INTERPLANETARY GUIDANCE SYSTEM REQUIREMENTS STUDY

VOLUME II

COMPUTER PROGRAM DESCRIPTION

PART 4

PERFORMANCE ASSESSMENT FOR ALL INERTIAL GUIDANCE SYSTEMS

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TABLE OF CONTENTS

TABLE OF CONTENTS

1.0 INTRODUCTION AND SUMMARY

AC Electronics has defined and programmed a digital computer program, (Program 117.1), which evaluates the performance of an inertial guidance system. The computer program provides the capability of conducting a performance analysis of an all-inertial guidance system along the reference trajectory.

The basic output of the program consists of the covariance matrix of the velocity and position errors due to independent error sources of the inertial guidance system. The reference trajectory and the state transition matrix are recorded on magnetic tape for use in repetitive runs of Block III for trade-off studies of inertial guidance systems.

The inertial guidance system error model is capable of simulating an inertial measurement unit in a gimballed, strapped-down, or carousel mode of operation. A total of three gyro error models and two accelerometer error models are currently programmed with provision for additional instrument error models included in the program structure. There are a total of 51 (maximum) independent error sources defined in the inertial guidance system model.

The program is designed to interface with free-flight programs for interplanetary guidance and navigation. The covariance matrix of velocity and position errors at the beginning of a boost trajectory is combined with the covariance matrix of position and velocity errors due to the inertial guidance system to furnish as output the total covariance of position and velocity errors at the end of the boost trajectory. Hence, a complete study capability is provided for trajectories composed of both boost and free-flight phases.

The description of the program given in the following paragraphs will furnish the engineer and programmer with the necessary information required to use and modify the program. A mathematical model and the detailed equations of the program are given in Paragraphs 2.0 and 3.0. A user's guide (Paragraph 4.0) and the input forms (Appendix B) give details of the actual operation of the program for the engineer. The programmer will find a program listing and details of computer operation in Appendix A.

2.0 MATHEMATICAL MODEL FOR INERTIAL SYSTEM ERRORS

The error models representing inertial guidance systems are discussed briefly in the following paragraphs. Detailed digital computer programs incorporating these models exist and are described in Paragraph 3.0 and Paragraph 4.0 of this document.

The error models are a mathematical representation of the factors that cause errors in the guidance system outputs as a function of the mission profile being simulated. The output errors are in the form of errors in the measured velocity and position and the error model must thus provide a valid method of calculating the errors in position and velocity for each mission profile for the guidance system being simulated. The results are handled statistically in terms of the covariance of the output errors as a function of the covariance of the guidance system errors in terms of the system error parameters as defined by the system model.

Inertial guidance systems employ two types of basic inertial sensors, namely, gyroscopes and accelerometers. Gyroscopes are sensitive to, and hence measure, angular motion relative to an inertial or non-accelerating coordinate frame. Accelerometers respond to or measure the difference between total acceleration and acceleration due to gravitational forces, again with respect to an inertial coordinate frame. The system determines its position and velocity by calculating and "remembering" all changes from its initial position and velocity using the angular and acceleration measurements from the system sensors. The gravitational accelerations are calculated as functions of position using the known gravitational fields of the appropriate celestial bodies.

The inertial guidance system accuracy is thus dependent upon its accurate determination of position and velocity changes, or of acceleration. The system error model, therefore, calculates the (vector) error in measured acceleration due to each of the error parameters incorporated in the model. The resultant position and velocity errors are obtained by integration of these acceleration errors along the mission trajectory profile.

The specific models by which system errors are related to acceleration errors and by which the acceleration errors are integrated into position and velocity errors are discussed in the following subparagraphs.

2.1 INERTIAL MEASUREMENT UNIT CONFIGURATION

Inertial instruments are subject to errors from a variety of causes, some of which are mission- and trajectory-independent and others that are functions of the mission-dependent environment in acceleration and angular rate, the inputs to which the instruments are sensitive. Thus, the errors will depend not only on the instrument error parameters but also on the trajectory profile. Furthermore, the errors will also be dependent upon the angular orientation of each instrument; that is, upon how it is oriented with respect to the impressed accelerations and angular rates.

The basic coordinate system in which all errors are calculated in the AC simulations is a planet-centered, inertially fixed (PCI), coordinate frame with reference axes denoted by X, Y, and Z. The trajectory data for the mission being simulated is input with respect to this coordinate frame. The pertinent trajectory data for inertial system error analyses consists of the components of acceleration, $a_X(t)$, $a_Y(t)$, and $a_Z(t)$, and the components of angular rate, $\omega_X(t)$, $\omega_Y(t)$, and $\omega_Z(t)$, and/or the vehicle orientation relative to the PCI coordinates in terms of Euler angles, $\alpha_1(t)$, $\alpha_2(t)$, and $\alpha_3(t)$. The acceleration error from each error source and the resultant position and velocity errors are calculated in PCI coordinates.

In the current AC Electronics inertial system error model, it is possible to evaluate three different types of inertial measurement unit. These are the gimballed, strapped-down, and carousel. From the point of view of inertial component errors, these are different in the manner in which the instrument orientation varies. These are discussed briefly as follows.

2.1.1 Gimballed

In a conventional gimballed inertial measurement unit, the instrument package or platform remains fixed with respect to inertial space. In the error model, the instrument package orientation is thus fixed in PCI coordinates. In the notation used in Paragraphs 3.0 and 4.0, the orientation of the platform with respect to X, Y, Z coordinates is specified by means of an orthonormal 3 x 3 matrix $[A_4]$, the orientation of each accelerometer with respect to the platform by an orthonormal matrix $[J_i]$, and the orientation of each gyro with respect to the platform by a matrix $[M_i]$. Thus, for a gimballed system the orientation of all instruments with respect to the trajectory-dependent parameters (acceleration) is specified by the 3 x 3 matrices $[J_i]$, $[M_i]$, and $[A_4]$.

2.1.2 Strapped-Down

In a strapped-down inertial system, the instrument package remains fixed with respect to the vehicle, and thus its orientation changes with angular motion of the vehicle. The initial orientation of the instrument package is specified in the same manner as for the gimballed system, but the orientation changes as a function of time are given by a trajectory-dependent attitude time history in terms of Euler angles $\alpha_1(t)$, $\alpha_2(t)$, and $\alpha_3(t)$.

2.1.3 Carousel

A carousel inertial measurement unit is essentially a gimballed unit in which the instrument package or platform is rotated with respect to an inertial reference according to a prespecified time program, usually a constant angular rate. Inertial systems of this type are employed in some missions, usually missions involving extended time periods, because the effect of many component errors, particularly bias errors, is reduced by virtue of the "geometric averaging" effect. This system is analyzed very much like the strapped-down system except that the time-varying platform attitude is specified by a non-trajectory-dependent, time-varying program of Euler angles $\eta_1(t)$, $\eta_2(t)$, and $\eta_3(t)$.

2.2 INSTRUMENT ERROR MODELS

The determination of measured acceleration error attributable to the various error parameters for each instrument type is discussed below: gyro errors in Paragraph 2.2.1 and accelerometer errors in Paragraph 2.2.2. In addition to instrument errors, inertial systems are subject to errors due to initial misalignment. These are incorporated in the model in a manner similar to the treatment of gyro errors.

2.2.1 Gyro Error Models

Gyroscopes serve to measure orientation or direction relative to an inertial frame, and thus all gyro errors will result in attitude errors that cause the system to measure the impressed acceleration along the wrong direction. For each gyro error model, the instantaneous misalignment $\varphi(t)$ due to each error parameter is calculated along the mission profile. The vector

$$\underline{\varphi(t)} = \begin{bmatrix} \varphi_X(t) \\ \varphi_Y(t) \\ \varphi_Z(t) \end{bmatrix}$$

is computed in PCI coordinates and is based on a small angle representation, each element representing the misalignment about one of the reference axes, X, Y, Z.

The resultant measured acceleration error, $\Delta\underline{a}$, is then given by

$$\Delta\underline{a} = \underline{a(t)} \times \underline{\varphi(t)}$$

where $\underline{a}$ (t) is the acceleration vector in PCI coordinates from the mission trajectory profile.

There are currently error models for three single-degree-of-freedom gyros included in AC Electronics simulation program. It should be pointed out that there are a number of types of gyros, some of unique or exotic design, for which none of the included error models is exactly correct. However, the models described are representative of the majority of gyroscope types likely to be employed in space missions.

2.2.1.1 Single-Axis Rate Gyro

A single-axis gyro has a mutually orthogonal axis system consisting of spin, (S), output (O), and input (I), axes. The ideal single-axis rate gyro exactly measures rotation about its input axis. The error terms that are accounted for in the model include a random or non-trajectory-dependent drift, acceleration-dependent drifts caused by mass unbalances within the gyro, second-order acceleration-dependent drifts caused by anisoelasticity of the gyro structure, errors due to the gyro's sensing axes being mechanically misaligned, and first- and second-order scale factor errors. In particular, there are error parameters denoted in the notation of Paragraphs 3.0 and 4.0, as $K_1 \ldots, K_8$ that result in drift rates about the gyro's input axis proportional to the magnitude of the parameters and to 1, a_I, a_S, $a_I a_S$, ω_O, ω_S, ω_I, and ω_I^2, where a represents acceleration, ω represents angular rate, and subscripts I, S and O indicate gyro input, spin, and output axes, respectively.

In addition, the error model incorporates a gyro parameter denoted by K_0 that represents the "stiffness" of the constraint torque about the gyro output axes. The gyro axes tilt about the output axis an amount proportional to ω_I, and K_0 is the proportionality factor. This effect is incorporated in the model.

The drift rate about the input axis due to each of the error parameters $K_1, \ldots, K_8$ is resolved into PCI coordinates and integrated to obtain the appropriate misalignment vector, $\underline{\eta}$.

2.2.1.2 Single-Axis Torque-Rebalanced Gyro

This is a single-axis rate gyro with a torque feedback servo loop. It is represented by an error model of the same type as the single-axis rate gyro above except that because of the feedback loop the "stiffness" of the constraint torque is essentially infinite, that is, equivalent to having the parameter $K_0 = 0$.

2.2.1.3 Single-Axis Platform

This instrument consists of a single-degree-of-freedom gyro mounted in a single-axis stabilized platform; that is, the gyro is stabilized or isolated from rotation about its input axis. The output of this instrument is the measured angular displacement about its input axis between the outer instrument case and the stabilized gyro element. This angle, θ, is equal to the integral of the angular rate about the instrument's input axis; that is,

$$\theta = \int_{t_o}^{t} \omega_I \, dt$$

Instruments of this type are used primarily in strapped-down system applications.

Since this instrument is based upon a single-axis gyro, its error model will include some of the same type of error parameters as the previous gyros. In this instrument the gyro element's spin (S) and output (O) axes do not remain fixed with respect to the instrument package or platform, but, in fact, rotate about its input axis by the angle θ. Thus, the error model for this instrument must resolve the acceleration and angular rate inputs into the platform fixed initial gyro axis system and then through the angle θ into the instantaneous gyro instrument axis system to determine the drift rate attributable to the various error parameters.

The error parameters incorporated in this model are the same as the parameters, $K_1, \ldots, K_8$ in the previous models, except for the omission of K_7 and K_8. These were the first- and second-order scale factor errors and this type of gyro is not subject to these errors because the gyro element is isolated from the angular rate about its input axis. That is, the ω_I experienced by the gyro element is zero.

2.2.2 Accelerometer Error Models

There are mathematical error models for two different types of accelerometers included in AC Electronics simulation programs. One of these is the pendulous integrating gyro accelerometer, or PIGA, and the other model represents a torque feedback, pendulum type of accelerometer. The following paragraphs discuss the error parameters for each of these error models and the resultant acceleration error for each of them.

2.2.2.1 PIGA-Type Accelerometer (See Reference in Paragraph 5.0)

This accelerometer is actually a single-axis stabilized platform, like the third type of gyro instrument discussed above, in which the gyro instrument has a deliberate and calibrated unbalance along its spin axis. That is, it is made to have a large "drift" sensitivity to acceleration along its input axis. Therefore, the rate at which it drifts, or rotates about its input axis relative to an inertial frame,is a measure of the acceleration along its input axis. The measurement output of this instrument is the rotation of the "stabilized" gyro element relative to the instrument case. If the instrument is being used in a configuration other than a gimballed IMU, then the angular output must be corrected for the rotation of the accelerometer case in inertial space.

The error sources for this accelerometer are to a certain extent related to the error sources in the single-axis platform gyro instrument. The residual torques that result in a random or bias drift cause a bias or random acceleration error. In the notation employed in Paragraphs 3.0 and 4.0, this error parameter is called K_9. Errors in the "drift" sensitivity to acceleration, that is, in the ratio of the gyro angular momentum to the mass unbalance, result in first-order scale factor errors, denoted by K_{10}. There are second-order scale factor, or nonlinearity, errors and errors due to misalignment of the accelerometer input axis. In addition, there will be an acceleration measurement error proportional to the angular rate about the input axis due to errors in measuring and/or compensating for this rotation.

In summary, there are in the model error parameters that result in acceleration measurement errors proportional to 1, a_I, a_I^2, $a_C + K_1' \omega_C$, $a_N + K_1' \omega N$, and ω_I, where subscripts I, C, and N represent the instrument's input axis, cross axis, and normal axis, respectively. The cross and normal axes are mutually orthogonal reference axes that are normal to the input axis. The terms $a_C + K_1' \omega_C$ and $a_N + K_1' \omega_N$ represent errors due to input axis misalignments about the N and C axes, respectively. The $K_1' \omega$ terms reflect the fact that the instrument actually measures angular rotation.

2.2.2.2 Torque Restrained Pendulum Accelerometer

The torque restrained pendulum accelerometer is a simple pendulum with a mass unbalance and a feedback torque device to balance the torque due to acceleration. The instrument has an imput axis, I, an output or normal axis, N, and a "cross" axis, C. There is an unbalanced mass along the cross axis such that an acceleration along the input axis causes a torque about the output axis. A torque feedback loop employing an electrical torque mechanism serves to null the rotation about the output axis by providing a counter torque. The output of the instrument is an electrical signal proportional to the feedback torque.

For this type of instrument, the error model provides error parameters that represent bias acceleration errors and acceleration errors proportional to a_I and a_I^2, these errors being due primarily to lack of linearity in the torque electronics. There is provision for an error parameter yielding an acceleration error proportional to $a_I a_C$. This is due to the fact that the torque feedback loop does not have infininte stiffness and therefore the input axis will tilt about the normal axis an amount proportional to a_I. The model also includes the effect of input axis misalignments about the C and N axes, these resulting in acceleration measurement errors proportional to a_N and a_C, respectively.

2.3 VELOCITY AND POSITION ERROR DETERMINATION

The preceding paragraphs have described how the mathematical error model calculates the acceleration error $\Delta \underline{a}(t)$ in PCI coordinates due to each error parameter as a function of time along the reference trajectory. To describe how these errors result in position and velocity errors, the equations of motion for the mission trajectory must be considered.

Let $\underline{X}(t)$ represent the six-element position-velocity vector along the trajectory in PCI coordinates; that is,

$$\underline{X}(t) = \begin{bmatrix} X(t) \\ Y(t) \\ Z(t) \\ \dot{X}(t) \\ \dot{Y}(t) \\ \dot{Z}(t) \end{bmatrix}$$

Then the differential equations of motion may be written as

$$\dot{\underline{X}} = \underline{g}(\underline{X}) + \underline{a}$$

where

$$\underline{g}(\underline{X}) = \begin{bmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \\ g_X(X, Y, Z) \\ g_Y(X, Y, Z) \\ g_Z(X, Y, Z) \end{bmatrix}$$

$$\underline{a} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ a_X \\ a_Y \\ a_Z \end{bmatrix}$$

and g_X , g_Y, and g_Z are the PCI components of the gravitational acceleration.

Then, if there is an error, $\Delta\underline{a}$ in the measured acceleration, the guidance system will calculate an erroneous position and velocity, $\underline{X} + \Delta\underline{X}$, satisfying the equation

$$\dot{\underline{X}} + \Delta\dot{\underline{X}} + \underline{g}(\underline{X} + \Delta\underline{X}) + \underline{a} + \Delta\underline{a},$$

where

$$\Delta\underline{a} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \Delta a_X \\ \Delta a_Y \\ \Delta a_Z \end{bmatrix}$$

Thus, the position and velocity error $\Delta\underline{X}$ satisfies the equation

$$\Delta\dot{\underline{X}} = \underline{g}(\underline{X} + \Delta\underline{X}) - \underline{g}(\underline{X}) + \Delta\underline{a}$$

Making first-order approximations, this becomes

$$\Delta\dot{\underline{X}} = \left[\frac{\partial\,\underline{g}(\underline{X})}{\partial\underline{X}}\right] \Delta\underline{X} + \Delta\underline{a}$$

where

$$\left[\frac{\partial\,\underline{g}(\underline{X})}{\partial\underline{X}}\right] = \left[\begin{array}{c|c} O\ (3 \times 3) & I\ (3 \times 3) \\ \hline \dfrac{\partial g_{X,Y,Z}}{\partial X,Y,Z} & O\ (3 \times 3) \end{array}\right] (6x6)$$

The matrix $[\,\partial\underline{g}/\partial\underline{X}]$ may be evaluated along the nominal mission trajectory so that the differential error equations are linear with time-varying coefficients.

The error, $\Delta\underline{X}(t)$, resulting from a particular acceleration error time history, $\Delta\underline{a}$, may then be obtained in terms of the integral expression

$$\Delta\underline{X}(t) = \Phi_1(t,\, t_0) \int_{t_0}^{t} \Phi_1^{-1}(\tau,\, t_0)\, \Delta\underline{a}\,(\tau)\, d\tau$$

in which t_0 is the trajectory start time and $\Phi_1(t,\, t_0)$ is the state transition matrix given by

$$\dot{\Phi}_1(t, t_0) = \left[\frac{\partial\underline{g}}{\partial\underline{X}}\right] \Phi_1(t,\, t_0)\ , \quad \Phi_1(t_0, t_0) = I \text{ (identity)}.$$

The simulation model provides an option whereby the state transition matrix Φ_1 may be approximated by

$$\Phi_1^{-1}(t, t_0) = \left[\begin{array}{c|c} I\ (3 \times 3) & (t_0 - t)\ I\ (3 \times 3) \\ \hline O\ (3 \times 3) & I\ (3 \times 3) \end{array}\right].$$

This is quite accurate for relatively short mission times, or for situations where the gravitational field is very small.

For each error parameter simulated, there is a resultant acceleration error vector,

$$\Delta \underline{a}\ (t) = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \Delta a_X \\ \Delta a_Y \\ \Delta a_Z \end{bmatrix}$$

In the notation used in Paragraphs 3.0 and 4.0, the 6 x 51 matrix G (t) denotes the matrix of $\Delta \underline{a}$ error vectors, each column being the error associated with a unit value of a particular error parameter. It follows then that the covariance matrix of errors [P] resulting from all simulated error sources is given by

$$[P] = \Phi_2(t, t_0)\ [P_I]\ \Phi_2^T(t, t_0),$$

where [P_I] represents the covariance matrix of all of the error parameters being simulated and

$$\Phi_2(t, t_0) = \Phi_1(t, t_0) \int_{t_0}^{t} \Phi_1^{-1}(\tau, t_0)\ G(\tau)\ d\tau\ .$$

The simulation model also provides for the incorporation of initial position and velocity errors at the start of the mission, in which case the resultant error covariance matrix is given by

$$[P(t)] = \Phi_1(t, t_0)[P_0]\Phi_1^T(t, t_0) + \Phi_2(t, t_0)\ [P_I]\ \Phi_2^T\ (t, t_0),$$

where [P_0] is the covariance matrix of initial errors.

3.0 COMPUTER PROGRAM DESCRIPTION

3.1 INTRODUCTION

This document contains the definition of a digital computer program for the performance assessment of all-inertial guidance systems during boost as they occur in interplanetary missions. The definition consists of flow charts and corresponding equations in the details necessary to make the presentation self-contained and ready for coding. No attempt is made to discuss the physical meaning of the mathematical model in detail. However, necessary references for further studies are included.

Flow charts provide the basic framework around which the remainder of the discussion is constructed. These diagrams serve to indicate the logical flow connecting different functional blocks. They do not describe literally the operation within the computer program itself, because many of the programming details are of little interest to most engineers.

The flow charts have been arranged and drawn according to a hierarchical structure. The "highest" level, designated as Level I, depicts the overall structure of the program. Each block appearing in this chart is described by another flow chart. These charts are designated as Level II. This policy is repeated for each block in every level until no further logic remains to be described. In almost all cases, three levels of flow charts suffice to accomplish this objective. The final set of flow charts at the lowest level are supplemented by the detailed equations which are used in the program

3.1.1 Schema for Flow Chart Presentation

As has already been stated, the flow charts are arranged according to "levels." In the resulting hierarchy, the Level I flow chart provides the most general description since it depicts the overall program. Each functional block is further described by lower level flow charts. These charts indicate the logical flow within the block and describe the input and output requirements of the block. The equations used to obtain the desired outputs are presented as a supplement to the lowest level flow chart. The number of levels that are required depends upon the logical complexity of the functional block.

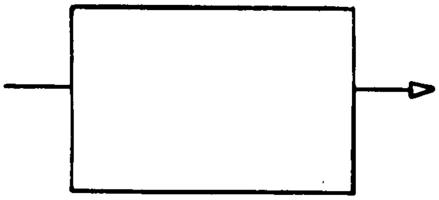
LEVEL I: This flow chart is designed to provide a very general description of the entire program. The titles assigned to the functional blocks are intended to be suggestive of the nature of the role to be performed within the block. Those functions that are to be performed in the basic computational cycle are designated by Roman numerals. Arabic symbols are used for functions that occur only once or play a passive role.

LEVEL II: The Level II flow charts provide the first concrete description of the program. Only the most important logical flow within each functional block is indicated on these diagrams. The quantities that are required for all logical and computational operations within this block are stated on this chart. These quantities are differentiated as being either INPUT (i. e., values provided initially by the engineer) or COMPUTED (i. e., values determined in other portions of the program). The quantities that are required in other parts of the program, either for printout or for computations, are also indicated on this flow chart. The functional blocks that appear on these diagrams are denoted by two symbols (e. g., II. 1 when discussing the "first" block in the Level II flow chart of functional block II) and a name. The names have been selected to provide some insight into the nature of the block.

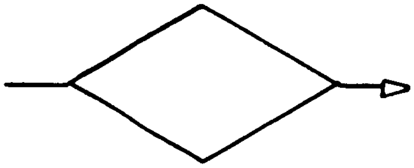
LEVEL III (and below): These diagrams provide additional details of the logical flow within the functional blocks depicted at Level II. In this program definition, Level III provide the description of the most intimate logical details in almost every case so no purpose was served by proceeding to lower levels. These flow diagrams are augmented by the equations programmed into the computer. The input and output requirements of these blocks are stated on the diagrams. All of these quantities are summarized on the Level II flow chart.

3.1.2 Definition of Flow Chart Symbols

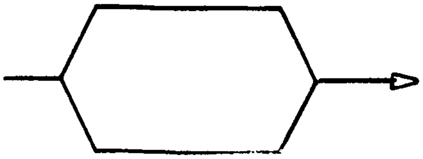
The following symbols represent the only ones that are used in the flow charts presented below.



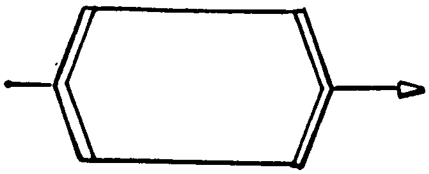
Set of operations that is to be described further by additional flow charts or by equations



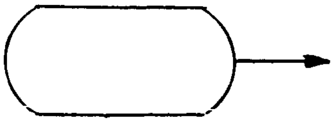
Logical Decision



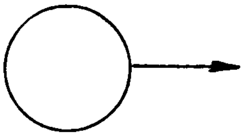
Operations that are predefined (i. e., in some other document)



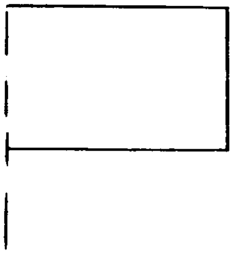
Operations are completely defined by the statements contained within the box



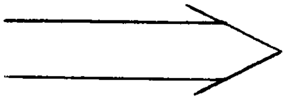
Connector used on Level II flow charts to indicate entry source and exit destimation



Connector used on Level III flow charts



Summary of all quantities required in computations of flow charts on which this symbol appears, or, alternatively, summary of all quantities computed in this flow chart which are required in other operations.



This broad arrow appears on Level I and Level II flow charts. It is used to indicate information flow from one block to another. The more important information is stated within the arrow. This symbol has been introduced to emphasize that many quantities are transmitted between the functional blocks in the higher level charts.

3.1.3 Definition of Mathematical Symbols

$a_{Ii}\,a_{Ci}\,a_{Ni}$	accelerations in i^{th} accelerometer coordinates	ft/sec^2
$a_{Ii}\,a_{Oi}\,a_{Si}$	accelerations in the i^{th} gyro coordinates	ft/sec^2
$a_X(t)\,a_Y(t)\,a_Z(t)$	PCI components of specific force to mass ratio	ft/sec^2
$[A_4]$ (3, 3)	matrix relating PCI coordinates to $P_{IO}\,Y_{AO}\,R_{OO}$ coordinates	
BUDG	number of budgets with the same IMU system and trajectory	
[C] (3, 3)	matrix relating PCI coordinates to IMU reference coordinates	
[C'] (3, 3)	matrix relating initial $P_{IO}Y_{AO}R_{OO}$ coordinates to reference IMU coordinates	
$[D_i]$ (3, 3)	matrix defining orientation of i^{th} gyro with respect to its initial orientation on the platform (used in rate gyro and single-axis platform gyro error models)	
(EP1i, EP2i, EP3i)	PCI direction cosines of the principal axis magnitude $\sqrt{LPi}$ (i = 1, 2, 3)	
(EV1i, EV2i, EV3i)	PCI direction cosines, of the principal axis magnitude, $\sqrt{LVi}$ (i = 1, 2, 3)	
Flag A	0 = gimbal system 1 = strapdown system 2 = Carousel	
Flag B	2 = two-degree-of-freedom gyros 1 = single-degree-of-freedom gyros	
Flag C	2 = (unspecified) 1 = (unspecified)	
Flag D	3 = single-degree-of-freedom platform gyros 2 = rate gyro 1 = torque rebalanced gyro	

Flag E	3 = PIGA 2 = proof mass accelerometer 1 = unspecified
Flag F	0 = state transition matrix, Φ_1^{-1} (t_o, t), set equal to that corresponding to boost trajectory in a constant gravitational field 1 = state transition matrix, Φ_1^{-1} (t_o, t) set equal to the Φ^{-1} (t_o, t) of the trajectory tape which corresponds to a boost trajectory in an inverse square gravitational field
Flag G	0 = print Φ_2 (t_f, t_o) 1 = do not print Φ_2 (t_f, t_o)
Flag 1	1 = print a data dump following each calculation of Block III-1 0 = do not print such a data dump
Flag 2	1 = print a data dump following each calculation of Block III-2 0 = do not print such a data dump
Flag 3	1 = print a data dump following each calculation of Block III-3 0 = do not print such a data dump
Flag 4	1 = print a data dump following each calculation of Block III-4 0 = do not print such a data dump
Flag 5	1 = print a data dump following each calculation of Block III-5 0 = do not print such a data dump
Flag 6	1 = print a data dump following each calculation of Block III-6 0 = do not print such a data dump
Flag 7	1 = print a data dump following each calculation of Block III-7 at $t = t_f$ 0 = do not print such a data dump

$[G]$ (6, 51)	matrix of acceleration errors due to independent unit error sources	ft/sec^2
$[G_{21}]$, $[G_{22}]$, $[G_{23}]$ (3, 8)	Submatrices of $[G]$ (6, 51) which represent the acceleration errors due to gyros No. 1, 2, 3, respectively	ft/sec^2
$[G_{24}]$, $[G_{25}]$, $[G_{26}]$ (3, 8)	Submatrices of $[G]$ (6, 51) which represent the acceleration errors due to accelerometers No. 1, 2, 3, respectively	ft/sec^2
$[G_{27}]$ (3, 3)	Submatrix of $[G]$ (6, 51) which represents the acceleration errors due to initial misalignments	ft/sec^2
(I, C, N)	reference accelerometer axes system refering to input, cross, and normal axes of accelerometer	
(I, O, S)	reference gyro coordinate system refering to input, output, and spin axes of gyro	
$[J_1][J_2][J_3]$ (3, 3)	matrices defining orientation of accelerometers No. 1, 2, 3 respectively, with respect to the IMU reference coordinates	
K_0	rate gyro parameter	sec
K'_1	PIGA error model parameter	ft/sec
K_1	conversion constant for gyro constant drift term	(rad/sec)/ [error budget 1σ unit]
K_2	conversion constant for gyro acceleration dependent drift term	(rad/sec)/ [(ft/sec^2)(error budget 1σ unit)]
K_3	conversion constant for gyro acceleration dependent drift term	(rad/sec)/ [(ft/sec^2)(error budget 1σ unit)]

K_4	conversion constant for gyro acceleration squared dependent drift term	(rad/sec)/ [(ft^2 /sec^4)(error budget 1σ unit)]
K_5	conversion constant for gyro input axes misalignment term	(rad/sec)/ [(rad/sec)(error budget 1σ unit)]
K_6	conversion constant for gyro input axis misalignment term	(rad/sec)/ [(rad/sec)(error budget 1σ unit)]
K_7	conversion constant for gyro rate scale factor term	(rad/sec)/ [(rad/sec)(error budget 1σ unit)]
K_8	conversion constant for gyro rate nonlinearity term	(rad/sec)/ [(rad^2/sec^2) (error budget 1σ unit)]
K_9	conversion constant for accelerometer bias term	(ft/sec^2)/[error budget 1σ unit]
K_{10}	conversion constant for accelerometer scale factor term	(ft/sec^2)/[(ft/sec^2) (error budget 1σ unit)]
K_{11}	conversion constant for accelerometer acceleration squared dependent term	(ft/sec^2)/ [(ft^2/sec^4)(error budget 1σ unit)]
K_{12}	conversion constant for accelerometer acceleration squared dependent term	(ft/sec^2)/ [(ft^2/sec^4)(error budget 1σ unit)]
K_{13}	conversion constant for acceleration input axis misalignment term	(ft/sec^2)/ [(ft/sec^2)(error budget 1σ unit)]
K_{14}	conversion constant for accelerometer input axis misalignment	(ft/sec^2)/ [(ft/sec^2)(error budget 1σ unit)]

K_{15}	conversion constant for accelerometer wheel speed error term	$(ft/sec^2)/$ $[(ft/sec^2)$(error budge 1σ unit)]
K_{16}	conversion constant for accelerometer angular rate dependent term	$(ft/sec^2)/$ [(rad/sec)(error budget 1σ unit)]
K_{17}	conversion constant for initial misalignment of instrument package	(rad)/[error budget 1σ unit]
K_{18}	conversion constant for initial misalignment of instrument package	(rad)/[error budget 1σ unit]
K_{19}	conversion constant for initial misalignment of instrument package	(rad)/[error budget 1σ unit]
LP1, LP2, LP3	eigenvalues of $[P_{11}]$ (3, 3). The square roots of these values are the principal axis magnitudes of position error ellipsoid	ft^2
LV1, LV2, LV3	eigenvalues of $[P_{22}]$ (3, 3). The square root of these values are the principal axis magnitudes of the velocity error ellipsoid	$(ft/sec)^2$
$[M_1], [M_2], [M_3](3,3)$	matrices defining orientation of gyros No. 1, 2, 3 respectively, with respect to IMU reference coordinates	
N	number of trajectory records to be skipped, every $(N+1)^{th}$ point is used as a trajectory data point	
[P] (6, 6)	covariance matrix of position and velocity error at $t = t_f$	
$[P_{11}], [P_{12}], [P_{21}],$ $[P_{22}]$:	(3, 3) submatrices of [P] (6, 6)	ft^2 (P_{11}) $ft^2/sec(P_{21}, P_{12})$ $(ft/sec)^2$ (P_{22})
(P_{IO}, Y_{AO}, R_{OO})	initial body axes; pitch, yaw, and roll unit vectors at $t = t_o$	
$[P_{INP}]$ (6, 6)	covariance matrix of position and velocity error at $t = t_f$ in a downrange, crossrange, and altitude coordinate system.	

$[P_o]$ (6,6)	initial covariance matrix of velocity and position uncertainties	
$P_{o(ij)}$	$(ij)^{th}$ element of P_o	(See P_{11}, P_{12}, P_{21}, P_{22})
PUNC	punch card option 1 = punch P matrix 2 = punch Φ_2 matrix	3 punch both
[Q] (6,51)	matrix of velocity and position errors, at time t due to independent unit error sources	
TAPE NO	number of prerecorded tape of trajectory	
TAPEP	tape write option 0 = don't punch cards 1 = do error analysis only 2 = print tape only 3 = print tape and do error analysis	
t	time	sec
t_f	computation end time	sec
t_o	Block III-6 state transistion matrix parameter	sec
[V] (3,3)	matrix defining orientation of initial misalignment coordinate system with respect to PCI coordinates	
(X, Y, Z)	reference PCI coordinate system	
$\alpha_1(t), \alpha_2(t), \alpha_3(t)$	inner, middle, and outer gimbal angles	radians
$\alpha_{11}, \alpha_{12}, \alpha_{13}$	Euler angles defining $[M_1]$ (3,3) matrix for orientation of gyro No. 1	radians
$\alpha_{21}, \alpha_{22}, \alpha_{23}$	Euler angles defining $[M_2]$ (3,3) matrix for orientation of gyro No. 2	radians
$\alpha_{31}, \alpha_{32}, \alpha_{33}$	Euler angles defining $[M_3]$ (3,3) matrix for orientation of gyro No. 3	radians
$\beta_{11}, \beta_{12}, \beta_{13}$	Euler angles defining a factor of [V] (3,3)	radians
$[Y_i]$ (1,8)	accelerometer error model with unity coefficients stated in matrix format	
$\Gamma_1, \Gamma_2, \Gamma_3$	Euler angle defining [C'] (3,3)	radians

Δt	input integration step size	seconds
$\eta_1(t), \eta_2(t), \eta_3(t)$	Euler angles defining orientation of IMU reference axes in Carousel mode: imputted as tabular data	
θ_1	angular displacement of the ith single-axis platform gyro about its input axis	radians
θ_{Oi}	angular displacement of the ith rate gyro about its output axis	radians
λ_1	first gyro constant drift $(1\sigma)^2$	$(\text{meru})^{2*}$
λ_2	first gyro unbalance along spin axis $(1\sigma)^2$	$(\text{meru}/g)^{2*}$
λ_3	first gyro unbalance along input axis $(1\sigma)^2$	$(\text{meru}/g)^{2*}$
λ_4	first gyro anisoelasticity $(1\sigma)^2$	$(\text{meru}/g^2)^{2*}$
λ_5	first gyro misalignment of gyro input axis in plane of the input and output axis $(1\sigma)^2$	$(\text{arc-sec})^{2*}$
λ_6	first gyro misalignment of gyro input axis in plane of the input and spin axis $(1\sigma)^2$	$(\text{arc-sec})^{2*}$
λ_7	first gyro scale factor uncertainty $(1\sigma)^2$	$(1 \times 10^{-6})^{2*}$
λ_8	first gyro nonlinearity $(1\sigma)^2$	$(1 \times 10^{-6})^{2*}$
$\lambda_9 \rightarrow \lambda_{16}$	(error budget values for second gyro)	
$\lambda_{17} \rightarrow \lambda_{24}$	(error budget values for third gyro)	
λ_{25}	first accelerometer bias $(1\sigma)^2$	$(1 \times 10^{-6} g)^{2*}$
λ_{26}	first accelerometer scale factor $(1\sigma)^2$	$(1 \times 10^{-6})^{2*}$
λ_{27}	first accelerometer nonlinearity $(1\sigma)^2$	$(1 \times 10^{-6}/g)^{2*}$
λ_{28}	first accelerometer cross axis nonlinearity $(1\sigma)^2$	$(1 \times 10^{-6}/g)^{2*}$
λ_{29}	first accelerometer sensitive axis misalignment in the plane of sensitive and normal axis $(1\sigma)^2$	$(\text{arc-sec})^{2*}$

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*Note: The units given are representative units, any appropriate units of the error sources may be employed, provided that the corresponding conversion constants $K_1 \rightarrow K_{19}$ are appropriately modified.

λ_{30}	first accelerometer sensitive axis misalignment in the plane of sensitive and cross axis $(1\sigma)^2$	$(\text{arc-sec})^{2}$*
λ_{31}	first accelerometer wheel speed change $(1\sigma)^2$	$(1 \times 10^{-6}\ \text{sec/rad})^{2}$*
λ_{32}	angular velocity uncertainty about the input axes of the first accelerometer $(1\sigma)^2$	$(1 \times 10^{-6}\ \text{sec/rad})^{2}$*
$\lambda_{33} \rightarrow \lambda_{40}$	(error budget values for second accelerometer)	
$\lambda_{41} \rightarrow \lambda_{48}$	(error budget values for third accelerometer)	
λ_{49}	initial misalignment of instrument package about first axis of misalignment coordinate system $(1\sigma)^2$	$(\text{arc-sec})^{2}$*
λ_{50}	initial misalignment of instrument package about second axis of misalignment coordinate system $(1\sigma)^2$	$(\text{arc-sec})^{2}$*
λ_{51}	initial misalignment of instrument package about third axis of misalignment coordinate system $(1\sigma)^2$	$(\text{arc-sec})^{2}$*
$[\varphi_i]$ (3,8)	matrix of drift angles about PCI axes due to each independent unit error source of the i^{th} gyro model (i = 1,2,3)	
$[\Phi_1^{-1}(t, t_o)]$	state transition matrix; linearily relating position and velocity perturbations at t to position and velocity perturbations at t_o	
$\Phi_{ij}^{-1}(t, t_o)$	the $(ij)^{th}$ component of $\Phi^{-1}(t, t_o)$	sec, 1/sec, or n. d. depending upon (ij)

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*Note: The units given are representative units, any appropriate units of the error sources may be employed, provided that the corresponding conversion constants $K_1 \rightarrow K_{19}$ are appropriately modified.

$[\Phi_2(t_f, t_o)]$ (6, 51)	matrix of velocity and position errors at $t = t_f$ due to unit independent error sources	
$\psi_{11}, \psi_{12}, \psi_{13}$	Euler angles defining $[J_1]$ (3, 3) matrix for orientation of accelerometer No. 1	radians
$\psi_{21}, \psi_{22}, \psi_{23}$	Euler angles defining $[J_2]$ (3, 3) matrix for orientation of accelerometer No. 2	radians
$\psi_{31}, \psi_{32}, \psi_{33}$	Euler angles defining $[J_3]$ (3, 3) matrix for orientation of accelerometer No. 3	radians
$\omega_1, \omega_2, \omega_3$	angular rates expressed in the IMU reference coordinate system	rad/sec
$\omega_1(t), \omega_2(t), \omega_3(t)$	angular rates of the IMU in a Carousel mode; imputted as tabular data	rad/sec
$\omega_{Ii}, \omega_{Ci}, \omega_{Ni}$	angular rates in the i^{th} accelerometer coordinates	rad/sec
$\omega_{Ii}, \omega_{Oi}, \omega_{Si}$	angular rates of missile in the i^{th} gyro coordinates	rad/sec
$\omega_{PI}(t), \omega_{YA}(t)\ \omega_{RO}(t)$	angular rate about the instantaneous pitch, yaw, and roll axes	rad/sec

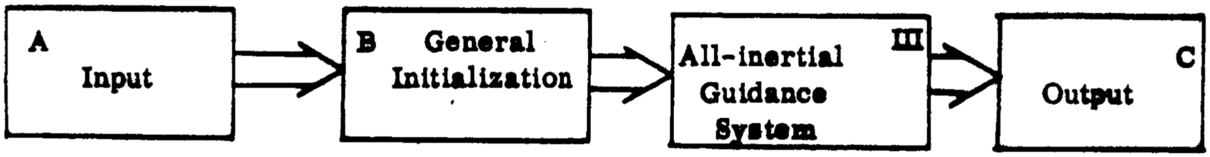
3.2 BASIC ORGANIZATION OF THE PROGRAM

The basic structure of the program is summarized in the flow chart below. It constitutes, according to preceding definitions, the Level I flow chart and consists of two different classes of blocks. Those which define the basic computational cycles of the program (Roman numerals), and those necessary to start the program in a prescribed way or define the required output (Arabic letters A, B, C).

Blocks A, B, and C are described in Section 3; Block III in Section 4.

The INPUT block represents a summary of the quantities that an engineer must input. No computations are contained within this block. In the GENERAL INITIALIZATION block, computations that must be performed once during a specific simulation run and/or logical decisions that must be made for proper operation within the basic computational cycle are accomplished. The OUTPUT block defines the quantities that are to be available for printout purposes (including storing on magnetic tape) and contains computations that are not required in the basic computational cycle.

The mathematical techniques applied in this program are based on linear perturbation theory.



Level I Flow Chart - Performance Assessment of All-inertial Guidance Systems for Boost

The guidance system employed is specified mathematically in Block III. This block computes the integrals which determine the errors in position and velocity generated by the errors in the all-inertial guidance system. These errors are statistically combined in the covariance matrix [P] which constitutes the major output of the program.

3.2.1 COORDINATE SYSTEMS

The basic coordinate system in Program 117.1 is the Planet Centered Inertial (PCI) coordinate system (X, Y, Z). The X and Y axes are in the Earth's equatorial plane and Z is along the direction of the Earth's positive rotation. When starting in Phase 1, the vehicles initial position is in the X-Z plane, specified by inputs of launch altitude, launch latitude, and planet radius. When starting in phases other than Phase 1, direct input of PCI coordinates is employed and the vehicle is initialized at an arbitrary point.

Another basic coordinate system in the program is the reference body axis coordinate system (P_I, Y_A, R_O). This Cartesian coordinate system is initially oriented by inputs of latitude, longitude and azimuth when starting in Phase 1. These coordinates rotate with respect to the PCI coordinates with the commanded body rates of the space booster vehicle. If starting in a phase other than 1, the initial orientation is specified by inputting three gimbal angles which define body axes orientation with respect to the initial triad computed in initialization of Phase 1.

The coordinate systems employed in Block III, All Inertial Guidance System, are referenced to the Planet Centered Inertial, (PCI), coordinate system. The rotational transformations relating one coordinate system to another is, in general, defined in terms of three Euler angle rotations. These Euler angle transformations have the following general format.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_3 & \sin\theta_3 \\ 0 & -\sin\theta_3 & \cos\theta_3 \end{bmatrix} \begin{bmatrix} \cos\theta_2 & 0 & -\sin\theta_2 \\ 0 & 1 & 0 \\ \sin\theta_2 & 0 & \cos\theta_2 \end{bmatrix} \begin{bmatrix} \cos\theta_1 & \sin\theta_1 & 0 \\ -\sin\theta_1 & \cos\theta_1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} U \\ V \\ W \end{bmatrix}$$

$$= [F(\theta_1, \theta_2, \theta_3)] \begin{bmatrix} U \\ V \\ W \end{bmatrix}$$

The positive sense of the angles θ_1, θ_2, and θ_3 is specified by the usual right-hand convention.

There are ten distinct Cartesian coordinate systems used in Block III. They are:

1.	PCI axes	The reference planet centered inertial coordinates
2.	P_{IO}, Y_{AO}, R_{OO} axes	The initial orientation of the space booster body axes as specified by Block OO

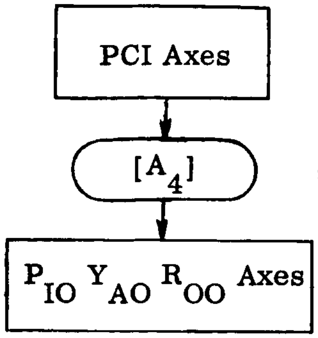
3.	IMU axes	The inertial measurement unit reference axes
4.	Gyro No. 1 axes	The reference input, output and spin axes of the first gyro
5.	Gyro No. 2 axes	The reference input, output and spin axes of the second gyro
6.	Gyro No. 3 axes	The reference input, output and spin axis of the third gyro
7.	Accelerometer No. 1 axes	The reference input, cross and normal axes of the first accelerometer
8.	Accelerometer No. 2 axes	The reference input, cross and normal axes of the second accelerometer
9.	Accelerometer No. 3 axes	The reference input, cross and normal axes of the third accelerometer
10.	Initial misalignment axes	The coordinate axes in which initial misalignments are specified.

The transformation relating the PCI axes and the P_{IO}, Y_{AO}, R_{OO} axes is the matrix $[A_4]$.

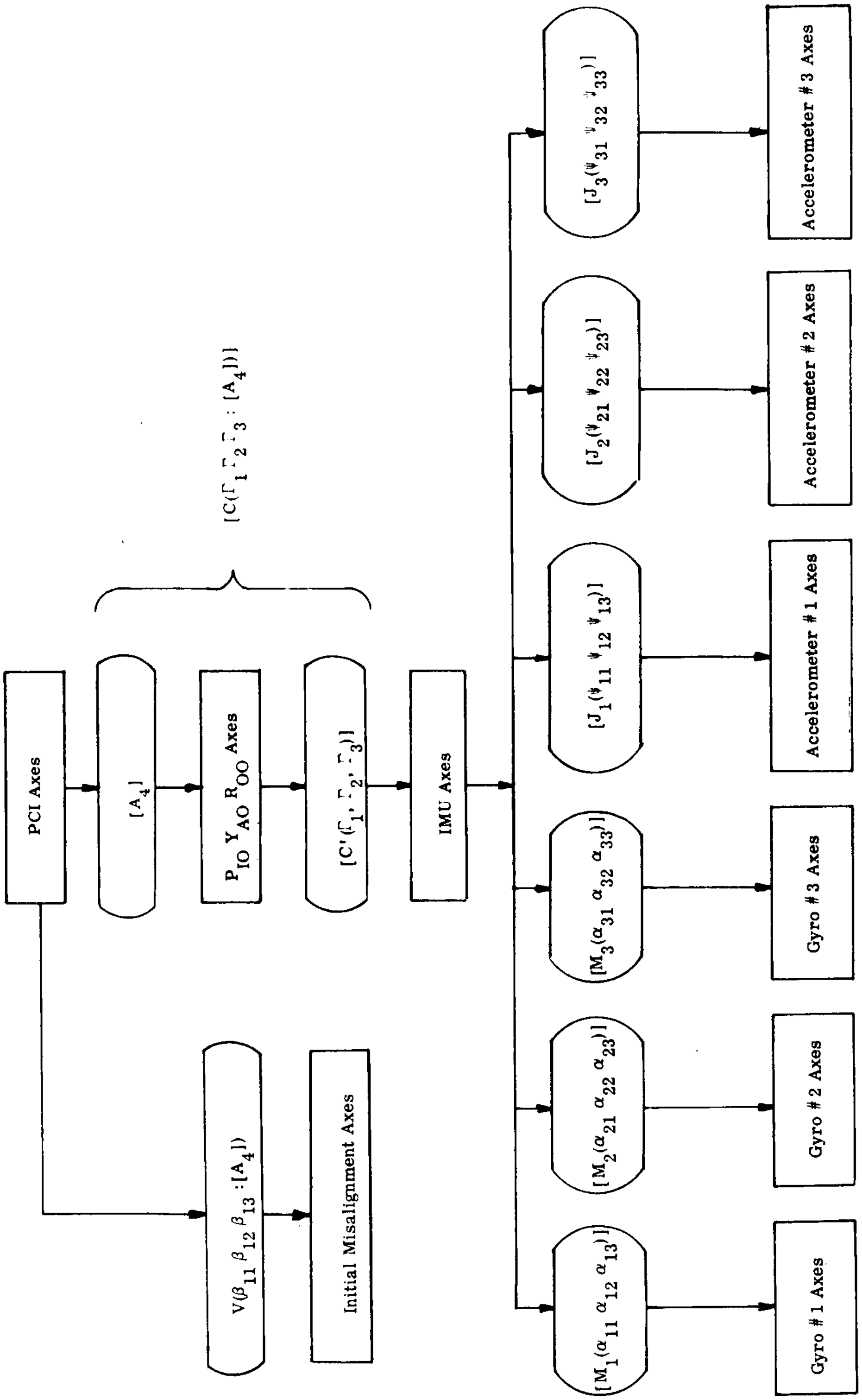
$$\overline{X}_{(P_{IO}\ Y_{AO}\ R_{OO})} = [A_4]\ \overline{X}_{(PCI)}$$

$[A_4]$ is defined by input initial latitude, longitude and azimuth in Block B, General Initialization, and is inputted into Block III on the reference trajectory tape. All other transformations between coordinate systems are in the general Euler angle format just defined.

The interrelationship of these coordinate systems is shown in the following diagram. The symbol convention employed is defined by the example:



$$\underline{\underline{Df}} \quad \overline{X}_{(P_{IO}\ Y_{AO}\ R_{OO})} = [A_4]\ \overline{X}_{(PCI)}$$



Relationship of Coordinate System and Transformation in Block III

All the transformations except C' $(\Gamma_1, \Gamma_2, \Gamma_3)$ are constant. C'$(\Gamma_1, \Gamma_2, \Gamma_3)$ is time varying for a strapdown system and a carousel system, and constant for a gimballed stabilized platform system. It is evident from the diagram that when C' $(\Gamma_1, \Gamma_2, \Gamma_3)$ is time varying, the IMU axes and all inertial instrument axes are rotating together, maintaining a fixed orientation to each other, but a time varying orientation with respect to the PCI axes.

3.3 Input, General Initialization, Output

3.3.1 Definition of Flags

FLAG "A"	0 = gimbal system 1 = strapdown system 2 = Carousel
FLAG "B"	2 = two-degree-of-freedom gyro 1 = single degree
FLAG "C"	2 = unspecified 1 = unspecified
FLAG "D"	3 = single-degree-of-freedom platform 2 = rate gyro 1 = torque rebalanced gyro
FLAG "E"	3 = PIGA 2 = proof mass accelerometer 1 = unspecified
FLAG "F"	0 = state transition matrix specified by Block III-6 1 = state transition matrix specified by Block II
FLAG "G"	0 = no print of $\Phi_2 (t_f, t_o)$ matrix 1 = print $\Phi_2 (t_f, t_o)$ matrix
PUNC	1 = punch $[P](t_f)$ on cards 2 = punch $\Phi_2 (t_f, t_o)$ matrix on cards 3 = punch both on cards
BUDG	specifies number of budgets used for one IMU configuration and one trajectory
TAPEP	1 = do error analysis only 2 = print tape only 3 = print tape and do error analysis

3.3.2 Definition of Input Quantities

Input Classification	Data Symbol	Simulation Output Symbol	Units	Description
Trajectory Selection	Run Number	RUN		Selects desired trajectory from trajectory tape record by matching run number. Can be used as program control input to skip Block III calculations by using a value > 100.
Simulation Operational Parameters	Δt	DELTA T	sec.	Input integration step size.
	t_o	T*O	sec.	Block III-6 state transition matrix parameter.
	t_f	T FINAL	sec.	Computation end time; must be less than or equal to last time of trajectory record
	N	N		Specifies the number of trajectory records to be skipped during computation - every $(N+1)^{th}$ point is used as a trajectory data point.
	BUDGETS	BUDG		Number of budgets to be cycled on a single IMU and trajectory
	Punch	PUNC		0 = don't punch cards 1 = punch [P] on cards 2 = punch $[\Phi_2]$ on cards 3 = punch both
	Title Card	HEADING		Contains engineer's title for the run; is printed on top of each page of output.
	Rank	RANK		Specified Output Print 0 = print output only 1 = print output card input.

Input Classification	Data Symbol	Simulation Output Symbol	Unit	Description
	Flag F	FLAG F		2 = prints output card input, A_4 matrix and trajectory records used (specified by N) 0 = state transition matrix, $\Phi_1^{-1}(t_o,t)$, set equal to that corresponding to boost trajectory in a constant gravitational field 1 = state transition matrix, $\Phi_1^{-1}(t_o,t)$ set equal to the $\Phi^{-1}(t_o,t)$ of the trajectory tape which corresponds to a boost trajectory in an inverse square gravitational field.
	Flag G	FLAG G		0 = print $\Phi_2(t_f,t_o)$ 1 = do not print $\Phi_2(t_f,t_o)$
	Flag 1	FLAG 1		1 = print a data dump following each calculation of Block III-1 0 = do not print such a data dump
	Flag 2	FLAG 2		1 = print a data dump following each calculation of Block III-2 0 = do not print such a data dump
	Flag 3	FLAG 3		1 = print a data dump following each calculation of Block III-3 0 = do not print such a data dump
	Flag 4	FLAG 4		1 = print a data dump following each calculation of Block III-4 0 = do not print such a data dump
	Flag 5	FLAG 5		1 = print a data dump following each calculation of Block III-5 0 = do not print such a data dump

Input Classification	Data Symbol	Simulation Output Symbol	Units	Description
	Flag 6	FLAG 6		1 = print a data dump following each calculation of Block III-6 0 = do not print such a data dump
	Flag 7	FLAG 7		1 = print a data dump following each calculation of Block III-7 at $t = t_f$ 0 = do not print such a data dump
	TAPEP	TAPE OPT		1 = error analysis only 2 = print tape only 3 = print tape and do error analysis
	TAPENO	TAPE NO.		Trajectory tape number
Inertial Guidance System Specification	Flag A	FLAG A		0 = gimbal system 1 = strapdown system 2 = Carousel
	Flag B	FLAG B		2 = two-degree-of-freedom gyros 1 = single-degree-of-freedom gyros
	Flag C	FLAG C		2 = unspecified 1 = unspecified
	Flag D	FLAG D		3 = single-degree-of-freedom platform gyro 2 = rate gyro 1 = torque rebalanced gyro
	Flag E	FLAG E		3 = PIGA 2 = proof mass accelerometer 1 = unspecified
	K'_1	K*1 PRIME	ft/sec	PIGA error model parameter relating acceleration error and angular rate about a axis normal to the nominal input axis when the input axis is misaligned in that plane

Input Classification	Data Symbol	Simulation Output Symbol	Units	Description
	K_0	K*0	sec	rate gyro constant relating the angular displacement of the output axis to the angular rate about the input axis.
Sensor Orientation	α_{11}	ALPHA*1, 1	rad.	Euler angles specifying orientation of first gyro with respect to IMU reference coordinates.
	α_{12}	ALPHA*1, 2	rad.	
	α_{13}	ALPHA*1, 3	rad.	
	α_{21}	ALPHA*2, 1	rad.	Euler angles specifying orientation of second gyro with respect to IMU reference coordinates.
	α_{22}	ALPHA*2, 2	rad.	
	α_{23}	ALPHA*2, 3	rad.	
	α_{31}	ALPHA*3, 1	rad.	Euler angles specifying orientation of third gyro with respect to the IMU reference coordinates.
	α_{32}	ALPHA*3, 2	rad.	
	α_{33}	ALPHA*3, 3	rad.	
	ψ_{11}	PSI*1, 1	rad.	Euler angles specifying orientation of first accelerometer with respect to IMU reference coordinates.
	ψ_{12}	PSI*1, 2	rad.	
	ψ_{13}	PSI*1, 3	rad.	
	ψ_{21}	PSI*2, 1	rad.	Euler angles specifying orientation of the second accelerometer with respect to IMU reference coordinates.
	ψ_{22}	PSI*2, 2	rad.	
	ψ_{23}	PSI*2, 3	rad.	

Input Classification	Data Symbol	Simulation Output Symbol	Units	Description
	ψ_{31}	PSI*3,1	rad.	Euler angles specifying orientation of the third accelerometer with respect to IMU reference coordinates.
	ψ_{32}	PSI*3,2	rad.	
	ψ_{33}	PSI*3,3	rad.	
	β_{11}	BETA*1,1	rad.	Euler angles specifying orientation of the coordinate system with respect to PCI reference coordinates in which initial misalignments are specified.
	β_{12}	BETA*1,2	rad.	
	β_{13}	BETA*1,3	rad.	
[For Carousel sensor orientations and angular rate environment.]	η_1 Table	ETA*1 TABLE		
	t min	MIN	sec.	t min $\le t_o$
	t max	MAX	sec.	t max $\ge t_f$
	(2j), No. of Values in η_1 Table			$4 \le 2j \le 54$
	$t_1 = t_{min}$	INDEP. VARIABLE	sec.	
	η_1 (t_1)	DEPEN. VARIABLE	rad.	Time points can be arbitrarily selected between t_{min} and t_{max} but must be ordered in a monotonic increasing sense, i.e., for $m < n$, $t_m < t_n$
	⋮	⋮	⋮	
	$t_j = t_{max}$	INDEP. VARIABLE	sec.	
	η_1 (t_j)	DEPEN. VARIABLE	rad.	

Input Classification	Data Symbol	Simulation Output Symbol	Units	Description
	η_2 Table	ETA*2 TABLE		
	t_{min}	MIN	sec.	$t_{min} \geq t_o$
	t_{max}	MAX	sec.	$t_{max} \geq t_f$
	(2j), No. of Values in η_2 Table			$4 \leq 2j \leq 54$
	$t_1 = t_{min}$	INDEP. VARIABLE	sec.	
	$\eta_2(t_1)$	DEPEN. VARIABLE	rad.	Time points can be arbitrarily selected between t_{min} and t_{max}; but must be ordered in a monotonic increasing sense: $m < n$, $t_m < t_n$.
	⋮	⋮	⋮	
	t_j	INDEP. VARIABLE	sec.	
	$\eta_2(t_j)$	DEPEN. VARIABLE	rad.	
	η_3 Table	ETA*3 TABLE		
	t_{min}	MIN	sec.	$t_{min} \leq t_o$
	t_{max}	MAX	sec.	$t_{max} \geq t_f$
	(2j), No. of Values in η_3 Table			$4 \leq 2j \leq 54$
	$t_1 = t_{min}$	INDEP. VARIABLE	sec.	
	$\eta_3(t_1)$	DEPEN. VARIABLE	rad.	Time points can be arbitrarily selected between t_{min} $_{max}$; but must be ordered in a monotonic increasing sense; $m < n$, $t_m < t_n$.
	⋮	⋮	⋮	
	t_j	INDEP. VARIABLE	sec.	
	$\eta_3(t_j)$	DEPEN. VARIABLE	rad.	

Input Classification	Data Symbol	Simulation Output Symbol	Units	Description
	ω_1 Table	OMEGA*1 TABLE		
	t_{min}	MIN	sec.	$t_{min} \le t_o$
	t_{max}	MAX	sec.	$t_{max} \ge t_f$
	(2j), No. of Entries in ω_1 Table			$4 \le 2j \le 54$
	$t_1 = t_{min}$	INDEP. VARIABLE	sec.	
	$\omega_1(t_1)$	DEPEN. VARIABLE	rad/sec	Time points can be arbitrarily selected between t_{min} and t_{max} but must be ordered in a monotonic increasing sense, for $m < n$,
	⋮	⋮	⋮	
	$t_j = t_{max}$	INDEP. VARIABLE	sec.	$t_m < t_n$
	$\omega_1(t_j)$	DEPEN. VARIABLE	rad/sec	
	ω_2 Table	OMEGA*2 TABLE		
	t_{min}	MIN	sec.	$t_{min} \le t_o$
	t_{max}	MAX	sec.	$t_{max} \ge t_f$
	(2j), No. of Entries in ω_2 Table			$4 \le 2j \le 54$
	$t_1 = t_{min}$	INDEP. VARIABLE	sec.	
	$\omega_2(t_1)$	DEPEN. VARIABLE	rad/sec	Time points can be arbitrarily selected between t_{min} and t_{max} but must be ordered in a monotonic increasing sense, for $m < n$,
	⋮	⋮	⋮	
	$t_j = t_{max}$	INDEP. VARIABLE	sec.	$t_m < t_n$
	$\omega_2(t_j)$	DEPEN. VARIABLE	rad/sec	

Input Classification	Data Symbol	Simulation Output Symbol	Units	Description
	ω_3 Table	OMEGA*3 TABLE		
	t_{min}	MIN	sec.	$t_{min} \le t_o$
	t_{max}	MAX	sec.	$t_{max} \ge t_1$
	(2j), No. of Entries in ω_3 Table			$4 \le 2j \le 54$
	$t_1 = t_{min}$	INDEP. VARIABLE	sec.	
	$\omega_3(t_1)$	DEPEN. VARIABLE	rad/sec	Time points can be arbitrarily selected between t_{min} and t_{max} but must be ordered in a monotonic increasing sense, for $m < n$, $t_m < t_n$
	⋮	⋮	⋮	
	$t_j = t_{max}$	INDEP. VARIABLE	sec.	
	$\omega_3(t_j)$	DEPEN. VARIABLE	rad/sec	
Error Budget	K_1	K*1	(rad/sec)/ [error budget 1σ unit]	Conversion constant for gyro constant drift term
	K_2	K*2	(rad/sec)/ [(ft/sec^2)(error budget 1σ unit)]	Conversion constant for gyro acceleration dependent drift term
	K_3	K*3	(rad/sec)/ [(ft/sec^2)(error budget 1σ unit)]	Conversion constant for gyro acceleration dependent drift term
	K_4	K*4	(rad/sec)/ [(ft^2/sec^4)(error budget 1σ unit)]	Conversion constant for gyro acceleration squared dependent drift term
	K_5	K*5	(rad/sec)/ [(rad/sec)(error budget 1σ unit)]	Conversion constant for gyro input axes misalignment term

Input Classification	Data Symbol	Simulation Output Symbol	Units	Description
	K_6	K*6	(rad/sec)/ [(rad/sec)(error budget 1σ unit)]	Conversion constant for gyro input axis misalignment term
	K_7	K*7	(rad/sec)/ [(rad/sec)(error budget 1σ unit)]	Conversion constant for gyro rate scale factor term
	K_8	K*8	(rad/sec)/ [(rad^2/sec^2)(error budget 1σ unit)]	Conversion constant for gyro rate non-linearity term
	K_9	K*9	(ft/sec^2)/ [error budget 1σ unit]	Conversion constant for accelerometer bias term
	K_{10}	K*10	(ft/sec^2)/ [(ft/sec^2)(error budget 1σ unit)]	Conversion constant for accelerometer scale factor term
	K_{11}	K*11	(ft/sec^2)/ [(ft^2/sec^4)(error budget 1σ unit)]	Conversion constant for accelerometer acceleration squared dependent term
	K_{12}	K*12	(ft/sec^2)/ [(ft^2/sec^4)(error budget 1σ unit)]	Conversion constant for accelerometer acceleration squared dependent term
	K_{13}	K*13	(ft/sec^2)/ [(ft/sec^2)(error budget 1σ unit)]	Conversion constant for acceleration input axis misalignment term
	K_{14}	K*14	(ft/sec^2)/ [(ft/sec^2)(error budget 1σ unit)]	Conversion constant for accelerometer input axis misalignment

Input Classification	Data Symbol	Simulation Output Symbol	Units	Description
	K_{15}	K*15	$(ft/sec^2)/[(ft/sec^2)$(error budget 1σ unit)]	Conversion constant for accelerometer wheel speed error term
	K_{16}	K*16	$(ft/sec^2)/[(rad/sec)$(error budget 1σ unit)]	Conversion constant for accelerometer angular rate dependent term
	K_{17}	K*17	(rad)/[error budget 1σ unit]	Conversion constant for initial misalignment of instrument package
	K_{18}	K*18	(rad)/[error budget 1σ unit]	Conversion constant for initial misalignment of instrument package
	K_{19}	K*19	(rad)/[error budget 1σ unit]	Conversion constant for initial misalignment of instrument package
	λ_1	LAMBDA*1	$(meru)^{2*}$	First gyro constant drift $(1\sigma)^2$
	λ_2	LAMBDA*2	$(meru/g)^{2*}$	First gyro unbalance along spin axis $(1\sigma)^2$
	λ_3	LAMBDA*3	$(meru/g)^{2*}$	First gyro unbalance along input axis $(1\sigma)^2$
	λ_4	LAMBDA*4	$(meru/g^2)^{2*}$	First gyro anioselasticity $(1\sigma)^2$
	λ_5	LAMBDA*5	$(arc\text{-}sec)^{2*}$	First gyro misalignment of gyro input axis in plane of the input and output axis $(1\sigma)^2$
	λ_6	LAMBDA*6	$(arc\text{-}sec)^{2*}$	First gyro misalignment of gyro input axis in plane of the input and spin axis $(1\sigma)^2$

* Note: The units given are representative units, any appropriate units of the error sources may be employed, provided that the corresponding conversion constants $K_1 \rightarrow K_{19}$ are appropriately modified.

Input Classification	Data Symbol	Simulation Output Symbol	Units	Description
	λ_7	LAMBDA*7	$(1 \text{ x } 10^{-6})^{2*}$	First gyro scale factor uncertainty $(1\sigma)^2$
	λ_8	LAMBDA*8	$(1 \text{ x } 10^{-6})^{2*}$	First gyro nonlinearity $(1\sigma)^2$
	$\lambda_9 \rightarrow \lambda_{16}$	(Error budget values for second gyro)		
	$\lambda_{17} \rightarrow \lambda_{24}$	(Error budget values for third gyro)		
	λ_{25}	LAMBDA*25	$(1 \text{ x } 10^{-6} g)^{2*}$	First Accelerometer bias $(1\sigma)^2$
	λ_{26}	LAMBDA*26	$(1 \text{ x } 10^{-6})^{2*}$	First accelerometer scale factor $(1\sigma)^2$
	λ_{27}	LAMBDA*27	$(1 \text{ x } 10^{-6}/g)^{2*}$	First accelerometer nonlinearity $(1\sigma)^2$
	λ_{28}	LAMBDA*28	$(1 \text{ x } 10^{-6}/g)^{2*}$	First accelerometer cross axis nonlinearity $(1\sigma)^2$
	λ_{29}	LAMBDA*29	$(\text{arc-sec})^{2*}$	First accelerometer sensitive axis misalignment in the plane of sensitive and normal axis $(1\sigma)^2$
	λ_{30}	LAMBDA*30	$(\text{arc-sec})^{2*}$	First accelerometer sensitive axis misalignment in the plane of sensitive and cross axis $(1\sigma)^2$
	λ_{31}	LAMBDA*31	$(1 \text{ x } 10^{-6} \text{sec/rad})^{2*}$	First accelerometer wheel speed change $(1\sigma)^2$

*Note: The units given are representative units, any appropriate units of the error sources may be employed, provided that the corresponding conversion constants $K_1 \rightarrow K_{19}$ are appropriately modified.

Input Classification	Data Symbol	Simulation Output Symbol	Units	Description
	λ_{32}	LAMBDA*32	$(1 \times 10^{-6}$ sec/rad$)^{2*}$	Angular velocity uncertainty about the input axes of the first accelerometer $(1\sigma)^2$
	$\lambda_{33} \rightarrow \lambda_{40}$	(Error budget values for second accelerometer)		
	$\lambda_{41} \rightarrow \lambda_{48}$	(Error budget values for third accelerometer)		
	λ_{49}	LAMBDA*49	(arc-sec)^{2*}	Initial misalignment of instrument package about first axis of misalignment coordinate system $(1\sigma)^2$
	λ_{50}	LAMBDA*50	(arc-sec)^{2*}	Initial misalignment of instrument package about second axis of misalignment coordinate system $(1\sigma)^2$
	λ_{51}	LAMBDA*51	(arc-sec)^{2*}	Initial misalignment of instrument package about third axis of misalignment coordinate system $(1\sigma)^2$
Initial Covariance Matrix of Velocity and Position Uncertainties	$P_{0(11)}$	P*01,1	ft^2	The initial covariance matrix of velocity and position uncertainties is input to calculate in one run, the entire resultant covariance of velocity and position errors.
	$P_{0(12)}$	P*01,2	ft^2	
	$P_{0(13)}$	P*01,3	ft^2	
	$P_{0(14)}$	P*01,4	ft^2/sec	

*Note: The units given are representative units, any appropriate units of the error sources may be employed, provided that the corresponding conversion constants $K_1 \rightarrow K_{19}$ are appropriately modified.

Input Classification	Data Symbol	Simulation Output Symbol	Units	Description
	$P_{0(15)}$	P*01,5	ft^2/sec	The initial covariance matrix of velocity and position uncertainties is input to calculate in one run, the entire resultant covariance of velocity and position errors.
	$P_{0(16)}$	P*01,6	ft^2/sec	
	$P_{0(21)}$	P*02,1	ft^2	
	$P_{0(22)}$	P*02,2	ft^2	
	$P_{0(23)}$	P*02,3	ft^2	
	$P_{0(24)}$	P*02,4	ft^2/sec	
	$P_{0(25)}$	P*02,5	ft^2/sec	
	$P_{0(26)}$	P*02,6	ft^2/sec	
	$P_{0(31)}$	P*03,1	ft^2	
	$P_{0(32)}$	P*03,2	ft^2	
	$P_{0(33)}$	P*03,3	ft^2	
	$P_{0(34)}$	P*03,4	ft^2/sec	
	$P_{0(35)}$	P*03,5	ft^2/sec	
	$P_{0(36)}$	P*03,6	ft^2/sec	
	$P_{0(41)}$	P*04,1	ft^2/sec	
	$P_{0(42)}$	P*04,2	ft^2/sec	

Input Classification	Data Symbol	Simulation Output Symbol	Units	Description
	$P_{0(43)}$	P*04,3	ft^2/sec	The initial covariance matrix of velocity and position uncertainties is input to calculate in one run, the entire resultant covariance of velocity and position errors.
	$P_{0(44)}$	P*04,4	ft^2/sec^2	
	$P_{0(45)}$	P*04,5	ft^2/sec^2	
	$P_{0(46)}$	P*04,6	ft^2/sec^2	
	$P_{0(51)}$	P*05,1	ft^2/sec	
	$P_{0(52)}$	P*05,2	ft^2/sec	
	$P_{0(53)}$	P*05,3	ft^2/sec	
	$P_{0(54)}$	P*05,4	ft^2/sec^2	
	$P_{0(55)}$	P*05,5	ft^2/sec^2	
	$P_0(56)$	P*05,6	ft^2/sec^2	
	$P_0(61)$	P*06,1	ft^2/sec	
	$P_0(62)$	P*06,2	ft^2/sec	
	$P_0(63)$	P*06,3	ft^2/sec	
	$P_{0(64)}$	P*06,4	ft^2/sec^2	
	$P_{0(65)}$	P*06,5	ft^2/sec^2	
	$P_{0(66)}$	P*06,6	ft^2/sec^2	

Input Classification	Data Symbol	Simulation Output Symbol	Units	Description
Tape Input of Reference Trajectory Data.	$\omega_{PI}(t)$	W*PI	rad/sec	Angular rate about the instantaneous pitch axis
	$\omega_{YA}(t)$	W*YA	rad/sec	Angular rate about the instantaneous yaw axis
	$\omega_{RO}(t)$	W*RO	rad/sec	Angular rate about the instantaneous roll axis
	$\alpha_1(t)$	ALPHA*1	rad.	Inner gimbal angle
	$\alpha_2(t)$	ALPHA*2	rad.	Middle gimbal angle
	$\alpha_3(t)$	ALPHA*3	rad.	Outer gimbal angle
	$a_X(t)$	A*X	ft/sec^2	X-component, (PCI), of vehicle's specific force to mass ratio
	$a_Y(t)$	A*Y	ft/sec^2	Y-component, (PCI), of vehicle's specific force to mass ratio
	$a_Z(t)$	A*Z	ft/sec^2	Z-component, (PCI), of vehicle's specific force to mass ratio
	t	TIME	sec.	Time, reference value is defined by booster simulation
	Run Number	RUN		Run number of booster simulation used as identification by Block III to select correct reference trajectory from tape.

Input Classification	Data Symbol	Simulation Output Symbol	Units	Description
	$\Phi_{11}^{-1}(t,t_o)$	PHI-1*1,1	n.d.	Elements of the state transition matrix, $\Phi^{-1}(t,t_o)$ along the reference powered flight trajectory in an inverse square gravitational field.
	$\Phi_{12}^{-1}(t,t_o)$	PHI-1*1,2	n.d.	
	$\Phi_{13}^{-1}(t,t_o)$	PHI-1*1,3	n.d.	
	$\Phi_{14}^{-1}(t,t_o)$	PHI-1*1,4	sec.	
	$\Phi_{15}^{-1}(t,t_o)$	PHI-1*1,5	sec.	
	$\Phi_{16}^{-1}(t,t_o)$	PHI-1*1,6	sec.	
	Φ_{21}^{-1}	PHI-1*2,1	n.d.	
	$\Phi_{22}^{-1}(t,t_o)$	PHI-1*2,2	n.d.	
	$\Phi_{23}^{-1}(t,t_o)$	PHI-1*2,3	n.d.	
	$\Phi_{24}^{-1}(t,t_o)$	PHI-1*2,4	sec.	
	$\Phi_{25}^{-1}(t,t_o)$	PHI-1*2,5	sec.	
	$\Phi_{26}^{-1}(t,t_o)$	PHI-1*2,6	sec.	
	$\Phi_{31}^{-1}(t,t_o)$	PHI-1*3,1	n.d.	

Input Classification	Data Symbol	Simulation Output Symbol	Units	Description
	$\Phi^{-1}_{32}(t,t_o)$	PHI-1*3,2	n.d.	Elements of the state transition matrix, $\Phi^{-1}(t,t_o)$ along the reference powered flight trajectory in an inverse square gravitational field.
	$\Phi^{-1}_{33}(t,t_o)$	PHI-1*3,3	n.d.	
	$\Phi^{-1}_{34}(t,t_o)$	PHI-1*3,4	sec.	
	$\Phi^{-1}_{35}(t,t_o)$	PHI-1*3,5	sec.	
	$\Phi^{-1}_{36}(t,t_o)$	PHI-1*3,6	sec.	
	$\Phi^{-1}_{41}(t,t_o)$	PHI-1*4,1	1/sec.	
	$\Phi^{-1}_{42}(t,t_o)$	PHI-1*4,2	1/sec.	
	$\Phi^{-1}_{43}(t,t_o)$	PHI-1*4,3	1/sec.	
	$\Phi^{-1}_{44}(t,t_o)$	PHI-1*4,4	n.d.	
	$\Phi^{-1}_{45}(t,t_o)$	PHI-1*4,5	n.d.	
	$\Phi^{-1}_{46}(t,t_o)$	PHI-1*4,6	n.d.	
	$\Phi^{-1}_{51}(t,t_o)$	PHI-1*5,1	1/sec.	
	$\Phi^{-1}_{52}(t,t_o)$	PHI-1*5,2	1/sec.	

Input Classification	Data Symbol	Simulation Output Symbol	Units	Description
	$\Phi_{53}^{-1}(t, t_o)$	PHI-1*5,3	1/sec.	Elements of the state transition matrix, $\Phi^{-1}(t, t_o)$ along the reference powered flight trajectory in an inverse square gravitational field.
	$\Phi_{54}^{-1}(t, t_o)$	PHI-1*5,4	n.d.	
	$\Phi_{55}^{-1}(t, t_o)$	PHI-1*5,5	n.d.	
	$\Phi_{56}^{-1}(t, t_o)$	PHI-1*5,6	n.d.	
	$\Phi_{61}^{-1}(t, t_o)$	PHI-1*6,1	1/sec.	
	$\Phi_{62}^{-1}(t, t_o)$	PHI-1*6,2	1/sec.	
	$\Phi_{63}^{-1}(t, t_o)$	PHI-1*6,3	1/sec.	
	$\Phi_{64}^{-1}(t, t_o)$	PHI-1*6,4	n.d.	
	$\Phi_{65}^{-1}(t, t_o)$	PHI-1*6,5	n.d.	
	$\Phi_{66}^{-1}(t, t_o)$	PHI-1*6,6	n.d.	

3.3.3 Input - Block A

$\omega_{PI}(t)$, $\omega_{YA}(t)$, $\omega_{RO}(t)$

$\alpha_1(t)$, $\alpha_2(t)$, $\alpha_3(t)$

$a_X(t)$, $a_Y(t)$, $a_Z(t)$

α_{11}, α_{12}, α_{13}

α_{21}, α_{22}, α_{23}

α_{31}, α_{32}, α_{33}

ψ_{11}, ψ_{12}, ψ_{13}

ψ_{21}, ψ_{22}, ψ_{23}

ψ_{31}, ψ_{32}, ψ_{33}

β_{11}, β_{12}, β_{13}

t_o

t_f

FLAG "A"

FLAG "B"

FLAG "C"

FLAG "D"

FLAG "E", FLAG "F", FLAG "G"

$\omega_1(t)$, $\omega_2(t)$, $\omega_3(t)$

$\eta_1(t)$, $\eta_2(t)$, $\eta_3(t)$

λ_i $i = 1, 2, \ldots . 51$

$[P_o]$ (6x6)

$\Phi_1^{-1}(t, t_o)$

K_1 through K_{19}

$[A_4]$

K_o, K'_1

Δt

N

Rank

Run number

Tape number

Tape option

Number of budgets

Punch card option

3.3.4 General Initialization - Block B

Within this block the matrices that relate the instrument orientation to the instrument package orientations are computed. Also the matrix that relates the coordinate system, in which the initial alignment errors are given, to the Planet Centered Inertial coordinate system is computed.

INPUT: $\alpha_{11}, \alpha_{12}, \alpha_{13}, \alpha_{21}, \alpha_{22}, \alpha_{23}, \alpha_{31}, \alpha_{32}, \alpha_{33}$
$\psi_{11}, \psi_{12}, \psi_{13}, \psi_{21}, \psi_{22}, \psi_{23}, \psi_{31}, \psi_{32}, \psi_{33}$
$\beta_{11}, \beta_{12}, \beta_{13}$ $[A_4]$

OUTPUT: $[M_1]$, $[M_2]$, $[M_3]$, $[J_1]$, $[J_2]$, $[J_3]$, $[V]$

These matrices are computed according to the following equations.

$$[M_i] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha_{i3} & \sin\alpha_{i3} \\ 0 & -\sin\alpha_{i3} & \cos\alpha_{i3} \end{bmatrix} \begin{bmatrix} \cos\alpha_{i2} & 0 & -\sin\alpha_{i2} \\ 0 & 1 & 0 \\ \sin\alpha_{i2} & 0 & \cos\alpha_{i2} \end{bmatrix} \begin{bmatrix} \cos\alpha_{i1} & \sin\alpha_{i1} & 0 \\ -\sin\alpha_{i1} & \cos\alpha_{i1} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$i = 1, 2, 3$$

$$[J_i] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\psi_{i3} & \sin\psi_{i3} \\ 0 & -\sin\psi_{i3} & \cos\psi_{i3} \end{bmatrix} \begin{bmatrix} \cos\psi_{i2} & 0 & -\sin\psi_{i2} \\ 0 & 1 & 0 \\ \sin\psi_{i2} & 0 & \cos\psi_{i2} \end{bmatrix} \begin{bmatrix} \cos\psi_{i1} & \sin\psi_{i1} & 0 \\ -\sin\psi_{i1} & \cos\psi_{i1} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$i = 1, 2, 3$$

$$[V] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\beta_{13} & \sin\beta_{13} \\ 1 & -\sin\beta_{13} & \cos\beta_{13} \end{bmatrix} \begin{bmatrix} \cos\beta_{12} & 0 & -\sin\beta_{12} \\ 0 & 1 & 0 \\ \sin\beta_{12} & & \cos\beta_{12} \end{bmatrix} \begin{bmatrix} \cos\beta_{11} & \sin\beta_{11} & 0 \\ -\sin\beta_{11} & \cos\beta_{11} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \\ A_4 \\ \\ \end{bmatrix}$$

The M_1, M_2, M_3 matrices refer to the first, second, and third gyros respectively. The J_1, J_2, J_3 matrices refer to the first, second, and third accelerometers respectively. The [V] matrix refers to the initial misalignment coordinate system.

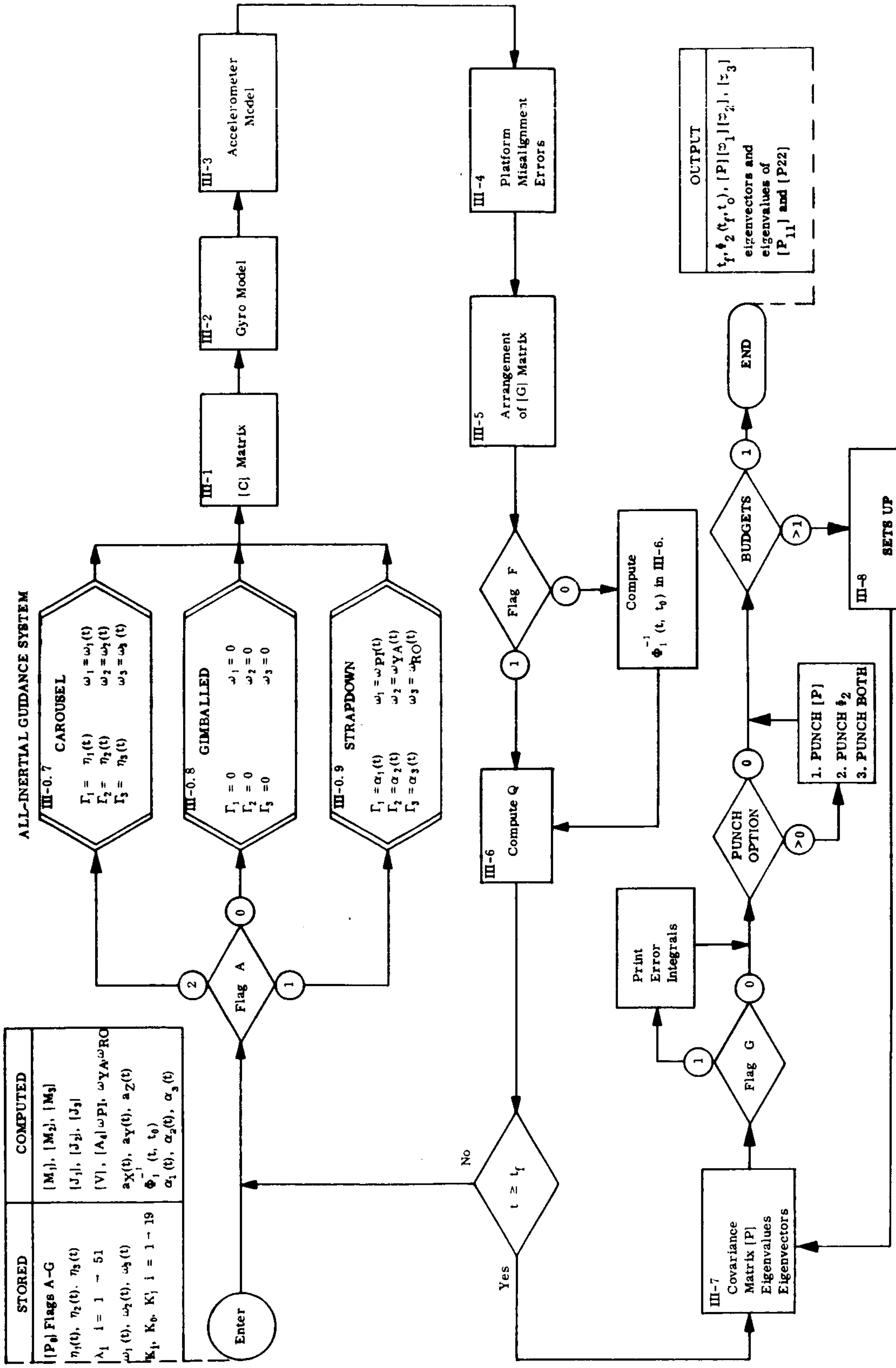
Set the following flags - Flag A through Flag G

3.3.5 Output - Block C

t_f	final time
$[\varphi_1], [\varphi_2], [\varphi_3](3,8)$	gyro drift of each potential error source for 1st, 2nd, and 3rd gyros
$[P]$ (6,6)	covariance matrix of erros
EP11 EP12 EP13	first eigenvector of position ellipsoid (P_{11})
$\sqrt{LP1}$	principal axis of position ellipsoid (P_{11})
EP21 EP22 EP23	second eigenvector of position ellipsoid (P_{11})
$\sqrt{LP2}$	principal axis of position ellipsoid (P_{11})
EP31 EP32 EP33	third eigenvector of position ellipsoid (P_{11})
$\sqrt{LP3}$	principal axis of position ellipsoid (P_{11})
EV11 EV12 EV13	first eigenvector of velocity ellipsoid (P_{22})
$\sqrt{LV1}$	principal axis of velocity ellipsoid (P_{22})
EV21 EV22 EV23	second eigenvector of velocity ellipsoid (P_{22})
$\sqrt{LV2}$	principal axis of velocity ellipsoid (P_{22})
EV31 EV32 EV33	third eigenvalue of velocity ellipsoid (P_{22})
$\sqrt{LV3}$	principal axis of velocity ellipsoid (P_{22})
$\Phi_2(t, t_o)(6, 51)$	generalized error integrals
$[P_{INP}](6,6)$	covariance matrix of errors in a downrange, crossrange, altitude coordinate system.

$EP_{INP}11$ $EP_{INP}12$ $EP_{INP}13$	first eigenvector of position ellipsoid (P_{INP11})
$\sqrt{LP_{INP}1}$	principal axis of position ellipsoid (P_{INP11})
$EP_{INP}21$ $EP_{INP}22$ $EP_{INP}23$	second eigenvector of position ellipsoid (P_{INP11})
$\sqrt{LP_{INP}2}$	principal axis of position ellipsoid (P_{INP11})
$EP_{INP}31$ $EP_{INP}32$ $EP_{INP}33$	third eigenvector of position ellipsoid (P_{INP11})
$\sqrt{LP_{INP}3}$	principal axis of position ellipsoid (P_{INP11})
$EV_{INP}11$ $EV_{INP}12$ $EV_{INP}13$	first eigenvector of velocity ellipsoid (P_{INP22})
$\sqrt{LV_{INP}1}$	principal axis of velocity ellipsoid (P_{INP22})
$EV_{INP}21$ $EV_{INP}22$ $EV_{INP}23$	second eigenvector of velocity ellipsoid (P_{INP22})
$\sqrt{LV_{INP}2}$	principal axis of velocity ellipsoid (P_{INP22})
$EV_{INP}31$ $EV_{INP}32$ $EV_{INP}33$	third eigenvector of velocity ellipsoid (P_{INP22})
$\sqrt{LV_{INP}^3}$	principal axis of velocity ellipsoid (P_{INP22})

3.4 All-Inertial Guidance System Basic Computational Blocks - Block III



3.4.1 Level II Flow Chart

3.4.1.1 Detailed Flow Charts and Equations

III-1 COORDINATE TRANSFORMATION DEFINITION: TRANSFORMATION FROM PCI INERTIAL COORDINATES TO IMU REFERENCE COORDINATES

The [C] matrix is computed to obtain the transformation from the PCI coordinate system to the IMU reference coordinate system. The [C] matrix is time varying in the case of the strapdown and carousel systems, and constant for the inertially stabilized gimballed system.

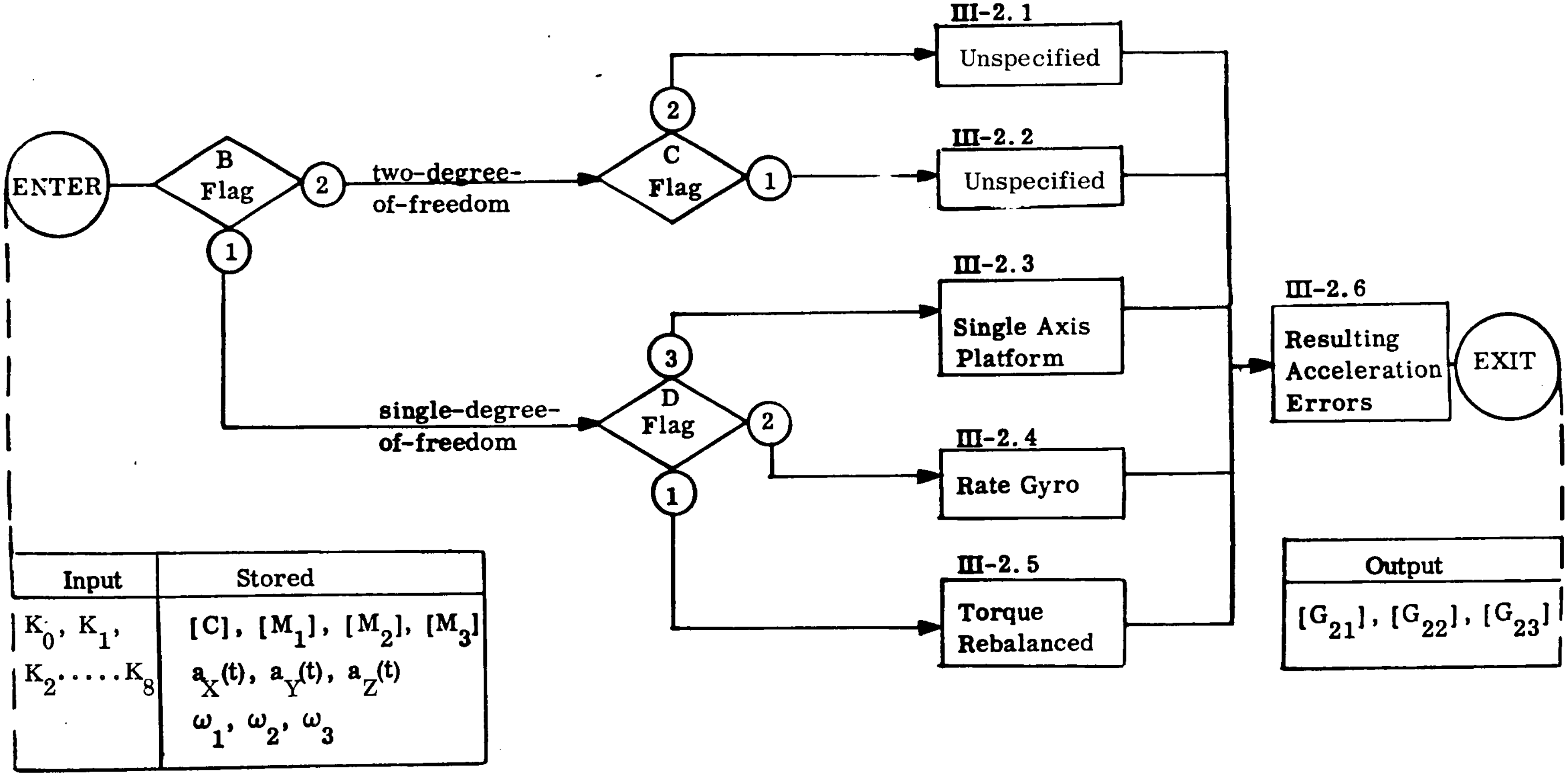
INPUT: $\Gamma_1, \Gamma_2, \Gamma_3$ - Block III-.7, .8, or .9
$[A_4]$ (3,3) - Block I

OUTPUT: [C] (3,3)

$$[C'] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\Gamma_3 & \sin\Gamma_3 \\ 0 & -\sin\Gamma_3 & \cos\Gamma_3 \end{bmatrix} \begin{bmatrix} \cos\Gamma_2 & 0 & -\sin\Gamma_2 \\ 0 & 1 & 0 \\ \sin\Gamma_2 & 0 & \cos\Gamma_2 \end{bmatrix} \begin{bmatrix} \cos\Gamma_1 & \sin\Gamma_1 & 0 \\ -\sin\Gamma_1 & \cos\Gamma_1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$[C] = [C'][A_4]$$

III-2.0 GYRO MODEL



III-2.3 GYRO ERRORS FOR SINGLE-AXIS PLATFORM

The inertial drift rates of the single axis platform gyro due to unit independent gyro error sources are integrated to define a 3 x 8 matrix of drift angles, measured about the reference PCI coordinate axes. The independent error sources are the acceleration insensitive drift rate, acceleration sensitive drift rates due to mass unbalance along the spin axis and along the input axis, anisoelasticity, and input axis misalignments about the spin and output axes. This form of gyro rotates about the input axis due to angular rates about its input axis. The matrix D_i accounts for such rotation. The following sequence of computations is performed for each of the three gyros (i = 1,2,3).

INPUT: [C] (3,3) - Block III-1

$[M_1]$ (3,3), $[M_2]$ (3,3), $[M_3]$ (3,3) - Block B-3

$[a_X(t), a_Y(t), a_Z(t)]$ (3,1) - Block I

$[\omega_1, \omega_2, \omega_3]$ (3,1) - Block III-.7, .8, or .9

$K_1, K_2, \ldots\ldots K_8$ - Block A

OUTPUT: $[\varphi_1]$ (3,8), $[\varphi_2]$ (3,8), $[\varphi_3]$ (3,8)

The total angle measured by the gyro since launch is computed by integrating the rate about the input axis.

$$\theta_i = \int_{t_o}^{t} \omega_{Ii}\, dt \qquad \theta_i(0) = 0$$

The $[D_i]$ matrix defines the changing relationship of the spin and output axis to the instrument package coordinate system due to rotations about the input axis.

$$[D_i] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_i & -\sin\theta_i \\ 0 & \sin\theta_i & \cos\theta_i \end{bmatrix}$$

The angular velocities about the instantaneous gyro axes are computed.

$$\begin{bmatrix} \omega_{Ii} \\ \omega_{Oi} \\ \omega_{Si} \end{bmatrix} = [D_i][M_i] \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \end{bmatrix} \quad (3,1)$$

The acceleration along the instantaneous three axes of the gyro is computed.

$$\begin{bmatrix} a_{Ii} \\ a_{Oi} \\ a_{Si} \end{bmatrix} = [D_i][M_i][C] \begin{bmatrix} a_X \\ a_Y \\ a_Z \end{bmatrix} \quad (3,1)$$

The angular error due to each unit independent error source is computed by integrating the corresponding angular rate in the reference PCI coordinate system.

$$[\varphi_i]\ (3,8) = \int_{t_0}^{t} C^T M_i^T D^T \begin{bmatrix} 1 & a_{Ii} & -a_{Si} & a_{Ii}a_{Si} & \omega_{Oi} & -\omega_{Si} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} K_1 & & 0 \\ & \ddots & \\ 0 & & K_8 \end{bmatrix} dt$$

III-2.4 GYRO ERRORS FOR THE RATE GYRO

The inertial drift rates for the rate gyro due to unit independent gyro error sources are integrated to define a 3 x 8 matrix of drift angles, measured about the reference PCI coordinate axes. The independent error sources are acceleration insensitive drift rate, acceleration sensitive drift rates due to mass unbalances along the spin and input axes, anisoelasticity, input axes misalignment about the spin and output axes, and angular rate scale factor and nonlinearity. This form of gyro has an elastic restraint upon angular motion about the output axis. The input parameter K_0 is employed to represent this effective spring stiffness. The following sequence of computations is performed for each of the three gyros, (i = 1, 2, 3).

INPUT: [C] (3, 3) - Block III-1
$[M_1]$, $[M_2]$, $[M_3]$ (3, 3) - Block B-3
$[a_X(t)\ \ a_Y(t)\ \ a_Z(t)]$ (3, 1) - Block I
$[\omega_1\ \ \omega_2\ \ \omega_3]$ (3, 1) - Block III-.7, .8, or .9
$K_0, K_1, K_2, \ldots . K_8$ - Block A

OUTPUT: $[\varphi_1]$ (3, 8), $[\varphi_2]$ (3, 8), $[\varphi_3]$ (3, 8)

The angular defection about the gyro output axis is defined by:

$$\theta_{Oi} = K_0\, \omega_{Ii} \ ; \ \theta_{Oi}\,(0) = 0$$

$$[D_i] = \begin{bmatrix} \cos \theta_{Oi} & 0 & -\sin \theta_{Oi} \\ 0 & 1 & 0 \\ \sin \theta_{Oi} & 0 & \cos \theta_{Oi} \end{bmatrix}$$

The angular velocities about the instantaneous input, output, and spin axis are computed.

$$\begin{bmatrix} \omega_{Ii} \\ \omega_{Oi} \\ \omega_{Si} \end{bmatrix} = [D_i]\,[M_i] \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \end{bmatrix} \quad (3, 1)$$

The accelerations along the instantaneous input, output, and spin axis are computed.

$$\begin{bmatrix} a_{Ii} \\ a_{Oi} \\ a_{Si} \end{bmatrix} = [D_i][M_i][C] \begin{bmatrix} a_X \\ a_Y \\ a_Z \end{bmatrix} \quad (3,1)$$

The angular error due to each unit independent error source is computed by integrating the corresponding angular rate in the reference PCI coordinate system.

$$[\varphi_i]\,(3,8) = \int_{t_o}^{t} C^T M_i^T D^T \begin{bmatrix} 1 & a_{Ii} & a_{Si} & a_{Ii}a_{Si} & -\omega_{Oi} & -\omega_{Si} & \omega_{Ii} & \omega_{Ii}^2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} K_1 & & 0 \\ & \ddots & \\ 0 & & K_8 \end{bmatrix} dt$$

III-2.5 GYRO ERRORS FOR THE TORQUE REBALANCED GYRO

The inertial drift rates of the torque rebalanced gyro due to unit independent gyro error sources are integrated to define a 3 x 8 matrix of drift angles, measured about the reference PCI coordinate axes. The independent error sources are the acceleration insensitive drift rate, acceleration sensitive drift rates due to mass unbalance along the spin and input axis, anisoelasticity, input axes misalignments about the spin and output axes, angular rate scale factor and nonlinearity. This form of gyro maintains a fixed orientation with respect to IMU reference axes. The following sequence of computations is performed for each of the three gyros, $(i = 1, 2, 3)$.

INPUT: $[C]$ - Block III-1

$[M_1]$, $[M_2]$, $[M_3]$ (3, 3) - Block B-3

$[a_X(t) \;\; a_Y(t) \;\; a_Z(t)]$ (3, 1) - Block I

$[\omega_1 \;\; \omega_2 \;\; \omega_3]$ (3, 1) - Block III-.7, .8, or .9

$K_1, K_2, \ldots\ldots K_8$ - Block A

OUTPUT: $[\varphi_1]$ (3,8), $[\varphi_2]$ (3,8), $[\varphi_3]$ (3,8)

The angular velocities about the instantaneous input, output, and spin axis are computed.

$$\begin{bmatrix} \omega_{Ii} \\ \omega_{Oi} \\ \omega_{Si} \end{bmatrix} = [M_i] \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \end{bmatrix} \quad (3, 1)$$

The accelerations along the instantaneous input, output, and spin axis are computed.

$$\begin{bmatrix} a_{Ii} \\ a_{Oi} \\ a_{Si} \end{bmatrix} = [M_i][C] \begin{bmatrix} a_X \\ a_Y \\ a_Z \end{bmatrix} \quad (3, 1)$$

The angular error due to each unit independent error source is computed by integrating the corresponding angular rate in the reference PCI coordinate system.

$$[\varphi_i]\,(3,8) = \int_{t_o}^{t} C^T M_i^T D^T \begin{bmatrix} 1 & a_{Ii} & -a_{Si} & a_{Ii}a_{Si} & \omega_{Oi} & -\omega_{Si} & \omega_{Ii} & \omega_{Ii}^2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} K_1 & & 0 \\ & \ddots & \\ 0 & & K_8 \end{bmatrix} dt$$

III-2.6 ACCELERATION ERRORS RESULTING FROM GYRO ERROR

INPUT: $[\varphi_1]$, $[\varphi_2]$, $[\varphi_3]$ (3, 8) - Block III-2.3, III-2.4, or III-2.5

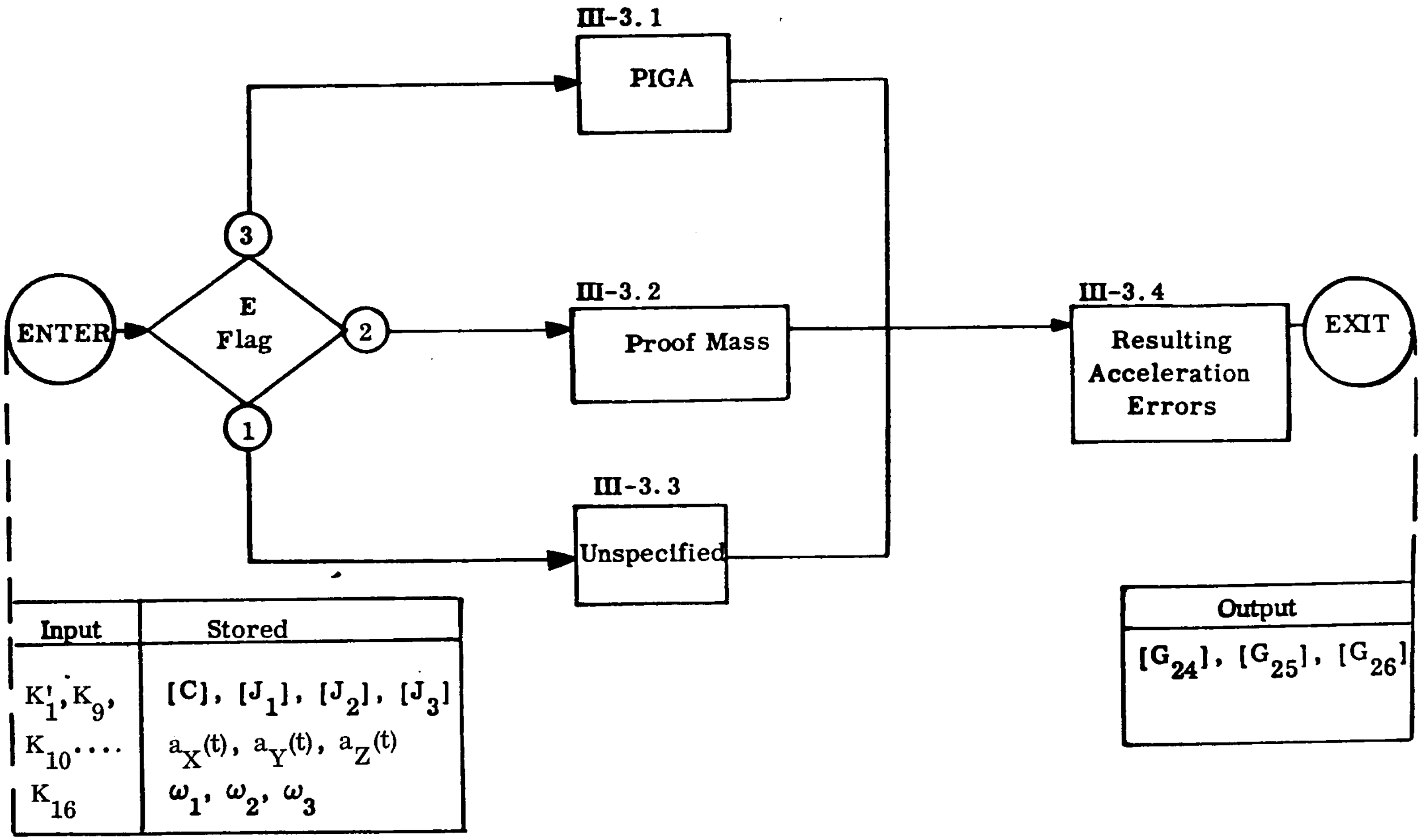
$[a_X, a_Y, a_Z]$ (3, 1) - Block I

OUTPUT: $[G_{21}]$, $[G_{22}]$, $[G_{23}]$ (3, 8)

The vector acceleration error due to a misalignment φ is calculated by applying the vector relationship $\Delta\underline{a} = \underline{a} \times \underline{\varphi}$. The calculation of the PCI acceleration error for each unit independent gyro error source is done in matrix format for each gyro, (i = 1, 2, 3).

$$[G_{2i}] = \begin{bmatrix} 0 & -a_Z & a_Y \\ a_Z & 0 & -a_X \\ -a_Y & a_X & 0 \end{bmatrix} [\varphi_i] \; (3,8)$$

III-3 ACCELEROMETER MODEL



Input	Stored
K_1', K_9, K_{10}.... K_{16}	[C], $[J_1]$, $[J_2]$, $[J_3]$ $a_X(t)$, $a_Y(t)$, $a_Z(t)$ ω_1, ω_2, ω_3

Output
$[G_{24}]$, $[G_{25}]$, $[G_{26}]$

III-3.1 PIGA ACCELEROMETER ERRORS

The PIGA accelerometer independent error sources are bias, scale factor uncertainty, nonlinearity, input axis misalignments about the cross and normal axes, which produce errors by coupling acceleration and angular rate, wheel speed, and the uncertainty of the angular rate about the input axis. K'_1 is the accelerometer scale factor that relates the angular rate about the input axis to the acceleration along that axis.

K_{12} should be set to zero when using the PIGA error model as there is no cross axis nonlinearity error source in this instrument. The following computations are performed for each accelerometer ($i = 1, 2, 3$).

INPUT:

$[C]$ - Block III-1
$\lfloor J_1 \rfloor$, $\lfloor J_2 \rceil$, $[J_3 \rfloor$ - Block B-3
$[a_X(t) \ a_Y(t) \ a_Z(t)]$ (3, 1) - Block I
$[\omega_1 \ \omega_2 \ \omega_3]$ (3, 1) - Block III-.7, -.8, or -.9
K'_1 - Block A

OUTPUT:

$\lfloor \gamma_1 \rceil$, $[\gamma_2 \rceil$, $[\gamma_3 \rceil$ (1, 8)

The accelerations along the instantaneous input, cross and normal axes of the PIGA accelerometer are computed.

$$\begin{bmatrix} a_{Ii} \\ a_{Ci} \\ a_{Ni} \end{bmatrix} = [J_i] \, [C] \begin{bmatrix} a_X \\ a_Y \\ a_Z \end{bmatrix}$$

The angular rates about the instantaneous input, cross and normal axes of the PIGA accelerometer are computed.

$$\begin{bmatrix} \omega_{Ii} \\ \omega_{Ci} \\ \omega_{Ni} \end{bmatrix} = \lfloor J_i \rfloor \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \end{bmatrix}$$

The matrix $[\gamma_i]$ is a statement of the PIGA error model with unit coefficients. In Block III-3.4 $[\gamma_i]$ is scaled by the constants K_9, K_{10}, . . . , K_{16}. This scaled product is then the matrix of acceleration errors for each unit independent error source.

$$\gamma_i = [1 \ \vdots \ a_{Ii} \ \vdots \ a_{Ii}^2 \ \vdots \ a_{Ii} \, a_{Ci} \ \vdots \ a_{Ci} + K'_1 \, \omega_{Ci} \ \vdots \ - a_{Ni} - K'_1 \, \omega_{Ni} \ \vdots \ a_{Ii} \ \vdots \ \omega_{Ii}]$$

III-3.2 PROOF MASS ACCELEROMETER

The proof mass accelerometer error model has as independent error sources: bias, scale factor, nonlinearity, cross axis nonlinearity, and input axis misalignment about the cross and normal axes. The following computations are performed for each accelerometer (i = 1, 2, 3).

INPUT: $[C]$ - Block III-1
$[J_1]$, $[J_2]$, $[J_3]$ - Block B-3
$[a_X(t)\ \ a_Y(t)\ \ a_Z(t)]$ (3, 1) - Block I

OUTPUT: $[\gamma_1]$, $[\gamma_2]$, $[\gamma_3]$ (1,8)

The accelerations along the instantaneous input, cross and normal axes of the accelerometer are computed.

$$\begin{bmatrix} a_{Ii} \\ a_{Ci} \\ a_{Ni} \end{bmatrix} = [J_i]\,[C] \begin{bmatrix} a_X \\ a_Y \\ a_Z \end{bmatrix}$$

The 1x8 matrix $[\gamma_i]$ is a statement of the proof mass accelerometer error model with unit coefficients. In Block III-3.4, $[\gamma_i]$ is scaled by the constants K_9, K_{10}, . . . , K_{16}. This scaled product is then the acceleration error for each unit independent error source.

$$[\gamma_i] = [1 \ \vdots\ a_{Ii} \ \vdots\ a_{Ii}^2 \ \vdots\ a_{Ii}\,a_{Ci} \ \vdots\ a_{Ci} \ \vdots\ -a_{Ni} \ \vdots\ 0 \ \vdots\ 0\,]$$

III-3.4 RESULTING ACCELERATION ERRORS IN THE REFERENCE PCI COORDINATE SYSTEM

The 1x8 matrices $[\gamma_i]$ are scaled by K_9, K_{10}, . . . , K_{16} to define the acceleration errors for each unit error source. The resulting acceleration errors are in instrument coordinates and are then transformed to the reference PCI coordinates. This computation is performed for each accelerometer (i = 1, 2, 3).

INPUT:

$[C]$ - Block III-1

$[J_1]$, $[J_2]$, $[J_3]$ - Block B-3

$[\gamma_1]$, $[\gamma_2]$, $[\gamma_3]$ - Block III-3

K_9, K_{10}, . . . , K_{16} - Block A

OUTPUT:

$[G_{24}]$, $[G_{25}]$, $[G_{26}]$ (3, 8)

$$G_{2(3+i)} = [C]^T [J_i]^T \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} [\gamma_i] \begin{bmatrix} K_9 & & 0 \\ & \ddots & \\ 0 & & K_{16} \end{bmatrix}$$

(Diagonal Matrix)

III-4. 0 ERROR DUE TO INITIAL MISALIGNMENT OF INSTRUMENT PACKAGE

The initial misalignments are measured in a coordinate system which is related to the reference PCI coordinate system by the [V] matrix. The PCI acceleration errors for unit misalignments are computed here.

INPUT: [V] (3, 3) - Block B. 3

$(a_X \; a_Y \; a_Z)$ (3 ,1) - Block I

K_{17}, K_{18}, K_{19} - Block A

OUTPUT: $[G_{27}]$ (3, 3)

$$[G_{27}] \, (3,3) = \begin{bmatrix} 0 & -a_Z & a_Y \\ a_Z & 0 & -a_X \\ -a_Y & a_X & 0 \end{bmatrix} \begin{bmatrix} V^T \end{bmatrix} \begin{bmatrix} K_{17} & 0 & 0 \\ 0 & K_{18} & 0 \\ 0 & 0 & K_{19} \end{bmatrix}$$

III-5.0 ARRANGEMENT OF ACCELEROMETER, GYRO, AND INITIAL MISALIGNMENT ERROR MATRICES INTO THE FINAL G MATRIX

The acceleration error due to unit, independent error sources of the three gyros, three accelerometers and the initial misalignments are assembled into a single 3, 51 matrix, [G]. These acceleration errors are expressed in the reference PCI coordinate system.

INPUT: $[G_{21}]$, $[G_{22}]$, $[G_{23}]$ (3, 8) - Block III-2.6
$[G_{24}]$, $[G_{25}]$, $[G_{26}]$ (3, 8) - Block III-3.4
$[G_{27}]$ (3, 3) - Block III-4.0

OUTPUT: $[G]$ (6, 51)

$$[G] = \left[\begin{array}{c|c|c|c|c|c|c} \multicolumn{7}{c}{0\ (3, 51)} \\ \hline G_{21} & G_{22} & G_{23} & G_{24} & G_{25} & G_{26} & G_{27} \end{array}\right] (6, 51)$$

III-6.0 SELECTION OF STATE TRANSITION MATRIX AND CALCULATION OF VELOCITY AND POSITION ERRORS

A simplified state transition matrix is defined in this block. The value of FLAG F is used as a criteria for selecting either this simplified model or the more complex state transition matrix computed in Block II and inputted to Block III on the reference trajectory tape. The matrix [Q] (6,51) of position and velocity errors is obtained by integrating the transformed [G] matrix.

INPUT:

[G(t)] (6,51) - Block III-5

$\Phi^{-1}(t, t_0)$ (6, 6) - Block II

t_0, FLAG F - Block A

OUTPUT:

[Q] (6,51)

$\Phi_1^{-1}(t, t_0)$ (6,6)

$$\Phi_1^{-1}(t, t_0)(\text{Block III}) = \left[\begin{array}{ccc|ccc} 1 & 0 & 0 & -(t-t_0) & 0 & 0 \\ 0 & 1 & 0 & 0 & -(t-t_0) & 0 \\ 0 & 0 & 1 & 0 & 0 & -(t-t_0) \\ \hline 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{array}\right]$$

$$\text{Select } \Phi_1^{-1}(t, t_0) = \Phi_1^{-1}(t, t_0)(\text{Block II}) \quad \text{FLAG F} = 1$$

$$= \Phi_1^{-1}(t, t_0)(\text{Block III}) \quad \text{FLAG F} = 0$$

$$Q = \int_{t_0}^{t_f} \Phi_1^{-1}(t, t_0)\, G(t)dt$$

III-7 COVARIANCE MATRIX OF VELOCITY AND POSITION ERRORS; MAGNITUDES AND DIRECTION COSINES OF THE PRINCIPAL AXES OF POSITION AND VELOCITY ERROR ELLIPSOIDS

The calculation of the covariance matrix of position and velocity errors at the final point of the reference powered trajectory is done in this block. The initial covariance matrix of position and velocity errors, $[P_0]$, is combined with the scaled position and velocity errors resulting from inertial guidance system error budget. The eigenvalues and eigen vectors of the submatrices P_{11} and P_{22} are computed to define the magnitude and direction of the principal axes of the position and velocity error ellipsoids. These values and the [P] matrix are outputted in the reference PCI coordinate system.

INPUT: [Q] (6,51) - Block III-6 $\vec{r}$ - Block A

λ_i $i = 1, 2, \ldots, 51$ - Block A $\vec{V}$ - Block A

$[P_0]$ (6,6) - Block A

$\Phi_1^{-1}(t_f, t_o)$ (6,6) - Block III-6

OUTPUT: [P] (6,6), $[\Phi_2(t_f,t_o)]$ (6,51), $[P_{INP}]$ (6,6)

EP11, EP12, EP13	$\sqrt{LP1}$	$EP_{INP}11$, $EP_{INP}12$, $EP_{INP}13$	$\sqrt{LP_{INP}1}$
EP21, EP22, EP23	$\sqrt{LP2}$	$EP_{INP}21$, $EP_{INP}22$, $EP_{INP}23$	$\sqrt{LP_{INP}2}$
EP31, EP32, EP33	$\sqrt{LP3}$	$EP_{INP}31$, $EP_{INP}32$, $EP_{INP}33$	$\sqrt{LP_{INP}3}$
EV11, EV12, EV13	$\sqrt{LV1}$	$EV_{INP}11$, $EV_{INP}12$, $EV_{INP}13$	$\sqrt{LV_{INP}1}$
EV21, EV22, EV23	$\sqrt{LV2}$	$EV_{INP}21$, $EV_{INP}22$, $EV_{INP}23$	$\sqrt{LV_{INP}2}$
EV31, EV32, EV33	$\sqrt{LV3}$	$EV_{INP}31$, $EV_{INP}32$, $EV_{INP}33$	$\sqrt{LV_{INP}3}$

COMPUTE:

$$\Phi_2(t_f, t_o) = \Phi_1(t_f, t_o) \int_{t_o}^{t_f} \Phi_1^{-1}(t, t_o)\, G(t)dt$$

$$[P](6,6) = \Phi_1(t_f, t_o)\,[P_o]\,\Phi_1^T(t_f, t_o) + \Phi_2(t_f, t_o)\begin{bmatrix} \lambda_1 & & 0 \\ & \ddots & \\ 0 & & \lambda_{51} \end{bmatrix}\Phi_2^T(t_f, t_o)$$

$$[P] = \begin{bmatrix} P_{11}(3,3) & \vdots & P_{12}(3,3) \\ \cdots\cdots\cdots & \vdots & \cdots\cdots\cdots \\ P_{21}(3,3) & \vdots & P_{22}(3,3) \end{bmatrix}$$

$$\vec{U}_p = \frac{\vec{r} \times \vec{V}}{|\vec{r} \times \vec{V}|} \qquad \begin{bmatrix} \vec{U}_v \\ \vec{U}_p \\ \vec{U}_r \end{bmatrix} = [INP] \begin{bmatrix} \vec{i} \\ \vec{j} \\ \vec{k} \end{bmatrix}$$

$$\vec{U}_r = \frac{\vec{r}}{|\vec{r}|}$$

$$\vec{U}_v = \vec{U}_p \times \vec{U}_r \qquad \left[P_{INP}\right] = \left[\begin{array}{c|c} INP & 0 \\ \hline 0 & INP \end{array}\right] [P] \left[\begin{array}{c|c} INP^T & 0 \\ \hline 0 & INP^T \end{array}\right]$$

FIND:

1. eigenvectors of $[P_{11}]$ (3,3)

   EP11, EP12, EP13
   EP21, EP22, EP23
   EP31, EP32, EP33

2. each of the eigenvalues associated with the eigenvectors of $[P_{11}]$ (3,3)

   LP1, LP2, LP3

3. eigenvectors of $[P_{22}]$ (3,3)

   EV11, EV12, EV13
   EV21, EV22, EV23
   EV31, EV32, EV33

4. each of the eigenvalues associated with the eigenvectors of $[P_{22}]$ (3,3)

   LV1, LV2, LV3

5. the principal axes of the position error ellipsoid

   $\sqrt{LP1}$, $\sqrt{LP2}$, $\sqrt{LP3}$

6. the principal axes of the velocity error ellipsoid

   $\sqrt{LV1}$, $\sqrt{LV2}$, $\sqrt{LV3}$

Same (1 through 6.) for $[P_{INP}]$

III-8 BUDGET SET UP

This block reads in the new budget, $[P_0]$ matrix and heading and repeats block III-7.

4.0 USER'S GUIDE: BLOCK III

4.1 INTRODUCTION AND SUMMARY

A guide to the use of simulation program 117.1, Block III, is presented. Program 117.1 provides the capability for the error analysis of an all-inertial guidance system during a boost trajectory. The boost trajectory data is assumed to be previously generated by program 118.0 or other programs. The guide gives a detailed explanation of the input required to specify the type of guidance system, inertial instrument error model, inertial instrument orientation, acceleration and angular rate environment and error budget.

The program outputs are the position and velocity errors at the end of the boost trajectory, both in the form of a covariance matrix and as position and velocity errors due to each of 51 independent error sources. The covariance matrix is presented in both the PCI coordinate system and in a downrange, crossrange, altitude coordinate system. An example case is included to illustrate the use of the program.

The function of Program 117.1 is to calculate a statistical estimate of the velocity and position errors due to the use of an all-inertial guidance system during a reference powered trajectory. The existence of a magnetic tape record of the reference powered trajectory as generated by Program 118.0 will be assumed.

References will be made to the input sheets for Block III, as well as to the block diagrams and equations of the program.

4.2 PROCEDURE

The program requires that the user select and define by input the following:

1. Type of inertial guidance system,
2. Type of gyros and accelerometers,
3. Geometrical orientation of the space booster, the platform, and the instruments in a reference planet centered inertial coordinate system (PCI).
4. Covariance matrix of initial position and velocity errors,
5. Reference trajectory,
6. Program control parameters.

These quantities are defined by entering the appropriate input on the set of 17 input sheets.

It is the purpose of this guide to clarify and emphasize the program requirements in terms of the actual input quantities in order to assist the program user to achieve the desired and correct program operation.

4.2.1 Input Sheets

All input data, except for the magnetic tape trajectory record, is entered on the set of 17 input sheets. A complete data deck, as defined by the input sheets, is required for the first run of a set. Additional runs only require the input of the data that is different from the input of the preceding run.

The integer in column 1 specifies the data array and the integer in columns 3,4 and 5 specifies the location of each input in the array. Data may be input in floating point with or without exponential notation in columns 11 through 72 using the existing forms provided. The data may also be entered in octal form by changing the "DEC" to "OCT". Data words are separated but not terminated by commas (,) and an optional asterisk (*) or column 73 will terminate data on a card. Data words are read into consecutive locations in an array.

The input sheets contain tabular input for the Euler angles $\eta_1(t)$, $\eta_2(t)$, $\eta_3(t)$ and the angular rates $\omega_1(t)$, $\omega_2(t)$, and $\omega_3(t)$. For every system configuration, gimballed, strapdown or carousel, a minimum input is required in these tables. The minimum input consists of t_{min}, t_{max}; and four data points, t_{min}, X, t_{max}, Y; where X and Y are arbitrary values for inertial or strapdown systems. For carousel systems, up to 27 time points can be entered, and they need not be at uniform time intervals. The last table entry should be selected at the time $t = t_{max} \geq t_f$.

4.2.2 System Specification

The selection of the type of inertial guidance system is made by the input Flag A (page 17 of input sheets). This flag defines the manner in which the inertial measurement unit (IMU) is oriented and the angular velocity environment of the IMU. For a gimballed system, Flag A = 0; for a strapdown system, Flag A = 1; for a carousel system, Flag A = 2. Flag entries are a decimal integral value and if a value not specified by the program is entered an error return results and the computer run is terminated.

4.2.3 Inertial Instrument Selection

The selection of the instrument error model, corresponding to the type of inertial instrument specified, is accomplished by setting Flags B through E (page 17 of input sheets). The values of the flags for different instruments are shown in the Level II and III flow charts and in the Input Data listing. The instrument error models consist of drift rate error equations for the gyros and acceleration error equations for the accelerometers. Flag entries are a decimal integral value and if a value not specified by the program is entered an error return results and the computer run is terminated.

In the present program formulation, there are no two-degree-of-freedom gyro error models, but the program control has provision for the inclusion of such models. Two instrument-dependent parameters, K_o and K'_1, are entered on page 1 of the input sheets. K_o is a rate gyro parameter related to the effective spring restraint on angular motion about the output axis. $K_o = 0$ corresponds to an infinitely stiff spring constraint. K'_1 is a PIGA parameter relating acceleration error to that component of cross and normal axis angular rates sensed by the input axis when an input axis misalignment is present. The value of K'_1 is the acceleration scale factor of the PIGA, with nominal units of $(\text{ft/sec}^2)/(\text{rad/sec})$.

The selection of instrument error models appropriate to various trajectories is left to the engineer's judgment.

4.2.4 Geometrical Orientations

4.2.4.1 Reference Inertial Coordinates to Reference IMU Coordinates

The relationship between the planet-centered inertial coordinates (PCI) and the reference IMU axes is specified in three different manners, depending upon the value of Flag A. The reference IMU axes are a right-handed orthogonal triad labeled [pitch, yaw, roll].

If Flag A = 0, a gimballed system is specified and the transformation from PCI coordinate to IMU reference coordinates is given by the matrix $[A_4]$. $[A_4]$ is input to the 117.1 program from the reference trajectory tape. $[A_4]$ relates the PCI coordinates to the initial (t = 0) orientation of the pitch, yaw, and roll axes of the space booster. These orientations are controlled by space booster input. The A_4 matrix is a constant matrix and hence simulates the function of a gyro-stabilized gimballed IMU.

If Flag A = 1, a strapdown system is specified and the relationship between PCI coordinates and the reference IMU coordinates is time varying. The time-varying matrix is defined in Block III-1 and is a function of three Euler angles: $\Gamma_1, \Gamma_2, \Gamma_3$, and the matrix $[A_4]$. The Euler angles are the gimbal angles of a three-gimbal platform and are input to the program from the reference trajectory tape. The angular rate environment of the IMU is also input to the program from the reference trajectory tape as angular rates about the reference IMU coordinate axes.

If Flag A = 2, a carousel system is specified and the attitude of the IMU reference coordinate is defined by the same time-varying matrix as for a strapdown system, except that the Euler angles are not specified by the program user as time-varying tabular input of the Euler angles, $\eta_1 = \Gamma_1$; $\eta_2 = \Gamma_2$; and $\eta_3 = \Gamma_3$. In addition, the

the inertial angular rates about the reference IMU coordinates are also inputted as tabular functions of time. There is one constraint when using this mode, that the time history of the Euler angles is consistent with the tabular inputted angular rate.

4.2.4.2 IMU Reference Coordinates and Inertial Instrument Coordinates

The rotational transformations relating individual inertial instrument reference axes to the reference IMU coordinates are constant transformations. There are three transformations for the three gyros $[M_i]$, and three transformations $[J_i]$ for the three accelerometers. Each transformation is defined by three Euler angles; hence a total of 18 Euler angles are needed to define the orientation of a set of three gyros and three accelerometers. Each instrument has a right-handed orthogonal triad associated with it: the gyro's triad is (input, output, spin); the accelerometer triad is (input, cross, normal). These transformations are defined in the Initialization Block B. 3.

4.2.4.3 Initial Alignment Coordinate System

In specific system applications, initial alignment errors are specified in a coordinate system of convenience; e.g., a prism mirror, theodolite system that is not aligned with any of the preceding coordinate systems. The transformation [V], also defined in Initial System Block B, relates the PCI system to the coordinate system in which the misalignment angles are given. The $[A_4]$ matrix and three Euler angles are used to define the [V] transformation.

4.2.5 Initial Covariance Matrix P_o and Error Budgets

4.2.5.1 Initial Covariance Matrix $[P_o]$

The covariance matrix $[P_o]$ of initial position and velocity errors can be inputted directly on the input sheets. The units of P_o elements are designated on the input sheets and are specified in the PCI coordinate system.

4.2.5.2 Error Budget

The error budget input consists of two parts: the first is the set of 19 conversion constants $K_1 \ldots . K_{19}$ which are used to scale and properly dimension the drift rate error matrices $[\varphi_1]$, $[\varphi_2]$, and $[\varphi_3]$; and the acceleration error matrices $[\gamma_1]$, $[\gamma_2]$, and $[\gamma_3]$. These 19 conversion contants must be consistent with the units of the error budget proper, $\lambda_1 \ldots . \lambda_{51}$; e.g. (meru's)^2, μg's^2 [degrees/hr/g)]^2, [arc-seconds]^2, etc. The use of conversion constants permits the error budget to be entered directly in convenient units. This convenience puts an added responsibility on the program user, but use of the program at AC Electronics has justified this procedure. For this reason, the units for $K_1, \ldots , K_{19}$ and $\lambda_1 \ldots . \lambda_{51}$ are not specified on the input sheets. The error budget values are entered as variances (σ^2), not as standard deviations (1σ). In general, K_i is of the form A/B where A provides the correct dimension, either rad/sec or ft/sec^2 to an element of the error matrix; and B is the scaling into units of the 1σ error source.

4.2.6 Reference Trajectory and State Transition Matrix Definition

4.2.6.1 Reference Trajectory

The interface with the reference trajectory is only concerned with the selection of the proper reel of tape, which is a function of the computing facility procedure and the selection of the desired trajectory on that reel of tape, since several reference trajectories can be recorded on the same reel of tape. Such trajectory selection is made by a run number identification and requires a coordination of information between the user of the error analysis portion of 117.1 and whoever has made the reference trajectory tape. The run number must be a decimal integral value r, $1. \leq r < 100.$ and is entered on the input sheet on page 1.

4.2.6.2 State Transition Matrix

Flag F is used to select the state transition matrix model used in the calculations: Flag F = 1, selects a state transition matrix that is input on the reference trajectory tape. This state transition matrix is formulated for the reference trajectory in an inverse square, spherically symmetric, planet-centered gravitational field. This formulation supplies what is termed "gravity feedback" in the calculation of the covariance matrix P.

Flag F = 0 selects a simplified format for the state transition matrix, which is calculated in Block III-6 of 117.1. This state transition matrix is constant with respect to position and does not provide a coupling of position errors into gravity errors, as does the alternate formulation. The input t_0 (sheet 1) is used in this matrix and is set equal to the time of the first trajectory record, which will, in general, be zero.

The use of Flag F = 1 is recommended as it will always provide the most accurate result and its use does not increase computer run time.

4.2.7 Program Control

Input other than data specifying the physical system and its environment is classed as program control data. Program control type data are the Rank, heading, Δt, t_f, N, Flag G, Flags 1 through 7, BUDGETS, PUNCH, and TAPE option.

The Rank input controls the amount of printed output and is discussed in Section 3.0 Δt is the input integration step size and is functionally related to the input N. N is an integral number input which prescribes the number of reference trajectory data points which are skipped as input to the program. For example, N = 1 will control the reading of the reference trajectory tape so as to input the first, third, fifth, seventh, etc. data points on the tape to the program. N = 3 will input the first, fifth, ninth, etc. reference trajectory data points. The integration routine in the program will select the minimum (Δt, time between input data points) as the actual integration step size.

Therefore, it is usually satisfactory to set Δt equal to the time interval between nominal input data points of the reference trajectory. If a carousel system is employed, it may be necessary to decrease Δt to accurately integrate over the inputted tabular values of η_1, η_2, η_3, ω_1, ω_2, and ω_3.

The computer time used by 117. 1 is proportional to the actual integration step size defined by a Δt and N. Values of Δt and N, resulting in integration step sizes of 2 to 8 seconds have been found satisfactorily accurate for various space booster trajectories at AC Electronics. Larger Δt's are used when the trajectory has acceleration and angular rates that have small variations in magnitude and direction. The large acceleration discontinuities at staging may be skipped if $N \neq 0$. It is recommended that $N = 0$ for any space booster trajectories that involve staging.

The final time t_f is nominally set to the last time on the reference trajectory record. In certain cases, it is extremely difficult to stop the reference trajectory run at the terminal condition desired, hence a procedure of letting the run proceed beyond this condition is used. An examination of the trajectory record determines the time at which the desired terminal condition is met and this value is used as t_f in Block III input. t_f need not be a reference trajectory record time; any time less than or equal to the final record time is the only criterion for t_f.

Flag G controls the output print of Φ_2 (t_o, t_f). This print is not controlled by Rank input.

Flags 1 to 7 control data dumps at various points in the program cycle. Flags 1 to 6 set equal to 1. will trigger a data dump after each calculation of Blocks III-I to III-6, respectively. These dumps occur at each integration step. (See Level II Flow Chart in Preliminary Program Description.) Flag 7 = 1 will trigger a data dump after Block III-7 which occurs once only for each run. Flags 1 to 7 are used primarily for a programmer's diagnostic purposes, although Flag 7 can also be used to obtain calculated data that is not in the regular output.

BUDG specifies the number of budgets to be used on a single specified system and a single trajectory. This input is only necessary on the first run of the set. (BUDG $\geq$ 1.) This option allows varying budgets without integrating through the entire trajectory each time.

The punch option provides data output on cards of the final P-matrix or the Φ_2 matrix or both. An input of 0 means no punched cards desired, 1. provides the P-matrix only, 2. provides the Φ_2 matrix only and 3. provides both. The P-matrix (6x6) is output row wise 3 to a card and the Φ_2 matrix (6x51) is output column wise 3 to a card.

The tape option provides a means for reading the tape only, performing the error analysis only or both. An input of 1. provides the error analysis only, 2. provides reading and printing of the tape only and 3. provides both.

The second type of input required are the computer control cards.

At the end of each data set is an "END" card and at the end of final data set a "FIN" card is also used. The runs can be stacked with the very first run consisting of a complete input deck as specified by the input forms. Succeeding input need only be the data which is different from the preceding run. When the budget option is used, succeeding data can consist of a heading and changed budget inputs only.

The sequence of runs to be made by stacking input in this fashion must utilize reference trajectories that are all on one tape.

4.2.8 Program Output

The program printed output is controlled by the Rank input. The printed output carries a Rank value with its descriptive title. For Rank = 0., the output consists of t_f, $[\varphi_1]$ (3x8), $[\varphi_2]$ (3x8), $[\varphi_3]$ (3x8), P(6x6), the magnitude and direction cosines of the principle axes for both the position and velocity error ellipsoids, the P_{INP} (6x6) and its associated error ellipsoids.

For Rank = 1., the punched card input is printed in addition to the output for Rank = 0. For Rank = 2., the $[A_4]$ matrix and the actual data points used from the reference trajectory tape are printed in addition to the output for Rank = 1.

The arrangement of output and the titles are self-explanatory with the possible exception of the direction cosines of the principle axes. The direction cosines are listed directly below the corresponding magnitude and are ordered in an X, Y, Z sense. These cosines are defined with respect to the reference PCI coordinate system for the [P] (6x6) and with respect to the downrange, crossrange, altitude system (defined by the final position and velocity vectors) for the $[P_{INP}]$ (6x6).

4.2.9 Example

As an example of the use of program 117.1, two runs, selected from tradeoff studies of strapdown inertial guidance systems, will be described in detail. The reference powered trajectory is a deboost maneuver prior to earth atmospheric re-entry. The trade-off studies varied error budget magnitudes and type of gyros to determine the relationship to re-entry accuracy. A copy of the program output for this example is given in Paragraph 4.2.9.7.

4.2.9.1 Guidance System Specification

A strapdown system is specified by setting Flag A = 0.

4.2.9.2 Inertial Instrument Specification

A proof mass accelerometer model was selected by setting Flag E = 2. Single-degree-of-freedom gyros were selected by setting Flag B = 1. Two types of gyros were compared in the tradeoff studies. One run for each type is included in the attached example. The first run uses a single-degree-of-freedom platform gyro (Flag D = 3), the second run uses a rate gyro (Flag D = 2). The rate gyro parameter K_0 was set equal to zero. Flag C is set to 1.0 to avoid an error return as 0 is an illegal entry for Flag C.

4.2.9.3 Orientation Geometry

In the strapdown system, the orientation of the IMU reference coordinate system is done automatically by the program as it selects the gimbal angles from the trajectory tape as values for the Euler angles Γ_1, Γ_2, and Γ_3 which define $[C']$ (3,3). The engineer must define the orientation of the six inertial instruments with respect to the IMU reference coordinates by inputting six sets of Euler angles; α_{i1}, α_{i2}, α_{i3} (i = 1,2,3) for the three gyros and ψ_{i1}, ψ_{i2}, ψ_{i3} (i = 1,2,3) for the three gyros. In these example runs, instrument orientations along the reference body axes were defined by choosing the values given in Table 1. The units of angle are radians. These values were determined by aligning the I, O, S axes for gyros or the I, C, N axes for accelerometers along the P_{IO}, Y_{AO}, R_{OO} axes, respectively, and defining a set of Euler angle rotations which result in the desired orientation with respect to the P_{IO}, Y_{AO}, R_{OO} axes. The orientations defined in Table 1 puts the input axis of gyro No. 1 along the roll axis, gyro No. 2 input axis along the pitch axis, and gyro No. 3 input axis along the yaw axis. The accelerometers have the same orientation.

	GYROS			ACCELEROMETERS		
i	α_{i1}	α_{i2}	α_{i3}	ψ_{i1}	ψ_{i2}	ψ_{i3}
1	0.	-1.5707963	0.	0	-1.5707963	0
2	0.	0.	1.5707963	0	0	1.5707963
3	1.5707963	0.	1.5707963	1.5707963	0	1.5707963

Table 1

The initial misalignment axes were selected to be the P_{IO}, Y_{AO}, R_{OO} axes by setting $\beta_{11} = \beta_{12} = \beta_{13} = 0$. A minimum input of 4 entries is required in the tables for $\eta_1(t)$, $\eta_2(t)$, $\eta_3(t)$, $\omega_1(t)$, $\omega_2(t)$, and $\omega_3(t)$ to avoid error return on table reading logic.

4.2.9.4 Initial Covariance

The initial errors in position and velocity were defined to be zero by setting each element of $[P_o]$ equal to zero in the input sheets.

4.2.9.5 Error Budget and Conversion Constants

The specification of values for the error budget variances $\lambda_1, \ldots, \lambda_{51}$, and the conversion constants is dependent upon the units selected for the error budget. The basic unit of gyro drift error budget was selected to be the meru [1/1,000 of earth angular rate, equivalent to 0.015 degrees/hour]; the basic unit of accelerometer error was selected to be the μg [$(1/10^6)(32.174 \text{ ft/sec}^2)$]; and the arc-second is the unit of angular misalignment. With these as basic units, the error budget units are:

GYRO

$\lambda_1 \rightarrow (\text{meru})^2$	bias drift rate
$\lambda_2 \rightarrow (\text{meru/g})^2$	mass unbalance
$\lambda_3 \rightarrow (\text{meru/g})^2$	mass unbalance
$\lambda_4 \rightarrow (\text{meru/g}^2)^2$	anisoelasticity
$\lambda_5 \rightarrow (\text{arc-sec})^2$	input axis misalignment
$\lambda_6 \rightarrow (\text{arc-sec})^2$	input axis misalignment
$\lambda_7 \rightarrow (10^{-6})^2$	rate gyro scale factor uncertainty
$\lambda_8 \rightarrow [10^{-6}/(\text{rad/sec})]^2$	rate gyro nonlinearity
$\lambda_9 \rightarrow \lambda_{16}$	second gyro
$\lambda_{17} \rightarrow \lambda_{24}$	third gyro

ACCELEROMETER

$\lambda_{25} \rightarrow (\mu\text{g})^2$	bias acceleration error
$\lambda_{26} \rightarrow (\mu\text{g/g})^2$	scale factor uncertainty

$\lambda_{27} \rightarrow (\mu g/g^2)^2$	input axis nonlinearity
$\lambda_{28} \rightarrow (\mu g/g^2)^2$	cross axis nonlinearity
$\lambda_{29} \rightarrow (\text{arc-sec})^2$	input axis misalignment
$\lambda_{30} \rightarrow (\text{arc-sec})^2$	input axis misalignment
$\lambda_{31} = 0$	for proof mass accelerometer
$\lambda_{32} = 0$	for proof mass accelerometer
$\lambda_{33} \rightarrow \lambda_{40}$	second accelerometer
$\lambda_{41} \rightarrow \lambda_{48}$	third accelerometer

INITIAL MISALIGNMENTS

$\lambda_{49}, \lambda_{50}, \lambda_{51} \rightarrow (\text{arc-sec})^2$

With this choice of units, the values of $K_1 \rightarrow K_{19}$ are:

$$K_1 = \frac{7.2921149 \text{ x } 10^{-5}}{1000} = 7.2921149 \text{ x } 10^{-8} \text{ (rad/sec)/meru}$$

$$K_2 = \frac{7.2921149 \text{ x } 10^{-5}}{(1000)(32.174)} = 2.2646320 \text{ x } 10^{-9} \text{ (rad/sec)/(meru/g)}$$

$$K_3 = K_2 = 2.2646320 \text{ x } 10^{-9} \text{ (rad/sec)/(meru/g)}$$

$$K_4 = \frac{7.2921149 \text{ x } 10^{-5}}{(1000)(32.174)^2} = 7.0330184 \text{ x } 10^{-11} \text{ (rad/sec)/(meru/}g^2\text{)}$$

$$K_5 = K_6 = 4.8481368 \text{ x } 10^{-6} \text{ (rad/sec)/arc-sec}$$

$$K_7 = 10^{-6} \text{ (rad/sec)/(}10^6 \text{ rad/sec)}$$

$$K_8 = 10^{-6} \text{ (rad/sec)/(rad/sec)}^2 \; 10^{-6}\text{/(rad/sec)}$$

$$K_9 = \frac{32.174}{10^6} = 3.2174 \text{ x } 10^{-5} \text{ (ft/sec}^2\text{)/}\mu g$$

$$K_{10} = 10^{-6} \text{ (ft/sec}^2\text{)/(ft/sec}^2\text{)(}\mu g/g\text{)}$$

$$K_{11} = K_{12} = \frac{1}{(32.174) \; 10^6} = 3.1080997 \text{ x } 10^{-8} \text{ (ft/sec}^2\text{)/(ft}^2\text{/sec}^2\text{)(}\mu g/g^2\text{)}$$

$K_{13} = K_{14} = 4.8481368 \times 10^{-6}$ (ft/sec^2)/(ft/sec^2)(arc-sec)

K_{15}, K_{16} (not used in proof mass accelerometer model)

$K_{17} = K_{18} = K_{19} = 4.8481368 \times 10^{-6}$ (rad)/(arc-sec)

The error budget magnitudes that are entered on the input sheet were selected by the engineer, and are entered as variances $(1\sigma)^2$.

4.2.9.6 Program Control

The reference trajectory is characterized by "smooth" behavior of acceleration and angular rates. The data points on the reference trajectory tape are at 2-second intervals. Therefore, a large effective Δt may be used to obtain accurate results. Input values of Δt = 8. and N = 3. were selected to produce an actual machine Δt of 8 seconds as the time interval between input data points is also 8 seconds. $t_o = 0.$ and $t_f = 418.$ were values corresponding to data points on the reference trajectory tape.

A run number corresponding to the run number of the reference tape is input as 6. The input data deck was assembled in the following sequence, since two successive runs were desired.

Data for run 7D-SDF-10-30
END
Data for run 7E-RATE-3-10
END
FIN

4.2.9.7 Output

The actual output for the example just described is reproduced in this paragraph.

The amount of output is controlled by the Rank input which was set to 1.0. This value gave all the output except the print of the reference trajectory data which had previously been recorded. All punched card input is printed and the computed output of $[\omega_i]$ (3x8) (i = 1, 2, 3) and $[P]$ (6, 6) with the principal axes of position and velocity error ellipsoids and their orientations is given; e.g., in the first run the largest position semi-axes is 505.23602 feet, and has direction cosines -0.22361882, 0.83163428, and -0.5083090991 in an X Y Z ordering in the PCI coordinate system.

Flag G was set at 1.0 to obtain an output of $\Phi_2(t_f, t_o)$ (6, 51). This output is actually printed in (51, 6) order to conform to the dimension of machine paper. This matrix shows the position and velocity errors due to the 51 independent error sources.

```
SINGLE  1   1 BCI ,7E RATE GYRO SYSTEM BUDGET 3-10                            DATA0000
SINGLE  2   1 DEC 6.,1.,1.,2.0,0.,8.,418.,0.,3.,1.,0.                          DATA0001
SINGLE  3   1 DEC .72921151E-7,.22646320E-8,.22646320E-3,.70330186E-10         DATA0002
SINGLE  3   5 DEC .48481368E-5,.48481368E-5,1.E-6,1.E-6                        DATA0003
SINGLE  3   9 DEC .3217E-4,1.E-6,.31080997E-7,.31080997E-7                     DATA0004
SINGLE  3  13 DEC .48481368E-5,.48481368E-5,1.E-6,1.E-6                        DATA0005
SINGLE  3  17 DEC .48481368E-5,.48481368E-5,.48481368E-5                       DATA0006
SINGLE  4   1 DEC 36.,225.,31.,36.,36.,36.,25.,640000.                         DATA0007
SINGLE  4   9 DEC 36.,225.,81.,36.,36.,36.,25.,640000.                         DATA0008
SINGLE  4  17 DEC 36.,225.,81.,36.,36.,36.,25.,640000.                         DATA0009
SINGLE  4  25 DEC 10000.,4900.,400.,0.,36.,36.,0.,0.                           DATA0010
SINGLE  4  33 DEC 10000.,4900.,400.,0.,36.,36.,0.,0.                           DATA0011
SINGLE  4  41 DEC 10000.,4900.,400.,0.,36.,36.,0.,0.                           DATA0012
SINGLE  4  49 DEC 900.,900.,900.                                               DATA0013
SINGLE  5   1 DEC 0.,-1.5707963,0.                                             DATA0014
SINGLE  5   4 DEC 0.,0.,1.5707963                                              DATA0015
SINGLE  5   7 DEC 1.5707963,0.,1.5707963                                       DATA0016
SINGLE  5  10 DEC 0.,-1.5707963,0.                                             DATA0017
SINGLE  5  13 DEC 0.,0.,1.5707963                                              DATA0018
SINGLE  5  16 DEC 1.5707963,0.,1.5707963                                       DATA0019
SINGLE  5  19 DEC 0.,0.,0.                                                     DATA0020
SINGLE  6   1 DEC 0.,0.,0.,0.,0.,0.                                            DATA0021
SINGLE  6   7 DEC 0.,0.,0.,0.,0.,0.                                            DATA0022
SINGLE  6  13 DEC 0.,0.,0.,0.,0.,0.                                            DATA0023
SINGLE  6  19 DEC 0.,0.,0.,0.,0.,0.                                            DATA0024
SINGLE  6  25 DEC 0.,0.,0.,0.,0.,0.                                            DATA0025
SINGLE  6  31 DEC 0.,0.,0.,0.,0.,0.                                            DATA0026
SINGLE  7   1 DEC 0.,418.                                                      DATA0027
SINGLE  7   6 DEC 0.,0.,418.,0.                                                DATA0028
SINGLE  7  61 DEC 0.,418.                                                      DATA0029
SINGLE  7  66 DEC 0.,0.,418.,0.                                                DATA0030
SINGLE  7 121 DEC 0.,418.                                                      DATA0031
SINGLE  7 126 DEC 0.,0.,418.,0.                                                DATA0032
SINGLE  7 181 DEC 0.,418.                                                      DATA0033
SINGLE  7 186 DEC 0.,0.,418.,0.                                                DATA0034
SINGLE  7 241 DEC 0.,418.                                                      DATA0035
SINGLE  7 246 DEC 0.,0.,418.,0.                                                DATA0036
SINGLE  7 301 DEC 0.,418.                                                      DATA0037
SINGLE  7 306 DEC 0.,0.,418.,0.                                                DATA0038
SINGLE  8   1 DEC 1.,1.,1.,2.,2.,1.,1.                                         DATA0039
SINGLE  9   1 DEC 0.,0.,0.,0.,0.,0.,0.                                         DATA0040
                END                                                            DATA0041
```

```
          7E RATE GYRO SYSTEM BUDGET 3-10                                                        PAGE  1

1DELTA T         1T FINAL          1K*1 PRIME        1N                1RANK             1K*0
 0.80000000E 01   0.41800000E 03    0.00000000E-38    0.30000000E 01    0.10000000E 01   -0.00000000E-19

1T*0             1RUN              1BUDGETS          1PUNCH OPT        1TAPE OPT
 0.00000000E-38   0.60000000E 01    0.10000000E 01    0.00000000E-38    0.10000000E 01

1K*1             1K*2              1K*3              1K*4              1K*5              1K*6
 0.72921151E-07   0.22646320E-08    0.22646320E-08    0.70330185E-10    0.48481368E-05    0.48481368E-05

1K*7             1K*8              1K*9              1K*10             1K*11             1K*12
 0.10000000E-05   0.10000000E-05    0.32170000E-04    0.10000000E-05    0.31080997E-07    0.31080997E-07

1K*13            1K*14             1K*15             1K*16             1K*17             1K*18
 0.48481368E-05   0.48481368E-05    0.10000000E-05    0.10000000E-05    0.48481368E-05    0.48481368E-05

1K*19
 0.48481368E-05

1LAMBDA* 1       1LAMBDA* 2        1LAMBDA* 3        1LAMBDA* 4        1LAMBDA* 5        1LAMBDA* 6
 0.36000000E 02   0.22500000E 03    0.81000000E 02    0.36000000E 02    0.36000000E 02    0.36000000E 02

1LAMBDA* 7       1LAMBDA* 8        1LAMBDA* 9        1LAMBDA*10        1LAMBDA*11        1LAMBDA*12
 0.25000000E 02   0.64000000E 06    0.36000000E 02    0.22500000E 03    0.81000000E 02    0.36000000E 02

1LAMBDA*13       1LAMBDA*14        1LAMBDA*15        1LAMBDA*16        1LAMBDA*17        1LAMBDA*18
 0.36000000E 02   0.36000000E 02    0.25000000E 02    0.64000000E 06    0.36000000E 02    0.22500000E 03

1LAMBDA*19       1LAMBDA*20        1LAMBDA*21        1LAMBDA*22        1LAMBDA*23        1LAMBDA*24
 0.81000000E 02   0.36000000E 02    0.36000000E 02    0.36000000E 02    0.25000000E 02    0.64000000E 06

1LAMBDA*25       1LAMBDA*26        1LAMBDA*27        1LAMBDA*28        1LAMBDA*29        1LAMBDA*30
 0.10000000E 05   0.49000000E 04    0.40000000E 03    0.00000000E-38    0.36000000E 02    0.36000000E 02

1LAMBDA*31       1LAMBDA*32        1LAMBDA*33        1LAMBDA*34        1LAMBDA*35        1LAMBDA*36
 0.00000000E-38   0.00000000E-38    0.10000000E 05    0.49000000E 04    0.40000000E 03    0.00000000E-38

1LAMBDA*37       1LAMBDA*38        1LAMBDA*39        1LAMBDA*40        1LAMBDA*41        1LAMBDA*42
 0.36000000E 02   0.36000000E 02    0.00000000E-38    0.00000000E-38    0.10000000E 05    0.49000000E 04

1LAMBDA*43       1LAMBDA*44        1LAMBDA*45        1LAMBDA*46        1LAMBDA*47        1LAMBDA*48
 0.40000000E 03   0.00000000E-38    0.36000000E 02    0.36000000E 02    0.00000000E-38    0.00000000E-38

1LAMBDA*49       1LAMBDA*50        1LAMBDA*51
 0.90000000E 03   0.90000000E 03    0.90000000E 03
```

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                 ZE RATE GYRO SYSTEM BUDGET 3-10                                                    PAGE  2

          1ALPHA MATRIX(3X3)

          1ALPHA*1,1           1ALPHA*1,2           1ALPHA*1,3
           0.00000000E-38      -0.15707963E 01       0.00000000E-38

          1ALPHA*2,1           1ALPHA*2,2           1ALPHA*2,3
           0.00000000E-38       0.00000000E-38       0.15707963E 01

          1ALPHA*3,1           1ALPHA*3,2           1ALPHA*3,3
           0.15707963E 01       0.00000000E-38       0.15707963E 01

          1PSI MATRIX(3X3)

          1PSI*1,1             1PSI*1,2             1PSI*1,3
           0.00000000E-38      -0.15707963E 01       0.00000000E-38

          1PSI*2,1             1PSI*2,2             1PSI*2,3
           0.00000000E-38       0.00000000E-38       0.15707963E 01

          1PSI*3,1             1PSI*3,2             1PSI*3,3
           0.15707963E 01       0.00000000E-38       0.15707963E 01

          1BETA MATRIX(3X3)

          1BETA*1,1            1BETA*1,2            1BETA*1,3
           0.00000000E-38       0.00000000E-38       0.00000000E-38

          1P*0 MATRIX(6X6)

          1P*01,1              1P*01,2              1P*01,3              1P*01,4              1P*01,5              1P*01,6
           0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38

          1P*02,1              1P*02,2              1P*02,3              1P*02,4              1P*02,5              1P*02,6
           0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38

          1P*03,1              1P*03,2              1P*03,3              1P*03,4              1P*03,5              1P*03,6
           0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38

          1P*04,1              1P*04,2              1P*04,3              1P*04,4              1P*04,5              1P*04,6
           0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38

          1P*05,1              1P*05,2              1P*05,3              1P*05,4              1P*05,5              1P*05,6
           0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38

          1P*06,1              1P*06,2              1P*06,3              1P*06,4              1P*06,5              1P*06,6
           0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38

         1FLAG A          1FLAG B          1FLAG C          1FLAG D          1FLAG E          1FLAG F          1FLAG G
          0.10E 01         0.10E 01         0.10E 01         0.20E 01         0.20E 01         0.10E 01         0.10E 01

         1FLAG 1          1FLAG 2          1FLAG 3          1FLAG 4          1FLAG 5          1FLAG 6          1FLAG 7
          0.00E-38         0.00E-38         0.00E-38         0.00E-38         0.00E-38         0.00E-38         0.00E-38
```

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                         7E RATE GYRO SYSTEM BUDGET 3-10                                                        PAGE  3

            1ETA*1 TABLE                               1ETA*2 TABLE                               1ETA*3 TABLE
1INDEP. VARIABLE     1DEPEN. VARIABLE     1INDEP. VARIABLE     1DEPEN. VARIABLE     1INDEP. VARIABLE     1DEPEN. VARIABLE
= 0.00000000E-38                          MIN= 0.00000000E-38                       MIN= 0.00000000E-38
MAX= 0.41800000E 03                       MAX= 0.41800000E 03                       MAX= 0.41800000E 03
2                                         2                                         2
0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38
0.41800000E 03       0.00000000E-38       0.41800000E 03       0.00000000E-38       0.41800000E 03       0.00000000E-38


                         7E RATE GYRO SYSTEM BUDGET 3-10                                                        PAGE  4

            1OMEGA*1 TABLE                             1OMEGA*2 TABLE                             1OMEGA*3 TABLE
1INDEP. VARIABLE     1DEPEN. VARIABLE     1INDEP. VARIABLE     1DEPEN. VARIABLE     1INDEP. VARIABLE     1DEPEN. VARIABLE
0.00000000E-38                            MIN= 0.00000000E-38                       MIN= 0.00000000E-38
AX= 0.41800000E 03                        MAX= 0.41800000E 03                       MAX= 0.41800000E 03
2                                         2                                         2
0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38
0.41800000E 03       0.00000000E-38       0.41800000E 03       0.00000000E-38       0.41800000E 03       0.00000000E-38
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                         7E RATE GYRO SYSTEM BUDGET 3-10                                                            PAGE   5

   OTIME
    0.41800000E 03


   OPHI*1 MATRIX(3X8)

 OPHI*1 1,1      OPHI*1 1,2      OPHI*1 1,3      OPHI*1 1,4      OPHI*1 1,5      OPHI*1 1,6      OPHI*1 1,7      OPHI*1 1,8
  0.237808E-04   -0.272467E-04   -0.808140E-12    0.116704E-11    0.240948E-13    0.139903E-06    0.528075E-12    0.504536E-18

 OPHI*1 2,1      OPHI*1 2,2      OPHI*1 2,3      OPHI*1 2,4      OPHI*1 2,5      OPHI*1 2,6      OPHI*1 2,7      OPHI*1 2,8
 -0.355055E-05    0.380332E-05    0.111031E-12   -0.147573E-12   -0.417469E-13   -0.126734E-07   -0.587656E-13   -0.682418E-19

 OPHI*1 3,1      OPHI*1 3,2      OPHI*1 3,3      OPHI*1 3,4      OPHI*1 3,5      OPHI*1 3,6      OPHI*1 3,7      OPHI*1 3,8
 -0.187205E-04    0.216933E-04    0.645065E-12   -0.943325E-12    0.162516E-13   -0.117717E-06   -0.434242E-12   -0.403720E-18


   OPHI*2 MATRIX(3X8)

 OPHI*2 1,1      OPHI*2 1,2      OPHI*2 1,3      OPHI*2 1,4      OPHI*2 1,5      OPHI*2 1,6      OPHI*2 1,7      OPHI*2 1,8
  0.171344E-04   -0.232692E-14   -0.411801E-09   -0.240500E-17   -0.186460E-11   -0.792781E-14    0.212330E-07    0.474464E-10

 OPHI*2 2,1      OPHI*2 2,2      OPHI*2 2,3      OPHI*2 2,4      OPHI*2 2,5      OPHI*2 2,6      OPHI*2 2,7      OPHI*2 2,8
  0.171002E-04   -0.232230E-14   -0.410980E-09   -0.240021E-17   -0.186088E-11   -0.791309E-14    0.211906E-07    0.473518E-10

 OPHI*2 3,1      OPHI*2 3,2      OPHI*2 3,3      OPHI*2 3,4      OPHI*2 3,5      OPHI*2 3,6      OPHI*2 3,7      OPHI*2 3,8
  0.185227E-04   -0.251545E-14   -0.445167E-09   -0.259987E-17   -0.201568E-11   -0.856954E-14    0.229534E-07    0.512906E-10


   OPHI*3 MATRIX(3X8)

 OPHI*3 1,1      OPHI*3 1,2      OPHI*3 1,3      OPHI*3 1,4      OPHI*3 1,5      OPHI*3 1,6      OPHI*3 1,7      OPHI*3 1,8
  0.834481E-05    0.210928E-09   -0.293229E-12   -0.107022E-16   -0.100447E-11   -0.583394E-07    0.747174E-14    0.106246E-19

 OPHI*3 2,1      OPHI*3 2,2      OPHI*3 2,3      OPHI*3 2,4      OPHI*3 2,5      OPHI*3 2,6      OPHI*3 2,7      OPHI*3 2,8
 -0.249744E-04   -0.600493E-09    0.860051E-12    0.294231E-16    0.273020E-11    0.151189E-06    0.206249E-15   -0.310965E-19

 OPHI*3 3,1      OPHI*3 3,2      OPHI*3 3,3      OPHI*3 3,4      OPHI*3 3,5      OPHI*3 3,6      OPHI*3 3,7      OPHI*3 3,8
  0.153372E-04    0.359260E-09   -0.522752E-12   -0.172634E-16   -0.159134E-11   -0.856115E-07   -0.710254E-14    0.188802E-19
```

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              7E RATE GYRO SYSTEM BUDGET 3-10                                                    PAGE  6

OERRORS IN PCI COORDINATES

OP MATRIX(6X6)-COVARIANCE MATRIX

OP1,1                OP1,2                OP1,3                OP1,4                OP1,5                OP1,6
 0.15672551E 06       0.11496128E 05       0.62149761E 05       0.91453326E 03       0.76941111E 02       0.43985139E 03

OP2,1                OP2,2                OP2,3                OP2,4                OP2,5                OP2,6
 0.11496128E 05       0.24624062E 06      -0.19785539E 05       0.58671564E 02       0.15701243E 04      -0.14151040E 03

OP3,1                OP3,2                OP3,3                OP3,4                OP3,5                OP3,6
 0.62149761E 05      -0.19785538E 05       0.19552987E 06       0.45675865E 03      -0.15840621E 03       0.11858632E 04

OP4,1                OP4,2                OP4,3                OP4,4                OP4,5                OP4,6
 0.91453326E 03       0.58671562E 02       0.45675865E 03       0.56680689E 01       0.41430148E 00       0.33543318E 01

OP5,1                OP5,2                OP5,3                OP5,4                OP5,5                OP5,6
 0.76941113E 02       0.15701242E 04      -0.15840621E 03       0.41430148E 00       0.10573004E 02      -0.11141007E 01

OP6,1                OP6,2                OP6,3                OP6,4                OP6,5                OP6,6
 0.43985139E 03      -0.14151040E 03       0.11858632E 04       0.33543318E 01      -0.11141006E 01       0.75994251E 01



OP*11 POSITION ERROR ELLIPSOID MAGNITUDE OF PRINCIPLE AXES
 0.32836623E 03       0.50521536E 03       0.48521027E 03

ODIRECTION COSINE OF PRINCIPLE AXES
 0.79027893E 00      -0.22362214E 00       0.57048425E 00
-0.15053961E 00       0.83163495E 00       0.53452881E 00
-0.59396715E 00      -0.50830734E 00       0.62355962E 00

OP*14 VELOCITY ERROR ELLIPSOID MAGNITUDE OF PRINCIPLE AXES
 0.17348404E 01       0.33337483E 01       0.31172018E 01

ODIRECTION COSINE OF PRINCIPLE AXES
 0.78472283E 00      -0.24138854E 00       0.57091293E 00
-0.13219017E 00       0.83469362E 00       0.53461412E 00
-0.60558711E 00      -0.49499301E 00       0.62309398E 00
```

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                        7E RATE GYRO SYSTEM BUDGET 3-10                                                   PAGE  7

ODOWNRANGE, CROSSRANGE, ALTITUDE ERRORS

OP MATRIX(6X6)-COVARIANCE MATRIX

OP1,1             OP1,2             OP1,3             OP1,4             OP1,5             OP1,6
 0.10855037E 06    0.74913184E 03    0.10288017E 05    0.56818767E 03    0.50903473E 01    0.71494236E 02

OP2,1             OP2,2             OP2,3             OP2,4             OP2,5             OP2,6
 0.74913379E 03    0.23542463E 06   -0.85859375E 02    0.60427399E 01    0.14676558E 04   -0.67894363E 00

OP3,1             OP3,2             OP3,3             OP3,4             OP3,5             OP3,6
 0.10288018E 05   -0.85861328E 02    0.25452098E 06    0.10156396E 03   -0.74565887E 00    0.16346771E 04

OP4,1             OP4,2             OP4,3             OP4,4             OP4,5             OP4,6
 0.56818767E 03    0.60427494E 01    0.10156396E 03    0.30789905E 01    0.43011442E-01    0.74479152E 00

OP5,1             OP5,2             OP5,3             OP5,4             OP5,5             OP5,6
 0.50903435E 01    0.14676558E 04   -0.74566269E 00    0.43011427E-01    0.97166704E 01   -0.62475801E-02

OP6,1             OP6,2             OP6,3             OP6,4             OP6,5             OP6,6
 0.71494228E 02   -0.67892456E 00    0.16346771E 04    0.74479154E 00   -0.62475502E-02    0.11044836E 02



OP*11 POSITION ERROR ELLIPSOID MAGNITUDE OF PRINCIPLE AXES
 0.32836623E 03    0.48521027E 03    0.50521536E 03

ODIRECTION COSINE OF PRINCIPLE AXES
 0.99753229E 00    0.60064159E-02    0.69951561E-01
-0.59035232E-02    0.99998116E 00   -0.16775578E-02
-0.69960319E-01    0.12604574E-02    0.99754896E 00

OP*14 VELOCITY ERROR ELLIPSOID MAGNITUDE OF PRINCIPLE AXES
 0.17348404E 01    0.31172018E 01    0.33337482E 01

ODIRECTION COSINE OF PRINCIPLE AXES
 0.99571028E 00    0.65924770E-02    0.92290344E-01
-0.64713811E-02    0.99997775E 00   -0.16113229E-02
-0.92298915E-01    0.10071648E-02    0.99573080E 00
```

7E RATE GYRO SYSTEM BUDGET 3-10

OPHI*2(T*F,T*0) MATRIX(6,51) GENERALIZED ERROR INTEGRALS

	OX	OY	OZ	OX DOT	OY DOT	OZ DOT
1	0.23999448E 00	0.23962075E 00	0.25937216E 00	0.47196287E-02	0.47127263E-02	0.51007651E-02
2	-0.19689291E 00	-0.19657832E 00	-0.21279699E 00	-0.41776342E-02	-0.41712567E-02	-0.45151504E-02
3	-0.54473028E-08	-0.54386237E-08	-0.58872707E-08	-0.11669199E-09	-0.11651338E-09	-0.12611978E-09
4	0.48231560E-08	0.48152308E-08	0.52129066E-08	0.11585053E-09	0.11566395E-09	0.12521542E-09
5	0.32606889E-07	0.32574938E-07	0.35222586E-07	0.32203698E-09	0.32193918E-09	0.34781101E-09
6	0.64349693E-03	0.64480299E-03	0.69312082E-03	-0.35637272E-05	-0.35289129E-05	-0.38727875E-05
7	-0.12735067E-07	-0.12723651E-07	-0.13755937E-07	-0.78436295E-10	-0.78509052E-10	-0.84657238E-10
8	0.27477198E-14	0.27429855E-14	0.29699395E-14	0.65640484E-16	0.65533008E-16	0.70948079E-16
9	-0.83034514E 01	0.25333960E 02	-0.15668967E 02	-0.84960933E-01	0.24728887E 00	-0.14915515E 00
10	0.13415948E-07	-0.40671415E-07	0.25088234E-07	0.11738146E-09	-0.34806034E-09	0.21192621E-09
11	0.92187685E-04	-0.28446969E-03	0.17677034E-03	0.10781366E-05	-0.30912417E-05	0.18495369E-05
12	-0.30224912E-14	0.18171629E-13	-0.13859465E-13	0.16013830E-14	-0.41092141E-14	0.23138487E-14
13	-0.91921969E-06	0.29945953E-05	-0.19078012E-05	0.12925282E-08	-0.49947695E-09	-0.64196223E-09
14	0.46020404E-06	-0.14302870E-05	0.89279334E-06	0.23739046E-08	-0.76214109E-08	0.48066637E-08
15	0.19060093E-01	-0.61987576E-01	0.39415870E-01	0.57405174E-04	-0.21058276E-03	0.13930088E-03
16	-0.31845153E-04	0.10022293E-03	-0.62837624E-04	-0.24527664E-06	0.73898042E-06	-0.45259883E-06
17	0.16967032E 02	0.16952102E 02	0.18326373E 02	0.16313894E 00	0.16311174E 00	0.17617920E 00
18	0.18842155E-03	0.18831578E-03	0.20343736E-03	0.20303699E-05	0.20300081E-05	0.21924898E-05
19	-0.43403400E-06	-0.43359722E-06	-0.46886217E-06	-0.47223512E-08	-0.47200405E-08	-0.51008319E-08
20	-0.43340132E-11	-0.43303420E-11	-0.46806402E-11	-0.69123980E-13	-0.69058286E-13	-0.74679281E-13
21	0.19835963E-05	0.19829745E-05	0.21419404E-05	-0.13046488E-08	-0.12520176E-08	-0.14401397E-08
22	0.19737164E 00	0.19738583E 00	0.21297928E 00	0.59745760E-03	0.60135148E-03	0.64242657E-03
23	-0.19944740E-06	-0.19926913E-06	-0.21547491E-06	-0.10063006E-08	-0.10081501E-08	-0.10857114E-08
24	0.15090993E-13	0.15075283E-13	0.16302393E-13	0.16855206E-15	0.16845756E-15	0.18206871E-15
25	0.21651533E 01	-0.30854361E 00	-0.17155103E 01	0.10084820E-01	-0.12043312E-02	-0.81977283E-02
26	-0.18775967E 01	0.26645475E 00	0.14891027E 01	-0.11715094E-01	0.14069950E-02	0.95236098E-02
27	0.18270814E 01	-0.25550850E 00	-0.14529585E 01	0.16485575E-01	-0.19399958E-02	-0.13447491E-01
28	-0.25673615E-04	0.38412273E-05	0.20132362E-04	-0.45388699E-06	0.49336010E-07	0.37417978E-06
29	0.12528659E-03	-0.21173339E-04	-0.96183201E-04	0.11897225E-05	-0.13758270E-06	-0.97251828E-06
30	0.25544335E-06	-0.36034061E-07	-0.20274332E-06	0.16875045E-08	-0.20091800E-09	-0.13735791E-08
31	0.00000000E-38	0.00000000E-38	-0.00000000E-38	0.00000000E-38	0.00000000E-38	-0.00000000E-38
32	0.00000000E-38	0.00000000E-38	-0.00000000E-38	0.00000000E-38	0.00000000E-38	-0.00000000E-38
33	0.15515186E 01	0.15516633E 01	0.16740483E 01	0.72657769E-02	0.72906578E-02	0.78272955E-02
34	-0.23379919E-08	-0.23381155E-08	-0.25233597E-08	-0.57050907E-12	-0.63213226E-12	-0.57606369E-12
35	0.60014410E-16	0.59968306E-16	0.64816950E-16	0.52154300E-18	0.52163212E-18	0.56311922E-18
36	0.16954834E-08	0.16960286E-08	0.18295510E-08	-0.12736538E-10	-0.12660186E-10	-0.13801613E-10
37	-0.65345743E 01	-0.65331177E 01	-0.70530611E 01	-0.41076301E-01	-0.41143628E-01	-0.44304910E-01
38	0.89044764E-04	0.89068295E-04	0.96025811E-04	0.86466740E-06	0.86513568E-06	0.93306404E-06
39	-0.00000000E-38	-0.00000000E-38	0.00000000E-38	-0.00000000E-38	-0.00000000E-38	0.00000000E-38
40	-0.00000000E-38	-0.00000000E-38	0.00000000E-38	-0.00000000E-38	-0.00000000E-38	0.00000000E-38
41	0.72822725E 00	-0.23638931E 01	0.15016762E 01	0.36215632E-02	-0.11773392E-01	0.74433208E-02
42	0.77520045E-05	-0.27977677E-04	0.18559625E-04	0.92305876E-07	-0.27416993E-06	0.16681958E-06
43	0.21829705E-08	-0.84836999E-08	0.57714221E-08	0.17115627E-10	-0.54675905E-10	0.34292481E-10
44	-0.85580519E-05	0.27654482E-04	-0.17552909E-04	-0.17815376E-06	0.49488529E-06	-0.29144607E-06
45	-0.31092316E 01	0.98903306E 01	-0.62298044E 01	-0.20921728E-01	0.64401894E-01	-0.39818135E-01
46	0.97910843E-07	-0.31197292E-06	0.19665559E-06	0.62195077E-09	-0.19319386E-08	0.11991898E-08
47	-0.00000000E-38	-0.00000000E-38	0.00000000E-38	-0.00000000E-38	-0.00000000E-38	0.00000000E-38
48	-0.00000000E-38	-0.00000000E-38	0.00000000E-38	-0.00000000E-38	-0.00000000E-38	0.00000000E-38
49	-0.31093573E 01	0.98903517E 01	-0.62297091E 01	-0.20922925E-01	0.64402028E-01	-0.39817172E-01
50	0.64731427E 01	0.64717109E 01	0.69867429E 01	0.40582260E-01	0.40649286E-01	0.43771689E-01
51	0.88557687E 00	0.88529640E 00	0.95593238E 00	0.62646542E-02	0.62716449E-02	0.67593617E-02

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      SINGLE  4    1 DEC 400.,2500.,900.,400.,400.,400.,0.,0.                DATA0042
      SINGLE  4    9 DEC 400.,2500.,900.,400.,400.,400.,0.,0.                DATA0043
      SINGLE  4   17 DEC 400.,2500.,900.,400.,400.,400.,0.,0.                DATA0044
      SINGLE  4   25 DEC 90000.,44100.,3600.,0.,324.,324.,0.,0.              DATA0045
      SINGLE  4   33 DEC 90000.,44100.,3600.,0.,324.,324.,0.,0.              DATA0046
      SINGLE  4   41 DEC 90000.,44100.,3600.,0.,324.,324.,0.,0.              DATA0047
      SINGLE  4   49 DEC 3400.,3400.,3400.                                   DATA0048
      SINGLE  8    4 DEC 3.                                                  DATA0049
                     END                                                     DATA0050
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                     7E RATE GYRO SYSTEM BUDGET 3-10                                                      PAGE  1

1DELTA T           1T FINAL           1K*1 PRIME         1N                 1RANK              1K*0
 0.80000000E 01     0.41800000E 03     0.00000000E-38     0.30000000E 01     0.10000000E 01    -0.00000000E-19

1T*0               1RUN               1BUDGETS           1PUNCH OPT         1TAPE OPT
 0.00000000E-38     0.60000000E 01     0.10000000E 01     0.00000000E-38     0.10000000E 01

1K*1               1K*2               1K*3               1K*4               1K*5               1K*6
 0.72921151E-07     0.22646320E-08     0.22646320E-08     0.70330185E-10     0.48481368E-05     0.48481368E-05

1K*7               1K*8               1K*9               1K*10              1K*11              1K*12
 0.10000000E-05     0.10000000E-05     0.32170000E-04     0.10000000E-05     0.31080997E-07     0.31080997E-07

1K*13              1K*14              1K*15              1K*16              1K*17              1K*18
 0.48481368E-05     0.48481368E-05     0.10000000E-05     0.10000000E-05     0.48481368E-05     0.48481368E-05

1K*19
 0.48481368E-05

1LAMBDA* 1         1LAMBDA* 2         1LAMBDA* 3         1LAMBDA* 4         1LAMBDA* 5         1LAMBDA* 6
 0.40000000E 03     0.25000000E 04     0.90000000E 03     0.40000000E 03     0.40000000E 03     0.40000000E 03

1LAMBDA* 7         1LAMBDA* 8         1LAMBDA* 9         1LAMBDA*10         1LAMBDA*11         1LAMBDA*12
 0.00000000E-38     0.00000000E-38     0.40000000E 03     0.25000000E 04     0.90000000E 03     0.40000000E 03

1LAMBDA*13         1LAMBDA*14         1LAMBDA*15         1LAMBDA*16         1LAMBDA*17         1LAMBDA*18
 0.40000000E 03     0.40000000E 03     0.00000000E-38     0.00000000E-38     0.40000000E 03     0.25000000E 04

1LAMBDA*19         1LAMBDA*20         1LAMBDA*21         1LAMBDA*22         1LAMBDA*23         1LAMBDA*24
 0.90000000E 03     0.40000000E 03     0.40000000E 03     0.40000000E 03     0.00000000E-38     0.00000000E-38

1LAMBDA*25         1LAMBDA*26         1LAMBDA*27         1LAMBDA*28         1LAMBDA*29         1LAMBDA*30
 0.90000000E 05     0.44100000E 05     0.36000000E 04     0.00000000E-38     0.32400000E 03     0.32400000E 03

1LAMBDA*31         1LAMBDA*32         1LAMBDA*33         1LAMBDA*34         1LAMBDA*35         1LAMBDA*36
 0.00000000E-38     0.00000000E-38     0.90000000E 05     0.44100000E 05     0.36000000E 04     0.00000000E-38

1LAMBDA*37         1LAMBDA*38         1LAMBDA*39         1LAMBDA*40         1LAMBDA*41         1LAMBDA*42
 0.32400000E 03     0.32400000E 03     0.00000000E-38     0.00000000E-38     0.90000000E 05     0.44100000E 05

1LAMBDA*43         1LAMBDA*44         1LAMBDA*45         1LAMBDA*46         1LAMBDA*47         1LAMBDA*48
 0.36000000E 04     0.00000000E-38     0.32400000E 03     0.32400000E 03     0.00000000E-38     0.00000000E-38

1LAMBDA*49         1LAMBDA*50         1LAMBDA*51
 0.34000000E 04     0.34000000E 04     0.34000000E 04
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                                  7E RATE GYRO SYSTEM BUDGET 3-10                                                          PAGE   2

     1ALPHA MATRIX(3X3)

     1ALPHA*1,1           1ALPHA*1,2           1ALPHA*1,3
      0.00000000E-38      -0.15707963E 01       0.00000000E-38

     1ALPHA*2,1           1ALPHA*2,2           1ALPHA*2,3
      0.00000000E-38       0.00000000E-38       0.15707963E 01

     1ALPHA*3,1           1ALPHA*3,2           1ALPHA*3,3
      0.15707963E 01       0.00000000E-38       0.15707963E 01

     1PSI MATRIX(3X3)

     1PSI*1,1             1PSI*1,2             1PSI*1,3
      0.00000000E-38      -0.15707963E 01       0.00000000E-38

     1PSI*2,1             1PSI*2,2             1PSI*2,3
      0.00000000E-38       0.00000000E-38       0.15707963E 01

     1PSI*3,1             1PSI*3,2             1PSI*3,3
      0.15707963E 01       0.00000000E-38       0.15707963E 01

     1BETA MATRIX(3X3)

     1BETA*1,1            1BETA*1,2            1BETA*1,3
      0.00000000E-38       0.00000000E-38       0.00000000E-38

     1P*0 MATRIX(6X6)

     1P*01,1              1P*01,2              1P*01,3              1P*01,4              1P*01,5              1P*01,6
      0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38

     1P*02,1              1P*02,2              1P*02,3              1P*02,4              1P*02,5              1P*02,6
      0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38

     1P*03,1              1P*03,2              1P*03,3              1P*03,4              1P*03,5              1P*03,6
      0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38

     1P*04,1              1P*04,2              1P*04,3              1P*04,4              1P*04,5              1P*04,6
      0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38

     1P*05,1              1P*05,2              1P*05,3              1P*05,4              1P*05,5              1P*05,6
      0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38

     1P*06,1              1P*06,2              1P*06,3              1P*06,4              1P*06,5              1P*06,6
      0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38       0.00000000E-38

    1FLAG A           1FLAG B           1FLAG C           1FLAG D           1FLAG E           1FLAG F           1FLAG G
     0.10E 01          0.10E 01          0.10E 01          0.30E 01          0.20E 01          0.10E 01          0.10E 01

    1FLAG 1           1FLAG 2           1FLAG 3           1FLAG 4           1FLAG 5           1FLAG 6           1FLAG 7
     0.00E-38          0.00E-38          0.00E-38          0.00E-38          0.00E-38          0.00E-38          0.00E-38
```

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                    7E RATE GYRO SYSTEM BUDGET 3-10                                                          PAGE

              1ETA*1 TABLE                             1ETA*2 TABLE                             1ETA*3 TABLE
   1INDEP. VARIABLE   1DEPEN. VARIABLE   1INDEP. VARIABLE   1DEPEN. VARIABLE   1INDEP. VARIABLE   1DEPEN. VARIABLE

MIN=  0.00000000E-38                     MIN=  0.00000000E-38                     MIN=  0.00000000E-38

   MAX=  0.41800000E 03                     MAX=  0.41800000E 03                     MAX=  0.41800000E 03

    2                                        2                                        2

     0.00000000E-38     0.00000000E-38     0.00000000E-38     0.00000000E-38     0.00000000E-38     0.00000000E-38

     0.41800000E 03     0.00000000E-38     0.41800000E 03     0.00000000E-38     0.41800000E 03     0.00000000E-38

                    7E RATE GYRO SYSTEM BUDGET 3-10                                                          PAGE    4

              1OMEGA*1 TABLE                           1OMEGA*2 TABLE                           1OMEGA*3 TABLE
   1INDEP. VARIABLE   1DEPEN. VARIABLE   1INDEP. VARIABLE   1DEPEN. VARIABLE   1INDEP. VARIABLE   1DEPEN. VARIABLE

MIN=  0.00000000E-38                     MIN=  0.00000000E-38                     MIN=  0.00000000E-38

   MAX=  0.41800000E 03                     MAX=  0.41800000E 03                     MAX=  0.41800000E 03

    2                                        2                                        2

     0.00000000E-38     0.00000000E-38     0.00000000E-38     0.00000000E-38     0.00000000E-38     0.00000000E-38

     0.41800000E 03     0.00000000E-38     0.41800000E 03     0.00000000E-38     0.41800000E 03     0.00000000E-38
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                    7E RATE GYRO SYSTEM BUDGET 3-10                                                    PAGE   5
  QTIME
   0.41800000E 03


  OPHI*1 MATRIX(3X8)

OPHI*1 1,1      OPHI*1 1,2      OPHI*1 1,3      OPHI*1 1,4      OPHI*1 1,5      OPHI*1 1,6      OPHI*1 1,7      OPHI*1 1,8
 0.237808E-04   -0.272467E-04    0.807833E-12    0.116631E-11    0.411249E-13    0.139903E-06   -0.000000E-38   -0.000000E-38

OPHI*1 2,1      OPHI*1 2,2      OPHI*1 2,3      OPHI*1 2,4      OPHI*1 2,5      OPHI*1 2,6      OPHI*1 2,7      OPHI*1 2,8
-0.355055E-05    0.380332E-05   -0.111000E-12   -0.147500E-12    0.387712E-13   -0.126734E-07   -0.000000E-38   -0.000000E-38

OPHI*1 3,1      OPHI*1 3,2      OPHI*1 3,3      OPHI*1 3,4      OPHI*1 3,5      OPHI*1 3,6      OPHI*1 3,7      OPHI*1 3,8
-0.187205E-04    0.216933E-04   -0.644809E-12   -0.942717E-12   -0.738359E-13   -0.117717E-06   -0.000000E-38   -0.000000E-38


  OPHI*2 MATRIX(3X8)

OPHI*2 1,1      OPHI*2 1,2      OPHI*2 1,3      OPHI*2 1,4      OPHI*2 1,5      OPHI*2 1,6      OPHI*2 1,7      OPHI*2 1,8
 0.171344E-04   -0.232692E-14   -0.296506E-06   -0.182890E-14    0.189951E-11   -0.284409E-13   -0.000000E-38   -0.000000E-38

OPHI*2 2,1      OPHI*2 2,2      OPHI*2 2,3      OPHI*2 2,4      OPHI*2 2,5      OPHI*2 2,6      OPHI*2 2,7      OPHI*2 2,8
 0.171002E-04   -0.232230E-14   -0.295915E-06   -0.182526E-14    0.189572E-11   -0.283854E-13    0.000000E-38    0.000000E-38

OPHI*2 3,1      OPHI*2 3,2      OPHI*2 3,3      OPHI*2 3,4      OPHI*2 3,5      OPHI*2 3,6      OPHI*2 3,7      OPHI*2 3,8
 0.185227E-04   -0.251545E-14   -0.320530E-06   -0.197709E-14    0.205342E-11   -0.307447E-13   -0.000000E-38   -0.000000E-38


  OPHI*3 MATRIX(3X8)

OPHI*3 1,1      OPHI*3 1,2      OPHI*3 1,3      OPHI*3 1,4      OPHI*3 1,5      OPHI*3 1,6      OPHI*3 1,7      OPHI*3 1,8
 0.834481E-05    0.210928E-09   -0.817445E-12   -0.169344E-16    0.102004E-11   -0.583394E-07    0.000000E-38    0.000000E-38

OPHI*3 2,1      OPHI*3 2,2      OPHI*3 2,3      OPHI*3 2,4      OPHI*3 2,5      OPHI*3 2,6      OPHI*3 2,7      OPHI*3 2,8
-0.249744E-04   -0.600493E-09    0.255118E-11    0.423378E-16   -0.277808E-11    0.151189E-06    0.000000E-38    0.000000E-38

OPHI*3 3,1      OPHI*3 3,2      OPHI*3 3,3      OPHI*3 3,4      OPHI*3 3,5      OPHI*3 3,6      OPHI*3 3,7      OPHI*3 3,8
 0.153372E-04    0.359260E-09   -0.159908E-11   -0.234213E-16    0.162115E-11   -0.856115E-07    0.000000E-38    0.000000E-38
```

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                    7E RATE GYRO SYSTEM BUDGET 3-10                                              PAGE  6

    0ERRORS IN PCI COORDINATES

    0P MATRIX(6X6)-COVARIANCE MATRIX

    0P1,1             0P1,2             0P1,3             0P1,4             0P1,5             0P1,6
     0.11916552E 07    0.53186634E 05    0.28539644E 06    0.69291943E 04    0.42432244E 03    0.23395435E 04

    0P2,1             0P2,2             0P2,3             0P2,4             0P2,5             0P2,6
     0.53186634E 05    0.16269375E 07   -0.11176194E 06    0.28594300E 03    0.10565510E 05   -0.84425043E 03

    0P3,1             0P3,2             0P3,3             0P3,4             0P3,5             0P3,6
     0.28539644E 06   -0.11176193E 06    0.13880135E 07    0.24671754E 04   -0.97215943E 03    0.84642230E 04

    0P4,1             0P4,2             0P4,3             0P4,4             0P4,5             0P4,6
     0.69291944E 04    0.28594301E 03    0.24671754E 04    0.43615658E 02    0.25470853E 01    0.20891358E 02

    0P5,1             0P5,2             0P5,3             0P5,4             0P5,5             0P5,6
     0.42432243E 03    0.10565510E 05   -0.97215942E 03    0.25470853E 01    0.74428076E 02   -0.71669326E 01

    0P6,1             0P6,2             0P6,3             0P6,4             0P6,5             0P6,6
     0.23395434E 04   -0.84425044E 03    0.84642229E 04    0.20891358E 02   -0.71669328E 01    0.55798400E 02



    0P*11 POSITION ERROR ELLIPSOID MAGNITUDE OF PRINCIPLE AXES
     0.98490539E 03    0.12973859E 04    0.12463374E 04

    0DIRECTION COSINE OF PRINCIPLE AXES
     0.79371347E 00   -0.21094473E 00    0.57054464E 00
    -0.16392776E 00    0.82906941E 00    0.53457601E 00
    -0.58578712E 00   -0.51782830E 00    0.62346387E 00

    0P*14 VELOCITY ERROR ELLIPSOID MAGNITUDE OF PRINCIPLE AXES
     0.52048008E 01    0.88293015E 01    0.82943112E 01

    0DIRECTION COSINE OF PRINCIPLE AXES
     0.78510884E 00   -0.23990735E 00    0.57100657E 00
    -0.13379974E 00    0.83446648E 00    0.53456826E 00
    -0.60473271E 00   -0.49609484E 00    0.62304749E 00
```

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                 7E RATE GYRO SYSTEM BUDGET 3-10                                                          PAGE   7

          ODOWNRANGE, CROSSRANGE, ALTITUDE ERRORS

          OP MATRIX(6X6)-COVARIANCE MATRIX

          OP1,1               OP1,2               OP1,3               OP1,4               OP1,5               OP1,6
           0.97213408E 06      0.34989297E 04      0.38405187E 05      0.50812811E 04      0.26845139E 02      0.31648769E 03

          OP2,1               OP2,2               OP2,3               OP2,4               OP2,5               OP2,6
           0.34989297E 04      0.15533362E 07     -0.38490625E 03      0.33718811E 02      0.98858955E 04     -0.35353394E 01

          OP3,1               OP3,2               OP3,3               OP3,4               OP3,5               OP3,6
           0.38405191E 05     -0.38489062E 03      0.16811356E 07      0.54397827E 03     -0.40760803E 01      0.10991750E 05

          OP4,1               OP4,2               OP4,3               OP4,4               OP4,5               OP4,6
           0.50812811E 04      0.33718887E 02      0.54397832E 03      0.27507870E 02      0.27202129E 00      0.45817225E 01

          OP5,1               OP5,2               OP5,3               OP5,4               OP5,5               OP5,6
           0.26845123E 02      0.98858954E 04     -0.40762329E 01      0.27202153E 00      0.68793819E 02     -0.39762974E-01

          OP6,1               OP6,2               OP6,3               OP6,4               OP6,5               OP6,6
           0.31648773E 03     -0.35354309E 01      0.10991750E 05      0.45817230E 01     -0.39763451E-01      0.77540437E 02



          OP*11 POSITION ERROR ELLIPSOID MAGNITUDE OF PRINCIPLE AXES
           0.98490537E 03      0.12463374E 04      0.12973859E 04

          ODIRECTION COSINE OF PRINCIPLE AXES
           0.99852651E 00      0.60977563E-02      0.53922247E-01
          -0.60252807E-02      0.99998070E 00     -0.15065431E-02
          -0.53930394E-01      0.11794265E-02      0.99854399E 00

          OP*14 VELOCITY ERROR ELLIPSOID MAGNITUDE OF PRINCIPLE AXES
           0.52048007E 01      0.82943112E 01      0.88293015E 01

          ODIRECTION COSINE OF PRINCIPLE AXES
           0.99587947E 00      0.67031244E-02      0.90438314E-01
          -0.65820478E-02      0.99997699E 00     -0.16369597E-02
          -0.90447206E-01      0.10349453E-02      0.99590068E 00
```

7E RATE GYRO SYSTEM BUDGET 3-10 PAGE 8

OPHI*2(T*F,T*0) MATRIX(6,51) GENERALIZED ERROR INTEGRALS

	OX	OY	OZ	OX DOT	OY DOT	OZ DOT
1	0.23999447E 00	0.23962048E 00	0.25937219E 00	0.47196285E-02	0.47127244E-02	0.51007653E-02
2	-0.19689292E 00	-0.19657829E 00	-0.21279699E 00	-0.41776343E-02	-0.41712564E-02	-0.45151506E-02
3	0.54475354E-08	0.54388582E-08	0.58875211E-08	0.11669208E-09	0.11651348E-09	0.12611987E-09
4	0.48232682E-08	0.48153365E-08	0.52130287E-08	0.11584401E-09	0.11565733E-09	0.12520838E-09
5	-0.33461878E-07	-0.33428458E-07	-0.36146738E-07	-0.33696989E-09	-0.33685014E-09	-0.36395013E-09
6	0.64349726E-03	0.64480068E-03	0.69312176E-03	-0.35637249E-05	-0.35289318E-05	-0.38727812E-05
7	0.00000000E-38	0.00000000E-38	-0.00000000E-38	0.00000000E-38	0.00000000E-38	-0.00000000E-38
8	0.00000000E-38	0.00000000E-38	-0.00000000E-38	0.00000000E-38	0.00000000E-38	-0.00000000E-38
9	-0.83034514E 01	0.25333959E 02	-0.15668968E 02	-0.84960934E-01	0.24728888E 00	-0.14915515E 00
10	0.13415948E-07	-0.40671418E-07	0.25088233E-07	0.11738146E-09	-0.34806034E-09	0.21192621E-09
11	0.22249864E 00	-0.67717426E 00	0.41839197E 00	0.21700818E-02	-0.63524033E-02	0.38428221E-02
12	0.46094496E-09	-0.13912459E-08	0.85638072E-09	0.50769664E-11	-0.14644980E-10	0.87965765E-11
13	0.88012952E-06	-0.28737263E-05	0.18325669E-05	-0.15966754E-08	0.14137254E-08	0.82112456E-10
14	0.53194267E-06	-0.16538287E-05	0.10324359E-05	0.28369579E-08	-0.90503836E-08	0.56920514E-08
15	0.00000000E-38	0.00000000E-36	-0.00000000E-38	0.00000000E-38	0.00000000E-38	-0.00000000E-38
16	0.00000000E-38	0.00000000E-38	-0.00000000E-38	0.00000000E-38	0.00000000E-38	-0.00000000E-38
17	0.16967031E 02	0.16952102E 02	0.18326374E 02	0.16313894E 00	0.16311174E 00	0.17617920E 00
18	0.18842156E-03	0.18831578E-03	0.20343736E-03	0.20303699E-05	0.20300081E-05	0.21924899E-05
19	-0.14349890E-05	-0.14326107E-05	-0.15511403E-05	-0.18777760E-07	-0.18756204E-07	-0.20292134E-07
20	0.70790476E-11	0.70679779E-11	0.76512741E-11	0.64125228E-13	0.64079999E-13	0.69281643E-13
21	-0.19395088E-05	-0.19389217E-05	-0.20943255E-05	0.16997959E-08	0.16471812E-08	0.18668128E-08
22	0.19737164E 00	0.19738583E 00	0.21297928E 00	0.59745759E-03	0.60135148E-03	0.64242656E-03
23	-0.00000000E-38	-0.00000000E-38	0.00000000E-38	-0.00000000E-38	-0.00000000E-38	0.00000000E-38
24	-0.00000000E-38	-0.00000000E-38	0.00000000E-38	-0.00000000E-38	-0.00000000E-38	0.00000000E-38
25	0.21651533E 01	-0.30854361E 00	-0.17155103E 01	0.10084820E-01	-0.12043312E-02	-0.81977283E-02
26	-0.18775967E 01	0.26645475E 00	0.14891027E 01	-0.11715094E-01	0.14069950E-02	0.95236098E-02
27	0.18270814E 01	-0.25550850E 00	-0.14529585E 01	0.16485575E-01	-0.19399958E-02	-0.13447491E-01
28	-0.25673615E-04	0.38412273E-05	0.20182362E-04	-0.45388699E-06	0.49336010E-07	0.37417978E-06
29	0.12528659E-03	-0.21173339E-04	-0.96183201E-04	0.11897225E-05	-0.13758270E-06	-0.97251828E-06
30	0.25544335E-06	-0.36084061E-07	-0.20274332E-06	0.16875045E-08	-0.20091800E-09	-0.13735791E-08
31	0.00000000E-38	0.00000000E-38	-0.00000000E-38	0.00000000E-38	0.00000000E-38	-0.00000000E-38
32	0.00000000E-38	0.00000000E-38	-0.00000000E-38	0.00000000E-38	0.00000000E-38	-0.00000000E-38
33	0.15515186E 01	0.15516633E 01	0.16740483E 01	0.72657769E-02	0.72906578E-02	0.78272955E-02
34	-0.23379919E-08	-0.23381155E-08	-0.25233597E-08	-0.57050907E-12	-0.63213226E-12	-0.57606369E-12
35	0.60014410E-16	0.59968306E-16	0.64816950E-16	0.52154300E-18	0.52163212E-18	0.56311922E-18
36	0.16954834E-08	0.16960286E-08	0.18295510E-08	-0.12736538E-10	-0.12660186E-10	-0.13801613E-10
37	-0.65345743E 01	-0.65331177E 01	-0.70530611E 01	-0.41076301E-01	-0.41143628E-01	-0.44304910E-01
38	0.89044764E-04	0.89068295E-04	0.96025811E-04	0.86466740E-06	0.86513568E-06	0.93306404E-06
39	-0.00000000E-38	-0.00000000E-38	0.00000000E-38	-0.00000000E-38	-0.00000000E-38	0.00000000E-38
40	-0.00000000E-38	-0.00000000E-38	0.00000000E-38	-0.00000000E-38	-0.00000000E-38	0.00000000E-38
41	0.72822725E 00	-0.23638931E 01	0.15016762E 01	0.36215632E-02	-0.11773392E-01	0.74433208E-02
42	0.77520045E-05	-0.27977677E-04	0.18559625E-04	0.92305876E-07	-0.27416993E-06	0.16681958E-06
43	0.21629705E-08	-0.84836999E-08	0.57714221E-08	0.17115627E-10	-0.54675905E-10	0.34292481E-10
44	-0.85580519E-05	0.27654482E-04	-0.17552909E-04	-0.17815376E-06	0.49488529E-06	-0.29144607E-06
45	-0.31092316E 01	0.98903306E 01	-0.62298044E 01	-0.20921728E-01	0.64401894E-01	-0.39818135E-01
46	0.97910843E-07	-0.31197292E-06	0.19665559E-06	0.62195077E-09	-0.19319386E-08	0.11991898E-08
47	-0.00000000E-38	-0.00000000E-38	0.00000000E-38	-0.00000000E-38	-0.00000000E-38	0.00000000E-38
48	-0.00000000E-38	-0.00000000E-38	0.00000000E-38	-0.00000000E-38	-0.00000000E-38	0.00000000E-38
49	-0.31093573E 01	0.98903517E 01	-0.62297091E 01	-0.20922925E-01	0.64402028E-01	-0.39817172E-01
50	0.64731427E 01	0.64717109E 01	0.69867429E 01	0.40582260E-01	0.40649286E-01	0.43771689E-01
51	0.88557687E 00	0.88529640E 00	0.95593238E 00	0.62646542E-02	0.62716449E-02	0.67593617E-02

5.0 REFERENCES

1. BSD TR 64-347; "Effect of Rotation on Velocity Error in a Pulse Integrating Gyro Accelerometer [PIGA]. Mobile Mid Range Ballistic Missile Guidance and Control Subsystem", Systems Division, General Precision Aerospace. GPI Document 823.077-015, Contract AF 04(694)-558 30 June 1964

APPENDIX A

COMPUTER PROGRAM 117.1

A.1 INTRODUCTION

The material in this appendix is designed to furnish the data required by a programmer for a detailed understanding of Program 117.1. A complete program listing is given, supplemented by descriptions of utility subroutines, tape format, and operational guide/or an IBM 7094 Mod II. This data will facilitate the operational application of Program 117.1 and aid the programmer in possible future modifications or additions.

A.2 PROGRAMMER'S OPERATIONAL INFORMATION

A.2.1 SYSTEM CONFIGURATION (IBSYS VERSION 13)

			LOGICAL	
FUNCTION	SYMBOL	PHYSICAL	FORTRAN II	FORTRAN IV
Library 1	SYSLB1	A1	1	
Library 2	SYSLB2	Unassigned		
Library 3	SYSLB3	Unassigned		
Library 4	SYSLB4	Unassigned		
Card Reader	SYSCRD	RDA		
On-Line Printer	SYSPRT	PRA		
Card Punch	SYSPCH	A0		
Output	SYSOU1	A3	6	6
Alternate Output	SYSOU2	A3		
Input	SYSIN1	B3	5	5
Alternate Input	SYSIN2	B3		
Peripheral Punch	SYSPP1	B4	7	7
Alt. Peripheral Punch	SYSPP2	B2		
Check Point	SYSCK1	B5		
Alternate Check Point	SYSCK2	B5		
Utility 1	SYSUT1	A4	4	1
Utility 2	SYSUT2	B1	8	2
Utility 3	SYSUT3	A2	2	3
Utility 4	SYSUT4	B2	3	4
Utility 5	SYSUT5	Unassigned		
Utility 6	SYSUT6	Unassigned		
Utility 7	SYSUT7	Unassigned		
Utility 8	SYSUT8	Unassigned		
Utility 9	SYSUT9	Unassigned		

ATTACHED UNITS NOT ASSIGNED OR RESERVED

A5	B6
A6	B7
A7	B8
A8	B9
A9	B0

INTER SYSTEM RESERVE UNITS

NONE

A.2.2 PROGRAMMER'S GUIDE FOR 117.1

I Error Conditions

A. Error conditions result in program dump in floating point form with XR4 being key to location where error occurred.

B. Hints on Error Conditions

1) Make very sure input data is correct
2) XR4 should tell where error occurred
3) Make sure end cards END and FIN are present and used correctly
4) Double check deck makeup
5) Table input data is frequent error on engineer's part.

A.2.3 OPERATOR'S GUIDE FOR 117.1 ON IBM 7094 MOD II

I Machine Configuration (System Requirements)

A. Channel A
   1) A1 = IBSYS VERSION 13
   2) A2 = Utility tape
   3) A3 = List tape (output print tape)
   4) A4 = Utility tape

B. Channel B
   1) B1, B2, and B5 = Utility tape
   2) B4 = Punch tape (Card output)
   3) B3 = Card-to-tape (Input)

C. Core Storage
   1) 32K

II Deck Setup

A. Control Cards at Beginning of Deck
   1) $DATE
   2) $IBSYS
   3) $RESTORE
   4) $JOB
   5) $ID
   6) $EXECUTE
   7) $IBJOB

II Deck Setup (con't)

B. Program Deck

1) NINPUT
2) NLØGIC
3) I93Z
4) MTAPEW
5) CPUNCH
6) NEVAL
7) NINTL
8) NPRCØN
9) 79NSUB
10) 31NSUB
11) 32NSUB
12) 33NSUB
13) 34NSUB
14) 36NSUB
15) 37NSUB
16) 38NSUB
17) NTAPER
18) NØUTPT
19) ONØUT
20) INØUT
21) EIGEN
22) INVERT
23) ADMAT
24) SBMAT
25) TRMAT
26) YMATMY
27) AMATMY

II Deck Setup (con't)

B. Program Deck (con't)

28) INTP

29) NINTG

C. Control Cards at End of Program Deck

1) $ENTRY

2) 7/8

3) Data Cards (Not Control Cards)

4) 7/8

5) $IBSYS

6) $ENDFILE SYS0U1

7) $ENDFILE SYSPP1

8) $ST0P

H. Devices Used by Program

1) Fortran Logical 2 tape unit = B1

I. Built-in Pauses

1) Pause 77777 with 77777 right justified in AC means to make sure either a special tape or a blank tape is to be mounted on B1, then hit start.

2) Pause 66666 with 66666 right-justified in AC means the problem is completed and save tape from B1 before going to next job; then hit start.

A.2.4 TAPE FORMAT FOR 117.1 (58 WORD RECORD)

Record No. 1 - Heading Record (All Floating or BCI)

1) -3.0
2) Run No.
3) Phase No.
4-13) Heading
14-54) 0
55-58) 4 BCI Blank Words

Record No. 2

1) -2.0
2) Run No.
3) Phase No.

$$\left.\begin{array}{rl} 4) & P_{IX_o} \\ 5) & P_{IY_o} \\ 6) & P_{IZ_o} \\ 7) & Y_{AX_o} \\ 8) & Y_{AY_o} \\ 9) & Y_{AZ_o} \\ 10) & R_{OX_o} \\ 11) & R_{OY_o} \\ 12) & R_{OZ_o} \end{array}\right\} A_4 \text{ matrix in row form}$$

13-54) 0
55-58) 4 BCI Blank Words

Record No. 3 and All Others Except Special End Records

1) TIME
2) Run No.
3) Phase No.
4-6) $\omega_{PI}, \omega_{YA}, \omega_{RO}$
7-12) $X, Y, Z, \dot{X}, \dot{Y}, \dot{Z}$
13-18) $a_x, a_y, a_z, \alpha_1, \alpha_2, \alpha_3$
* 19-54) $\left.\begin{matrix} \varphi_{11}^{-1}, \varphi_{21}^{-1}, \varphi_{31}^{-1}, \varphi_{41}^{-1}, \varphi_{51}^{-1}, \varphi_{61}^{-1} \\ \varphi_{12}, \text{------} \qquad \text{------} \end{matrix}\right\}$ In Error Analysis Program Read in as Transpose

55-58) 4BCI Words

<u>Record N</u> (Record Separating Cases) Special End Record

1) Time = 1.E20
2) Run No.
3) Phase No.
4) Remaining words are garbage thru word 58

<u>Record (N + 1)</u>

1) If end of all runs duplicate of record N
2) If another case same format as preceding case on tape.

* Note: $(t_o - t)$ is in $\varphi_{41}^{-1}, \varphi_{52}^{-1}, \varphi_{63}^{-1}$ This option is built in error analysis portion of program

A. 3 PROGRAM LISTING, PROGRAM 117. 1

The original of the compilation listing has been supplied with the program decks.

APPENDIX B

Input Forms for Program 117.1

PROGRAM 117.1

Performance Assessment of an All-inertial System

Engineer ____________________ Work Order No. ______________ Date ____________

Phone ____________________ Page 1 of 17

☐ Use trajectory tape No. __________

☐ Run, estimated run time ______________ ☐ Punch and return cards to Engineer

1 5	7 10	11			72

Heading Title: Appears as heading on each page of output.

1 1	BCI	,			
		RUN NO.	RANK	TAPE PRINT OPTION	TAPE NUMBER
2 1	DEC	,	,	,	
		t_0 (secs)	Δt (secs)	t_f (secs)	K_1' (ft/sec) PIGA
2 5	DEC	,	,	,	
		N	BUDG	PUNCH	K_0 (sec) Rate Gyro
2 9	DEC	,	,	,	
		K_1	K_2	K_3	K_4
3 1	DEC	,	,	,	
		K_5	K_6	K_7	K_8
3 5	DEC	,	,	,	
		K_9	K_{10}	K_{11}	K_{12}
3 9	DEC	,	,	,	
		K_{13}	K_{14}	K_{15}	K_{16}
3 13	DEC	,	,	,	
		K_{17}	K_{18}	K_{19}	
3 17	DEC	,	,		

PROGRAM 117.1

Date ____________
Page 2 of 17

1 5	7 10	11			72
4 1	DEC	$\lambda_1(\sigma^2)$,	λ_2 ,	λ_3 ,	λ_4
4 5	DEC	λ_5 ,	λ_6 ,	λ_7 ,	λ_8
4 9	DEC	λ_9 ,	λ_{10} ,	λ_{11} ,	λ_{12}
4 13	DEC	λ_{13} ,	λ_{14} ,	λ_{15} ,	λ_{16}
4 17	DEC	λ_{17} ,	λ_{18} ,	λ_{19} ,	λ_{20}
4 21	DEC	λ_{21} ,	λ_{22} ,	λ_{23} ,	λ_{24}
4 25	DEC	λ_{25} ,	λ_{26} ,	λ_{27} ,	λ_{28}
4 29	DEC	λ_{29} ,	λ_{30} ,	λ_{31} ,	λ_{32}
4 33	DEC	λ_{33} ,	λ_{34} ,	λ_{35} ,	λ_{36}
4 37	DEC	λ_{37} ,	λ_{38} ,	λ_{39} ,	λ_{40}
4 41	DEC	λ_{41} ,	λ_{42} ,	λ_{43} ,	λ_{44}
4 45	DEC	λ_{45} ,	λ_{46} ,	λ_{47} ,	λ_{48}
4 49	DEC	λ_{49} ,	λ_{50} ,	λ_{51}	

PROGRAM 117.1

Date ____________
Page 3 of 17

1 5	7 10	11			72
		α_{11}(rad)	α_{12}	α_{13}	
5 1	DEC	,	,		
		α_{21}	α_{22}	α_{23}	
5 4	DEC	,	,		
		α_{31}	α_{32}	α_{33}	
5 7	DEC	,	,		
		ψ_{11}	ψ_{12}	ψ_{13}	
5 10	DEC	,	,		
		ψ_{21}	ψ_{22}	ψ_{23}	
5 13	DEC	,	,		
		ψ_{31}	ψ_{32}	ψ_{33}	
5 16	DEC	,	,		
		β_{11}	β_{12}	β_{13}	
5 19	DEC	,	,		

PROGRAM 117.1

Date ____________

Page 4 of 17

1 5	7 10	11				72
6 1	DEC	$P_{o(11)}$ (ft^2) ,	$P_{o(12)}$,	$P_{o(13)}$,	$P_{o(14)}$ (ft^2/sec)	
6 5	DEC	$P_{o(15)}$,	$P_{o(16)}$,	$P_{o(21)}$,	$P_{o(22)}$	
6 9	DEC	$P_{o(23)}$,	$P_{o(24)}$,	$P_{o(25)}$,	$P_{o(26)}$	
6 13	DEC	$P_{o(31)}$,	$P_{o(32)}$,	$P_{o(33)}$,	$P_{o(34)}$	
6 17	DEC	$P_{o(35)}$,	$P_{o(36)}$,	$P_{o(41)}$,	$P_{o(42)}$	
6 21	DEC	$P_{o(43)}$,	$P_{o(44)}$,	$P_{o(45)}$,	$P_{o(46)}$	
6 25	DEC	$P_{o(51)}$,	$P_{o(52)}$,	$P_{o(53)}$,	$P_{o(54)}$	
6 29	DEC	$P_{o(55)}$,	$P_{o(56)}$,	$P_{o(61)}$,	$P_{o(62)}$	
6 33	DEC	$P_{o(63)}$,	$P_{o(64)}$,	$P_{o(65)}$,	$P_{o(66)}$	

PROGRAM 117.1

η_1 TABLE

Date ______

Page 5 of 17

1 5	7 10	11			72
		t_{min} (secs) $t_{min} < t_o$	t_{max} (secs) $t_{max} \ge t_f$		
7 1	DEC	,			
		$t_1 = t_{min}$ (secs)	$\eta_1(t_1)$(rad)	t_2	$\eta_1(t_2)$
7 6	DEC	,	,	,	
		t_3	$\eta_1(t_3)$	t_4	$\eta_1(t_4)$
7 10	DEC	,	,	,	
		t_5	$\eta_1(t_5)$	t_6	$\eta_1(t_6)$
7 14	DEC	,	,	,	
		t_7	$\eta_1(t_7)$	t_8	$\eta_1(t_8)$
7 18	DEC	,	,	,	
		t_9	$\eta_1(t_9)$	t_{10}	$\eta_1(t_{10})$
7 22	DEC	,	,	,	
		t_{11}	$\eta_1(t_{11})$	t_{12}	$\eta_1(t_{12})$
7 26	DEC	,	,	,	
		t_{13}	$\eta_1(t_{13})$	t_{14}	$\eta_1(t_{14})$
7 30	DEC	,	,	,	
		t_{15}	$\eta_1(t_{15})$	t_{16}	$\eta_1(t_{16})$
7 34	DEC	,	,	,	
		t_{17}	$\eta_1(t_{17})$	t_{18}	$\eta_1(t_{18})$
7 38	DEC	,	,	,	
		t_{19}	$\eta_1(t_{19})$	t_{20}	$\eta_1(t_{20})$
7 42	DEC	,	,	,	

PROGRAM 117.1

η_1 TABLE (continued)

Date ______________

Page 6 of 17

1 5	7 10	11 t_{21} (secs)	$\eta_1(t_{21})$(rad)	t_{22}	$\eta_1(t_{22})$ 72
7 46	DEC	,	,	,	
		t_{23}	$\eta_1(t_{23})$	t_{24}	$\eta_1(t_{24})$
7 50	DEC	,	,	,	
		t_{25}	$\eta_1(t_{25})$	t_{26}	$\eta_1(t_{26})$
7 54	DEC	,	,	,	
		$t_{27} = t_{max}$	$\eta_1(t_{27})$		
7 58	DEC	,			

PROGRAM 117.1

η_2 TABLE

Date ____________

Page 7 of 17

1 5	7 10	11			72
		t_{min}(secs) $t_{min} \le t_o$		t_{max}(secs) $t_{max} \ge t_f$	
7 61	DEC	,			
		$t_1 = t_{min}$(secs)	$\eta_2(t_1)$(rad)	t_2	$\eta_2(t_2)$
7 66	DEC	,	,	,	
		t_3	$\eta_2(t_3)$	t_4	$\eta_2(t_4)$
7 70	DEC	,	,	,	
		t_5	$\eta_2(t_5)$	t_6	$\eta_2(t_6)$
7 74	DEC	,	,	,	
		t_7	$\eta_2(t_7)$	t_8	$\eta_2(t_8)$
7 78	DEC	,	,	,	
		t_9	$\eta_2(t_9)$	t_{10}	$\eta_2(t_{10})$
7 82	DEC	,	,	,	
		t_{11}	$\eta_2(t_{11})$	t_{12}	$\eta_2(t_{12})$
7 86	DEC	,	,	,	
		t_{13}	$\eta_2(t_{13})$	t_{14}	$\eta_2(t_{14})$
7 90	DEC	,	,	,	
		t_{15}	$\eta_2(t_{15})$	t_{16}	$\eta_2(t_{16})$
7 94	DEC	,	,	,	

PROGRAM 117.1

η_2 TABLE (continued)

Date ____________
Page 8 of 17

1 5	7 10	11			72
		t_{17}(secs)	$\eta_2(t_{17})$(rad)	t_{18}	$\eta_2(t_{18})$
7 98	DEC	,	,	,	
		t_{19}	$\eta_2(t_{19})$	t_{20}	$\eta_2(t_{20})$
7 102	DEC	,	,	,	
		t_{21}	$\eta_2(t_{21})$	t_{22}	$\eta_2(t_{22})$
7 106	DEC	,	,	,	
		t_{23}	$\eta_2(t_{23})$	t_{24}	$\eta_2(t_{24})$
7 110	DEC	,	,	,	
		t_{25}	$\eta_2(t_{25})$	t_{26}	$\eta_2(t_{26})$
7 114	DEC	,	,	,	
		$t_{27} = t_{max}$	$\eta_2(t_{27})$		
7 118	DEC	,			

PROGRAM 117.1

η_3 TABLE

Date ________

Page 9 of 17

1 5	7 10	11 72
7 121	DEC	t_{min}(secs) $t_{min} < t_o$, t_{max}(secs) $t_{max} \geq t_f$
7 126	DEC	$t_1 = t_{min}$(secs) , $\eta_3(t_1)$(rad) , t_2 , $\eta_3(t_2)$
7 130	DEC	t_3 , $\eta_3(t_3)$, t_4 , $\eta_3(t_4)$
7 134	DEC	t_5 , $\eta_3(t_5)$, t_6 , $\eta_3(t_6)$
7 138	DEC	t_7 , $\eta_3(t_7)$, t_8 , $\eta_3(t_8)$
7 142	DEC	t_9 , $\eta_3(t_9)$, t_{10} , $\eta_3(t_{10})$
7 146	DEC	t_{11} , $\eta_3(t_{11})$, t_{12} , $\eta_3(t_{12})$
7 150	DEC	t_{13} , $\eta_3(t_{13})$, t_{14} , $\eta_3(t_{14})$
7 154	DEC	t_{15} , $\eta_3(t_{15})$, t_{16} , $\eta_3(t_{16})$

PROGRAM 117.1

η_3 TABLE (continued)

Date __________
Page 10 of 17

1 5	7 10	11			72
		t_{17}(secs)	$\eta_3(t_{17})$(rad)	t_{18}	$\eta_3(t_{18})$
7 158	DEC	,	,	,	
		t_{19}	$\eta_3(t_{19})$	t_{20}	$\eta_3(t_{20})$
7 162	DEC	,	,	,	
		t_{21}	$\eta_3(t_{21})$	t_{22}	$\eta_3(t_{22})$
7 166	DEC	,	,	,	
		t_{23}	$\eta_3(t_{23})$	t_{24}	$\eta_3(t_{24})$
7 170	DEC	,	,	,	
		t_{25}	$\eta_3(t_{25})$	t_{26}	$\eta_3(t_{26})$
7 174	DEC	,	,	,	
		$t_{27} = t_{max}$	$\eta_3(t_{27})$		
7 178	DEC	,			

PROGRAM 117.1
ω_1 TABLE

Date ________

Page 11 of 17

1 5	7 10	11			72
		t_{min}(secs) $t_{min} < t_o$		t_{max}(secs) $t_{max} \geq t_f$	
7 181	DEC	,			
		$t_1 = t_{min}$(secs)	$\omega_1(t_1)$(rad/sec)	t_2	$\omega_1(t_2)$
7 186	DEC	,	,	,	
		t_3	$\omega_1(t_3)$	t_4	$\omega_1(t_4)$
7 190	DEC	,	,	,	
		t_5	$\omega_1(t_5)$	t_6	$\omega_1(t_6)$
7 194	DEC	,	,	,	
		t_7	$\omega_1(t_7)$	t_8	$\omega_1(t_8)$
7 198	DEC	,	,	,	
		t_9	$\omega_1(t_9)$	t_{10}	$\omega_1(t_{10})$
7 202	DEC	,	,	,	
		t_{11}	$\omega_1(t_{11})$	t_{12}	$\omega_1(t_{12})$
7 206	DEC	,	,	,	
		t_{13}	$\omega_1(t_{13})$	t_{14}	$\omega_1(t_{14})$
7 210	DEC	,	,	,	
		t_{15}	$\omega_1(t_{15})$	t_{16}	$\omega_1(t_{16})$
7 214	DEC	,	,	,	

PROGRAM 117.1

ω_1 TABLE (continued)

Date ____________

Page 12 of 17

1 5	7 10	11			72
		t_{17}(secs)	$\omega_1(t_{17})$(rad/sec)	t_{18}	$\omega_1(t_{18})$
7 218	DEC	,	,	,	
		t_{19}	$\omega_1(t_{19})$	t_{20}	$\omega_1(t_{20})$
7 222	DEC	,	,	,	
		t_{21}	$\omega_1(t_{21})$	t_{22}	$\omega_1(t_{22})$
7 226	DEC	,	,	,	
		t_{23}	$\omega_1(t_{23})$	t_{24}	$\omega_1(t_{24})$
7 230	DEC	,	,	,	
		t_{25}	$\omega_1(t_{25})$	t_{26}	$\omega_1(t_{26})$
7 234	DEC	,	,	,	
		$t_{27} = t_{max}$	$\omega_1(t_{27})$		
7 238	DEC	,			

PROGRAM 117.1

Date __________
Page 13 of 17

ω_2 TABLE

1 5	7 10	11 t_{min}(secs $t_{min} < t_o$		t_{max}(secs) $t_{max} \geq t_f$	72
7 241	DEC				
		$t_1 = t_{min}$(secs)	$\omega_2(t_1)$(rad/sec)	t_2	$\omega_2(t_2)$
7 246	DEC	,	,	,	
		t_3	$\omega_2(t_3)$	t_4	$\omega_2(t_4)$
7 250	DEC	,	,	,	
		t_5	$\omega_2(t_5)$	t_6	$\omega_2(t_6)$
7 254	DEC	,	,	,	
		t_7	$\omega_2(t_7)$	t_8	$\omega_2(t_8)$
7 258	DEC	,	,	,	
		t_9	$\omega_2(t_9)$	t_{10}	$\omega_2(t_{10})$
7 262	DEC	,	,	,	
		t_{11}	$\omega_2(t_{11})$	t_{12}	$\omega_2(t_{12})$
7 266	DEC	,	,	,	
		t_{13}	$\omega_2(t_{13})$	t_{14}	$\omega_2(t_{14})$
7 270	DEC	,	,	,	
		t_{15}	$\omega_2(t_{15})$	t_{16}	$\omega_2(t_{16})$
7 274	DEC	,	,	,	

PROGRAM 117.1

ω_2 TABLE (continued)

Date ____________

Page 14 of 17

1 5	7 10				72
		t_{17}(sec)	$\omega_2(t_{17})$(rad/sec)	t_{18}	$\omega_2(t_{18})$
7 278	DEC	,	,	,	
		t_{19}	$\omega_2(t_{19})$	t_{20}	$\omega_2(t_{20})$
7 282	DEC	,	,	,	
		t_{21}	$\omega_2(t_{21})$	t_{22}	$\omega_2(t_{22})$
7 286	DEC	,	,	,	
		t_{23}	$\omega_2(t_{23})$	t_{24}	$\omega_2(t_{24})$
7 290	DEC	,	,	,	
		t_{25}	$\omega_2(t_{25})$	t_{26}	$\omega_2(t_{26})$
7 294	DEC	,	,	,	
		$t_{27} = t_{max}$	$\omega_2(t_{27})$		
7 298	DEC	,			

PROGRAM 117.1

ω_3 TABLE

Date ____________
Page 15 of 17

1 5	7 10	11				72
		t_{min}(secs) $t_{min} < t_o$		t_{max}(secs) $t_{max} > t_o$		
7 301	DEC		,			
		$t_1 = t_{min}$(secs	$\omega_3(t_1)$(rad/sec)	t_2	$\omega_3(t_2)$	
7 306	DEC	,	,	,		
		t_3	$\omega_3(t_3)$	t_4	$\omega_3(t_4)$	
7 310	DEC	,	,	,		
		t_5	$\omega_3(t_5)$	t_6	$\omega_3(t_6)$	
7 314	DEC	,	,	,		
		t_7	$\omega_3(t_7)$	t_8	$\omega_3(t_8)$	
7 318	DEC	,	,	,		
		t_9	$\omega_3(t_9)$	t_{10}	$\omega_3(t_{10})$	
7 322	DEC	,	,	,		
		t_{11}	$\omega_3(t_{11})$	t_{12}	$\omega_3(t_{12})$	
7 326	DEC	,	,	,		
		t_{13}	$\omega_3(t_{13})$	t_{14}	$\omega_3(t_{14})$	
7 330	DEC	,	,	,		
		t_{15}	$\omega_3(t_{15})$	t_{16}	$\omega_3(t_{16})$	
7 334	DEC	,	,	,		

PROGRAM 117.1

ω_3 TABLE (continued)

Date ______

Page 16 of 17

1 5	7 10	11			72
		t_{17}(secs)	$\omega_3(t_{17})$(rad/sec)	t_{18}	$\omega_3(t_{18})$
7 338	DEC	,	,	,	
		t_{19}	$\omega_3(t_{19})$	t_{20}	$\omega_3(t_{20})$
7 342	DEC	,	,	,	
		t_{21}	$\omega_3(t_{21})$	t_{22}	$\omega_3(t_{22})$
7 346	DEC	,	,	,	
		t_{23}	$\omega_3(t_{23})$	t_{24}	$\omega_3(t_{24})$
7 350	DEC	,	,	,	
		t_{25}	$\omega_3(t_{25})$	t_{26}	$\omega_3(t_{26})$
7 354	DEC	,	,	,	
		$t_{27} = t_{max}$	$\omega_3(t_{27})$		
7 358	DEC	,			

PROGRAM 117.1

Date ____________
Page 17 of 17

1 5	7 10	11 72
8 1	DEC	FLAG A , FLAG B , FLAG C , FLAG D
8 5	DEC	FLAG E , FLAG F , FLAG G
9 1	DEC	FLAG 1 , FLAG 2 , FLAG 3 , FLAG 4
9 5	DEC	FLAG 5 , FLAG 6 , FLAG 7
	END	
	FIN	(Very last card of entire run.)