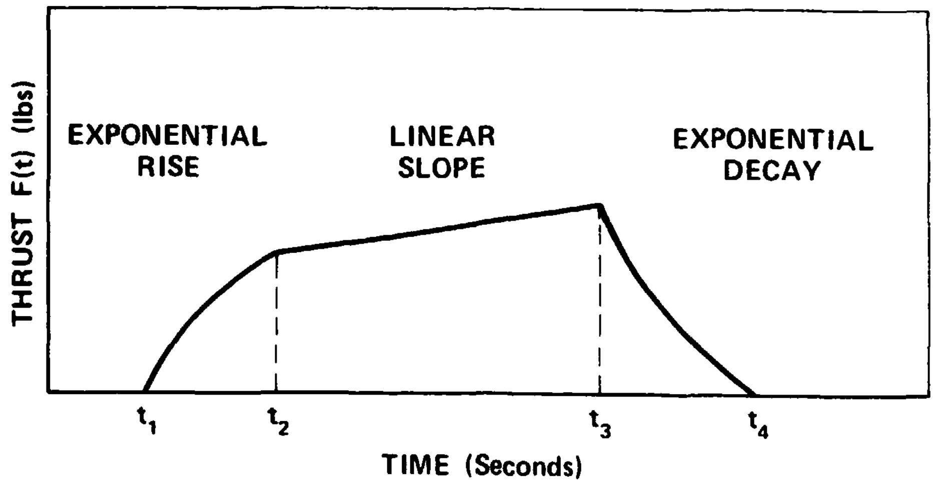


Figure 18. Thrust Time History

The analytic expressions for the thrust loading time history are as follows.

$$
\begin{array}{ll}
t < t_1 & F(t) = 0 \\
t_1 \le t \le t_2 & F_1(t) = A[1 - e^{-B(t-t_1)}] \\
t_2 \le t \le t_3 & F_2(t) = F_1(t_2) + C(t - t_2) \\
t_3 \le t \le t_4 & F_3(t) = F_2(t_3)\left[\dfrac{t_4 - t}{t_4 - t_3}\right] e^{-D(t-t_3)} \\
t > t_4 & F(t) = 0
\end{array}
\qquad (1)
$$

The total impulse under the thrust loading time curve is obtained by integration. The impulse is used to apply the increment in velocity to the trajectory of the spacecraft. The mean time, at which the velocity increment is applied, is obtained as follows.

$$\bar{t} = \frac{\int_{t_1}^{t_4} t\,F(t)\,dt}{\int_{t_1}^{t_4} F(t)\,dt} \tag{2}$$

The appropriate expressions for the three pieces of the thrust loading time curve are given below.

For

$$t_1 \leq t \leq t_2$$

$$I_1 \triangleq \int_{t_1}^{t_2} F_1(t)\,dt = A\left[\Delta t_{21} - \frac{1}{B}\left(1 - e^{-B\Delta t_{21}}\right)\right]$$

$$M_1 \triangleq \int_{t_1}^{t_2} t\,F_1(t)\,dt = A\Delta t_{21}\left[\frac{\Delta t_{21}^2}{2} + \frac{1}{B}e^{-B\Delta t_{21}}\right] - \frac{F_1(t_2)}{B^2} \tag{3}$$

For

$$t_2 \leq t \leq t_3$$

$$I_2 \triangleq \int_{t_2}^{t_3} F_2(t)\,dt = F_1(t_2)\Delta t_{32} + \frac{1}{2}C\Delta t_{32}^2$$

$$M_2 \triangleq \int_{t_2}^{t_3} (t + \Delta t_{21})F_2(t)\,dt \tag{4}$$

$$= F_1(t_2)\Delta t_{32}\left[\Delta t_{21} + \frac{1}{2}\Delta t_{32}\right] + \frac{1}{2}C\Delta t_{32}^2\left[\Delta t_{21} + \frac{2}{3}\Delta t_{32}\right]$$

For

$$t_3 \le t \le t_4$$

$$I_3 \triangleq \int_{t_3}^{t_4} F_3(t)\,dt = \frac{F_2(t_3)}{D}\left[1 - \frac{1 - e^{-D\Delta t_{43}}}{D\Delta t_{43}}\right]$$

$$M_3 \triangleq \int_{t_3}^{t_4} (t + \Delta t_{32}) F_3(t)\,dt \tag{5}$$

$$= \frac{F_2(t_3)}{D^2}\left[D\Delta t_{31} + 2 - \frac{(D\Delta t_{41} + 2)(1 - e^{-D\Delta t_{43}})}{D\Delta t_{43}}\right]$$

where $\Delta t_{21} = t_2 - t_1$, $\Delta t_{31} = t_3 - t_1$, $\Delta t_{41} = t_4 - t_1$ etc.

Thus, the mean time for which the impulsive thrusting is applied is given as

$$\bar{t} = \frac{I_1 + I_2 + I_3}{M_1 + M_2 + M_3} \tag{6}$$

The magnitude of change of velocity at $\bar{t}$ is given as

$$\Delta V = \frac{I_1 + I_2 + I_3}{M_s} \tag{7}$$

where M_s = Mass of the entire spacecraft.

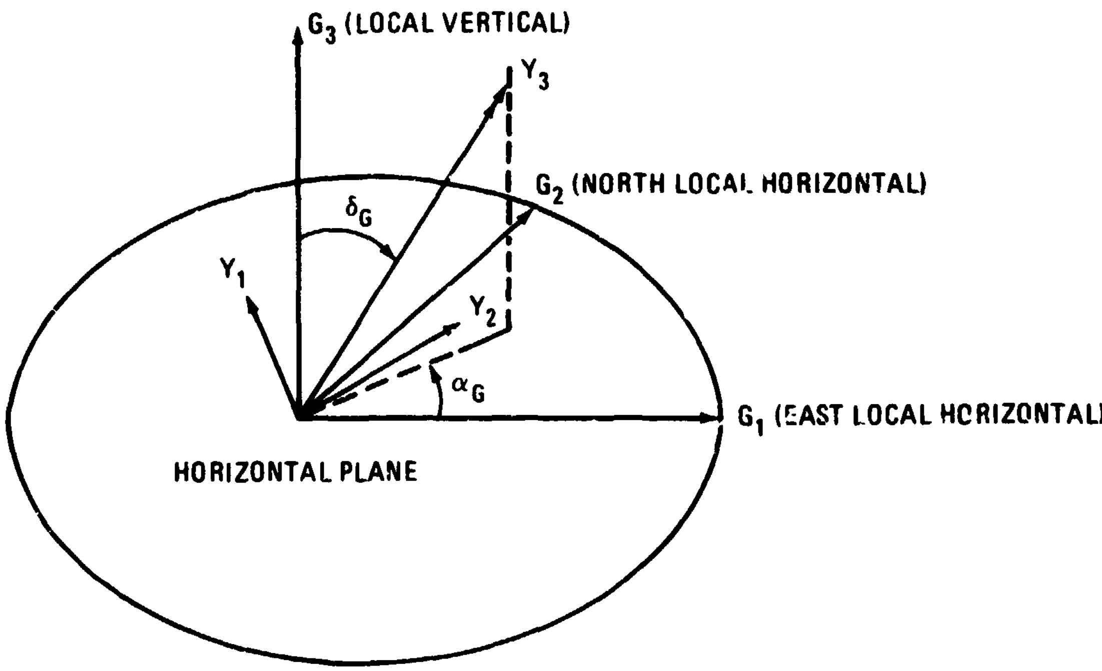


Figure 19. Transformation Between Local Geographical Frame G and Body Frame Y

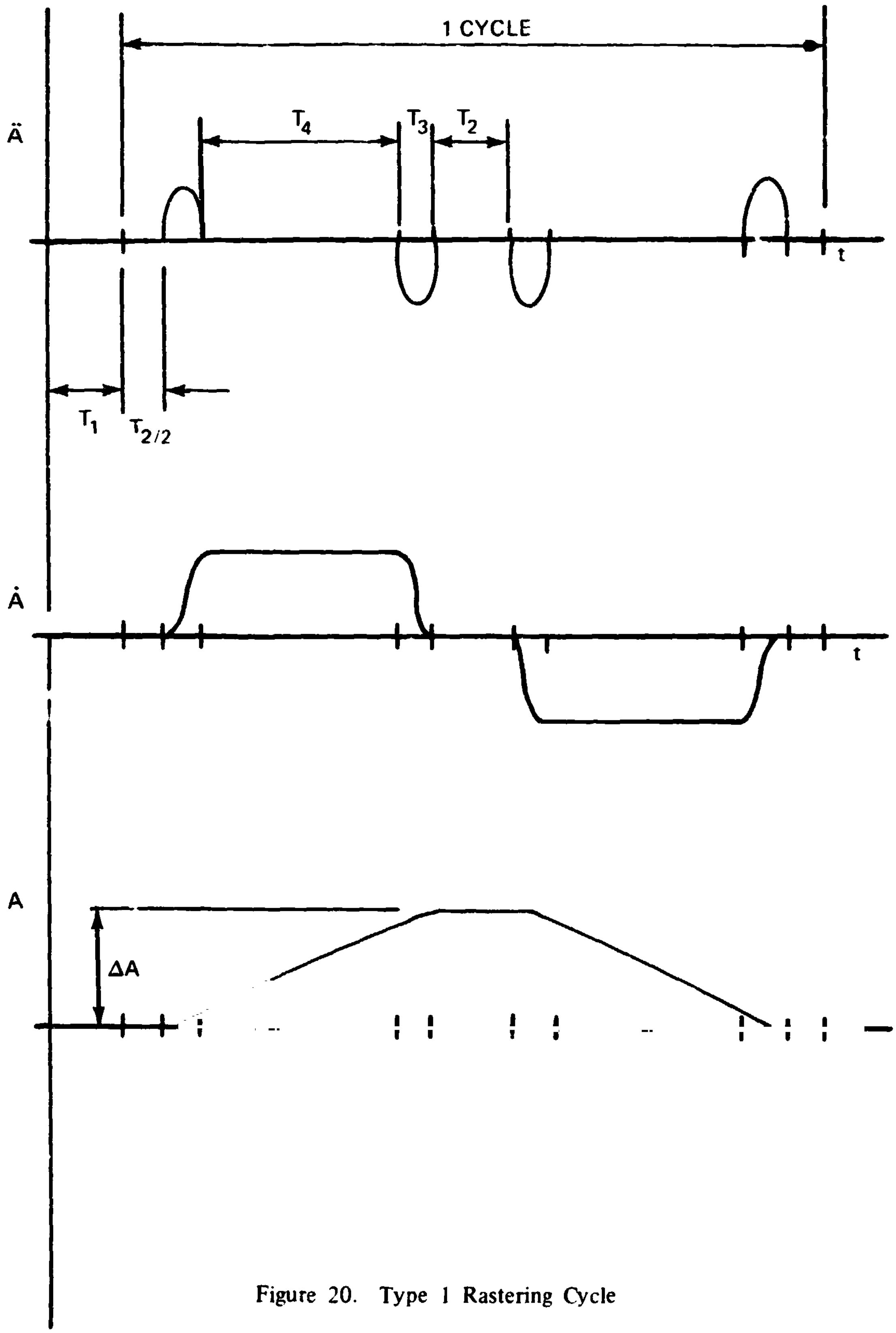


Figure 20. Type 1 Rastering Cycle

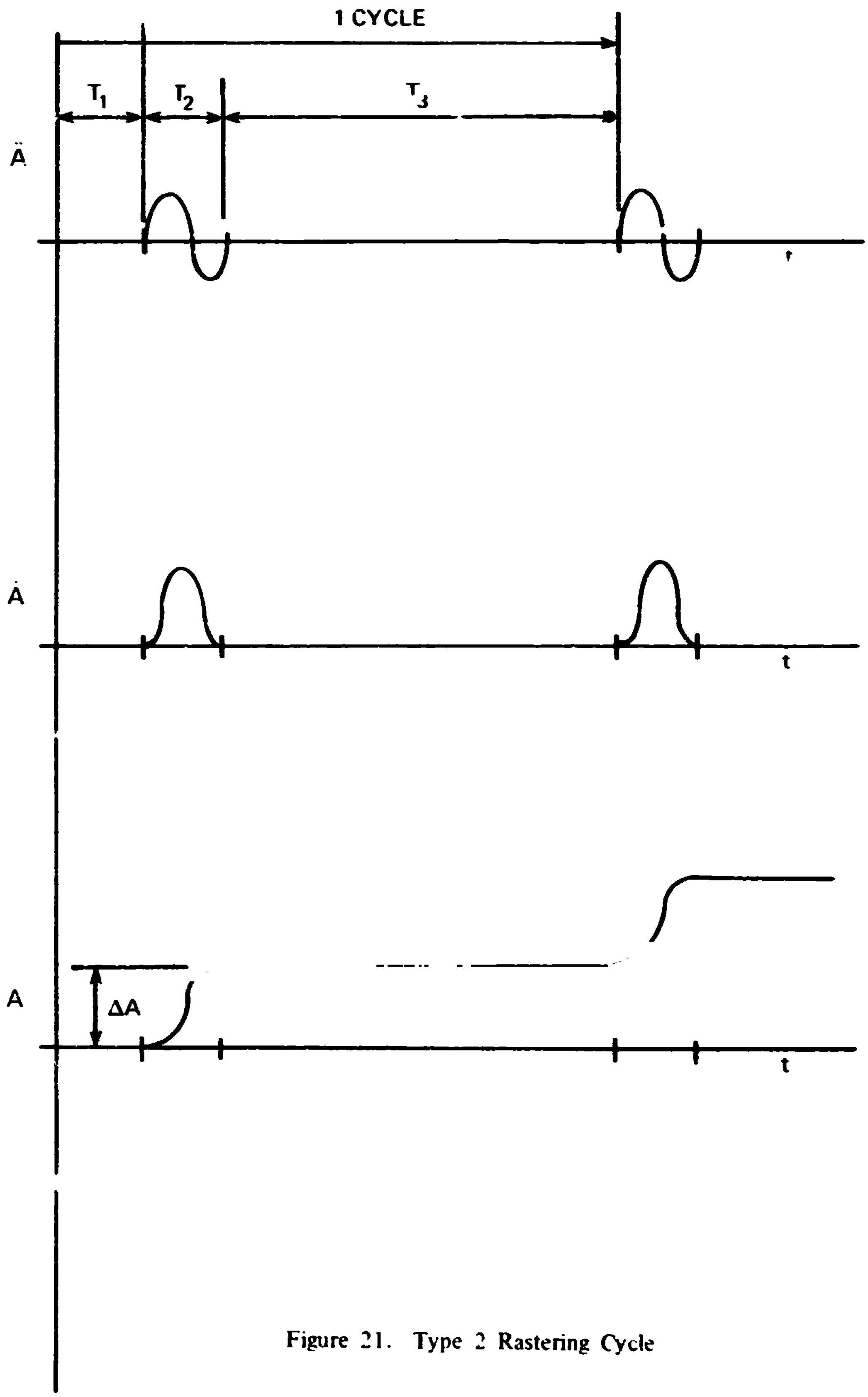


Figure 21. Type 2 Rastering Cycle

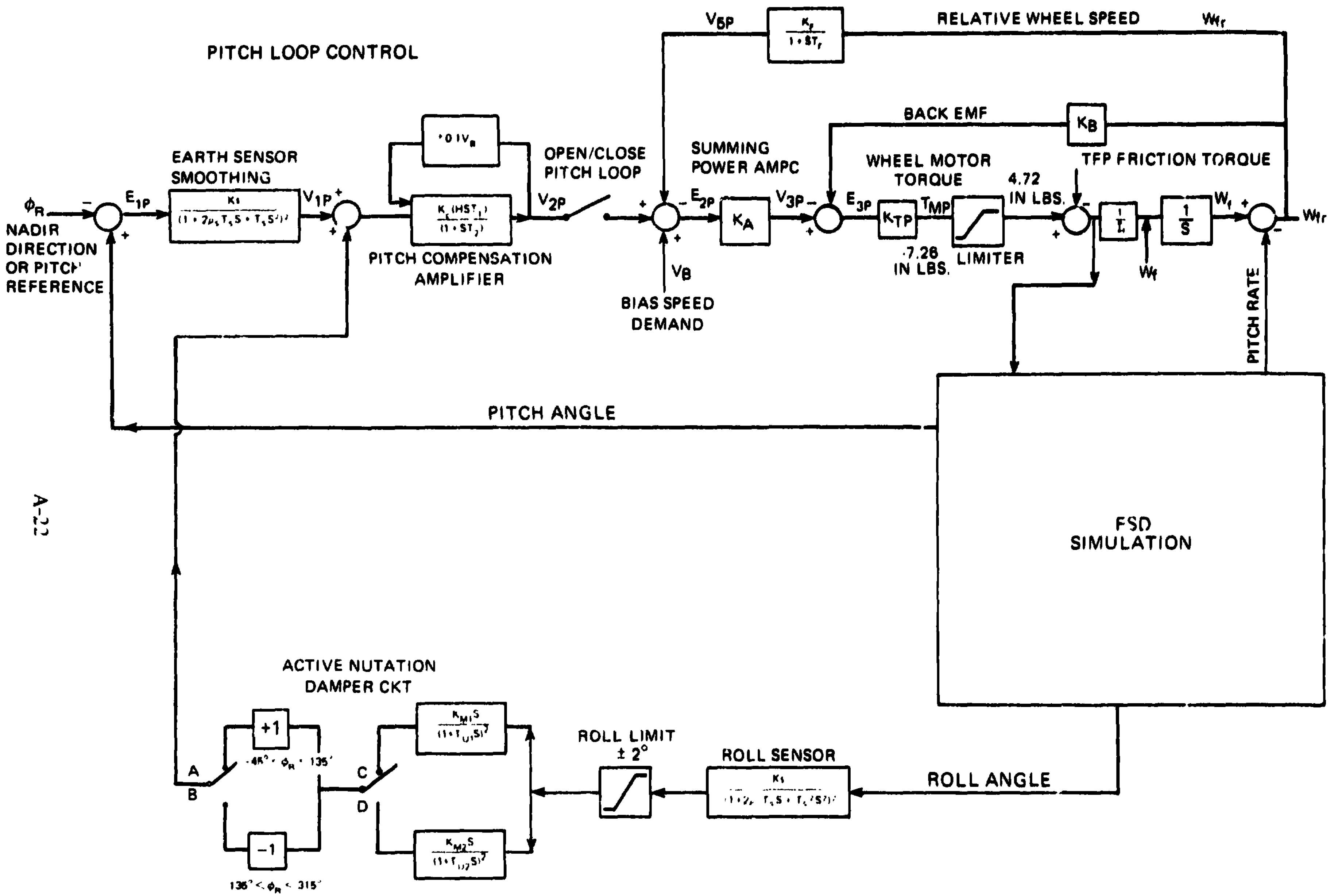


Figure 22. Dynamic Explorer-B Pitch and Active Nutation Damper Block Diagram

MATHEMATICAL FORMULATION FOR DUAL SPIN CONTROL SYSTEM SIMULATION

A block diagram of the system to be simulated is given in Figure 22. This block diagram is represented as a set of first order ordinary differential equations, which are integrated in parallel with the equations of motion for the rest of the spacecraft, using the same time step and integration algorithm. (The subroutine ADMIMP.)

For the most part, the control components are linear dynamic systems. For such components, the stated transfer functions have been converted to state variable equations using standard techniques. This transformation, however, is not always unique. Hence, it is necessary to state the exact form utilized in each case.

In the equations following, the subscripts 1, 2 etc. are used primarily for convenience. However, the ordering of variables is the same as in program code. Hence a fourth order model with state variables $x_1 \ldots x_4$ may appear in program code as $x_6 \ldots x_9$. The actual subscripts used in program code are given in the section on program inputs. Also, in this section, the symbols u and y denote (respectively) the input to and output from the given transfer function. In the system simulation, the blocks are coupled together.

Pitch or roll sensor (2nd order model)

The transfer function

$$\frac{K_s}{(1+sT_s)^2}$$

is represented as

$$\frac{d}{dt}\begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix} = \begin{bmatrix} -\frac{1}{T_s} & \frac{K_s}{T_s} \\ 0 & -\frac{1}{T_s} \end{bmatrix}\begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix} + \begin{Bmatrix} 0 \\ \frac{1}{T_s} \end{Bmatrix} u$$

$$y = x_1$$

Pitch or roll sensor (4th order model)

The transfer function

$$\frac{K_s}{(1+2\zeta_s T_s s + T_s^2 s^2)^2}$$

is represented as

$$\frac{d}{dt}\begin{Bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{Bmatrix} = \begin{bmatrix} 0 & \frac{1}{T_S} & 0 & 0 \\ -\frac{1}{T_S} & -2\frac{\zeta_S}{T_S} & \frac{K_S}{T_S} & 0 \\ 0 & 0 & 0 & \frac{1}{T_S} \\ 0 & 0 & -\frac{1}{T_S} & -2\frac{\zeta_S}{T_S} \end{bmatrix} \begin{Bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{Bmatrix} + \begin{Bmatrix} 0 \\ 0 \\ 0 \\ \frac{1}{T_S} \end{Bmatrix} u$$

$$y = x_1$$

Nutation Damper Phase Shift Circuit

The transfer function

$$\frac{K_M S}{(1 + S T_M)^2}$$

is represented as

$$\frac{d}{dt}\begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix} = \begin{bmatrix} -\frac{1}{T_M} & \frac{1}{T_M} \\ 0 & -\frac{1}{T_M} \end{bmatrix} \begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix} + \begin{Bmatrix} \frac{K_M}{T_M^2} \\ -\frac{K_M}{T_M^2} \end{Bmatrix}, \quad y = -x_1$$

(the minus sign includes the sign inversion corresponding to path A in Figure 22)

The inversion of sign at various roll angles and the switch between primary and secondary damper may be simulated by changing the input parameters.

Tachometer

The transfer function

$$\frac{K_F}{1 + S T_F}$$

is represented as

$$\frac{d}{dt} x_1 = -\frac{1}{T_F} x_1 + \frac{K_F}{T_F} u$$

$$y = x_1$$

For the reference control system, the tachometer is significantly faster than the other dynamic elements. This causes the tachometer equation to dominate the time step control in numerical integration, while having little effect on system performance. Replacing the above transfer function with the static operator $y = K_F U$ permits a significant reduction in program execution time. This alternative model is optionally available in the modified program.

Pitch Compensation Amplifier

In unsaturated operation, the transfer function

$$\frac{K_c(1 + sT_1)}{(1 + sT_2)}$$

is represented as

$$\frac{d}{dt} X_1 = -\frac{1}{T_2} Y + \frac{K_c}{T_2} U$$

$$Y = X_1 + K_c \frac{T_1}{T_2} U$$

Saturation occurs if

$$|Y| > V_{LIM}$$

If this occurs, Y is replaced by V_{lim} sign (Y).

Y_1, Y_2, Y_3	BODY FRAME
Z_{10}, Z_{20}, Z_{30}	GIMBLE MOTION FRAME
$Z_{1AZ}, Z_{2AZ}, Z_{3AZ}$	AZIMUTH GIMBLE FRAME
$Z_{1EL}, Z_{2EL}, Z_{3EL}$	ELEVATION GIMBLE FRAME

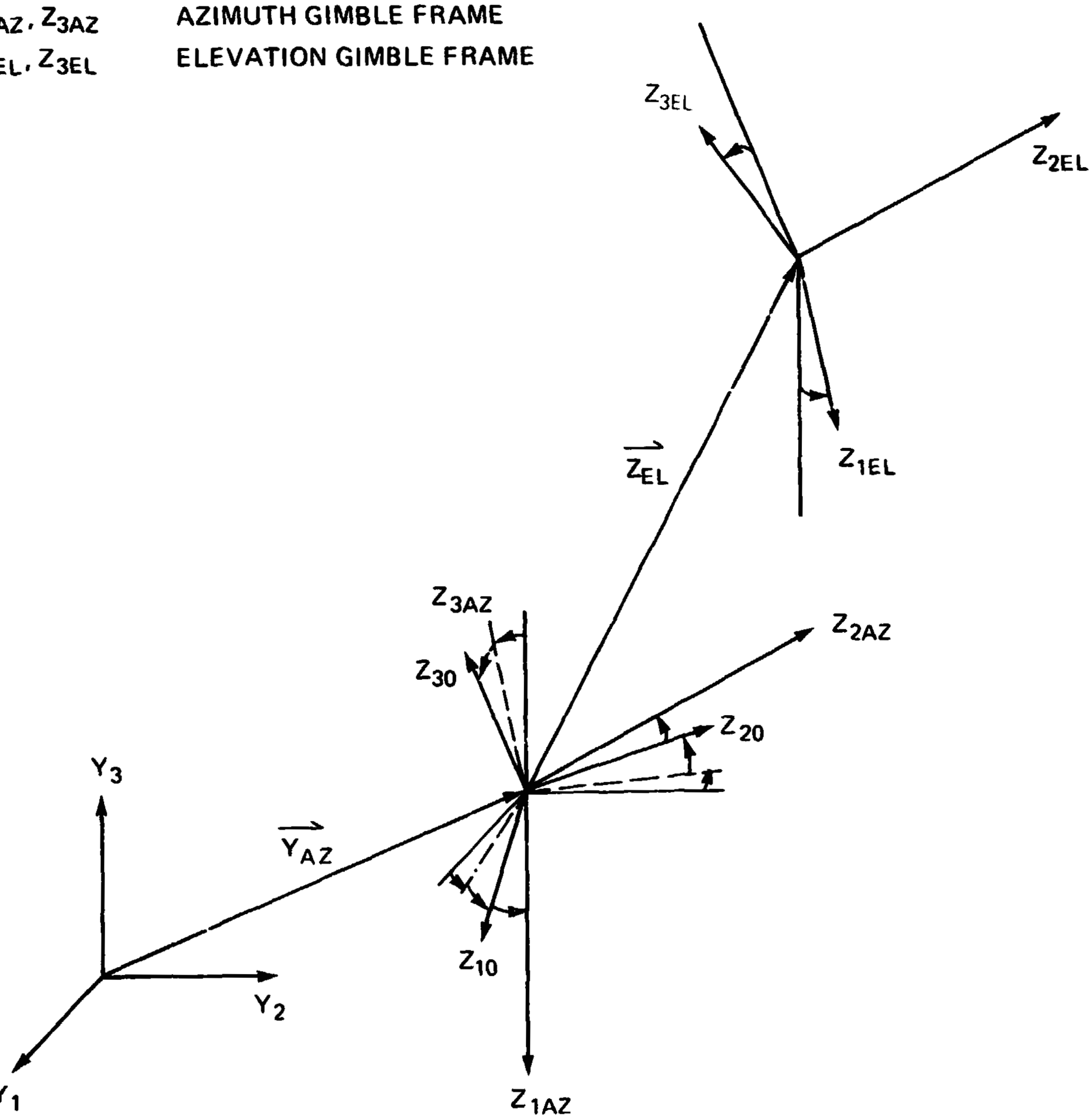


FIGURE 23. Gimble Simulation Reference Frames

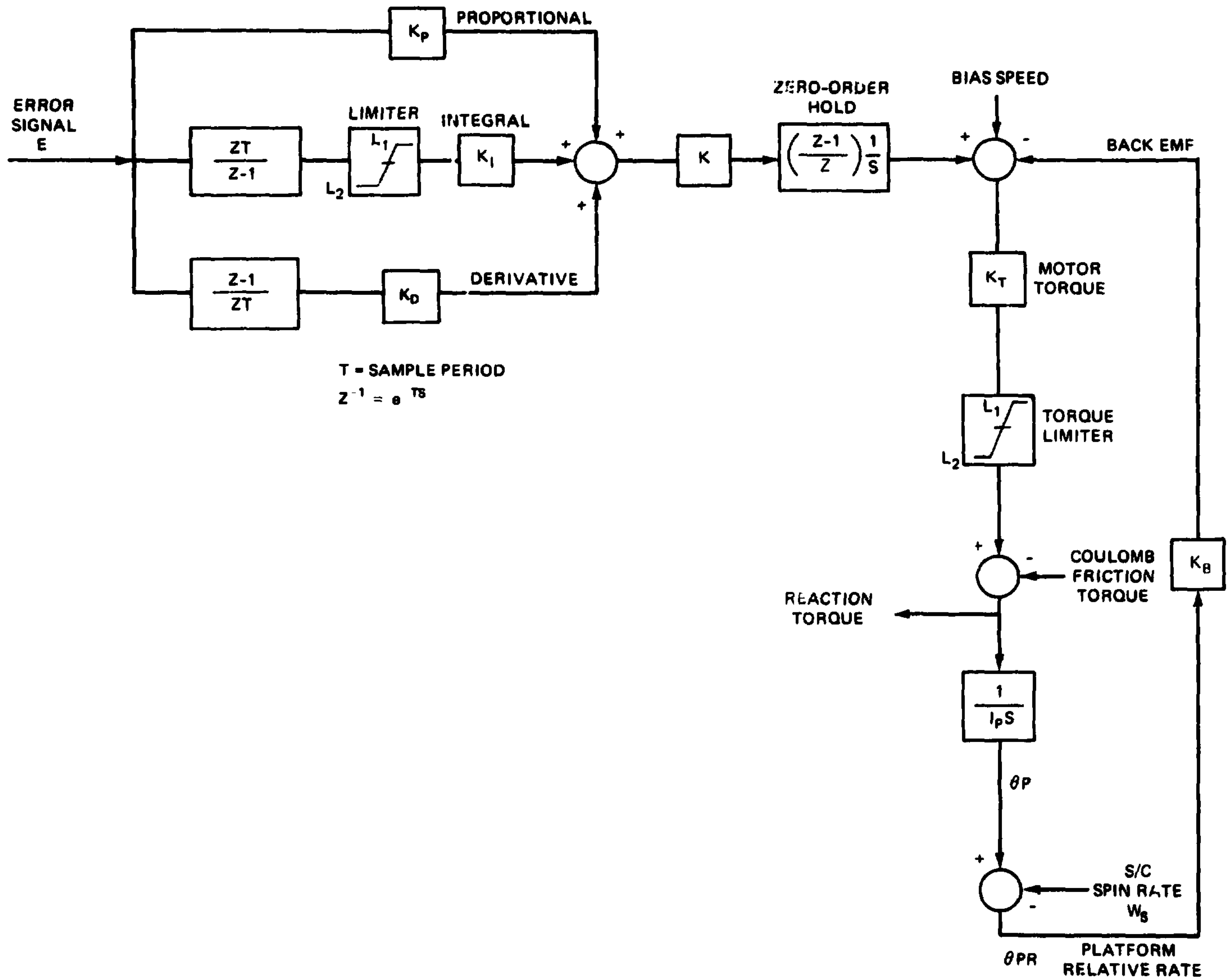


FIGURE 24. Generic Azimuth and Elevation PID Digital Controller for Magnetic Field Tracing Control System

APPENDIX B

EXAMPLES OF RAE, IMP-I AND DE-B SPACECRAFT INPUT

RAE SPACECRAFT INPUT

```
INPUT CARDS READ
DATA*H*********** DYNAMICS STUDY FOR RAE-B MAIN X-BOOM DEPLOYMENT ************        *DATA
DATA*H************************** DIPOLES ARE IN ********************************       *DATA
DATA* AEARTH 1738.5700  WMO 88.CC0  FLAT 4829.3600  ZMU 4.902778D+03                    *DATA
DATA* J2 0.000  J3 0.000  J4 0.CC0  J22 C.C00  ZJ20 0.000                              *DATA
DATA* TVER 6.804D+06  ECLPTC 1.5350+00                                                 *DATA
DATA* ITAPE 0  IORB 0                                                                  *DATA
DATA*H******** INCLINATICN = 64.0 DEG.  ECCENTRICITY = 0.005                          *DATA
DATA* XSAT 2838.570  0.0  0.0                                                          *DATA
DATA* XSATDT 0.0  -0.576120  -1.181222                                                 *DATA
DATA* CD 0.0  AREA 10 7036  WMASS 14.1925  ICENS 0                                     *DATA
DATA* YEAR 1973.0  ZMONTH 4.0  DAY 17.0                                                *DATA
DATA* IDATE 730417                                                                     *DATA
DATA* TIME 0.0                                                                         *DATA
DATA* TSTOP 948.0                                                                      *DATA
DATA* FREQ 30.0                                                                        *DATA
DATA* IPLOT 2                                                                          *DATA
DATA* INOPT 2                                                                          *DATA
DATA* IDAMP 0                                                                          *DATA
DATA* IHAMLT 1                                                                         *DATA
DATA* IGRAV 1                                                                          *DATA
DATA* DELTAT 0.001                                                                     *DATA
DATA* BDYMI  17.155 0.285 0.0 0.285 18.178 0.0 0.0 0.0 21.953                          *DATA
DATA* ZMS 14.1925                                                                      *DATA
DATA* SCO 10.0036                                                                      *DATA
DATA* NELMTS 6                                                                         *DATA
DATA* NDAMPR 2                                                                         *DATA
DATA* ZLO 1.C  1.0  1.0  1.0  1.C  1.0  1.C  1.0                                       *DATA
DATA* ZL1 0.0  0.0  0.50  C.50  C.53  C.50  C.0  0.0                                   *DATA
DATA* ZLA  0.C 0.0 0.0 0.0 0.0 C.0 0.0 0.0                                             *DATA
DATA* ZBZ(1.1)2  1.384 -1.384 1.C97 -1.097 1.097 -1.097 0.0 0.0                        *DATA
DATA* ZBZ(2.1)2  0.371 -C.371 0.C 0.0 C.0 C.0 0.0 0.0                                  *DATA
DATA* ZBZ(3.1)2  -0.227 -0.227 C.493 0.493 -0.383 -0.383 0.0 0.0                       *DATA
DATA* ALFAEK 0.0 0.0 0.0 0.0 0.0 0.0 0.0 C.0                                           *DATA
DATA* BETAEK C.0 0.0 -60.C -120.C 60.0 120.0 0.0 0.0                                   *DATA
DATA* GAMAEK 15.0 -165.0 0.0 0.0 C.0 0.0 C.0 180.0                                     *DATA
DATA* VIZM(1.1)2  0.0                                                                  *DATA
DATA* VIZM(2.1)2  C.0                                                                  *DATA
DATA* VIZM(3.1)2  -1.846                                                               *DATA
DATA* MODES(1-2) 0                                                                     *DATA
DATA* MODES(3-6) 1                                                                     *DATA
DATA* MODES(7-8) 0                                                                     *DATA
DATA* EMODLS(1-8) 1.1E7                                                                *DATA
DATA* RTUBE(1-2) 0.2625                                                                *DATA
DATA* RTUBE(3-6) 0.290                                                                 *DATA
DATA* RTUBE(7-8) 0.290                                                                 *DATA
DATA* HTUBE(1-8) 0.0022                                                                *DATA
DATA* THERMC(1-6) 8.85E-6                                                              *DATA
DATA* TIPMS(1-2) 0.0                                                                   *DATA
DATA* TIPMS(3-6) 0.00513                                                               *DATA
DATA* TIPMS(7-8) 0.0                                                                   *DATA
DATA* SAO(1-8)  4.830-2                                                                *DATA
DATA* A(3.1)1  0.000  C.00C  0.0C0  0.00C                                              *DATA
DATA* ADOT(3.1)1  C.000  0.000  C.000  0.CC0                                           *DATA
DATA* B(3.1)1  0.000  0.000  C.CC0  0.000                                              *DATA
DATA* BDOT(3.1)1  C.000  0.000  C.000  0.CCC                                           *DATA
DATA* DIN(7.1)1  0.000  0.000                                                          *DATA
DATA* DINDOT(7.1)1  0.00C  C.00C                                                       *DATA
DATA* DOUT(7.1)1  0.000  0.000                                                         *DATA
DATA* DOUTDT(7.1)1  0.000  C.000                                                       *DATA
DATA* STMK(1-8) 0.0                                                                    *DATA
DATA* RHOK(1-2) 4.5652E-4                                                              *DATA
DATA* RHOK(3-6) 4.3478E-4                                                              *DATA
DATA* RHOK(7-8) 4.5963E-4                                                              *DATA
DATA* POO 0.0                                                                          *DATA
DATA* CDAMP(1.1-6) 0.0                                                                 *DATA
DATA* DTOO  0.0                                                                        *DATA
DATA* AERO 0.0                                                                         *DATA
DATA* BETLD 0.0                                                                        *DATA
DATA* GAMLD 65.0                                                                       *DATA
DATA* PHILD 0.0                                                                        *DATA
DATA* DPHILD 0.0                                                                       *DATA
DATA* PHIS 35.0                                                                        *DATA
DATA* ZK1D 1.036E-02                                                                   *DATA
DATA* ZK2D 2.0                                                                         *DATA
DATA* DECAY 20.0                                                                       *DATA
DATA* ZMDO 0.98E-03                                                                    *DATA
DATA* ZMDBO 0.0                                                                        *DATA
DATA* DPRMI(1.1)2 0.1  0.0  0.0                                                        *DATA
DATA* DPRMI(2.1)2 0.0  0.1  0.0                                                        *DATA
DATA* DPRMI(3.1)2 0.0  0.0  0.1                                                        *DATA
DATA* ALFAE 0.0                                                                        *DATA
DATA* BETAE 30.0                                                                       *DATA
DATA* GAMAE 196.0                                                                      *DATA
DATA* OMBC(1) 0.0  OMBC(2) -0.02666                                                    *DATA
DATA* OMBC(3) 1.5                                                                      *DATA
DATA* NLAST 0  NDPLY 1  DOPLY 0                                                        *DATA
DATA*1                                                                                 *DATA
```

IMP-I SPACECRAFT INPUT

```
INFLT CARCS READ
DATA* XSAT 0.06444  251.30  12373.0                                    *DATA
CATA* XSAIDT C.30017SE2  -5.6714  0.13384                              *DATA
DATA* CC 2.0  AREA 26.6  VMASS 15.5658  IDENS C                        *DATA
DATA* YEAR 1975.0  ZMCNTH 3.C  CAY 21.0391                             *DATA
DATA* IORR 0                                                           *DATA
CATA* ITAPE 0                                                          *DATA
DATA* TSTCPO 396CC.0                                                   *DATA
DATA* ICATE 75C321                                                     *DATA
CATA* TIME 32838.0                                                     *DATA
CATA* ISTOP 20C.                                                       *DATA
DATA* FREQ 1.0                                                         *DATA
CATA* IPLCT 2                                                          *DATA
DATA* INOPT 1                                                          *DATA
CATA* IHAMLT 0                                                         *DATA
CATA* IGRAV 0                                                          *DATA
DATA* MCDES(1-6) 1                                                     *DATA
DATA* MCPLY 1                                                          *DATA
CATA* CELTAT 0.01                                                      *DATA
DATA* FACTOR C.5                                                       *DATA
DATA* BCYMI 90.0 0.0 0.C 0.C 90.C C.C 0.0 0.0 117.0                   *DATA
DATA* SCC 26.5995                                                      *DATA
DATA* ZMS 19.5658                                                      *DATA
CATA* NELMTS 6                                                         *DATA
DATA* ZLO 200. 200. 20C. 200. 1C. 1C.                                  *DATA
DATA* ZL1 0. 0. 0. C. C.1 0.1                                          *DATA
DATA* ZEZ(1.1)2 1.8C547 -1.24310 -1.80947 1.24310 C.0 0.0             *DATA
CATA* ZEZ(2.1)2 1.2431C 1.8C547 -1.24310 -1.8C547 C.C C.0             *DATA
DATA* ZEZ(3.1)2 -0.22CCE -0.22CCE -C.22008 -0.22008 9.6 -9.6          *DATA
DATA* ALFAEK(1-6) 0.0                                                  *DATA
CATA* BETAEK C. C. 0. 0. -90. 9C.                                      *CATA
DATA* GAMAEK 34.485 124.489 214.485 304.485 0.C 0.0                   *CATA
CATA* EMODLS(1-4) 1.5E7                                                *DATA
CATA* EMCDLS(5-6) 3.CE7                                                *CATA
DATA* RTUBE(1-4) 0.25                                                  *DATA
DATA* RTUBE(5-6) C.56                                                  *DATA
DATA* HTUBE(1-4) 2.0E-3                                                *DATA
DATA* HTUBE(5-6) 4.0E-3                                                *DATA
DATA* THERMC(1-6) 8.E5E-6                                              *DATA
CATA* TIEMS(1-6) 0.0                                                   *CATA
DATA* SAC(1-6) 0.0416                                                  *DATA
CATA* STMK(1-4) 0.                                                     *DATA
DATA* RHCK(1-4) 4.34652E-4                                             *DATA
DATA* RHCK(5-6) 3.4E-3                                                 *DATA
DATA* PCO 1.85E-7                                                      *DATA
CATA* CTCC 0.0                                                         *DATA
DATA* CCAMP(1.1)2 0.001 0.0C1 0.C01 C.001 C.7 0.7                     *DATA
CATA* CCAMP(2.1)2 0.0C1 0.001 C.C01 C.001 C.7 0.7                     *CATA
CATA* CCAMP(3.1)2 C.001 C.0C1 0.CC1 C.001 C.7 C.7                     *DATA
CATA* AERO 0.0                                                         *DATA
DATA* PSI1 0.0  THET1 -90.0  PHI1 9C.0                                 *DATA
DATA* CMEG 0.0 0.C 9C.                                                 *DATA
DATA* ETTA 90.0  ZETTA 90.0                                            *DATA
DATA* ISPIN3 C                                                         *DATA
CATA* ICAME 0                                                          *CATA
DATA* IVISCS 0                                                         *DATA
CATA* IATIDE 0                                                         *DATA
CATA* IWHEEL 0                                                         *DATA
CATA* IMGNTS 0                                                         *DATA
DATA* CPMAG 0.0 0.0 50.C                                               *DATA
CATA* MAGFLD 4                                                         *DATA
DATA* MLAST 0                                                          *DATA
DATA*1                                                                 *DATA
```

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DE-B SPACECRAFT & CONTROL SYSTEM INPUT

```
INPUT CARDS READ
DATA*H  DE-B SPACECRAFT & CONTROL SYSTEM                                          *DATA
DATA* ICRD 0  ITAPE 0                                                             *DATA
DATA* IPREF 1                                                                     *DATA
DATA* IPCALC  1                                                                   *DATA
DATA* IKPLR 1                                                                     *DATA
DATA* AS 7038.962 E 0.0499 EI 89.585 W 175.458 BW 160.799 F 270.0                 *DATA
DATA* AS 7116.  E 0.065  EI 90.0  W 0.0  BW 0.0  F 0.0                            *DATA
DATA* IDATE  810817                                                               *DATA
DATA* IFLCT 1                                                                     *DATA
DATA* TIME 0.0 TSTOP  20.0  FREQ  2.0                                             *DATA
DATA* DELTAT 0.01                                                                 *DATA
DATA* KPLCTS(1-5)  1                                                              *DATA
DATA* KPLCTS(11)  1 0 1 0 0 0 1 0 1 0 0 0 1 0 1 0 0 0 1 0 1 0 0 0 1 0 1 0 0 0     *DATA
DATA* KPLCTS(35)  1 0 1 0 0 0 1 0 1 0 0 0                                         *DATA
DATA* KPLCTS(41)  1 0 1 0 0 0                                                     *DATA
DATA* IGRAV 1                                                                     *DATA
DATA* MODES 1  1  1  1  0  0                                                      *DATA
DATA* MODES 1  1  1  1  1  1  0                                                   *DATA
DATA* MODES 0  0  0  0  0  0                                                      *DATA
DATA* DCYMI  68.75 0.0 0.0 0.0 63.75 0.0 0.0 0.0 66.58                            *DATA
DATA* SCC 26.0                                                                    *DATA
DATA* ZMS  14.0                                                                   *DATA
DATA* NELMTS 7                                                                    *DATA
DATA* ZLO   36.0   36.0   36.0   36.0    0.1    0.1   20.0  1.47                  *DATA
DATA* ZLA  0.0  0.0  0.0  0.0  0.0  0.0                                           *DATA
DATA* ZEZ(1,1)2  1.414 -1.414 -1.414  1.414  -1.6  -1.6  -2.0                     *DATA
DATA* ZEZ(2,1)2  0.1  0.1  0.1  0.1  2.0  -2.0  0.0                               *DATA
DATA* ZEZ(3,1)2 -1.414 -1.414  1.414  1.414  0.0  0.0  0.54                       *DATA
DATA* ALFAEK(1-7) 0.0                                                             *DATA
DATA* BETAEK  45.0  135.0  225.0  -45.0  0.0  0.0  180.0                          *DATA
DATA* GAMAEK  0.0  0.0  0.0  0.0  90.0 -90.0  -5.5                                *DATA
DATA* EMODLS(1-6)  1.156D+07                                                      *DATA
DATA* EMODLS(1-6)  1.412D+07                                                      *DATA
DATA* EMODLS(7)  1.340D+07                                                        *DATA
DATA* RTUBE(1-6) 0.562                                                            *DATA
DATA* RTUBE(7)  4.5                                                               *DATA
DATA* HTUBE(1-6) 0.0033                                                           *DATA
DATA* HTUBE(7)  0.062                                                             *DATA
DATA* THERMC(1-6) 8.85D-06                                                        *DATA
DATA* TIEMS(1-6)  3.420D-04                                                       *DATA
DATA* TIEMS(7)  0.262                                                             *DATA
DATA* SAC(1-7) 0.094                                                              *DATA
DATA* STMK(1-6) 0.0                                                               *DATA
DATA* STMK(7)  0.44                                                               *DATA
DATA* RHCK(1-6) 0.0021                                                            *DATA
DATA* RHCK(7)  0.0074                                                             *DATA
DATA* FCC   0.0                                                                   *DATA
DATA* FCC 1.89D-07                                                                *DATA
DATA* AEFC 0.0                                                                    *DATA
DATA* AEFC  2.2                                                                   *DATA
DATA* IDAMP 0  IVISCS 1  IATTDE 0  IWHEEL 0  INGHTS 0                             *DATA
DATA* IDAMP 0  IVISCS 1  IATTDE 0  IWHEEL 1  INGHTS 0                             *DATA
DATA* IDAMP 0  IVISCS 0  IATTDE 0  IWHEEL 1  INGHTS 0                             *DATA
DATA* SKOA(5,1)1   0.0  0.0                                                       *DATA
DATA* CDAMP(1,1)2  0.005   0.005   0.005   0.005   0.005   0.005                  *DATA
DATA* IBENDW  1                                                                   *DATA
DATA* IBENDW  0                                                                   *DATA
DATA* A(1,1)1   0.0   0.0   0.0   0.0   0.0   0.0                                 *DATA
DATA* ZETTAD  0.0                                                                 *DATA
DATA* ETTAD  0.0                                                                  *DATA
DATA* ETTAD  90.0                                                                 *DATA
DATA* DENSTY  56.2                                                                *DATA
DATA* FACTEE  0.465                                                               *DATA
DATA* RADRNG  16.62                                                               *DATA
DATA* VISCTY  2.0                                                                 *DATA
DATA* XMOMIN(3)  0.0                                                              *DATA
DATA* XMOMIN(1)  0.0                                                              *DATA
DATA* DTCC   1.0                                                                  *DATA
DATA*  DREC  0.0  0.0  0.0                                                        *DATA
DATA* INCFT 2 ALFAE 0.0 BETAE -60.0 GAMAE 0.0                                     *DATA
DATA* INCFT 2 ALFAE 0.0 BETAE   0.0 GAMAE 0.0                                     *DATA
DATA* INDFT 2 ALFAE 0.0   BETAE 180.0  GAMAE 180.0                                *DATA
DATA*$ INTEGRATOR MESSAGES                                                        *DATA
DATA*  IWHEEL 1 XMOMIN(2) .5305 VMOM(2) 4500. DVMOM(2) 0.0                        *DATA
DATA*$ KNTRL(1) 0--NOTHING 1--2ND ORDER SENSORS 2--4TH ORDER                      *DATA
DATA*$ KNTRL(2) 0--PITCH ONLY 1--[illegible]                                      *DATA
DATA*$ KNTRL(3) 0--NONE 1--TACHOMETER 1ST ORDER DYNAMICS                          *DATA
DATA*  KNTRL 2 0 1                                                                *DATA
DATA* KNTRL(9)  135791                                                            *DATA
DATA*  KNTRL 1 0 1                                                                *DATA
DATA*  KNTRL 1 0 0                                                                *DATA
DATA* KNTRL(10)  3                                                                *DATA
```

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DE-B SPACECRAFT & CONTROL SYSTEM INPUT (CONTINUED)

```
DATA* KNTRL(10)  0                                                        *DATA
DATA* CPARM(31)   0.06  0.02  0.0                                         *DATA
DATA* CNIC(1)  0.0                                                        *DATA
DATA*H    FOURTH ORDER SENSOR WITH TACHOMETER                             *DATA
DATA*  CPARM 1.6 60. 2500. .1 1. 110. 34.5 .08033 .16 .0605 0. .669 17.1 3.7  *DATA
DATA*  CPARM(15) 6.65 0.0416  0.0 0.4 0.0 0.0 1.0                        *DATA
DATA*  SVCS(1)  -1.047  0.0 -1.047 0.0                                    *DATA
DATA*  SVCS(1-20) 0.0 (11) -0.67  (15) 78.5                               *DATA
DATA*  SVCS(1-20) 0.0 (11)  0.0   (15) 78.5                               *DATA
DATA* CPARM(22) 0.0345                                                    *DATA
DATA* CPARM(23)  0.353  -0.605                                            *DATA
DATA* KFLCTS(216) 1 0 0 0 . 1                                             *DATA
DATA* KFLCTS(226) 1 0 0 0 1                                               *DATA
DATA* KFLCTS(216-220)  0                                                  *DATA
DATA* CPARM(21) -1.0                                                      *DATA
DATA* CPARM(21)  1.0                                                      *DATA
DATA* SVCS(11) 1.5                                                        *DATA
DATA* SVCS(11) 0.0                                                        *DATA
DATA* SVCS(13) 6.69                                                       *DATA
DATA* HUECCA(1)  0.0  0.0  0.0                                            *DATA
DATA* HUECCA(1) 30.0  26.4  30.0                                          *DATA
DATA* HUECP(1)  0.0  -0.9  0.0                                            *DATA
DATA* HUECP(1)  0.0  -1.2  0.3                                            *DATA
DATA* ICRAG 0                                                             *DATA
DATA* ICRAG 1                                                             *DATA
DATA* ICRAG 2                                                             *DATA
DATA* TC(1) 1039.778  1037.046  1051.66                                   *DATA
DATA* KF(1,1)2  20 20 20 20 20 20 20 20                                   *DATA
DATA* CPARM(41)  -3.14                                                    *DATA
DATA* KFLCTS(210)   0  0  0                                               *DATA
DATA* INGNTS   0                                                          *DATA
DATA* CRWAC(2)    145000.0                                                *DATA
DATA* CCILS(1)    145000.0                                                *DATA
DATA* KFLCTS(208)  1                                                      *DATA
DATA* KFLCTS(216)  1                                                      *DATA
DATA* SVCS(1)  3.14                                                       *DATA
DATA* LCFU  40                                                            *DATA
DATA* NLAST  0                                                            *DATA
DATA*1                                                                    *DATA

VERSION APR 1981
```