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PRESIMULATION REPORT

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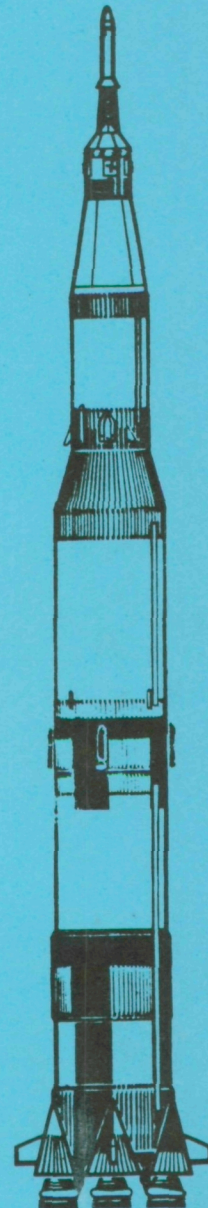
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This report describes equation and implementation requirements for a hybrid simulation of an O40C type delta wing orbiter with external propellant tank for study of aborts occurring during boost. The simulation is initiated at the time the abort is initiated and contains features which allow selection of the launch site or certain downrange sites for landing.

This report is submitted in fulfillment of the requirement for a Pre-simulation Report as specified by the Data Requirements List of Exhibit B of Contract NAS9-12183.

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ABSTRACT

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A description of a hybrid simulation of the 040C orbiter aborting from boost to specified landing sites is provided. The simulation starts when the abort is initiated and continues until a terminal energy state (associated with the selected landing site) is reached. At abort it is assumed that all SRM's are jettisoned with the external tank remaining with the orbiter. The simulation described has six degrees of freedom with the vehicle simulated as a rigid body. A conventional form of autopilot is provided to control engine gimbaling during powered flight. An ideal form of an autopilot is provided to test conventional autopilot function and provide pseudo RCS function during coasting flight. The simulation is proposed to provide means for studies of abort guidance function and to gain information concerning ability to control the abort trajectory.

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INTRODUCTION

A hybrid simulation will be developed to study abort procedures, parameter display, and control system requirements for reusable spacecraft aborts initiated during launch. Guidance will provide continuous attitude commands for either automatic or manual control modes. Parameter display involves conveying vehicle state information (position, velocity, vehicle rates, etc.) to the pilot.

The simulation will start at time of abort. The abort process includes both powered phase and an unpowered phase. The powered phase starts at abort and ends with orbiter fuel depletion. The coast phase ends when a terminal energy state is reached. The energy state is defined at 150,000 feet altitude at 7,800 feet per second, when a downrange landing site is desired, and at 100,000 feet altitude at 1,860 feet per second, when the launch pad is the desired landing site. Completion of the coast phase constitutes the end of the simulation run.

STUDY OBJECTIVES

In general, the simulation is designed to study aborts initiated during launch. The basic simulation variables are the man-machine interface and abort guidance procedure. The man-machine interface is divided into two parts. The first part involves display of parameters that are informative to the pilot. Both number of displays provided and information received will be considered. The intent will be to provide a small number of displays that are highly informative and allow adequate assessment of vehicle state. The second part involves definition of the manual control mode requirements. The displays must provide necessary information to allow competent manual control.

Study of abort guidance procedures will provide confidence in the prescribed abort methods. The procedure must provide continuous control of attitudes to avoid violation of vehicular constraints. The attitudes will be controlled in a manner to allow the vehicle to arrive at the powered abort end conditions with main engine propellant depleted.

The simulation objectives are to:

- a. Evaluate the adequacy of the various display parameters to convey information of abort status to the spacecraft crew
- b. Define manual control mode requirements
- c. Gain confidence in abort guidance procedures which could be used compatibly for both automatic and manual control during the abort phase.

SIMULATION IMPLEMENTATION

The launch and abort simulation is implemented by coupling a set of equations-of-motion, set of thrust limiting equations, a set of display parameter equations, a set of autopilot equations, and sets of launch abort equations with simulation of the spacecraft cockpit. The simulation is initiated at a preselected abort time. At abort time the vehicle is considered to consist of orbiter and external tank, where all SRM's have been jettisoned. The simulation does not consider aborts from the PAD or low altitude. When an abort is initiated, the abort guidance issues commands controlling the simulation with provisions for manual attitude and throttle control if necessary. At engine shutdown the orbiter separates from external fuel tank. The abort part of the simulation is terminated in a reentry footprint associated with a desired landing site. A diagram of the simulation is shown in Figure 1 and symbol definitions are shown in Table VIII.

Characteristics of the Simulated Vehicle

At the instant of abort, the vehicle simulated is a delta winged three engined orbiter with an external fuel cell attached. All SRM's are assumed to be jettisoned prior to abort starting the simulation. Center of gravity locations and moment of inertia information as a function of vehicle mass are shown in Table I. Engine location data is shown in Table II.

After engine shutdown the orbiter simulated is a delta winged vehicle similar to the 040C-Z spacecraft. Center of gravity locations and moment of inertia information as a function of vehicle mass are shown in Table I.

Engine out is simulated by the use of N_i . If $N_i = 1$, the i^{th} engine is producing thrust. If $N_i = 0$, the i^{th} engine is not producing thrust. The simulation will be initiated with information to allow the i^{th} engine to turn off at time t in launch time.

Additional propulsion and vehicle configuration data are shown in Table III.

Equations-of-Motion

The equations-of-motion are written in six degrees of freedom which provides summation of forces and moments along and about the orbiter/tank and orbiter body axes. The EOM are used to perform engine throttling and provide for pilot displays. A set of initialization constants for the EOM are shown in Table IV. The physical arrangement of the simulation parts are shown in the attached drawing. Aerodynamic details are shown in Tables V, VI and VII.

Equations-of-Motion (Continued)

The assumptions and limitations of the equations-of-motion are:

- a. The simulation was developed such that an abort can only take place at the preselected time during nominal launch.
- b. Both orbiter/tank and orbiter are simulated as a rigid body with mass symmetry in the body $X_B - Z_B$ plane.
- c. The earth is assumed to be a rotating sphere with atmospheric density (ρ) and ambient air temperature (T_n) to be the 1962 standard.
- d. The simulation assumes the orbiter contain ideal engine actuators and engines can be gimballed without inertial effects.
- e. Aerodynamics attitude control augmentation will not be required.
- f. Provisions for thrust tail-off are not required.
- g. The simulation assumes thrust forces along body X and Z axis are mainly dependent on engine pitch gimbal actuation. Hence, coupling can be ignored when computing forces in the X and Z direction for determining moments about the Y axis due to thrust.
- h. The simulation assumes the altitude at time of abort is high enough so that the orbiter main engines are adequate to maintain flight. Hence, at time of abort, it is assumed that the main SRM's and abort SRM's have been jettisoned.

Equations-of-Motion (Continued)

- i. No RCS jet dynamics or jet select logic will be simulated. During periods of time when the vehicle engines are burning, attitude control is accomplished by engine gimbaling. When engines are off and the vehicle is coasting, the autopilot will provide the required RCS control torques to the appropriate moment equation. Thus, the pseudo RCS system will provide sufficient torques to keep attitude errors small.
- j. Tables for aerodynamic data for the spacecraft are compatible for angles of attack up to 60° . If angles of attack (α) between 60° and 90° are desired, the aerodynamic coefficient for an α of 60° is used. If α is greater than 90° , aerodynamic coefficients are set to zero. If α is less than zero the tables are interrogated with the magnitude of α . Maneuvers requiring large angles of attack (α greater than 60°) will be restricted to times when the dynamic pressure (q) is small. Thus, errors of the above process are assumed small with respect to thrusting effects.
- k. Interrogation of aerodynamic tables for large angle-of-sideslip (β) is assumed to be a linear extrapolation of the data tables.
- l. The aerodynamic force and moment equations are written in body axis.
- m. Aerodynamic force and moment coefficients are assumed to be a linear function of α about the trim value for the longitudinal derivatives and a linear function β about the trim value for the lateral derivatives. For the simulation mechanization, all of the linear coefficients will be programmed and looked-up as a function of Mach number and α or β .

Equations-of-Motion (Continued)

The four right-handed orthogonal coordinate systems used in the equations-of-motion are described below.

Earth Inertial Coordinates - The origin of the earth inertial system is the center of the earth. The X_F axis is in the equatorial plane through a reference position of the Greenwich meridian. The Z_F is along the earth spin axis pointing north. The Y_F axis completes the right-handed triad.

Platform Inertial Coordinates - The origin of the platform system is the center of the earth. The platform system is erected while the vehicle is on the launch pad with the X_p axis pointing upward along an earth radial. The Z_p axis is the intersection of the launch plane and the local horizontal plane pointing in the direction the vehicle will be launched. The Y_p axis completes the right-handed triad.

Local Vertical Coordinates - The origin of the local vertical system is at the vehicle center of gravity. The X_{LV} -axis is pointing upward along an earth radial. The Y_{LV} -axis is the vector product of a unit radial into the vehicle relative velocity vector. The Z_{LV} -axis completes the right-handed triad and points along the local horizontal in the direction the vehicle is traveling.

Body B-Frame - The origin of the body frame is the center of gravity of the vehicle. The body axes are defined such that X_B is positive forward, Y_B is positive out the right wing, and Z_B is positive towards the bottom of the vehicle. The body system is oriented such that X_B , Y_B , and Z_B are

Equations-of-Motion (Continued)

parallel to X_p , Y_p , and Z_p , respectively at the instant of launch. The vehicle attitude is measured by the Euler angles θ , ψ , and ϕ between the platform system and the B-frame.

The EOM model is used to provide throttle information. This is computed by summing unthrottled thrust forces and aerodynamic forces. The result is compared with vehicle limit forces to provide a throttle factor which varies between zero and positive unity. The throttle factor is used to reduce the thrust force to maintain vehicle acceleration at the limiting acceleration for the vehicle in question. The limiting acceleration is given in Table IV.

The EOM model is used to provide information for certain pilot displays. Brief descriptions of display parameters are provided in the section entitled Simulator Crew Station. Basic flight equations are described in references 1 and 2. The atmospheric model is described in reference 3.

Master Control-Digital Program

The master control program is used to sequence the autopilots and abort guidance programs, provide or accept mission time, and establish discretely that control the simulation. The vehicle engines are turned off or on when necessary and a discrete is set which indicates when orbiter/tank separation takes place. A discrete is also set which indicates whether the spacecraft is operating in an abort downrange or an abort for return to launch site mode.

Master Control-Digital Program (Continued)

The master control as shown in Figure 2 provides mission time in 0.2 second intervals. This should not be construed to indicate that the digital program should control time. Analog generated time could be used. However, if separate time generators are used, i.e. analog generated time and digital generated time, the two time generators should be synchronized. It should be noted that the digital autopilot require time in 0.2 second intervals and the guidance programs require time in one second intervals. The abort time must be inputted to initialize time and obtain ground elapsed time.

Interface information for the master control program is shown on Sheet 3 of Figure 1. A flow chart of the digital program is shown in Figure 2 with corresponding symbol definitions shown in Table X. Values of constants required by master control are shown in Table IX.

Abort Guidance-Digital Program

The objective of an aborted shuttle mission is the safe return of the crew and vehicle. Abort guidance provides a technique for steering to a landing site after an abort during launch.

In the simulation an abort is commanded to take place at a preselected time from launch. If an abort simulation is desired K seconds after launch, K is assigned to the TABT variable in the Master control program.

Abort Guidance-Digital Program (Continued)

When an abort is commanded an abort guidance procedure controls the spacecraft to targets associated with the selected landing site. Near the target, the engines are shut down when fuel is depleted and the vehicle is commanded to follow an attitude selecting process as it descends to earth.

The simulation ends when the orbiter reaches an energy state corresponding to 150,000 feet altitude and 7800 feet per second velocity when a downrange landing site is selected and at 100,000 feet altitude and 1860 feet per second velocity when the launch pad is the desired landing site. The abort guidance controls the vehicle attitude to avoid violating vehicle constraints and assures that the vehicle reaches the vicinity of the selected landing site.

The abort guidance technique is divided into three basic parts. The first consists of a targeting function. The second consists of a steering function which directs the vehicle to the target. The third consists of an attitude control for initial reentry in the earth's atmosphere. The specific form of the procedure is in the process of revision at the present time. The guidance procedure is described in References 1, 4 and 5. Some results of testing in a digital program are shown in Reference 6.

Abort Targeting - The basic targeting problem is to determine a desired engine burnout state vector given the vehicle's present state vector and the

Abort Guidance-Digital Program (Continued)

desired landing site. The burnout velocity (V_{BO}) is determined as a function of the central angle (θ_c). θ_c is the earth's central angle between the burnout position vector and landing site position vector. An estimate of θ_c is obtained by taking the difference between θ_R and θ_B . θ_R is the central angle between the present position vector of the vehicle and position vector of the landing site. An estimate of θ_B is obtained as a function of the average of present vehicle velocity and velocity to be gained in the local horizontal plane, time to go to target and earth radius. Then $\theta_c = \theta_R - \theta_B$. Burnout velocity (V_{BO}) is the sum of the results of the iterative process, described above, and the velocity of the landing site. The burnout altitude is the sum of the earth radius and burnout altitude. Burnout altitude is selected as a function of landing site position and vehicular constraints.

Abort Guidance - The function of the abort guidance is to steer the vehicle to the desired burnout state vectors. The guidance frame used is a local vertical frame with the X axis pointing up along the local vertical. The Z axis points toward the landing site. The Y axis completes the right-handed triad. The guidance equations used for radial steering (E-Guidance) were adapted from Reference 7. A constant acceleration command is used to produce the desired downrange and out-of-plane components of velocity at burnout.

Post Burnout Control - The function of this procedure is to provide vehicle attitudes during descent after engines are shut down. The process involves control of angle of attack. Angle of attack is modulated while maintaining a near zero bank angle. By using this process violation of vehicle constraints and guidelines is avoided.

Abort Guidance-Digital Program (Continued)

Post Burnout Control requires the use of a wind axis coordinate system with the origin located at the vehicle center of gravity. The unit x-axis is in the direction of the orbiter velocity relative to the earth's surface. Unit y-axis is the vector product of unit x into a unit radial (unit vector pointing from earth's center to orbiter center of gravity). Unit z-axis completes the right-handed triad.

A table of initialization values for post burnout control program is shown in Table XI. A flow chart of the program is shown in Figure 3 with symbol definitions shown in Table XII.

Conventional Autopilot - Digital Program

An autopilot is provided that uses a conventional engine control law. The form of the control law is

$$\delta = a_0 + a_1 \theta_E + a_2 \dot{\theta}_E$$

where:

- δ - engine deflection
- a_1, a_2 - weighting coefficients or gains
- θ_E - present vehicle attitude error
- $\dot{\theta}_E$ - present vehicle attitude rate error

Conventional Autopilot - Digital Program (Continued)

The a_o term is a bias term that corresponds to the engine gimbal deflection at the end of the present computation cycle. Then

$$\delta_{TRIM} = \delta_{TRIM} + .2 \frac{(\theta_{EL} + \theta_E)}{2}$$

$$a_o = .2 \delta_{TRIM}$$

where:

θ_{EL} - attitude error from the past computation cycle

provides an estimate of a_o and is used in the pitch engine gimbal computations. Attitude rate feedback is accomplished once per second. Provisions for manual control are included.

Values needed to initialize the conventional autopilot are shown in Table XIII. Gains used for the 161C delta wing orbiter are shown in Table XIV. A flow chart of the program is provided in Figure 4 with symbol definitions shown in Table XV.

Ideal Autopilot - Digital Program

The ideal autopilot attempts to attain between 95% and 105% of the body angular change desired, up to X degrees, in one second. If an angular change greater than X degrees is requested, the vehicle is allowed to coast at or near the rate of X degrees per second until the desired angular change is achieved, at which time the vehicle rate is cancelled (or nearly so). Included in the autopilot are angular acceleration and rotational rate limits which have been arbitrarily selected.

The ideal autopilot consists of the AUTOPI Routine and the acceleration subroutine, ACC. The AUTOPI Routine determines the differences between the requested inertial attitude angles from abort Guidance and the existing inertial attitude angles from EOM. The inertial angular differences are then transformed to body angular differences and output to the displays as body angular errors. The body angular differences are also provided (along with other quantities) to the acceleration subroutine, ACC, which computes the necessary angular acceleration to bring about the desired angular change.

Vehicle Control Functions

The control function of the autopilot is determined from the equation:

$$M = I\alpha$$

where:

M = Desired moment about the particular axis.

I = Moment of inertia about the respective axis.

α = Necessary angular acceleration (from ACC).

The moment equation for the sum of the moments about the Y-body axis (pitch) is as follows:

$$\Sigma My = F_{TXi} [Z_i - Z_{CG}] + F_{TZi} [X_{CG}]$$

where

F_{TXi} = Forces in the X-body direction due to thrust from the i^{th} engine.

F_{TZi} = Forces in the Z-body direction due to thrust from the i^{th} engine.

X_{CG} = Distance from the engine gimbal mounting plane to the vehicle center of gravity.

Z_{CG} = Distance from the X-Y plane to the vehicle center of gravity.

Z_i = Distance from the X-Y plane to the engine mounting center-line of the i^{th} engine.

Since:

$$F_{TXi} = F_{Ti} [\cos(\beta_p)] [\cos(\beta_y)]$$

and

$$F_{TZi} = -F_{Ti} [\sin(\beta_p)] [\cos(\beta_y)]$$

the moment about the Y-body is then:

$$\Sigma My = F_{Ti} [Z_i - Z_{CG}] [\cos(\beta_p)] \cos(\beta_y) - F_{Ti} [X_{CG}] [\sin(\beta_p)] \cos(\beta_y)$$

where:

β_p = pitch gimbal angle of the i^{th} engine.

β_y = yaw gimbal angle of the i^{th} engine.

The minus sign preceding the second term is due to a positive pitch angle creating a force in the negative Z-body direction.

An assumption is made regarding the above equation in that the maximum yaw angle (β_y) does not appreciably affect the moment about the Y-body axis. Since $\cos(7^\circ) = .9925$, the $\cos(\beta_y)$ term is dropped from the equation resulting in:

$$\Sigma M_y = F_{Ti} [Z_i - Z_{cg}] \cos(\beta_p) - F_{Ti} [X_{cg}] \sin(\beta_p)$$

The above equation is in the form:

$$M_y = A \cos x - B \sin x$$

Through manipulation and use of a trigonometric identity, the pitch angle, β_p , is determined as:

$$\beta_p = X = \sin^{-1} \left[\frac{A}{\sqrt{A^2 + B^2}} \right] - \sin^{-1} \left[\frac{M_y}{\sqrt{A^2 + B^2}} \right]$$

where $M_y = I_{yy} \alpha_y$

The yaw engine gimbal angle is determined in a similar manner resulting in

$$\beta_y = \sin^{-1} \left[\frac{M_z}{\sqrt{A^2 + B^2}} \right] + \sin^{-1} \left[\frac{A}{\sqrt{A^2 + B^2}} \right]$$

Since roll control is to be affected by use of the pitch engine gimbal angle, the necessary pitch angle for roll is found from:

$$\beta_R = \sin^{-1} \left[\frac{M_x - M_{xFY}}{F_{Ti} |Y_i - Y_{cg}| \cos(\beta_y)} \right]$$

where

M_{xFY} = Moment about X-body axis due to thrust forces in the Y-body direction.

Half of the engines will be commanded to a positive β_p and half to a negative β_p . The total pitch angle will be the sum of the β_p and β_R components.

For a more detailed derivation of the engine gimbal angles, see reference 1. Implementation details are shown in Tables XVI, XVII, XVIII and Figure 5.

Angular Acceleration Computations

The angular acceleration computations are performed in the ACC Subroutine. This subroutine determines a suitable or computes system gain, detects impending overshoot and compensates accordingly, computes the desired angular acceleration, and selectively applies the system gain. For a detailed description of the ACC Subroutine, see reference 1, a flow chart of the program is shown in Figure 6 with symbol definitions shown in Table XIX.

RCS

The moments as computed by the ideal autopilot math model may be used for an RCS system. Presently a pseudo RCS system is used in that the moments computed by the autopilot are applied to the EOM when the main engines are off, as if caused by an RCS system.

Manual Control

Manual take-over capability is also provided in the autopilot. The system is a rate-feedback system with the input proportional to the out-of-detent position of the rotational hand controller. The desired body angular accelerations are computed from:

$$\alpha = \frac{\omega_{DET} - \omega_E}{T_{MAX}}$$

where

α = Computed angular acceleration about the axis.

ω_{DET} = Desired rotational rate from hand controller.

ω_E = Present body rate about the axis ($\dot{\theta}$, $\dot{\psi}$, $\dot{\phi}$).

T_{MAX} = One second.

The angular accelerations computed for each axis are then used in the desired moment equations (for the respective axes) and either engine gimbal angles are determined or the moments are applied as a pseudo RCS system.

SIMULATOR CREW STATION

The crew station shall be provided with certain vehicle controls and data displays. Manual control is limited to the spacecraft during an abort. Manual controls are spacecraft attitude control, engine throttle control, and auto-manual mode select switch. This switch in the manual position configures the simulation to recognize manual control commands.

One of the objectives of the simulation is to study useability of the various display parameters proposed. A tentative display list is shown on Sheet 3 of Figure 1. Equations required by the displays are shown on Sheets 1 and 2. Each of the displays and control features are described in the following paragraphs.

Mission Time (t) - Since an abort can occur at any time after launch, time is started at the instant of launch. Time provides a coordination reference and is displayed digitally in minutes and seconds.

SIMULATOR CREW STATION (Continued)

EADI - This display will give altitude (H), relative flight path angle (γ_R), dynamic pressure ($\bar{q}$), mach number (M), pilot's pitch angle (θ_p), pilot's yaw angle (ψ_p), and pilot's roll angle (ϕ_p). Altitude will range between 0 and 400,000 feet; relative flight path angle between -20° and 150° ; dynamic pressure 0 to 600 pounds per square inch; Mach number 0 to 20; pilot's pitch angle $\pm 90^\circ$; pilot's yaw angle $\pm 90^\circ$; and pilot's roll angle $\pm 90^\circ$.

Rate of Change of Altitude (H) - This display indicates the rate of change displacement along a radial from the earth's center. The display range should be -100 ft/sec to 2000 ft/sec.

Groundspeed (V_G) - This display indicates total velocity in the horizontal ground plane. When in abort mode the range should be 0 to 18,000 ft/sec.

Bank Angle ϕ_B - This display indicates rotation about the vehicle velocity vector. During abort back to the launch site, a 180° bank can be expected. Range should be set for $\pm 180^\circ$.

Commanded Throttle (E_{PTC}) - This display indicates throttle commanded either in auto or manual mode. It should be displayed as a bar that aligns with the desired throttle bar. Changes in alignment indicates manual throttle control is desired. Range of E_{PTC} is from zero to unity.

Desired Throttle E_{PTD} - This display provides actual throttle desired as provided by the EOM throttle equations. When in auto mode the display always aligns with the commanded throttle. When in manual mode a misalignment of display bar indicates a throttle change is desired. Range of E_{PTD} is from zero to unity.

SIMULATOR CREW STATION (Continued)

Body Attitude Rates (p, q, r) - These displays provide information of angular velocities about body axes. Range of these displays should be $\pm 20^\circ/\text{second}$.

Compass Heading (ψ_h) - This display provides heading angle between vehicle velocity projection in horizontal plane and due north. The range of this display will be 0 - 360 degrees.

Heading Angle to Landing Site (ψ_R) - This display provides heading angle between vehicle velocity vector in horizontal plane and a vector between vehicle and landing site in horizontal plane. Range of this display will be $\pm 180^\circ$.

Body Attitude Errors ($\theta_{EB}, \psi_{EB}, \phi_{EB}$) - These displays provide attitude errors about the body axes. Ranges for these displays will be $\pm 180^\circ$.

Vehicle Latitude and Longitude (λ_V, ϕ_V) - This information is to be displayed as an X-Y plot using a cathode ray tube. The plot will show a ground track of the vehicle in relation to an outline of the eastern seaboard of the United States. Presently, ground tracks of launch at 90° launch azimuth have not been defined. The range of these displays will be 15° to 45° latitude and -60° to -85° longitude.

Time to Abort Targets (T_{GOA}) - This display provides an estimated time required to reach abort targets. The display should be a digital display in minutes and seconds.

SIMULATOR CREW STATION (Continued)

Vehicle Range to Landing Site (X_{LS} , Y_{LS} , R_{LS}) - These displays provide the distance the vehicle must traverse to reach the landing site. The distances are along the earth's surface in nautical miles. ψ_{LS} is the angle between R_{LS} and X_{LS} and is termed heading to the landing site. Y_{LS} is the crossrange element and completes the right triangle made up by R_{LS} , X_{LS} , Y_{LS} , and ψ_R . The actual display range will be 0 to 2000 nautical miles.

Pilot's Attitude Controller - This control will be used to provide vehicle attitude command when in manual mode and an abort is being performed. The controller outputs vehicle attitudes as desired rotation about body axes. The actual form and use of the controller depends on availability of hardware.

Pilot's Throttle Controller - This control will be used to provide throttle commands when in manual mode and an abort is being simulated. The controller outputs a signal that varies from zero to unity.

Pilot's Auto-Manual Mode Switch - This control will be a two position switch which controls simulation mode when an abort is being simulated. When in the AUTO position the simulation is allowed to run automatically. When in the MANUAL mode the simulation is configured to accept and act upon manual attitude and throttle commands.

CONTROL SYSTEM

During an abort, two operation modes are available, automatic and manual. In the automatic mode spacecraft attitudes are controlled by engine gimbaling when engines are thrusting. Either the conventional or ideal autopilots can be used to

CONTROL SYSTEM (Continued)

control engine gimbaling. When engines are not thrusting the ideal autopilot is used to compute rotating torques which are proportional to the body attitude errors. The torques are inserted in the proper EOM moment equations to reduce the attitude error to near zero. Thus, the torque is always large enough to maintain small attitude errors.

When the simulation is in manual mode, the manual attitude controller is used to provide desired attitudes to the autopilot. The pilot commands the attitude to reduce the error. The attitude error is the difference between the desired values provided by the abort guidance and actual attitudes provided by the EOM. The autopilot acts on the manually generated attitudes to gimbal engines or provide RCS torques.

The throttle controller provides throttle commands that are used by the EOM in computing thrust forces. At the same time the EOM is providing the desired throttle setting. If the commanded throttle and desired throttle is the same, additional throttle is not required. Only when a difference is noted should a change in throttle command be provided from the manual controller. Manual throttle control is applicable only during an abort.

TEST SCHEDULE

The detailed test schedule will be determined at a later time. However, the scope of testing can be determined in general by consideration of the testing variables. The testing variables are defined in the following paragraphs and will be combined into a test matrix.

TEST SCHEDULE (Continued)

Number of Launch Trajectories - At least two basic launch trajectories into a 55 by 100 nautical mile orbit will be considered. The first is a launch from Cape Kennedy at a launch azimuth of 38.44° into an orbit inclined at 55° . The second is a launch from Cape Kennedy at a launch azimuth of 90° into an orbit inclined at 28.5° .

Abort Times - Aborts will be simulated for preselected intervals of time after launch. Several aborts to a landing site will be considered during launch. The simulation is not configured for PAD or near launch PAD aborts with the SRM configuration.

Abort Target Altitude - The abort is targeted to an altitude consistent with reentry to the selected landing site and compatible with vehicle constraints. This altitude is termed the "Burnout" altitude. As necessary, several "burnout" altitudes may be considered as required by orbiter destination after abort.

Landing Sites - The destination of the orbiter after abort depends on time of the abort, after launch, the launch trajectory, and available landing sites. A tentative list of landing sites is shown in Table IV.

TEST SCHEDULE (Continued)

The first week of testing will be devoted to checkout of the hybrid-man-in-the-loop simulation. The second week will be devoted to abort runs from one of the launch trajectories. The third week will be used to analyze data. The fourth week will be used to make runs from the second launch trajectory. The fifth week will be used for data processing. The sixth week will be devoted for cleanup aborts to complete the study. This tentative schedule is shown below:

	1 Wk	2 Wk	3 Wk	4 Wk	5 Wk	6 Wk
Checkout						
Aborts From 1st Launch Trajectory						
Data Processing						
Aborts From 2nd Launch Trajectory						
Cleanup Aborts						

SYSTEM CHECKOUT

System checkout will be divided into two phases.

Initial Checkout - Details of initial checkout will be determined later.

Daily Checkout - It is anticipated that the daily checkout will be an abort at 150 seconds with the launch pad as the desired landing site. Specific simulation output will be compared to values considered normal. The parameters specified for comparison will be determined later.

OUTPUTS

A tentative list of output parameters is shown on sheet 3 of Figure 1. Launch time will be used to coordinate information between the various recorders and listings. A tentative allocation of output parameters to recording medium is described in the following paragraphs.

Strip Chart Recorders - Body attitude rates (p, q, r), Body angular accelerations ($\dot{p}, \dot{q}, \dot{r}$), and inertial accelerations ($\ddot{X}, \ddot{Y}, \ddot{Z}$) will be outputted on strip chart recorders.

X-Y Plotter - The vehicle ground track will be outputted using an X-Y plotter. The plot will be vehicle latitude (λ_V) versus vehicle longitude (ϕ_V).

Digital Listings - Referring to sheet 3 of Figure 1, each output listing shall list the constant data once at the start of each run. $\alpha, \beta, \gamma_R, \phi_B, \theta_{EB}, \psi_{EB}$, and ϕ_{EB} shall be listed once per second. The remaining variables shall be listed once each five seconds.

REFERENCES

1. Boeing Document D2-118387-1A and D2-118387-2A, "Users Guide for Guidance and Control Launch and Abort Simulation for Spacecraft (LASS)", June 30, 1972.
2. Fogarty, L. E. and Howe, R. M., "Analog Computer Solution of the Orbital Flight Equations".
3. "U. S. Standard Atmosphere", prepared under sponsorship of: ESSA, NASA, and USAF, 1962.
4. NASA/MSC Memorandum EG6-71-7, "Orbiter Abort Targeting and Guidance for a Powered Downrange Abort During Launch", EG6/Chief, Control Requirements Branch, February 22, 1971.
5. NASA Internal Note, "A Suborbital Maneuver to Return the Orbiter to a Specified Landing Site Following an Abort During Boost", unpublished.
6. Boeing Report 5-2581-HOU-068, "Boost and Abort G&C System Requirements", April 27, 1972.
7. MIT Document R-456, "E Guidance - A General Explicit, Optimizing Guidance Law for Rocket Propelled Spacecraft", August 21, 1964.

APPENDIX A

EQUATIONS OF MOTION

This Appendix provides the necessary data to implement the Equations of motion as described in the attached drawings. Contents include mass data, engine, location data, initialization data, aerodynamic data, and symbol definitions.

TABLE I CG & MOMENT OF INERTIA AS A FUNCTION OF WEIGHT

ORBITER AND TANK

<u>Weight</u> <u>(slugs)</u>	<u>x_{cg}</u> <u>(ft)</u>	<u>y_{cg}</u> <u>(ft)</u>	<u>z_{cg}</u> <u>(ft)</u>	<u>I_{xx}</u> <u>(10⁶sl-ft²)</u>	<u>I_{yy}</u> <u>(10⁶sl-ft²)</u>	<u>I_{zz}</u> <u>(10⁶sl-ft²)</u>	<u>I_{xz}</u> <u>(10⁶sl-ft²)</u>
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T O B E D E T E R M I N E D

ORBITER

T O B E D E T E R M I N E D

TABLE II
ENGINE LOCATIONS (ft)

ENG. NO.(i)

Y_{REF}

Z_{REF}

T O B E D E T E R M I N E D

TABLE III
PROPULSION AND VEHICLE CONFIGURATION DATA

<u>NOMENCLATURE</u>	<u>VALUE</u>
Spacecraft engine nozzle exit area-extended (A_{EO})	TBD
Spacecraft engine nozzle exit area-nonextended (A_{NO})	TBD
Spacecraft engine thrust in a vacuum (T_{VO})	TBD
Spacecraft engine exhaust gas velocity (GEGVEL)	TBD
Fuel flow rate for spacecraft engine (W_0)	TBD
Weight of useable main propellant onboard tank (W_{FB})	TBD
Weight of spacecraft less main propellant (W_{VO})	TBD
Weight of orbiter plus tank less main booster propellant (W_{VB})	TBD
Distance between body X-axis and spacecraft engine cluster center line along the body Z-axis (Z_{CF0})	TBD

TABLE IV
EOM INITIALIZATION CONSTANTS

<u>NOMENCLATURE</u>	<u>VALUE</u>
Mean earth radius (R_E)	20,909,740 ft
Earth rotational velocity (ω_e)	7.292115×10^{-5} rad/sec
Earth's gravitational constant (u)	14.07654×10^{15} ft ³ /sec ²
Latitude of Launch Pad (λ_{LP})	28.532°
Longitude of Launch Pad (ϕ_{LP})	-80.565°
Initialization constants for inertial velocity:	
$\dot{x}_0$, $\dot{y}_0$, and $\dot{z}_0$ depend on time after launch at which abort is initiated	
Initialization constants for inertial position:	
x_0 , y_0 and z_0 depend on time after launch at which abort is initiated	
Initialization constants for body rotation rates:	
p_0 , q_0 , and r_0 depend on time after launch at which abort is initiated	
Initialization constants for the Euler angles:	
θ_0 , ψ_0 , and ϕ_0 depend on time after launch at which abort is initiated	
Initialization constant for fuel remaining:	
w_{F0} depend on time after launch at which abort is initiated	

Table IV (Continued)

Landing Sites:

<u>Latitude (λ_{LS})</u>	<u>Longitude (ϕ_{LS})</u>	<u>Place</u>
28.532°	-80.565°	Launch Pad
43°	-71°	Pease AFB
34.9°	-76.9°	Cherry Point
32.2°	-64.8°	Bermuda

<u>Limiting acceleration</u>	<u>Value</u>
Spacecraft acceleration limit(A_{LO})	3.0 gees

TABLE V
AERODYNAMIC CONSTANTS

	<u>ORBITER/TANK</u>	<u>ORBITER</u>
x_{AREF}	TBD	TBD
y_{AREF}	TBD	TBD
z_{AREF}	TBD	TBD
S	TBD	TBD
$\bar{c}$	TBD	TBD
b	TBD	TBD
length	TBD	TBD

TABLE VI

ORBITER/TANK CONFIGURATION AERO COEFFICIENTS

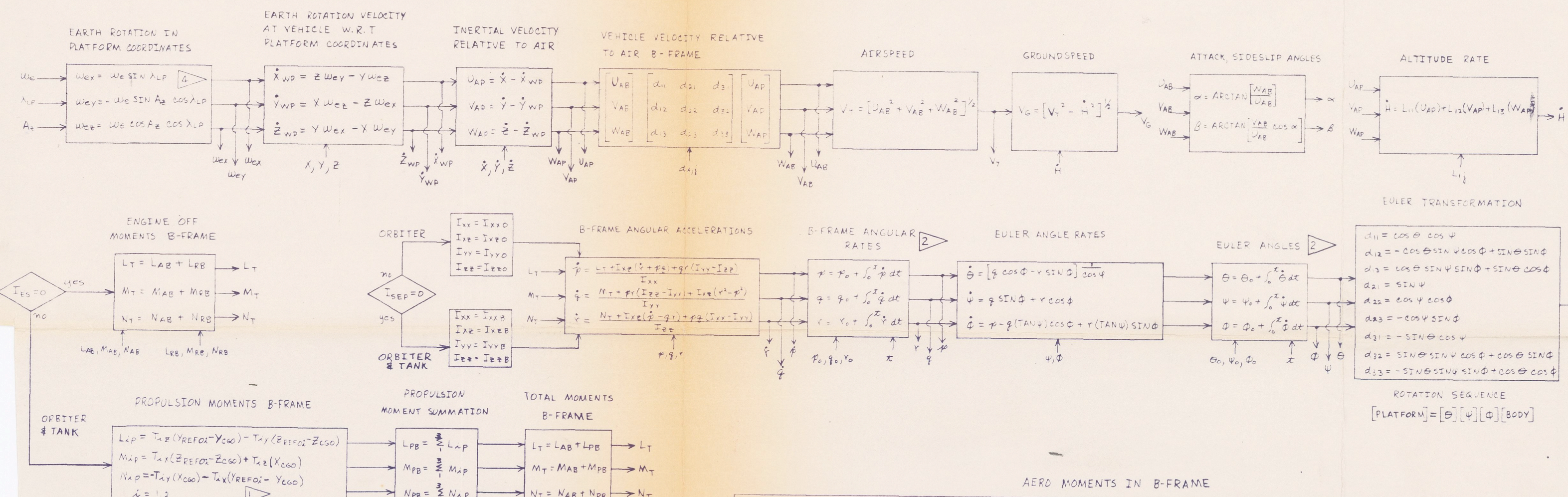
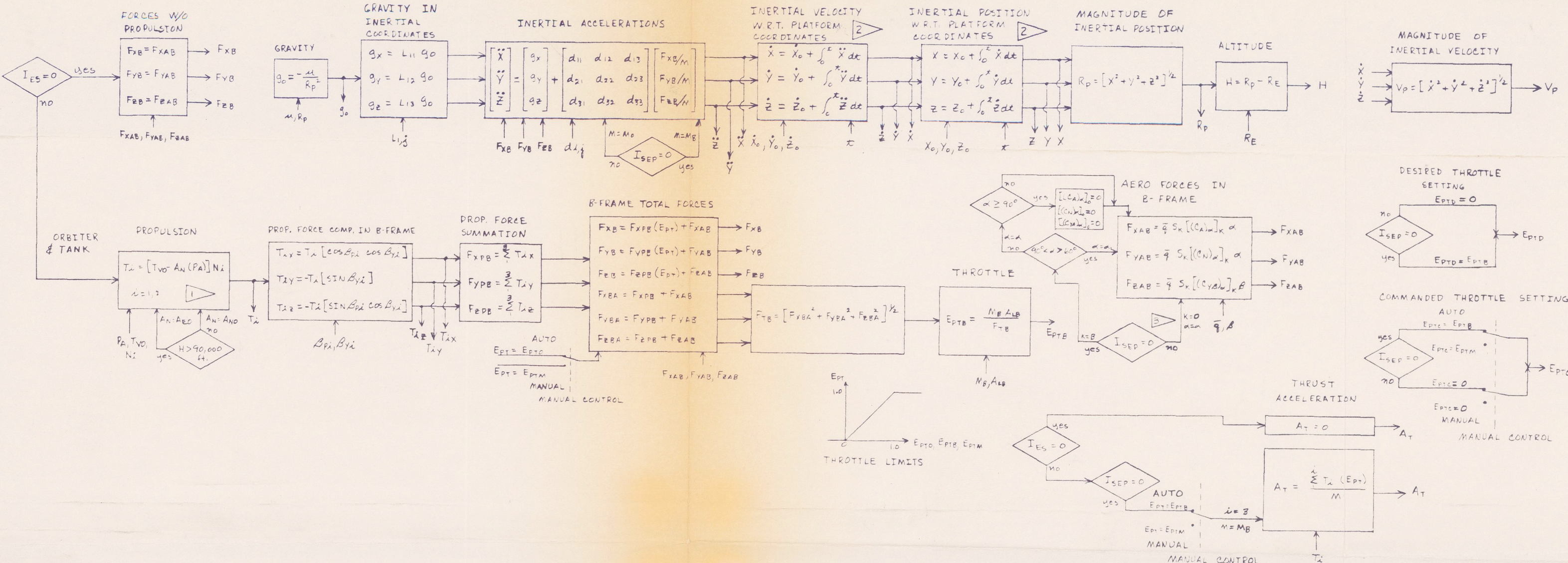
<u>M</u>	<u>C_A</u>	<u>C_N_{α=0°}</u>	<u>C_N_{α=1°}</u>	<u>C_m_{α=0°}</u>	<u>C_m_{α=1°}</u>	<u>C_y_{ρ=1°}</u>	<u>C_n_{ρ=1°}</u>	<u>C_l_{ρ=1°}</u>
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T B D

TABLE VII
ORBITER AERO COEFFICIENTS

<u>M/</u>	<u>$C_A = -C_X$</u>	<u>C_{Y_B}</u>	<u>$C_N = -C_Z$</u>	<u>C_{m_α}</u>	<u>C_{l_B}</u>	<u>C_{n_B}</u>	<u>C_{l_p}</u>	<u>C_{l_r}</u>	<u>C_{n_p}</u>	<u>C_{n_r}</u>
-----------	--------------------------------	-----------------------------	--------------------------------	----------------------------------	-----------------------------	-----------------------------	-----------------------------	-----------------------------	-----------------------------	-----------------------------

TBD



NOTE: FOR SYMBOL DEFINITIONS SEE "SIMULATION REPORT FOR LAUNCH AND ABORT SIMULATION FOR SPACECRAFT" JUNE 21, 1971; TABLE VIII OF APPENDIX A.

- 4 THESE EQUATIONS ARE FUNCTIONS OF CONSTANTS AND REQUIRE COMPUTATION ONCE PER SIMULATION RUN
- 3 AT SEPARATION AERODYNAMIC COEFFICIENTS WILL BE TAKEN FROM DIFFERENT TABLES
- 2 SIMULATION STARTS WHEN ABORT TAKES PLACE. INTEGRATION CONSTANTS DEPEND ON ABORT TIME.
- 1 ORBITER CONFIGURATION COULD HAVE AS MANY AS THREE MAIN ENGINES

SIGNATURES		DATE	NATIONAL AERONAUTICS & SPACE ADMINISTRATION
DR			MANNED SPACECRAFT CENTER - HOUSTON, TEXAS
ENG	H. Beckman	5-17-72	DETAILS FOR IMPLEMENTATION
CH			OF LASS
APP			
AUTH			
CODE IDENT NO.		SIZE	DWG NO.
36		E	FIGURE 1
SCALE		SHEET 1 OF 3	

FOLDOUT FRAME 1

TRANSFORMATION FROM EARTH INERTIAL TO PLATFORM COORDINATES

$$\begin{aligned} T_{11} &= \cos \lambda_P \cos \phi_P \\ T_{12} &= \cos \lambda_P \sin \phi_P \\ T_{13} &= \sin \lambda_P \\ T_{21} &= -\cos \lambda_P \sin \phi_P + \sin \lambda_P \sin \lambda_P \cos \phi_P \\ T_{22} &= \cos \lambda_P \cos \phi_P + \sin \lambda_P \sin \lambda_P \sin \phi_P \\ T_{23} &= -\sin \lambda_P \cos \phi_P \\ T_{31} &= -\sin \lambda_P \sin \phi_P - \cos \lambda_P \sin \lambda_P \cos \phi_P \\ T_{32} &= \sin \lambda_P \cos \phi_P - \cos \lambda_P \sin \lambda_P \sin \phi_P \\ T_{33} &= \cos \lambda_P \cos \phi_P \end{aligned}$$

VEHICLE POSITION IN EARTH INERTIAL COORDINATES

$$\begin{bmatrix} X_F \\ Y_F \\ Z_F \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{33} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

LATITUDE AND LONGITUDE OF VEHICLE

$$\lambda_V = \text{ARCSIN} \left(\frac{Y_F}{R_P} \right)$$

$$\phi_V = \text{ARCTAN} \left(\frac{Z_F}{X_F} \right) - \omega_e t$$

CENTRAL ANGLE TO LANDING SITE

$$\lambda_{CL} = \lambda_{LS} - \lambda_V$$

$$\phi_{CL} = \phi_V - \phi_{LS}$$

$$\theta_{CL} = \text{ARCCOS} [\cos \lambda_{CL} \cos \phi_{CL}]$$

RANGE TO LANDING SITE

$$R_{LS} = \frac{\theta_{CL} R_E}{6080.27}$$

DELTA LATITUDE AND LONGITUDE

$$\lambda_{LP} = \lambda_V - \lambda_{LP}$$

$$\phi_{LP} = \phi_V - \phi_{LP}$$

CENTRAL ANGLE TRAVERSED

$$\theta_{CA} = \text{ARCCOS} [\cos \lambda_{LP} \cos \phi_{LP}]$$

RANGE FROM LAUNCH PAD

$$R_{LP} = \frac{\theta_{CA} R_E}{6080.27}$$

INTEGRATION TIME

$$t = t_{GET} - t_{ABT}$$

TABLE LOOK UP AIR TEMPERATURE (°F) AS A FUNCTION OF ALTITUDE (T_n)_H

$$A = 49.1 (T_n)^{1/2}$$

MACH NUMBER

$$M = \frac{V_T}{A}$$

TABLE LOOK UP AIR DENSITY AS A FUNCTION OF ALTITUDE (ρ)_H

$$\bar{q} = \frac{1}{2} \rho V_T^2$$

DYNAMIC PRESSURE

$$\bar{q} = \frac{1}{2} \rho V_T^2$$

AMBIENT PRESSURE

$$P_A = 53.7 P_{Tn}$$

FUEL METERING

$$W_F = W - W_{FD} - \frac{1}{2} \sum_i W_{EFT} N_i$$

VEHICLE MASS

$$M = W_V + W_F$$

AXIAL AND NORMAL ACCELERATIONS

$$A_A = \frac{M}{F_{EB} g_{sl}}$$

$$A_N = \frac{M}{F_{EB} g_{sl}}$$

TRANSFORMATION BETWEEN LOCAL VERTICAL AND PLATFORM COORDINATES

$$\begin{aligned} L_{11} &= \frac{X}{R_P} \\ L_{12} &= \frac{Y}{R_P} \\ L_{13} &= \frac{Z}{R_P} \\ Q_1 &= V_{AP} L_{11} - W_{AP} L_{12} \\ Q_2 &= W_{AP} L_{11} - V_{AP} L_{12} \\ Q_3 &= U_{AP} L_{12} - V_{AP} L_{11} \end{aligned}$$

FLIGHT PATH ANGLE RELATIVE

$$\gamma_R = \text{ARCTAN} \left(\frac{\dot{H}}{V_0} \right)$$

RADIAL TO LANDING SITE EXPRESSED IN EARTH INERTIAL COORDINATES

$$\begin{aligned} X_{LSE} &= X_{LSE} \cos(\omega_e t) - Y_{LSE} \sin(\omega_e t) \\ Y_{LSE} &= X_{LSE} \sin(\omega_e t) + Y_{LSE} \cos(\omega_e t) \\ Z_{LSE} &= Z_{LSE} \end{aligned}$$

RADIAL TO LANDING SITE EXPRESSED IN PLATFORM COORD.

$$\begin{bmatrix} X_{LSP} \\ Y_{LSP} \\ Z_{LSP} \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{33} \end{bmatrix} \begin{bmatrix} X_{LSE} \\ Y_{LSE} \\ Z_{LSE} \end{bmatrix}$$

VECTOR FROM VEHICLE TO LANDING SITE EXPRESSED IN LOCAL VERTICAL COORD.

$$\begin{bmatrix} X_{LSPV} \\ Y_{LSPV} \\ Z_{LSPV} \end{bmatrix} = \begin{bmatrix} L_{11} & L_{12} & L_{13} \\ L_{21} & L_{22} & L_{23} \\ L_{31} & L_{32} & L_{33} \end{bmatrix} \begin{bmatrix} X_{LSP} \\ Y_{LSP} \\ Z_{LSP} \end{bmatrix}$$

RELATIVE HEADING ANGLE

$$\psi_R = \text{ARCTAN} \left(\frac{Y_{LSPV}}{X_{LSPV}} \right)$$

DOWNRANGE AND CROSS RANGE TO LANDING SITE

$$R_{LSOR} = R_{LS} \cos \psi_R$$

$$R_{LSOR} = R_{LS} \sin \psi_R$$

UNIT VECTOR POINTING EAST IN PLATFORM COORDINATES

$$\begin{aligned} Q_1 &= L_{13} \omega_{ey} - L_{12} \omega_{ex} \\ Q_2 &= L_{11} \omega_{ex} - L_{13} \omega_{ey} \\ Q_3 &= L_{12} \omega_{ex} - L_{11} \omega_{ey} \\ Q_4 &= (Q_1^2 + Q_2^2 + Q_3^2)^{1/2} \end{aligned}$$

COMPASS HEADING FOR DISPLAY

$$\psi_H = \text{ARCCOS} [L_{21} U_{E1} + L_{22} U_{E2} + L_{23} U_{E3}]$$

PILOT'S YAW ANGLE FOR DISPLAY

$$\psi_P = \text{ARCSIN} \left[\frac{d_{11} U_{E1} + d_{12} U_{E2} + d_{13} U_{E3}}{\cos \theta_P} \right]$$

PILOT'S PITCH ANGLE FOR DISPLAY

$$\theta_P = \text{ARCSIN} [d_{11} L_{11} + d_{12} L_{12} + d_{13} L_{13}]$$

PILOT'S ROLL ANGLE FOR DISPLAY

$$\phi_P = \text{ARCSIN} \left[\frac{-(d_{12} L_{11} + d_{13} L_{12} + d_{11} L_{13})}{\cos \theta_P} \right]$$

RADIAL TO LANDING SITE EXPRESSED IN EARTH FIXED COORDINATES

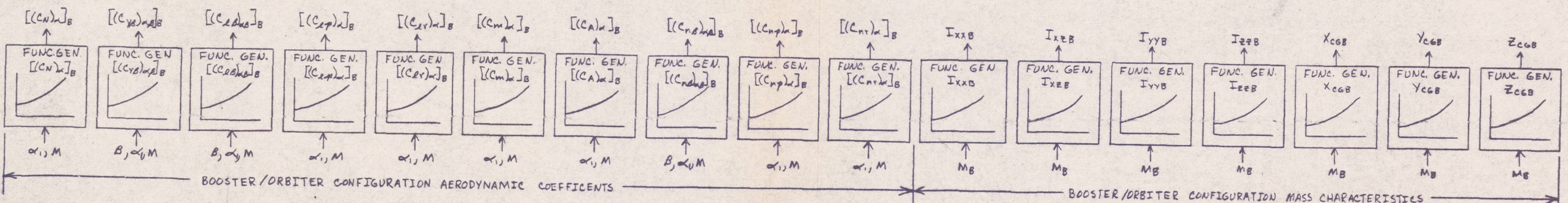
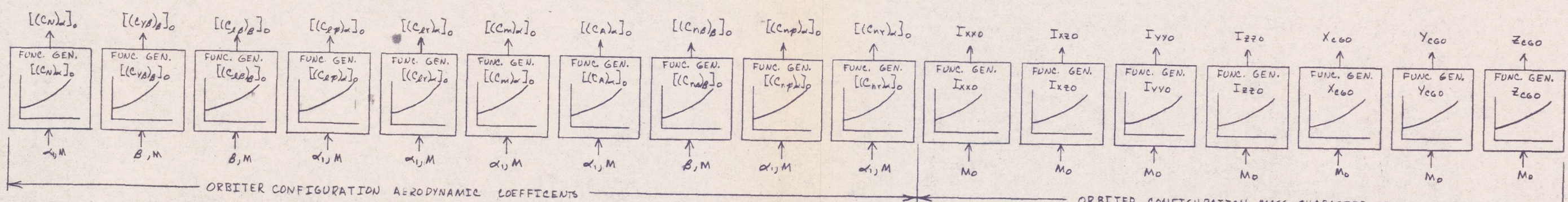
$$\begin{aligned} X_{LSE} &= R_E \cos \lambda_{LS} \cos \phi_{LS} \\ Y_{LSE} &= R_E \cos \lambda_{LS} \sin \phi_{LS} \\ Z_{LSE} &= R_E \sin \lambda_{LS} \end{aligned}$$

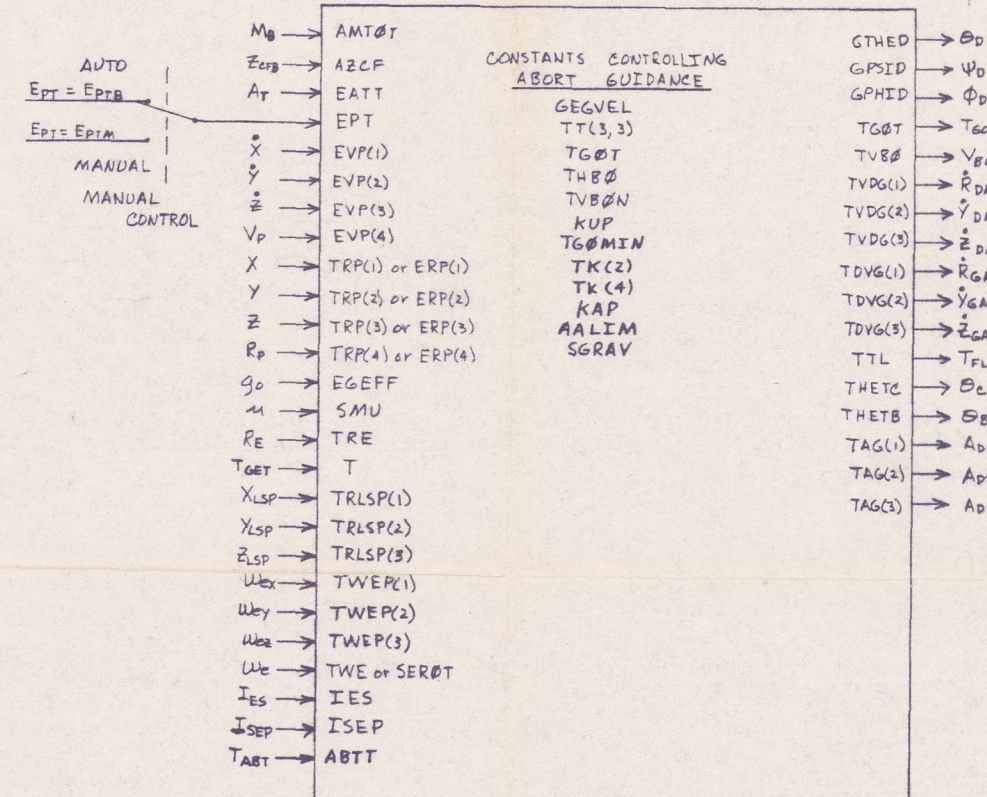
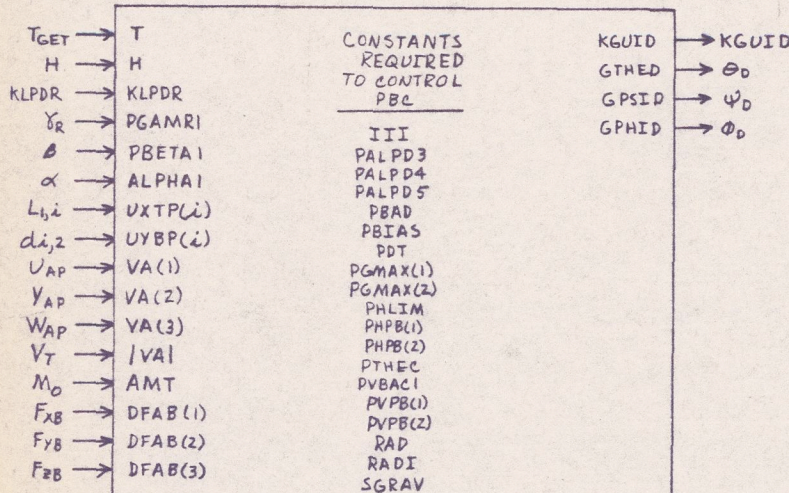
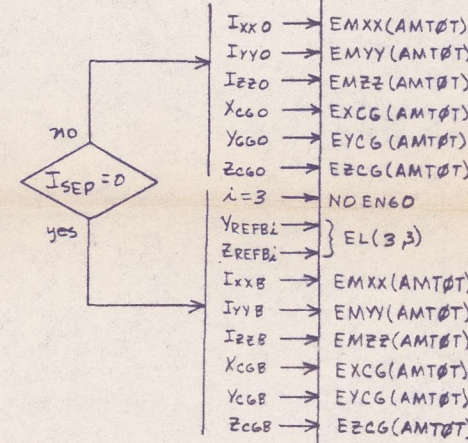
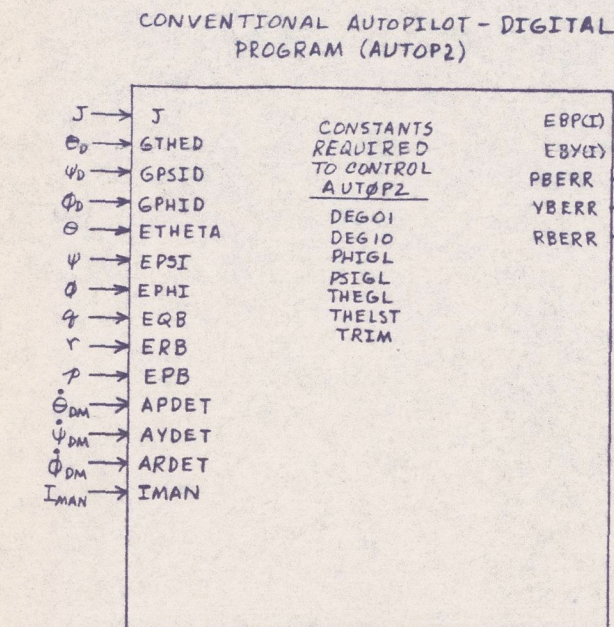
BANK ANGLE FOR DISPLAY

$$\phi_B = \text{ARCSIN} \left[\frac{-(d_{12} L_{11} + d_{13} L_{12} + d_{11} L_{13})}{\cos \theta_P} \right]$$

PSEUDO ANGLE OF ATTACK USED FOR TABLE LOOK UP

$$\alpha_i = \begin{cases} 60^\circ & \text{if } \alpha_i > 60^\circ \\ \alpha_i & \text{if } 0^\circ \leq \alpha_i \leq 60^\circ \\ |\alpha_i| & \text{if } \alpha_i < 0^\circ \end{cases}$$





TGET	TIME FROM LAUNCH
H	ALTITUDE
H	ALTITUDE RATE
V _G	GROUND SPEED
Φ _B	BANK ANGLE
EPTC	COMMANDED THROTTLE
EPTA	ACTUAL THROTTLE
ρ	BODY PITCH RATE
Ψ	BODY YAW RATE
γ	BODY ROLL RATE
γ _R	RELATIVE FLIGHT PATH ANGLE
q̇	DYNAMIC PRESSURE
M	MACH NUMBER
ψ _h	COMPASS HEADING
ψ _L	HEADING TO LANDING SITE
ϕ _L	PILOT'S PITCH ANGLE
ψ _P	PILOT'S YAW ANGLE
ϕ _D	PILOT'S ROLL ANGLE
W _F	FUEL REMAINING
λ _V	VEHICLE LATITUDE
φ _V	VEHICLE LONGITUDE
TGGA	TIME TO GO TO REACH ABORT TARGET
A _T	THRUST ACCELERATION
X _L	DOWNRANGE DISTANCE TO LANDING SITE
Y _L	CROSSRANGE DISTANCE TO LANDING SITE
R _L	RANGE TO LANDING SITE
Θ _{EB}	BODY PITCH ERROR
Ψ _{EB}	BODY YAW ERROR
Φ _{EB}	BODY ROLL ERROR

CONSTANT DATA		VARIABLE DATA	
λ_L	LANDING SITE LATITUDE	I_{ES}	PILOT'S DISPLAY PARAMETERS
ϕ_L	LANDING SITE LONGITUDE	I_{MAN}	ENGINE ON
I_{SEP}	TIME OF SEPARATION	R_{LP}	MANDAL CONTROL
T_{ABT}	ABORT TIME	α	RANGE FROM LAUNCH PAD
A_E	LAUNCH AZIMUTH	β	ANGLE OF ATTACK
H_{BD}	BURNOUT ALTITUDE	γ	ANGLE OF SIDESLIP
N_i	ENGINE OUT	$\dot{\gamma}_{DA}$	INERTIAL FLIGHT PATH ANGLE
		$\dot{\gamma}_{DA}$	} DESIRED TARGETED VELOCITY IN LOCAL VERTICAL COORDINATES FOR ABORT
		$\dot{\gamma}_{DA}$	
		$\dot{\gamma}_{CA}$	} VELOCITY TO BE GAINED IN LOCAL VERTICAL COORDINATES FOR ABORT
		$\dot{\gamma}_{CA}$	
		$\dot{\gamma}_{CA}$	} DESIRED ACCELERATIONS IN LOCAL VERTICAL COORDINATES FOR ABORT
		$\dot{\gamma}_{CA}$	
A_A	AXIAL ACCELERATION	$\dot{A}_{DX}$	} DESIRED ACCELERATIONS IN LOCAL VERTICAL COORDINATES FOR ABORT
A_N	NORMAL ACCELERATION	$\dot{A}_{DY}$	
E_{AG}	} ENGINE GIMBAL ANGLES	$\dot{A}_{DE}$	} BURNOUT VELOCITY FOR ABORT TARGET
E_{AG}		$\dot{A}_{DE}$	
L_{AB}	} MOMENTS DUE TO AERODYNAMIC FORCES	T_{FL}	TIME TO THRUST LIMIT DURING ABORT
M_{AB}		θ_C	CENTRAL ANGLE FOR COAST
N_{AB}		θ_B	CENTRAL ANGLE TO CUTOFF DURING ABORT
F_{XAB}	} FORCES DUE TO AERODYNAMIC EFFECTS	θ_{CL}	CENTRAL ANGLE TO LANDING SITE
F_{YAB}		$\dot{x}$	} VEHICLE INERTIAL VELOCITIES
F_{ZAB}	$\dot{y}$	} VEHICLE INERTIAL POSITION	
U_{AB}	$\dot{z}$		
V_{AB}	x		
W_{AB}	y		
		z	} TRANSLATIONAL ACCELERATIONS IN PLATFORM COORDINATES
		R_P	
		$\dot{R}_P$	} TRANSLATIONAL ACCELERATIONS IN PLATFORM COORDINATES
		$\dot{R}_P$	
		$\dot{x}$	} TRANSLATIONAL ACCELERATIONS IN PLATFORM COORDINATES
		$\dot{y}$	
		$\dot{z}$	} TRANSLATIONAL ACCELERATIONS IN PLATFORM COORDINATES
		$\dot{z}$	

TABLE VIII SYMBOL DEFINITIONS FOR EQUATION-OF-MOTION

ENGR SYM.	CODED SYM	SYMBOL DEFINITION OR USE	RANGE	UNITS
A		Speed of sound	0-1300	ft/sec
A_A		Axial acceleration	0 - 4	g's
A_{DX}		Desired radial acceleration in local vertical coordinates for abort	0-100	ft/sec ²
A_{DY}		Desired crossrange acceleration in local vertical coordinates for abort	0-50	ft/sec ²
A_{DZ}		Desired downrange acceleration in local vertical coordinates for abort	0-100	ft/sec ²
A_{EO}		Exit area of orbiter engine nozzle when extended	constant	ft ²
A_{LO}		Limiting orbiter thrust acceleration	constant	ft/sec ²
A_N		Normal acceleration	0 - 5	g's
A_{NO}		Exit area of orbiter engine nozzle when not extended	constant	ft ²
A_T		Total thrust acceleration	0-100	ft/sec ²
A_Z		Launch azimuth	constant	rad.
b_0		Aerodynamic span of orbiter	constant	ft.
$(C_A)_\alpha$		Aerodynamic axial force coeff.	table	unitless
$\bar{c}_B$		Aerodynamic chord for orbiter	constant	ft
$(C_l)_p_\alpha$		Aerodynamic rolling moment coeff. due to roll rate	table	unitless
$(C_l)_r_\alpha$		Aerodynamic rolling moment coeff. due to yaw rate	table	unitless

TABLE VIII (Continued)

CODED SYM.	ENGR. SYM.	SYMBOL DEFINITION OR USE	RANGE	UNITS
$(C_l)_\beta$		Aerodynamic rolling moment coeff. due to sideslip, β	table	unitless
$(C_m)_\alpha$		Aerodynamic pitching moment coeff. due to angle of attack, α	table	unitless
$(C_N)_\alpha$		Aerodynamic normal force coeff.	table	unitless
$(C_{n_p})_\alpha$		Aerodynamic yawing moment coeff. due to roll rate	table	unitless
$(C_{n_r})_\alpha$		Aerodynamic yawing moment coeff. due to yaw rate	table	unitless
$(C_{n_\beta})_\alpha$		Aerodynamic yawing moment coeff. due to sideslip	table	unitless
$\bar{c}_0$		Aerodynamic chord for orbiter	constant	ft.
$(C_Y)_\beta$		Aerodynamic side force coeff. due to sideslip	table	unitless
d_{ij}		Direction cosines between body and inertial coordinates	0-1	unitless
E_{PTB}		Throttle setting of orbiter engines	0-1	unitless
E_{PTC}		Commanded throttle setting	0-1	unitless
E_{PTD}		Desired throttle setting	0-1	unitless
E_{PTM}		Throttle setting commanded by throttle controller	0-1	unitless

TABLE VIII (Continued)

ENGR SYM.	CODED SYM	SYMBOL DEFINITION OR USE	RANGE	UNITS
F_{TB}		Total thrust and aerodynamic forces on vehicle	0-10x10 ⁶	lbs
F_{XAB}		Aerodynamic force along body X axis	0-1.5x10 ⁶	lbs
F_{XB}		Total body X force	0-10x10 ⁶	lbs
F_{XBA}		Total force along body X-axis without throttling	0-8x10 ⁶	lbs
F_{XPB}		Total propulsion forces along body X-axis	0-8x10 ⁶	lbs
F_{YAB}		Aerodynamic force along body Y-axis	0-5x10 ⁵	lbs
F_{YB}		Total body Y force	0-1x10 ⁶	lbs
F_{YBA}		Total force along body Y-axis without throttling	0-1x10 ⁶	lbs
F_{YPB}		Total propulsion forces along body Y-axis	0-1x10 ⁶	lbs
F_{ZAB}		Aerodynamic force along body Z-axis	0-1x10 ⁶	lbs
F_{ZB}		Total body Z force	0-2x10 ⁶	lbs
F_{ZBA}		Total force along body Z-axis without throttling	0-1x10 ⁶	lbs
F_{ZPB}		Total propulsion forces along body Z-axis	0-1x10 ⁶	lbs
g_0		Gravity effects	0-33	ft/sec ²
g_{SL}		Gravity at sea level	0 - 33	ft/sec ²
g_x		X component of gravity in platform coordinates	0-33	ft/sec ²
g_y		Y component of gravity in platform coordinates	0-33	ft/sec ²
g_z		Z component of gravity in platform coordinates	0-33	ft/sec ²

TABLE VIII (Continued)

ENGR SYM.	CODED SYM	SYMBOL DEFINITION OR USE	RANGE	UNITS
H		Vehicle altitude	0 to 400 K	ft.
$\dot{H}$		Rate of change of altitude	-100 to 2000	ft/sec
I _{ES}		Zero indicates engines are off	1 or 0	unitless
I _{SEP}		One indicates separation has taken place	1 or 0	unitless
I _{MAN}		One indicates the vehicle is under manual control	1 or 0	unitless
I _{XXB}		Moment of inertia about orbiter/tank body X-axis	Table	slug/ft ²
I _{XZB}		Moment of inertia about orbiter/tank body XZ plane	Table	slug/ft ²
I _{YYB}		Moment of inertia about orbiter tank body Y-axis	Table	slug/ft ²
I _{ZZB}		Moment of inertia about orbiter/tank body Z-axis	Table	slug/ft ²
I _{XX0}		Moment of inertia about orbiter body X-axis	Table	slug/ft ²
I _{XZ0}		Moment of inertia about orbiter body XZ plane	Table	slug/ft ²
I _{YY0}		Moment of inertia about orbiter body Y-axis	Table	slug/ft ²
I _{ZZ0}		Moment of inertia about orbiter body Z-axis	Table	slug/ft ²
J		Minor loop counter	1 - 5	unitless
KC $\emptyset$ AST		KC $\emptyset$ AST = 1 ; orbiter is in coasting flight	0 - 1	unitless
KGUID		KGUID = 1 ; orbiter has reached terminal energy state	0 - 1	unitless
KLPDR		KLPDR = 1 ; after abort orbiter returns to launch pad	0 - 1	unitless
L _{AB}		Aerodynamic moment about body X-axis	0-1x10 ⁶	ft-lbs
L _{i,j}		Direction cosines between local vertical and platform coordinates	0 to 1	unitless
L _{ip}		Propulsion moment about body X-axis from i th engine	0-1x10 ⁶	ft-lbs

TABLE VIII (Continued)

ENGR SYM.	CODED SYM	SYMBOL DEFINITION OR USE	RANGE	UNITS
L_{PB}		Total propulsion moment about body X axis	$0-6 \times 10^6$	ft-lb
L_{RB}		RCS moment about body X-axis	$0-2 \times 10^6$	ft-lb
L_T		Total moment about body X-axis	$0-7 \times 10^6$	ft-lb
M		Mach number	0-20	unitless
M_{AB}		Aerodynamic moment about body Y-axis	$0-1 \times 10^6$	ft-lb
M_B		orbiter/tank mass	Table	lbs
M_{iP}		Propulsion moment about body Y-axis from i^{th} engine	$0-1 \times 10^6$	ft-lbs
M_O		Orbiter mass	Table	lbs
M_{PB}		Total propulsion moment about body Y-axis	$0-1.2 \times 10^8$	ft-lbs
M_{RB}		RCS moment about body Y-axis	$0-2 \cdot 10^6$	ft-lbs
M_T		Total moment about body Y-axis	$0-1.5 \times 10^8$	ft-lbs
N_{AB}		Aerodynamic moment about body Z-axis	$0-1 \times 10^6$	ft-lbs
N_i		A zero indicates the i^{th} engine is not producing thrust	1 or 0	unitless
N_{iP}		Propulsion moment about body Z-axis from i^{th} engine	$0-1 \cdot 10^6$	ft-lbs
N_{PB}		Total propulsion moment about body Z-axis	$0-6 \times 10^6$	ft-lbs
N_{RB}		RCS moment about body Z-axis	$0-2 \times 10^6$	ft-lbs
N_T		Total moment about body Z-axis	$0-7 \times 10^6$	ft-lbs

TABLE VIII (Continued)

ENGR SYM.	CODED SYM	SYMBOL DEFINITION OR USE	RANGE	UNITS
p		Angular rate about body X-axis	± 20	deg/sec
$\dot{p}$		Angular acceleration about body X-axis	$\pm .2$	rad/sec ²
P_A		Ambient air pressure	0-20	lbs/ft ²
P_0		Integration constant for p	table	rad/sec
q		Angular rate about body Y-axis	± 20	deg/sec
$\dot{q}$		Angular acceleration about body Y-axis	$\pm .2$	rad/sec ²
$\bar{q}$		Dynamic pressure	0-600	lbs/ft ²
q_0		Integration constant for q	table	rad/sec
r		Angular rate about body Z-axis	± 20	deg/sec
$\dot{r}$		Angular acceleration about body Z-axis	$\pm .2$	rad/sec ²
$\dot{R}_{DA}$		Desired target radial velocity in local vertical coordinates for abort	0 to 1000	ft/sec
R_E		Mean earth radius	constant	ft.
$\dot{R}_{GA}$		Radial velocity to be gained in local vertical coordinates for abort	-1000 to 5000	ft/sec
R_{LP}		Range from launch pad	0 to 2000	N. mi.
R_{LS}		Range to landing site	0 to 2000	N. mi.
R_{LSCR}		Distance to landing site normal to velocity vector in local horizontal plane	0 to 2000	N. mi.
R_{LSDR}		Distance to landing site along velocity vector in local horizontal plane	0 to 2000	N. mi.

TABLE VIII (Continued)

ENGR SYM.	CODED SYM	SYMBOL DEFINITION OR USE	RANGE	UNITS
r_0		Integration constant for r	constant	rad/sec
R_p		Magnitude of inertial position	20 to 22 $\times 10^6$	ft.
S_B		Reference surface area of orbiter/tank	constant	ft ²
S_0		Reference surface area of orbiter	constant	ft ²
t		Integration time	0 to 500	sec.
T_{ABT}		Time abort is desired	0 to 400	sec.
T_{FL}		Time to thrust limit for abort	0-200	sec.
T_{GET}		Ground elapsed time	0 - 100	sec.
T_{GOA}		Time to go to abort target	0-250	sec.
T_i		Thrust from i^{th} engine	0 to 650,000	lbs.
T_{ij}		Direction cosines relating earth inertial coordinates with platform coordinates	0-1	unitless
T_{iT}		Engine thrust from i^{th} engine after throttling	0 to 650,000	lbs.
T_{iX}		Thrust from i^{th} engine along body X-axis	0 to 650,000	lbs
T_{iY}		Thrust from i^{th} engine along body Y-axis	0 to 650,000	lbs
T_{iZ}		Thrust from i^{th} engine along body Z-axis	0 to 650,000	lbs
T_n		Temperature of ambient air	table	R°
T_{VO}		Thrust from orbiter engine in a vacuum	constant	lbs.
U_{AB}		X component of B-Frame velocity relative to surrounding air	0 to 26,000	ft/sec
U_{AP}		Platform X component of inertial velocity relative to surrounding air	0 to 13,000	ft/sec

TABLE VIII (Continued)

ENGR SYM.	CODED SYM	SYMBOL DEFINITION OR USE	RANGE	UNITS
UE_1		Platform X-comp. of unit vector pointing east	0-1	unitless
UE_2		Platform Y-comp. of unit vector pointing east	0-1	unitless
UE_3		Platform Z-comp. of unit vector pointing east	0-1	unitless
V_{AB}		Y component of B-Frame velocity relative to surrounding air	0 to 26,000	ft/sec
V_{AP}		Platform Y component of inertial velocity relative to surrounding air	$\pm 10,000$	ft/sec
V_{BO}		Burnout velocity for abort target	0 to 15,000	ft/sec
V_G		Ground speed	0 to 18,000	ft/sec
V_P		Magnitude of inertial velocity	0 to 26,000	ft/sec
V_T		Airspeed	0 to 26,000	ft/sec
W_{AB}		Z component of B-Frame velocity relative to surrounding air	0 to 20,000	ft/sec
W_{AP}		Platform Z component of inertial velocity relative to surrounding air	-10,000 to 26,000	ft/sec
W_B		Fuel flow rate to orbiter engine	constant	lbs/sec
W_F		Fuel remaining	table	lbs
W_{FB}		Weight of orbiter/tank fuel	constant	lbs
W_{FO}		Weight of fuel consumed up to abort	0 to 800,000	lbs

TABLE VIII (Continued)

ENGR SYM.	CODED SYM	SYMBOL DEFINITION OR USE	RANGE	UNITS
w_R		Relative velocity normal to radial vector	0 to 26,000	ft/sec
w_{VB}		Orbiter/tank weight with tank empty	constant	lbs
w_{VO}		Empty orbiter weight	constant	lbs
x		Inertial position along platform X-axis	20×10^6 to 22×10^6	ft
$\dot{x}$		Inertial velocity along platform X-axis	-1000 to 15,000	ft/sec
$\ddot{x}$		Inertial acceleration along platform X-axis	0 to 100	ft/sec ²
x_{AREFB}		X body component of orbiter/tank center of pressure	Table	ft.
x_{AREFO}		X body component of orbiter center of pressure	Table	ft.
x_{CGB}		Body X component of orbiter/tank C.G. location	Table	ft.
x_{CGO}		Body X component of orbiter C.G. location	Table	ft.
x_F		X component of vehicle position in earth inertial coordinates	10×10^6 to 22×10^6	ft.
x_{LSE}		X comp of radial to landing site in earth fixed coordinates	10×10^6 to 21×10^6	ft.
x_{LSI}		X comp. of radial to landing site in earth inertial coordinates	10×10^6 to 21×10^6	ft.
x_{LSLV}		X comp. of radial to landing site in local vertical coordinates	10×10^6 to 21×10^6	ft.
x_{LSP}		X comp. of radial to landing site in platform coordinates	10×10^6 to 21×10^6	ft
x_0		Position integration constant	constant	ft.

TABLE VIII (Continued)

CODED SYM.	ENGR. SYM	SYMBOL DEFINITION OR USE	RANGE	UNITS
$\dot{x}_0$		Velocity integration constant	constant	ft/sec
$\dot{x}_{WP}$		Platform X-component of earth rotation at vehicle	0 to 2000	ft/sec
Y		Inertial position along platform Y-axis	$\pm 20^6$	ft
$\dot{Y}$		Inertial velocity along platform Y-axis	$\pm 15,000$	ft/sec
$\ddot{Y}$		Inertial acceleration along platform Y-axis	± 100	ft/sec ²
Y_{AREFB}		Y body component of orbiter/tank center of pressure	constant	ft.
Y_{AREFO}		Y body component of orbiter center of pressure	constant	ft.
Y_{CGB}		Body Y component of orbiter/tank C.G. location	Table	ft.
Y_{CGO}		Body Y component of orbiter C.G. location	Table	ft.
$\dot{Y}_{DA}$		Desired target crossrange velocity in local vertical coordinates for abort	$\pm 10,000$	ft/sec
Y_F		Y component of vehicle position in earth inertial coordinates	$\pm 10^6$	ft
$\dot{Y}_{GA}$		Crossrange velocity to be gained in local vertical coordinates for abort	$\pm 5,000$	ft/sec
Y_{LSE}		Y comp of radial to landing site in earth fixed coordinates	-21×10^6 to -10×10^6	ft

TABLE VIII (Continued)

ENGR SYM.	CODED SYM	SYMBOL DEFINITION OR USE	RANGE	UNITS
Y_{LSI}		Y comp. of radial to landing site in earth inertial coordinates	-21×10^6 to -10×10^6	ft.
Y_{LSLV}		Y comp. of radial to landing site in local vertical coordinates	$\pm 10^6$	ft.
Y_{LSP}		Y comp. or radial to landing site in platform coordinates	$\pm 10^6$	ft.
Y_0		Position integration constant	constant	ft.
$\dot{Y}_0$		Velocity integration constant	constant	ft/sec.
Y_{REF0i}^a		Body Y component of orbiter i^{th} engine centerline	Table	ft
$\dot{Y}_{WP}$		Platform Y-component of earth rotation at vehicle	0 to 2,000	ft/sec
Z		Inertial position along platform Z-axis	0 to 5×10^6	ft
$\dot{Z}$		Inertial velocity along platform Z-axis	0 to 26,000	ft/sec
$\ddot{Z}$		Inertial acceleration along platform Z-axis	0 to 100	ft/sec ²
Z_{AREFB}		Z body component of orbiter/tank center of pressure	constant	ft.
Z_{AREFO}		A body component of orbiter center of pressure	constant	ft.
Z_{CFB}		Distance between body X-axis and the orbiter engine cluster center line along the body Z-axis	constant	ft.
Z_{CGB}		Body Z component of orbiter/tank C.G. location	Table nt	ft.

TABLE VIII (Continued)

ENGR SYM.	CODED SYM	SYMBOL DEFINITION OR USE	RANGE	UNITS
Z_{CGO}		Body Z component of orbiter C.G. location	table	ft.
$\dot{Z}_{DA}$		Downrange target velocity in local vertical coordinates for abort	8,000 to 18,000	ft/sec.
Z_F		Z component of vehicle position in earth inertial coordinates	10×10^6 to 18×10^6	ft.
$\dot{Z}_{GA}$		Downrange velocity to be gained in local vertical coordinates for abort	0 to 10,000	ft/sec.
Z_{LSE}		Z comp of radial to landing site in earth fixed coordinates	10×10^6 to 20×10^6	ft
Z_{LSI}		Z comp. of radial to landing site in earth inertial coordinates	10×10^6 to 20×10^6	ft
Z_{LSLV}		Z comp. of radial to landing site in local vertical coordinates	0 to 10^6	ft
Z_{LSP}		Z comp. of radial to landing site in platform coordinates	0 to 10^6	ft
Z_0		Position integration constant	constant	ft
$\dot{Z}_0$		Velocity integration constant	constant	ft/sec
Z_{REFOi}		Body Z component of orbiter i^{th} engine centerline	Table	ft.
$\dot{Z}_{WP}$		Platform Z-component of earth rotation at vehicle	0 to 2000	ft/sec
α		Angle of attack	-20 to 150°	deg.
α_1		Angle of attack used to interrogate aero tables	0 to 60°	deg.
β		Angle of sideslip	$\pm 20^\circ$	deg.

TABLE VIII (Continued)

ENGR SYM.	CODED SYM	SYMBOL DEFINITION OR USE	RANGE	UNITS
θ_{Pi}		i^{th} engine pitch angle	$\pm .25$	rad
θ_{Yi}		i^{th} engine yaw angle	$\pm .2$	rad
γ_R		Relative flight path angle	-20° to 150°	deg.
θ		Rotation about platform Y-axis	$-.2$ to π	rad
$\dot{\theta}$		Rotation rate about platform Y-axis	$\pm .3$	rad/sec
θ_B		Central angle for burn to abort target	0 to $.5$	rad
θ_C		Central angle for coast after burnout	0 to $.5$	rad
θ_{CA}		Central angle traversed	0 to $.5$	rad
θ_{CL}		Total central between vehicle and landing site	0 to $.5$	rad
θ_D		Desired inertial pitch angle	$\pm \pi/2$	rad
$\dot{\theta}_{DM}$		Body pitch rate desired manually	$\pm .3$	rad/sec
θ_{EB}		Body pitch attitude error	0 to 180°	deg.
θ_o		Integration constant for θ	constant	rad.
θ_P		Pilot's pitch angle	-20° to 180°	deg.
λ_{CL}		Central angle of latitude to landing site	0 to $.2$	rad.
λ_{CP}		Central angle of latitude from launch pad	0 to $.3$	rad.
λ_{LP}		Latitude of launch pad	constant	deg.

TABLE VIII (Continued)

ENGR SYM.	CODED SYM	SYMBOL DEFINITION OR USE	RANGE	UNITS
λ_{LS}		Latitude of landing site	table	deg.
λ_V		Latitude of vehicle	15° to 45°	deg.
μ		Gravitational constant	constant	ft/3/sec ²
ρ		Air density	table	lbs/ft ²
ϕ		Rotation about body X-axis	$\pm \pi$	rad.
$\dot{\phi}$		Rotation rate about body X-axis	$\pm .4$	rad/sec
ϕ_B		Bank angle around vehicle velocity vector	$\pm 180^\circ$	deg.
ϕ_{CL}		Central angle of longitude to landing site	-1 to -2	rad
ϕ_{CP}		Central angle of longitude from launch pad	-1 to -2	rad
ϕ_D		Desired inertial roll angle	$\pm \pi$	rad
$\dot{\phi}_{DM}$		Body roll rate desired manually	$\pm .4$	rad/sec
ϕ_{EB}		Body roll attitude error	$\pm 180^\circ$	deg.
ϕ_{LP}		Longitude of launch pad	constant	deg.
ϕ_{LS}		Longitude of landing site	table	deg.
ϕ_0		Integration constant for ϕ	constant	rad.
ϕ_P		Pilot's roll angle	$\pm 180^\circ$	deg.
ϕ_V		Longitude of vehicle	-60° to -85°	deg.
ψ		Rotation about line of nodes	$\pm \pi/2$	rad
$\dot{\psi}$		Rotation rate about line of nodes	$\pm .4$	rad/sec

TABLE VIII (Continued)

ENGR SYM.	CODED SYM	SYMBOL DEFINITION OR USE	RANGE	UNITS
ψ_D		Desired inertial yaw angle	$\pm \pi/2$	rad
$\dot{\psi}_{DM}$		Body yaw rate desired manually	$\pm .4$	rad/sec
ψ_{EB}		Body yaw attitude error	± 10	deg.
ψ_h		Compass heading	$\pm 180^\circ$	deg.
ψ_0		Integration constant for ψ	constant	rad.
ψ_p		Pilot's yaw angle	$\pm 90^\circ$	deg.
ψ_R		Heading angle between projection of velocity vector and vector to target in local horizontal plane	$\pm 180^\circ$	deg.
ω_e		Angular rotation rate of the earth	constant	rad/sec
ω_{eLVX}		X comp. of earth rotation in local vertical coord.	0 to 1500	ft/sec
ω_{eLYY}		Y comp. of earth rotation in local vertical coord.	0 to 1500	ft/sec
ω_{eLVZ}		Z comp. of earth rotation in local vertical coord.	0 to 1500	ft/sec
ω_{eX}		ω_e expressed along platform X-axis	0 to 7.3×10^{-5}	rad/sec
ω_{eY}		ω_e expressed along platform Y-axis	0 to 7.3×10^{-5}	rad/sec
ω_{eZ}		ω_e expressed along platform Z-axis	0 to 7.3×10^{-5}	rad/sec

APPENDIX B

MASTER PROGRAM

This Appendix provides the necessary data to implement the master program. Contents include initialization data, flow charts, and symbol definitions.

TABLE IX INITIALIZATION VALUES FOR FUN
(MASTER CONTROL) SUBROUTINE

<u>NAME</u>	<u>NOMENCLATURE</u>	<u>VALUE</u>
AMASCØ	WEIGHT OF ORBITER LESS PROPELLANT	TBD
DTI	LIMITING TIME FOR TIME TO TARGET	1
IES	ENGINE ON FLAG	1
ISEP	SEPARATION FLAG	0
JØY	MAJOR LOOP COUNTER	1
JØYCØ	MAJOR LOOP CUTOFF	700
KCØAST	ORBITER IN COASTING FLIGHT	0
KGUID	TERMINAL ENERGY STATE	0
KGUIDN	PAST VALUE OF KGUID	0

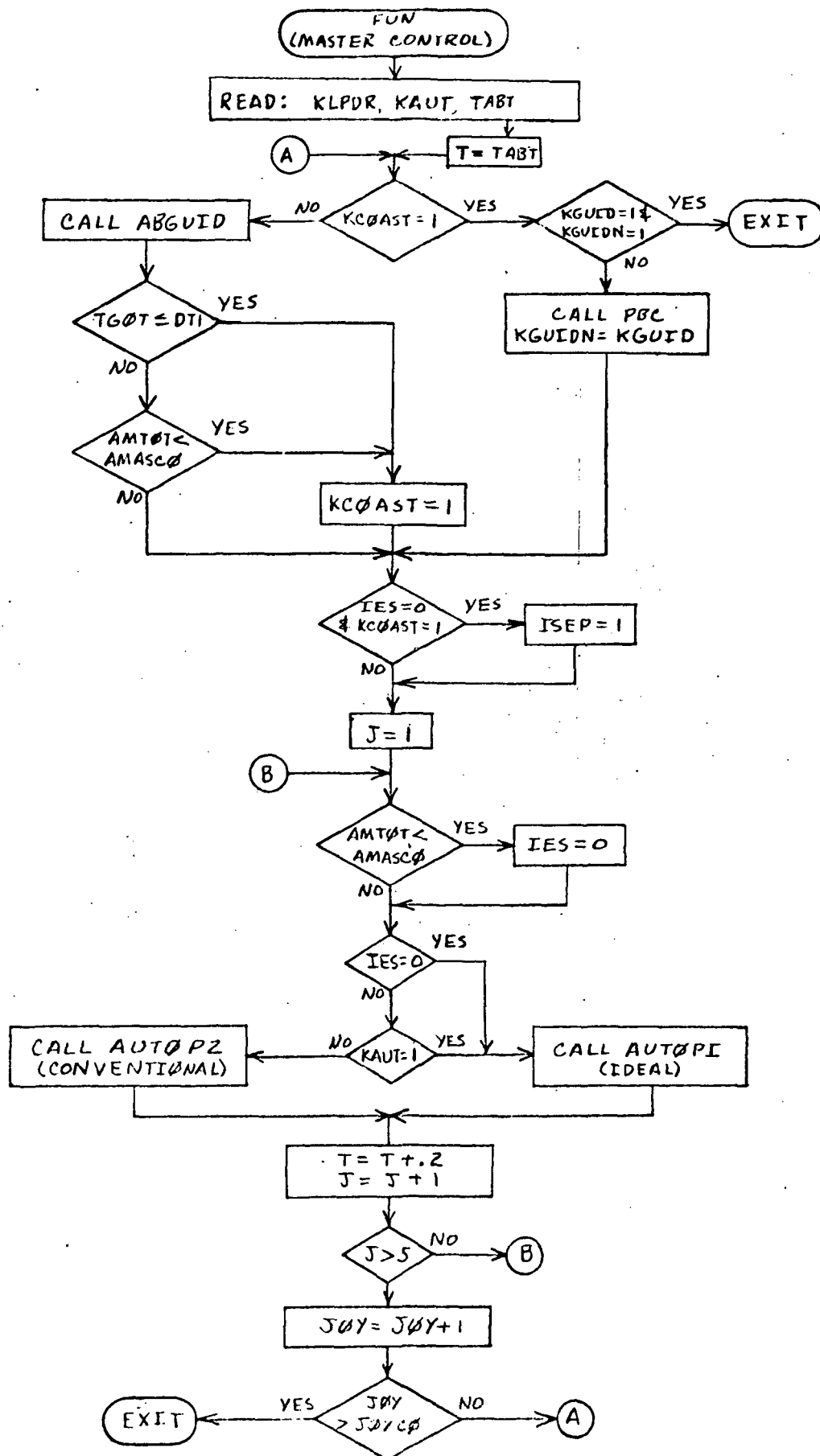


FIGURE 2 FLOW CHART FOR MASTER CONTROL PROGRAM

TABLE X
SYMBOL DEFINITIONS FOR FUN (MASTER CONTROL) SUBROUTINE

CODED SYM.	ENGR. SYM.	SYMBOL DEFINITION OR USE	UNITS
AMASCØ		Weight of orbiter less Propellant	lbs.
AMTOT		Present weight of vehicle	lbs.
DT1		Limiting time for time to target	sec
IES		Engine on flag; IES=1	discrete
ISEP		Separation flag; ISEP=1 Orbiter alone	discrete
J		Minor loop counter; 5 per second	unitless
JØY		Major loop counter; one per second	unitless
JØYCØ		Major loop cutoff	unitless
KAUT		Autopilot control; KAUT=0 selects conventional autopilot during engines on mode of flight; KAUT=1 selects ideal autopilot during all phases of abort	discrete
KCØAST		KCØAST=1; orbiter in coasting flight	discrete
KGUID		KGUID=1; orbiter has reached terminal energy state	discrete
KGUIDN		Past value of KGUID	discrete
KLPDR		KLPDR=1; after abort the orbiter returns to launch pad	discrete
T		Ground elapsed time after launch	sec.
TABT		Time abort is desired	sec.
TGØT		Time to reach guidance target	sec

APPENDIX C

ABORT GUIDANCE

The abort guidance is divided into three phases. These are targeting, powered guidance, and unpowered guidance. Basic initialization values, flow charts of the programs, and symbol definitions for targeting and powered guidance (targeting is called up by the powered guidance routine) will be added as they are finalized. For tentative interface information the reader is referred to sheet 3 of figure 1. Initialization values, flow chart of the program, and symbol definitions are provided for the unpowered guidance part of the abort process.

TABLE XI
INITIALIZATION VALUES FOR
PBC (POST BURNOUT CONTROL)
SUBROUTINE

<u>NAME</u>	<u>NOMENCLATURE</u>	<u>VALUE</u>
III	Control Flag	0
PALPD3	Angle of attack rate limit	5
PALPD4	Angle of attack rate limit	.5
PALPD5	Angle of attack rate limit	.5
PBAD	Bank angle rate limit	10
PBIAS	Flight Path angle rate limit	0
PDT	Cycle time of PBC	1
PGMAX(1)	Normal acceleration limit	1.8
PGMAX(2)	Normal acceleration limit	1.8
PHLIM	Altitude limit	220,000
PHPB(1)	Altitude-terminal energy state (downrange)	150,000
PHPB(2)	Altitude-terminal energy state (return to launch site)	100,000
PTHEC	Body X-axis attitude	25
PVBAC1	Desired bank angle	0
PVPB(1)	Velocity-terminal energy state (downrange)	7800
PVPB(2)	Velocity-terminal energy state (return to launch site)	1860
RAD	Conversion-Radians to Degrees	57.29578
RADI	Conversion-degrees to radians	.01745329
SGRAV	Acceleration due to gravity	32.17404

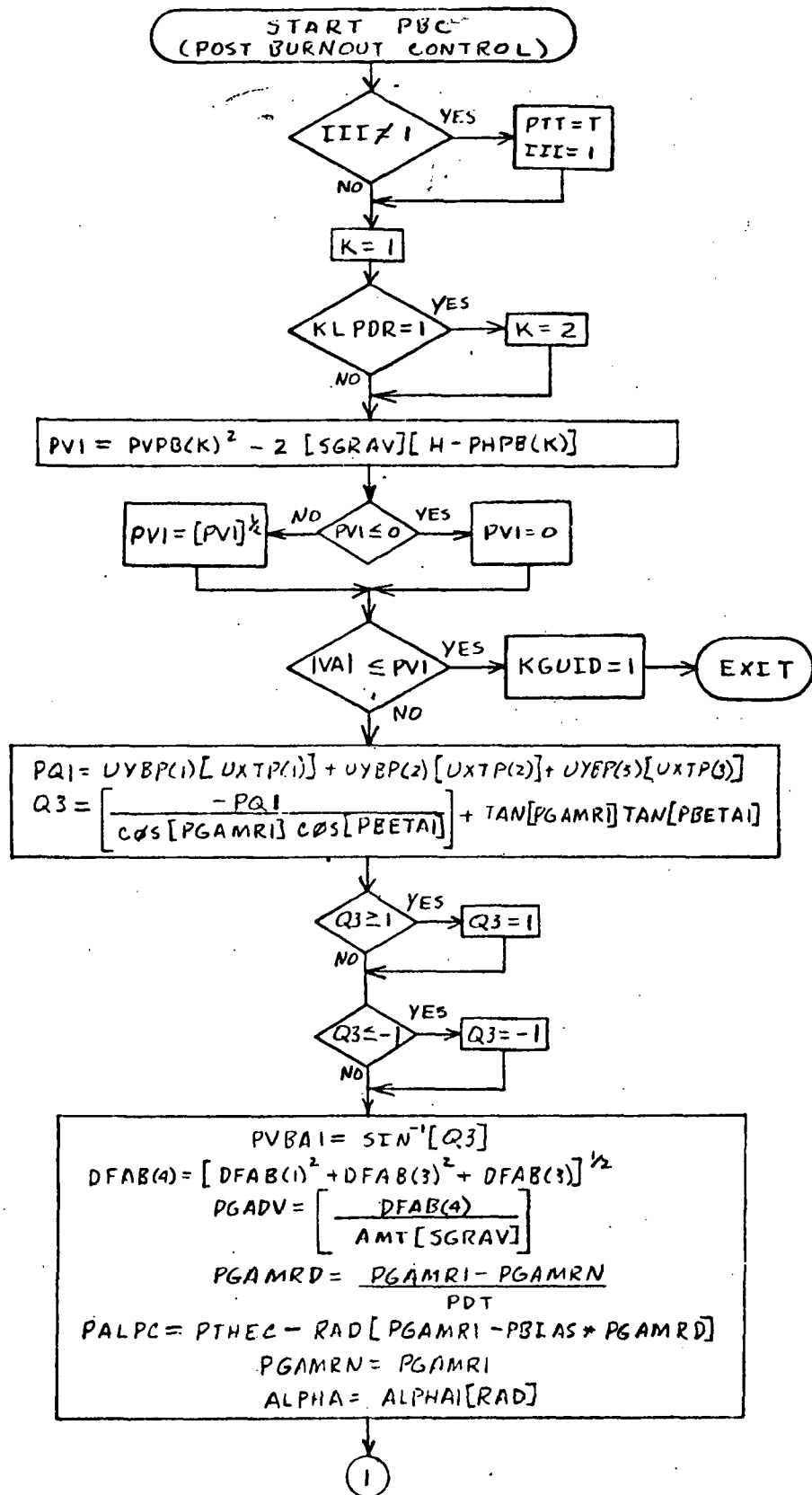


FIGURE 3 FLOW CHART FOR POST BURNOUT CONTROL PROGRAM

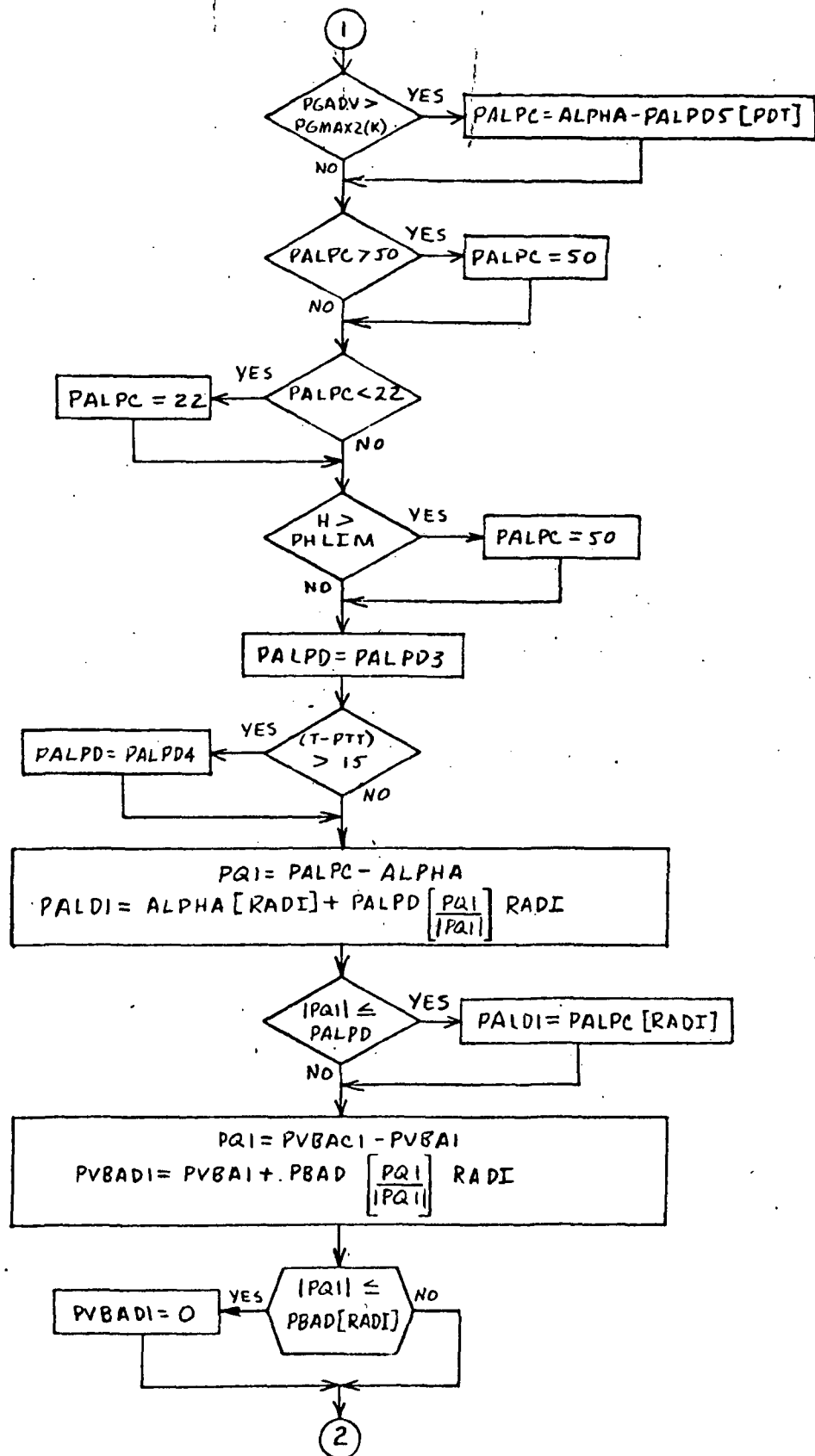


FIGURE 3 CONT'D

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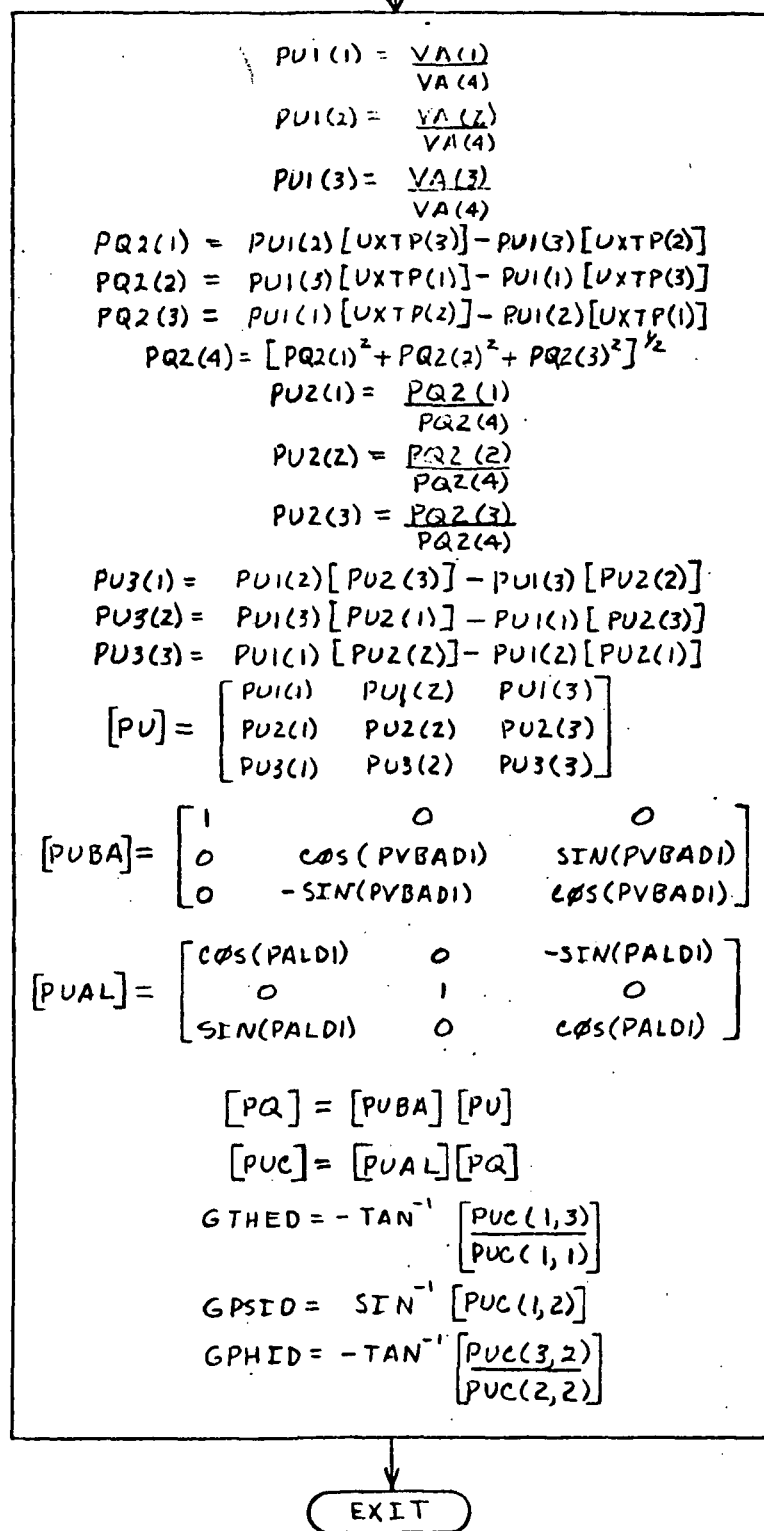


FIGURE 3 CONT'D

TABLE XII
SYMBOL DEFINITIONS FOR PBC
(POST BURNOUT CONTROL) SUBROUTINE

CODED SYM.	ENGR. SYM.	SYMBOL DEFINITION OR USE	UNITS
ALPHA		ANGLE OF ATTACK	DEGREES
ALPHA1		ANGLE OF ATTACK	RADIANS
AMT		TOTAL MASS OF VEHICLE	LBS
BETA		SIDESLIP ANGLE	DEGREES
DFAB		FORCES DUE TO AERODYNAMICS IN BODY COORDINATES	LBS
GPHID		INERTIAL ROLL ANGLE	RADIANS
GPSID		INERTIAL YAW ANGLE	RADIANS
GTHED		INERTIAL PITCH ANGLE	RADIANS
H		PRESENT VEHICLE ALTITUDE	FT
III		III=0 FOR FIRST PASS THRU PBC	DISCRETE
K		ARGUMENT OF VARIABLES; K=1 ABORT DOWNRANGE; K=2 ABORT RETURN TO LAUNCH SITE	DISCRETE
KGUID		PROGRAM TERMINATE FLAG	DISCRETE
KLPDR		KLPDR=1 FOR ABORT TO LAUNCH PAD	DISCRETE
PALD1		ANGLE OF ATTACK COMMANDED BY PBC	RADIANS
PALPC		ANGLE OF ATTACK COMMANDED	DEG
PALPD		ANGLE OF ATTACK RATE LIMIT	DEG/SEC
PALPD3		ANGLE OF ATTACK RATE LIMIT DURING INITIAL 15 SECONDS OF COAST	DEG/SEC
PALPD4		ANGLE OF ATTACK RATE LIMIT AFTER 15 SECONDS OF COAST	DEG/SEC
PALPD5		ANGLE OF ATTACK RATE LIMIT WHEN NORMAL ACCELERATION IS GREATER THAN 1.8 GEES	DEG/SEC
PBAD		BANK ANGLE RATE LIMIT	DEG
PBETA1		SIDESLIP ANGLE	RADIANS
PBIAS		FLIGHT PATH ANGLE RATE LIMIT	UNITLESS
PDT		POST-BURNOUT CYCLE TIME	SECONDS
PGADV		AERO DECELERATION	GEES
PGAMRD		FLIGHT PATH ANGLE RATE	RAD/SEC
PGAMRN		PAST VALUE OF FLIGHT PATH ANGLE	RADIANS
PGAMR1		PRESENT VALUE OF FLIGHT PATH ANGLE	RADIANS
PGMAX2(K)		LIMIT OF DECELERATION DUE TO AERODYNAMIC FORCES	GEES
PHLIM		ALTITUDE LIMIT	FT

CODED SYM.	ENGR. SYM.	SYMBOL DEFINITION OR USE	UNITS
PHPB		TERMINAL ALTITUDE CONSTRAINT	FT
PQ		PVC SCRATCH MATRIX	
PQ1		PVC SCRATCH VARIABLE	
PQ2		PVC SCRATCH VARIABLE	
PTHEC		BODY X-AXIS ATTITUDE ANGLE COMMAND	DEGREES
PTT		TIME AT BURNOUT	SEC
PU		TRANSFORMATION FROM BODY TO LOCAL VERTICAL COORDINATES	UNITLESS
PUAL		MATRIX TO ROTATE THRU ANGLE OF ATTACK	UNITLESS
PUBA		MATRIX TO ROTATE THRU BANK ANGLE	
PUC		TRANSFORMATION FROM LOCAL VERTICAL TO WIND AXIS COORDINATES	UNITLESS
PU1		X DIRECTION COSINES OF PU MATRIX	UNITLESS
PU2		Y DIRECTION COSINES OF PU MATRIX	UNITLESS
PU3		Z DIRECTION COSINES OF PU MATRIX	UNITLESS
PVBAC1		DESIRED BANK ANGLE	DEGREES
PVBAD1		ALLOWED BANK ANGLE	RADIANS
PVBA1		PRESENT BANK ANGLE	RADIANS
PVPB		TERMINAL VELOCITY CONSTRAINT	FT/SEC
PV1		VELOCITY REMAINING TO BE GAINED UNTIL TERMINAL ENERGY STATE IS REACHED	FT/SEC
Q3		PBC SCRATCH VARIABLE	
RAD		RAD=57.29578	DEG/RAD
RADI		RADI=.01745329	RAD/DEG
SGRAV		ACCELERATION DUE TO GRAVITY=32.17404	FT/SEC ²
T		GROUND ELAPSED TIME	SEC
UXTP		UNIT VECTOR ALONG RADIAL TO VEHICLE	UNITLESS
UYBP		DIRECTION COSINES RELATING BODY Y AXIS TO PLATFORM COORDINATES	UNITLESS
VA		INERTIAL VELOCITY VECTOR RELATIVE TO EARTH	FT/SEC

APPENDIX D

CONVENTIONAL AUTOPILOT

This Appendix provides necessary data to implement an autopilot which controls engine gimbaling in a conventional manner. Contents include initialization values, a set of gains, flow chart, and symbol definitions.

TABLE XIII
INITIALIZATION VALUES FOR AUTOP2
(CONVENTIONAL AUTOPILOT) SUBROUTINE

<u>NAME</u>	<u>NOMENCLATURE</u>	<u>VALUE</u>
DEG01	One degree constant	1.745329E-2
DEG10	Ten degree constant	1.745329E-1
DT	Cycle time of AUTOP2	.2
PHIGL	Past value of guidance roll angle	0
PSIGL	Past value of guidance yaw angle	0
THEGL	Past value of guidance pitch angle	0
THELST	Negative of last body pitch error	0
TRIM	Pitch trim angle	0

TABLE XIV - Conventional Autopilot Gains ($\omega = 1.5$)

TIME	PITCH		YAW		ROLL	
	PA0 ATTITUDE	PA1 RATE	YAO ATTITUDE	YA1 RATE	RAO ATTITUDE	RA1 RATE
0	1.39	1.30	1.35	1.26	1.67	1.55
74	.319	1.05	1.05	1.02	1.49	1.39
140	.922	.855	.968	.874	1.38	1.29
200	.737	.689	.720	.668	1.20	1.12
215	.737	.689	.720	.668	1.20	1.12
216	1.08	1.05	1.28	1.19	1.56	1.46
218	1.08	1.05	1.28	1.19	1.56	1.46
230	1.13	1.05	1.26	1.18	1.51	1.41
300	1.02	.954	1.15	1.07	1.23	1.15
430	.871	.797	.933	.870	.781	.729

Note: Gain table is for 161c delta wing orbiter.

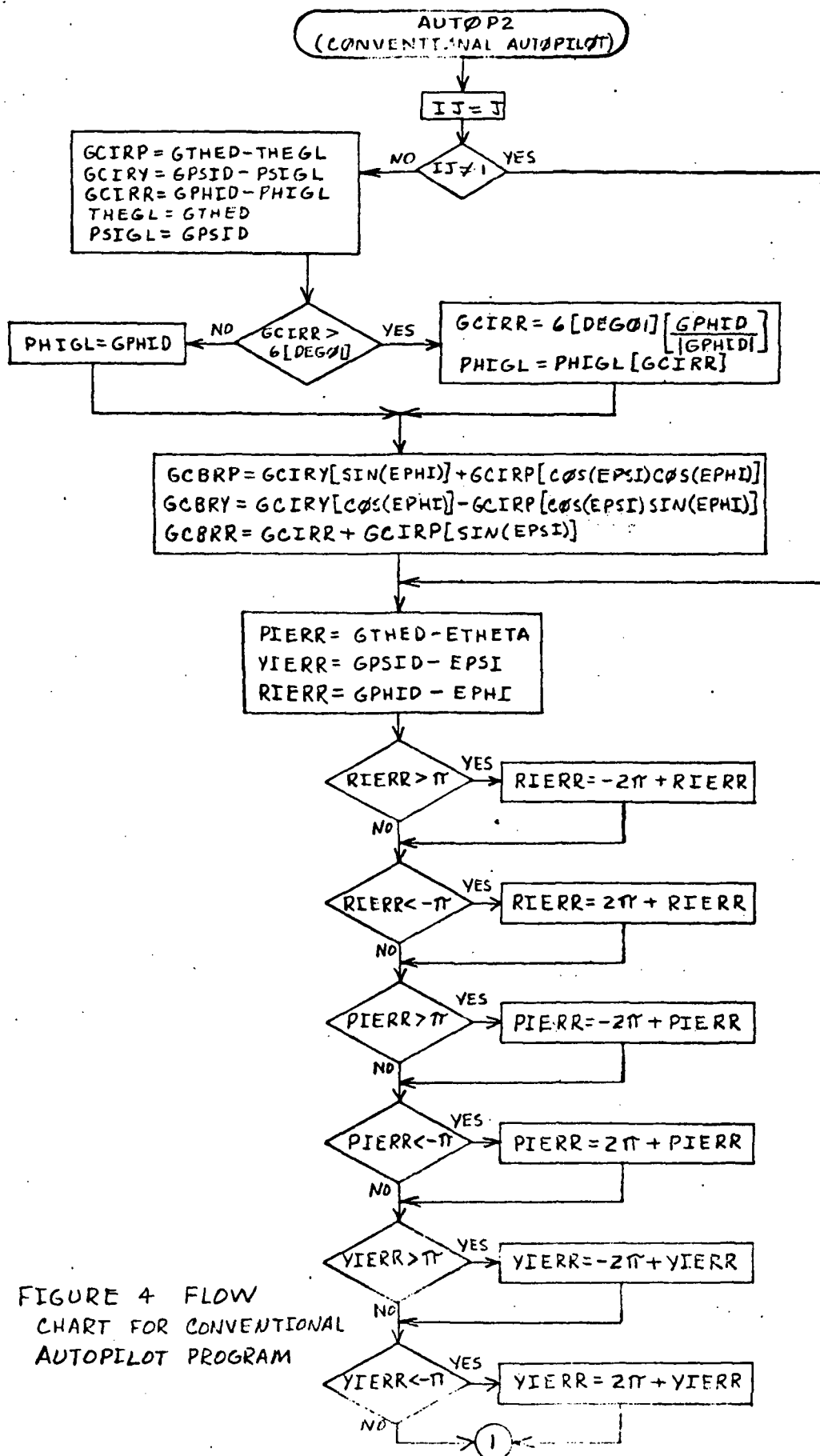


FIGURE 4 FLOW
CHART FOR CONVENTIONAL
AUTOPILOT PROGRAM

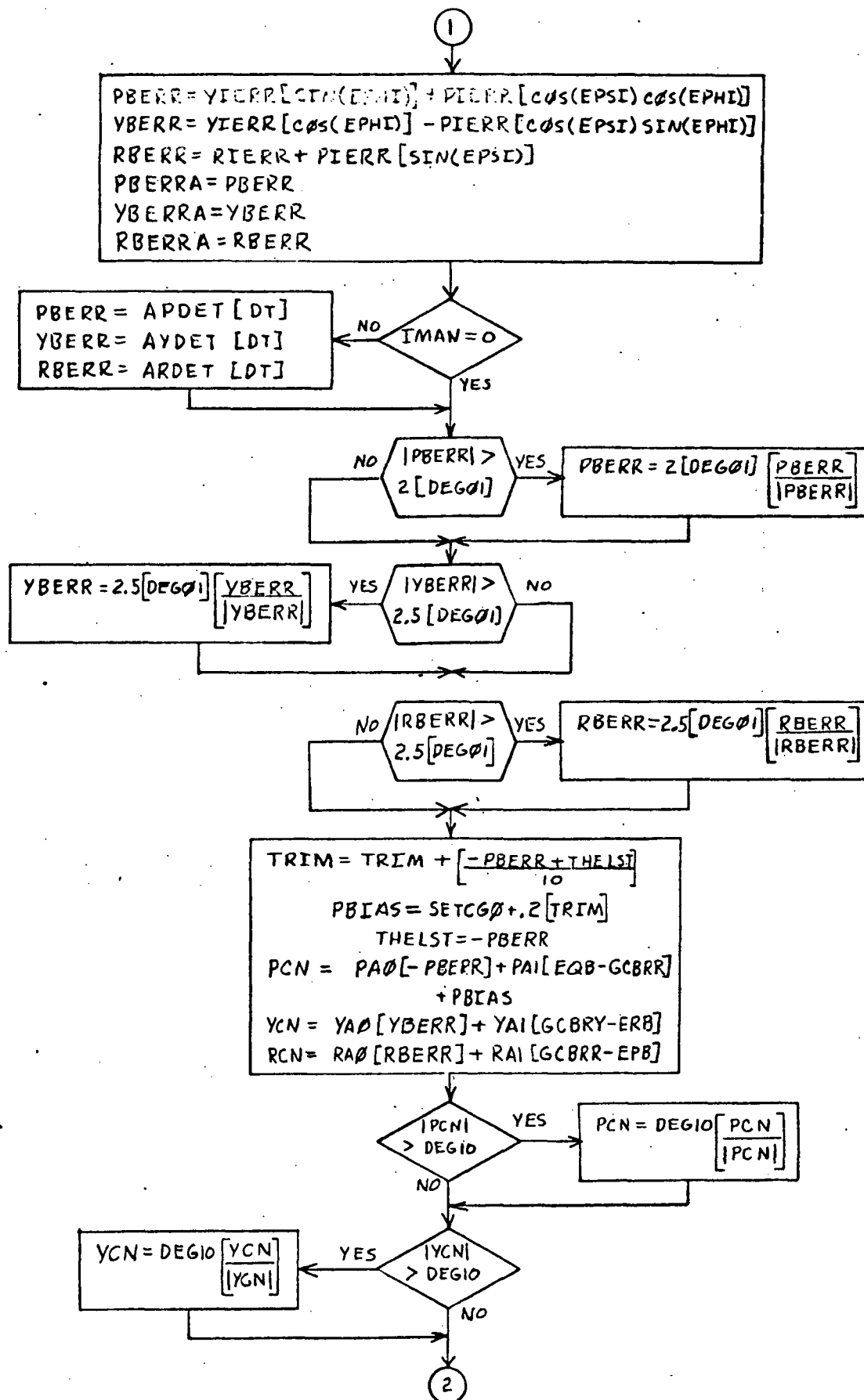
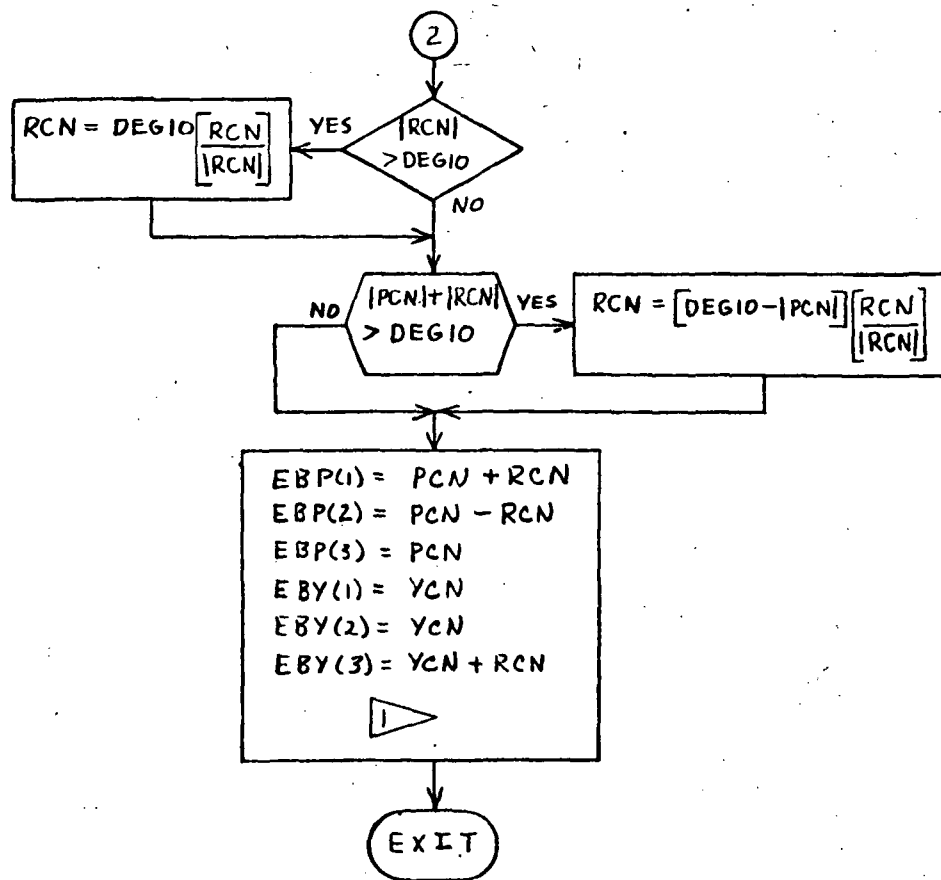


FIGURE 4 CONT'D



THE SIDE BY SIDE ENGINES WERE ASSIGNED NUMBERS 1 AND 2, IN A COUNTERCLOCKWISE DIRECTION. THESE EQUATIONS HAVE NOT BEEN TESTED ON A THREE ENGINE CONFIGURATION.

FIGURE 4 CONT'D

TABLE XV SYMBOL DEFINITIONS FOR AUTOP2
(CONVENTIONAL AUTOPILOT)

SUBROUTINE

CODED SYM.	ENGR. SYM.	SYMBOL DEFINITION OR USE	UNITS
APDET		HAND CONTROLLER PITCH RATE INPUT	RAD/SEC
EBP(3)		ENGINE GIMBAL PITCH ANGLE	RADIANS
EBY (3)		ENGINE GIMBAL YAW ANGLE	RADIANS
EPB		BODY ROLL RATE	RAD/SEC
EPHI		INERTIAL ROLL ANGLE	RADIANS
EPSI		INERTIAL YAW ANGLE	RADIANS
EQB		BODY PITCH RATE	RAD/SEC
ERB		BODY YAW RATE	RAD/SEC
ETHETA		INERTIAL PITCH ANGLE	RADIANS
GCBRP		BODY COORDINATE DIFFERENCE IN PRESENT AND PAST GUIDANCE PITCH ANGLE	RADIANS
GCBRR		BODY COORDINATE DIFFERENCE IN PRESENT AND PAST GUIDANCE ROLL ANGLE	RADIANS
GCBRY		BODY COORDINATE DIFFERENCE IN PRESENT & PAST GUIDANCE YAW ANGLE	RADIANS
GCIRP		PLATFORM DIFFERENCE BETWEEN PRESENT AND PAST GUIDANCE PITCH ANGLE	RADIANS
GCIRR		PLATFORM DIFFERENCE BETWEEN PRESENT AND PAST GUIDANCE ROLL ANGLE	RADIANS
GCIRY		PLATFORM DIFFERENCES BETWEEN PRESENT AND PAST GUIDANCE YAW ANGLE	RADIANS
GPHID		INERTIAL ROLL ANGLE REQUESTED FROM GUIDANCE	RADIANS
GPSID		INERTIAL YAW ANGLE REQUESTED FROM GUIDANCE	RADIANS
GTHED		INERTIAL PITCH ANGLE REQUESTED FROM GUIDANCE	RADIANS
IU		AUTOPILOT PASS COUNTER	
IMAN		CONTROL DISCRETE WHEN IN MANUAL MODE	
J		PASS COUNTER	
PAO		PITCH ATTITUDE GAIN	UNITLESS
PAI		PITCH RATE GAIN	UNITLESS
PBERR		BODY PITCH ANGLE ERROR	RADIANS
PδERRA		VALUE OF BODY PITCH ANGLE ERROR FOR DISPLAY	UNITLESS
PBIAS		PITCH BIAS DUE TO CG OFFSET AND TRIM	RADIANS
PCN		NEW TVC PITCH COMMAND	RADIANS

TABLE XV SYMBOL DEFINITIONS FOR AUTOP2
(CONVENTIONAL AUTOPILOT)

SUBROUTINE (Continued)

CODED SYM.	ENGR. SYM.	SYMBOL DEFINITION OR USE	UNITS
PHIGL		PAST VALUE OF GUIDANCE ROLL ANGLE	RADIANS
PIERR		INERTIAL PITCH ANGLE ERROR	RADIANS
PSIGL		PAST VALUE OF GUIDANCE YAW ANGLE	RADIANS
RAU		ROLL ATTITUDE GAIN	UNITLESS
RA1		ROLL RATE GAIN	UNITLESS
RBERR		BODY ROLL ANGLE ERROR	RADIANS
RBERRA		VALUE OF BODY ROLL ANGLE ERROR FOR DISPLAY	RADIANS
RCN		NEW TVC ROLL COMMAND	RADIANS
RIERR		INERTIAL ROLL ANGLE ERROR	RADIANS
SETCGO		ANGLE BETWEEN BODY X AND THRUST VECTOR AT LAUNCH	RADIANS
THEGL		PAST VALUE OF GUIDANCE PITCH ANGLE	RADIANS
THELST		NEGATIVE OF LAST BODY PITCH ERROR	RADIANS
TRIM		PITCH TRIM ANGLE	RADINAS
YAO		YAW ATTITUDE GAIN	
YA1		YAW RATE GAIN	
YBERR		BODY YAW ANGLE ERROR	RADIANS
YBERRA		VALUE OF BODY YAW ANGLE ERROR FOR DISPLAY	RADIANS
YCN		NEW TVC YAW COMMAND	RADIANS
YIERR		INERTIAL YAW ANGLE ERROR	RADIANS

APPENDIX E

IDEAL AUTOPILOT PROGRAM

This Appendix provides necessary data to initialize the Autopilot program. The program is divided into two subroutines. The AUTOPI subroutine provides outputs for engine gimbal angles and pseudo RCS moments. The ACC subroutine is used to compute necessary angular accelerations. Contents include initialization constants, flow chart and symbol definitions.

TABLE XVI INITIALIZATION VALUES FOR AUTOPI (IDEAL AUTOPILOT) SUBROUTINE

NAME	NOMENCLATURE	VALUE
* ACCLIM	Angular Acceleration limit	2.268928 E-1 rad/sec ²
* ACOMSM	Constant for zero angular acceleration commanded test	1.745329E-7 rad/sec ²
AGAIN 1	DESIRED ACCELERATION SYSTEM GAIN	0.9
AGAIN 2	Desired acceleration system gain	0.7
AMAXGA	Upper limit of AGAIN	1.3
AMINGA	Lower limit of AGAIN	0.35
AMINOM	Minimum percent of desired rotational rate	0.99
ANGLDB	Angle deadband	1.745329E-5 rad
ANGMAX	Upper limit of percent desired angle change	1.05
ANGMIN	Lower limit of percent desired angle change	0.95
ANOAER	Percent of max acceleration allowable with no air	0.7
ARATDB	Residual rate deadband	1.745329E-4 rad/sec
* ARATLM	Maximum allowable rotational rate	1.04719 E-1 rad/sec
AREVRS	Percent reversal of existing rotational rate	1.20
NOENGO	Number of Orbiter engines	3

* Values were suitable for B9U/161C configuration. They may require change for other configurations.

TABLE XVII COMMUNICATION BETWEEN AUTOPI (IDEAL AUTOPILOT)
AND ACC SUBROUTINES

ARGUMENT LIST

<u>AUTOPI</u>			<u>ACC</u>
<u>PITCH</u>	<u>YAW</u>	<u>ROLL</u>	
ADPDES	ADYDES	ADRDES	ADDES
ADINCP	ADINCY	ADINCR	ADINC
ADPTØT	ADYTØT	ADRTØT	ADTØT
ADPEND	ADYEND	ADREND	ADEND
AØMEGP	AØMEGY	AØMEGR	AØMEGA
AGAINP	AGAINY	AGAINR	AGAIN

COMMON LIST

ACCLIM	APRATE (5)
ACØMSM	ARATE (5)
ACTALP (5)	ARATLM
ACTPAC (5)	AREVRS
ACTRAC (5)	ARRATE (5)
ACTYAC (5)	AYRATE (5)
AGAIN1	IPITCH
AGAIN2	IRESID
ALPHAC (5)	IRØLL
ALPHPI (5)	ISEP
ALPHRØ (5)	IYAW
ALPHYA (5)	J
AMAXGA	P
AMINGA	
ANGMAX	
ANGMIN	
ANØAER	

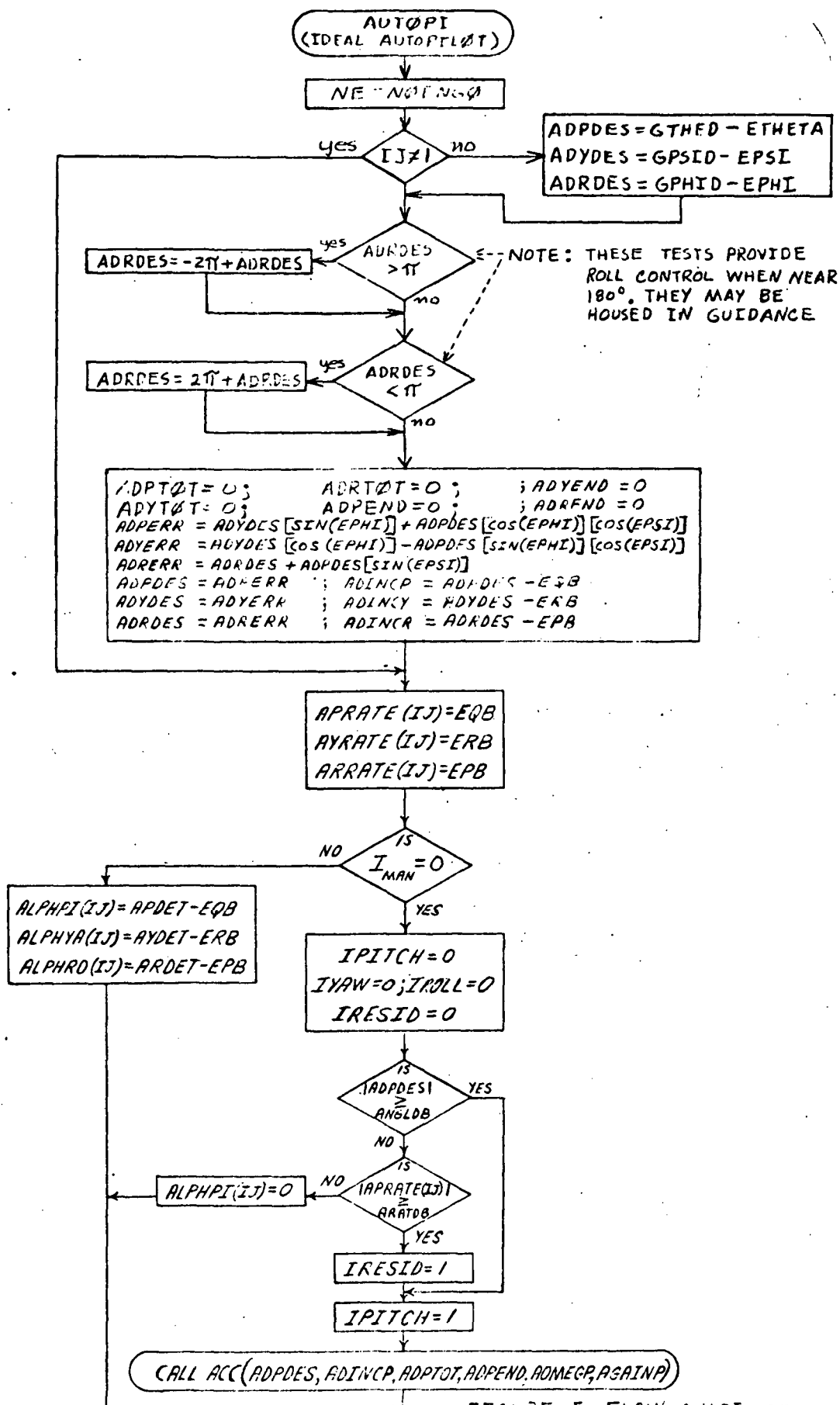


FIGURE 5 FLOW CHART OF
IDEAL AUTOFLAT
PROGRAM

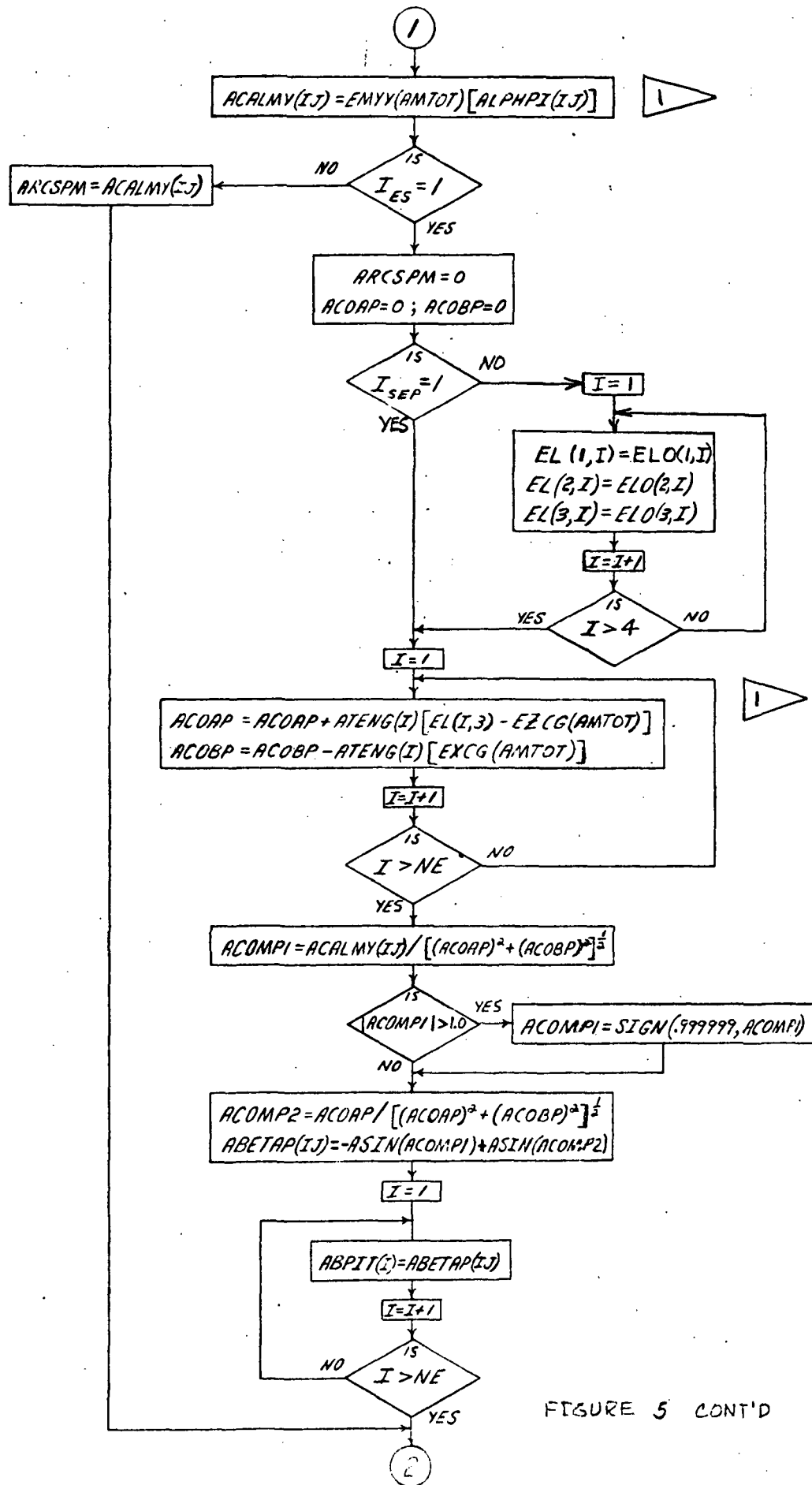


FIGURE 5 CONT'D

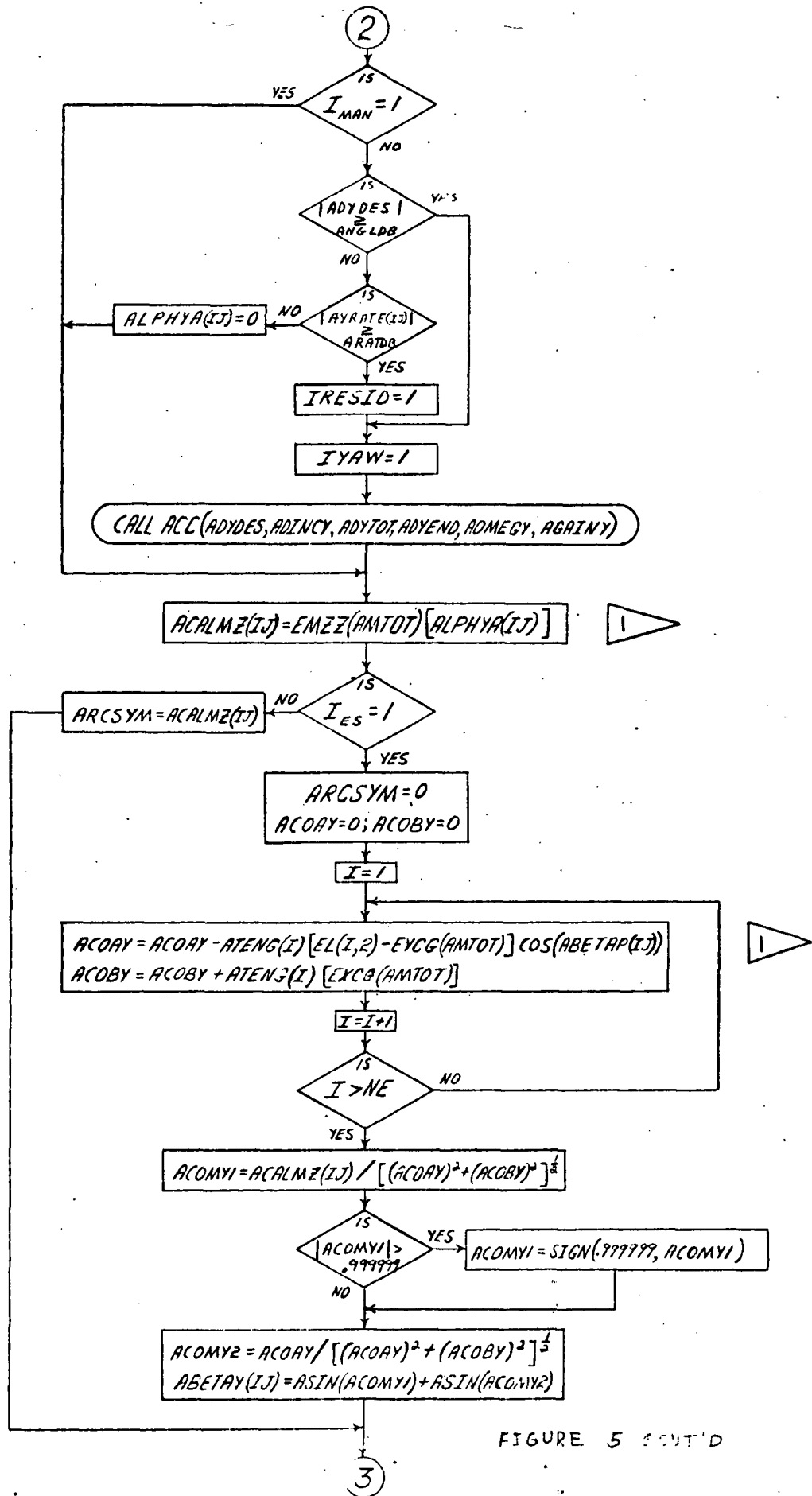


FIGURE 5 CONT'D

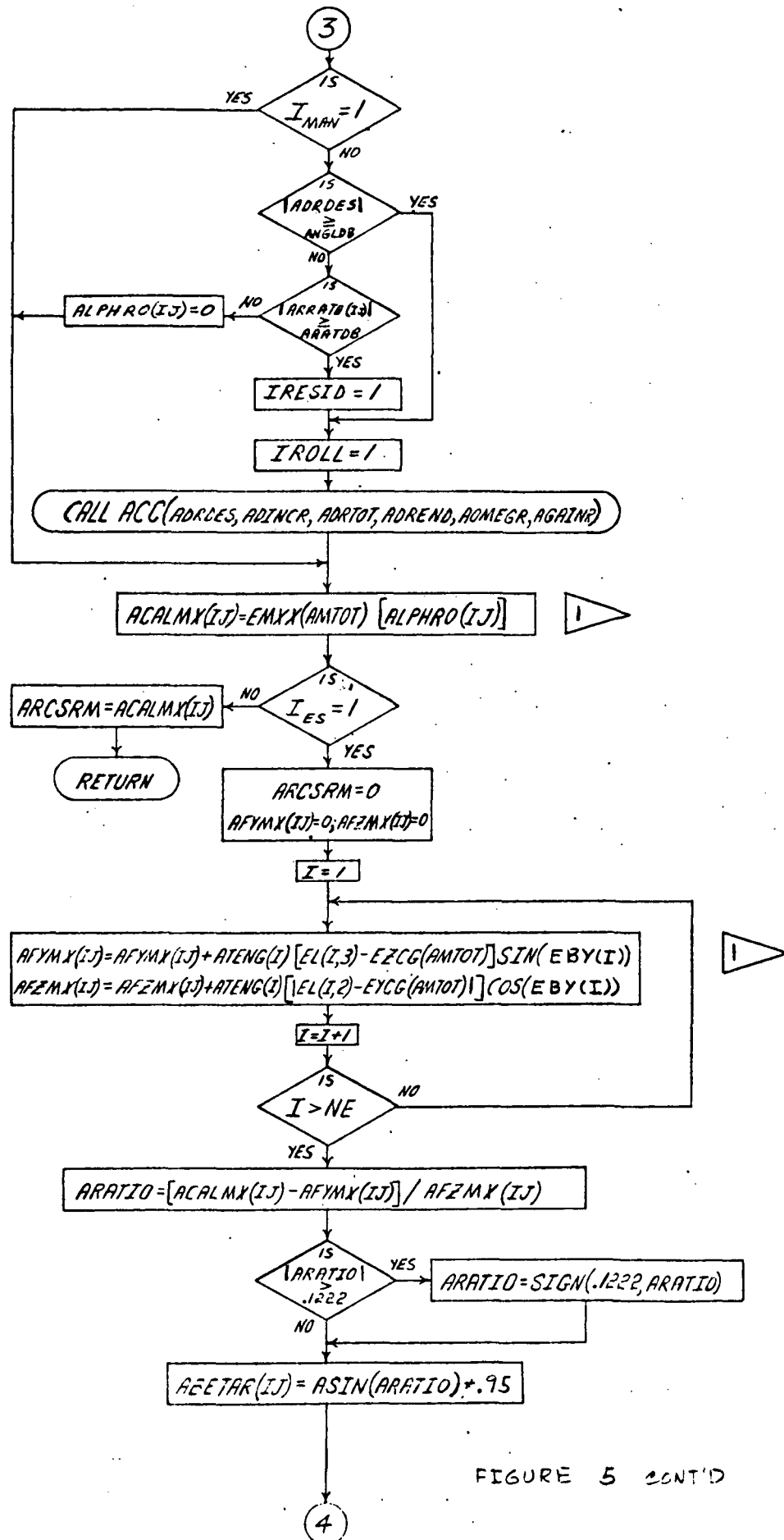
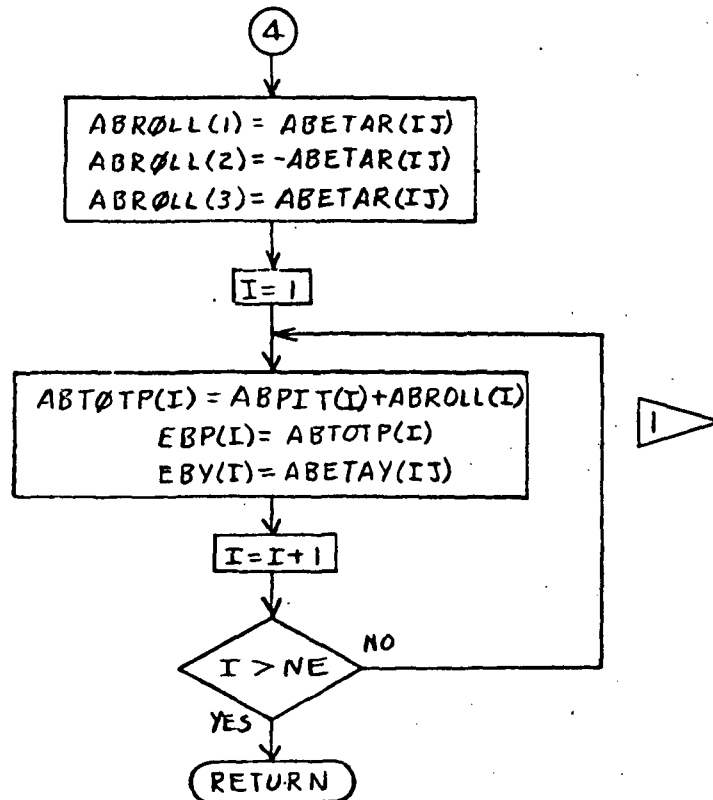


FIGURE 5 CONT'D



1 THESE EQUATIONS WERE DEVELOPED FOR A SIDE BY SIDE TWO ENGINE CONFIGURATION. THE EQUATIONS HAVE NOT BEEN CHECKED FOR VALIDITY WITH A THREE ENGINE CONFIGURATION

FIGURE 5 CONT'D

TABLE XVIII SYMBOL DEFINITION FOR AUTOPI (IDEAL AUTOPILOT) SUBROUTINE

CODED SYM.	ENGR. SYM	SYMBOL DEFINITION OR USE	UNITS
ABETAP (5)	β_p	Engine gimbal angle computed for pitch	rad
ABETAR (5)	β_R	Engine gimbal angle computed for roll	rad
ABETAY (5)	β_Y	Engine gimbal angle computed for yaw	rad
ABPIT (3)	θ_p	Pitch component of total pitch engine gimbal angle	rad
ABROLL (3)	θ_R	Roll component of total pitch engine gimbal angle	rad
ABTOTP (3)	θ_T	Total engine gimbal pitch angle	rad
ACALMX (5)	M_X	Desired moment about X-body axis	ft-lbs
ACALMY (5)	M_Y	Desired moment about Y-body axis	ft-lbs
ACALMZ (5)	M_Z	Desired moment about Z-body axis	ft-lbs
ACOAP	A_θ	Moment about Y-body axis due to forces in X-body direction	ft-lbs
ACOAY	A_ψ	Moment about Z-body axis due to forces in X-body direction	ft-lbs
ACOBP	B_θ	Moment about Y-body axis due to forces in Z-body direction	ft-lbs
ACOBY	B_ψ	Moment about Z-body axis due to forces in Y-body direction	ft-lbs
ACOMP1	P_1	Ratio of M_Y to $[A_\theta^2 + B_\theta^2]^{\frac{1}{2}}$	unitless
ACOMP2	P_2	Ratio of A_θ to $[A_\theta^2 + B_\theta^2]^{\frac{1}{2}}$	unitless
ACOMY1	Y_1	Ratio of M_Z to $[A_\psi^2 + B_\psi^2]^{\frac{1}{2}}$	unitless
ACOMY2	Y_2	Ratio of A_ψ to $[A_\psi^2 + B_\psi^2]^{\frac{1}{2}}$	unitless
ADINCP	$\Delta\theta$	Impending incremental pitch angle error due to pitch rate on first pass	rad
ADINCR	$\Delta\phi$	Impending incremental roll angle error due to roll rate on first pass	rad

TABLE XVIII (Continued)

CODED SYM.	ENGR. SYM	SYMBOL DEFINITION OR USE	UNITS
ADINCY	$\Delta\psi$	Impending incremental yaw angle error due to yaw rate on first pass	rad
ADPDES	$\Delta\theta_D$	Body pitch error	rad
ADPEND	$\Delta\theta_{END}$	Total pitch angle accumulated if the vehicle pitch rate is stopped at the end of present minor cycle	rad
ADPERR	θ_{ERR}	Desired body pitch angle change transformed from inertial angles	rad
ADPTOT	$\Delta\theta_{TOT}$	Total pitch angle accumulated since the start of the major cycle	rad
ADRDES	$\Delta\phi_D$	Body roll error	rad
ADREND	$\Delta\phi_{END}$	Total roll angle accumulated if the vehicle roll rate is stopped at the end of present minor cycle	rad
ADRERR	ϕ_{ERR}	Desired body roll angle change transformed from inertial angles	rad
ADRTOT	$\Delta\phi_{TOT}$	Total roll angle accumulated since the start of the major cycle	rad
ADYDES	$\Delta\psi_D$	Body yaw error	rad
ADYEND	$\Delta\psi_{END}$	Total yaw angle accumulated if the vehicle yaw rate is stopped at the end of present minor cycle	rad
ADYERR	ψ_{ERR}	Desired body yaw angle change transformed from inertial angles	rad
ADYTOT	$\Delta\psi_{TOT}$	Total yaw angle accumulated since the start of the major cycle	rad
AFYMX (5)	M_{XFY}	Moment about X-body axis due to Y-body forces	ft-lbs
AFZMX (5)	M_{XFZ}	Moment about X-body axis due to Z-body forces	ft-lbs
AGAINP	G_p	Pitch acceleration system gain	unitless
AGAINR	G_R	Roll acceleration system gain	unitless
AGAINY	G_Y	Yaw acceleration system gain	unitless
ALPHPI	$\alpha_{\theta COM}$	Pitch angular acceleration commanded	rad/sec ²

TABLE XVIII(Continued)

CODED SYM.	ENGR. SYM	SYMBOL DEFINITION OR USE	UNITS
ALPHRO	$\alpha_{\phi COM}$	Roll angular acceleration commanded	rad/sec ²
ALPHYA	$\alpha_{\psi COM}$	Yaw angular acceleration commanded	rad/sec ²
AMTOT	M	Present vehicle weight	slugs
ANGLDB	θ_{DB}, ψ_{DB}	Angle deadband; 1.745329 E-5	rad
AOMEGP	ω_P	Desired pitch rotational rate	rad/sec
AOMEGR	ω_R	Desired roll rotational rate	rad/sec
AOMEGY	ω_Y	Desired yaw rotational rate	rad/sec
APDET	$\dot{\theta}_{DET}$	Hand controller pitch rate input	rad/sec
APRATE (5)	$\dot{\theta}_B$	Body pitch rate	rad/sec
ARATDB	$\dot{\theta}_{DB}, \dot{\psi}_{DB}$	Residual rotational rate deadband	rad/sec
	$\dot{\phi}_{DB}$		
ARATIO	ARATIO	SIN of desired roll angle	unitless
ARCSPM		RCS pitch moment	ft-lbs
ARCSRM		RCS roll moment	ft-lbs
ARCSYM		RCS yaw moment	ft-lbs
ARDET	$\dot{\phi}_{DET}$	Hand controller roll rate input	rad/sec
ARRATE (5)	$\dot{\phi}_B$	Body roll rate	rad/sec
ATENG (3)	T	Engine thrust magnitude	lbs
	C_{GRAV}	Acceleration due to gravity at sea level, 32,17404	ft/sec ²
AYDET	$\dot{\psi}_{DET}$	Hand controller yaw rate input	rad/sec
AYRATE (5)	$\dot{\psi}_B$	Body yaw rate	rad/sec
EBP (3)	θ_{GIM}	Engine gimbal pitch angle	rad
EBY (3)	ψ_{BIM}	Engine gimbal yaw angle	rad
EL (3, 3)	EL	Orbiter engine locations	ft
ELO (3,3)	ELO	Orbiter engine locations	ft

TABLE XVIII (Continued)

CODED SYM.	ENGR. SYM	SYMBOL DEFINITION OR USE	UNITS
EMXX (14)	I_{XX}	Moment of inertia about X-body axis	slug-ft ²
EMYY (14)	I_{YY}	Moment of inertia about Y-body axis	slug-ft ²
EMZZ (14)	I_{ZZ}	Moment of inertia about Z-body axis	slug-ft ²
EPB	$\dot{\phi}_E$	Body roll rate	rad/sec
EPHI	ϕ_E	Inertial roll angle	rad
EPSI	ψ_E	Inertial yaw angle	rad
EQB	$\dot{\theta}_E$	Body pitch rate	rad/sec
ERB	$\dot{\psi}_E$	Body yaw rate	rad/sec
ETHETA	θ_E	Inertial pitch angle	rad
EXCG (14)	X_{CG}	Body X_{CG}	ft
EYCG (14)	Y_{CG}	Body Y_{CG}	ft
EZCG (14)	Z_{CG}	Body Z_{CG}	ft
GPHID	ϕ_G or ϕ_D	Inertial roll angle requested from Guidance	rad
GPSID	ψ_G or ψ_D	Inertial yaw angle requested from Guidance	rad
GTHED	θ_G or θ_D	Inertial pitch angle requested from Guidance	rad
I	I	Do loop counter	
IES	I_{ES}	Engine start flag	discrete
IJ	IJ	Autopilot pass counter	1-5
IMAN	I_{MAN}	Manual control flag	discrete

TABLE XVIII (Continued)

CODED SYM.	ENGR. SYM	SYMBOL DEFINITION OR USE	UNITS
IPITCH	I_{ϕ}	Pitch acceleration calculation flag	discrete
IRESID	I_R	Residual rate calculation	discrete
IROLL	I_{ϕ}	Roll acceleration calculation discrete	discrete
ISEP	I_{SEP}	Vehicle separation flag	discrete
IYAW	I_{ψ}	Yaw acceleration calculation flag	discrete
J	J	Pass counter	1-5
NE	i	Number of vehicle engines	
NOENGO	i_0	Number of orbiter engines $i_0 = 3$	

SUBROUTINE ACC(ADDES, ADINC, ADTOT, ADEND, AOMEGA, AGAIN)

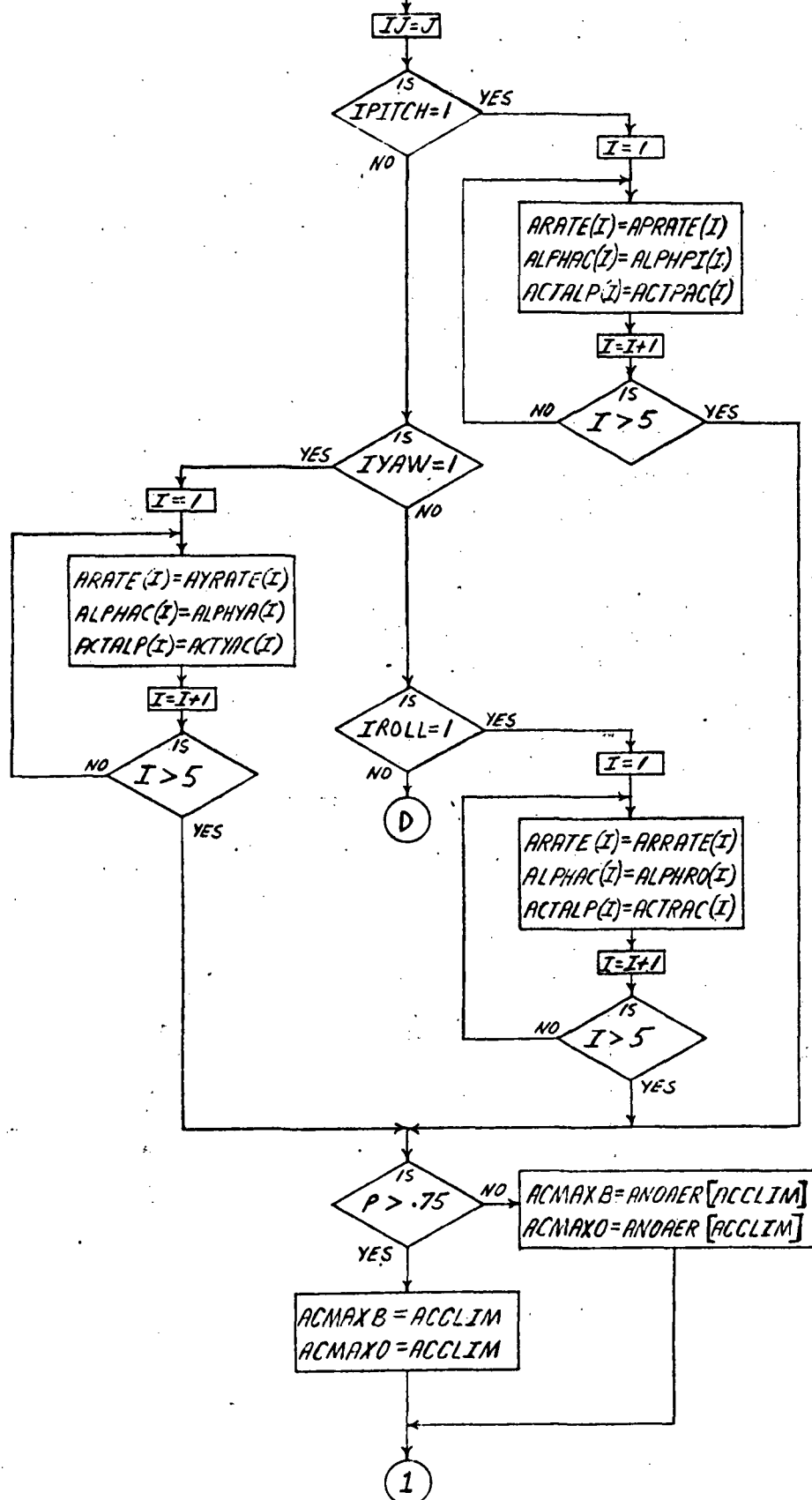


FIGURE 6 FLOW CHART OF ACC PROGRAM

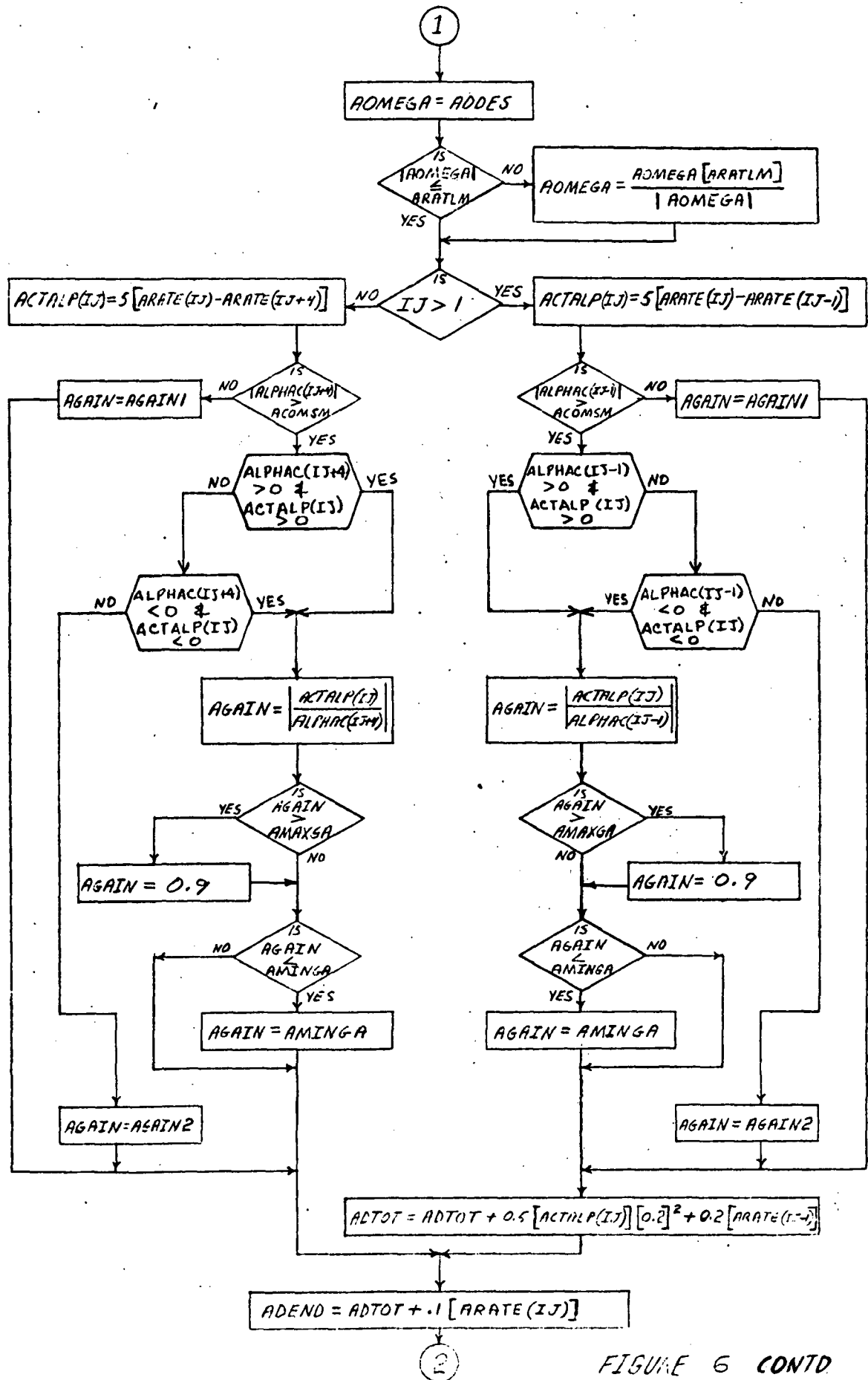


FIGURE 6 CONTO

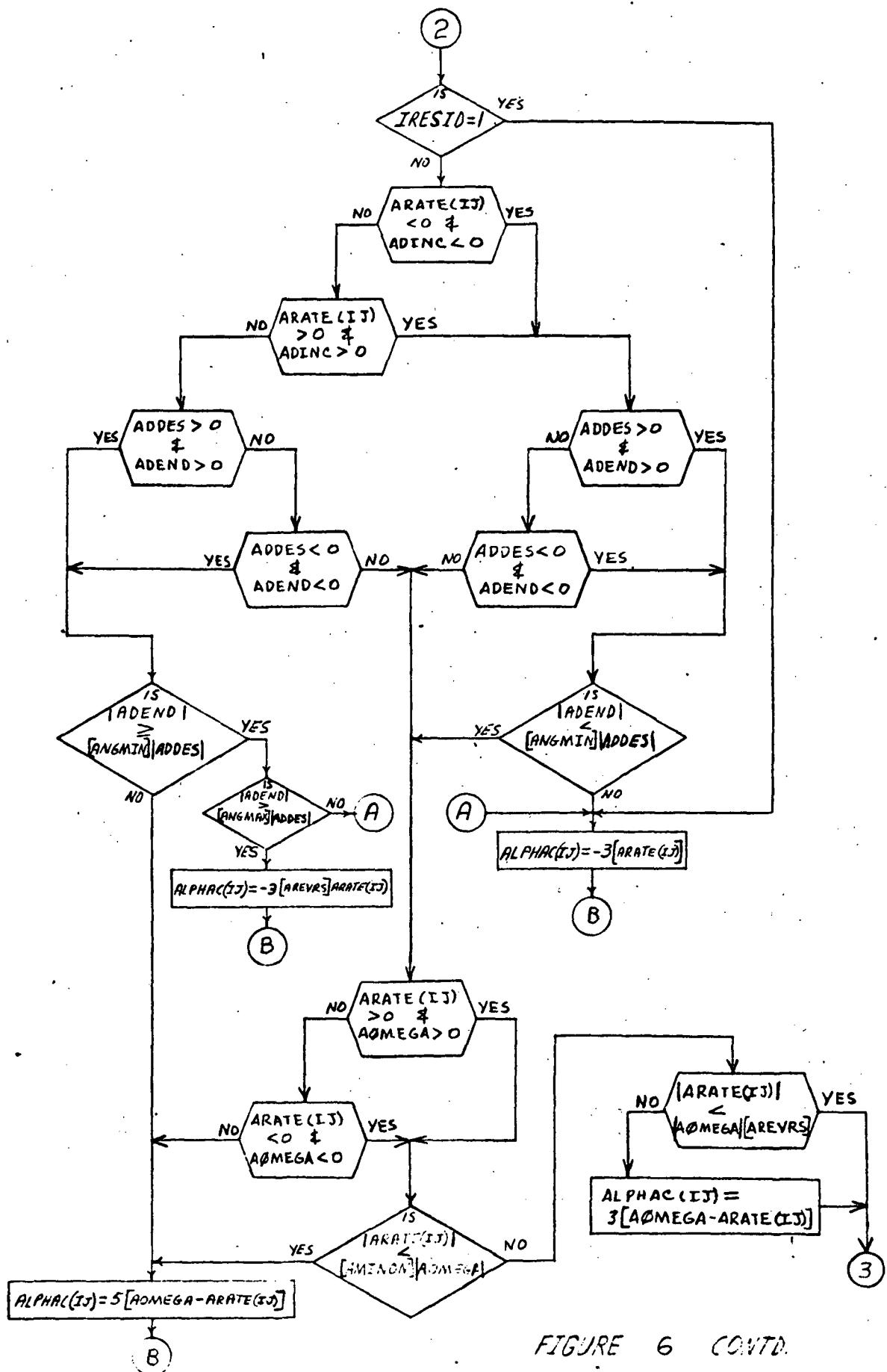


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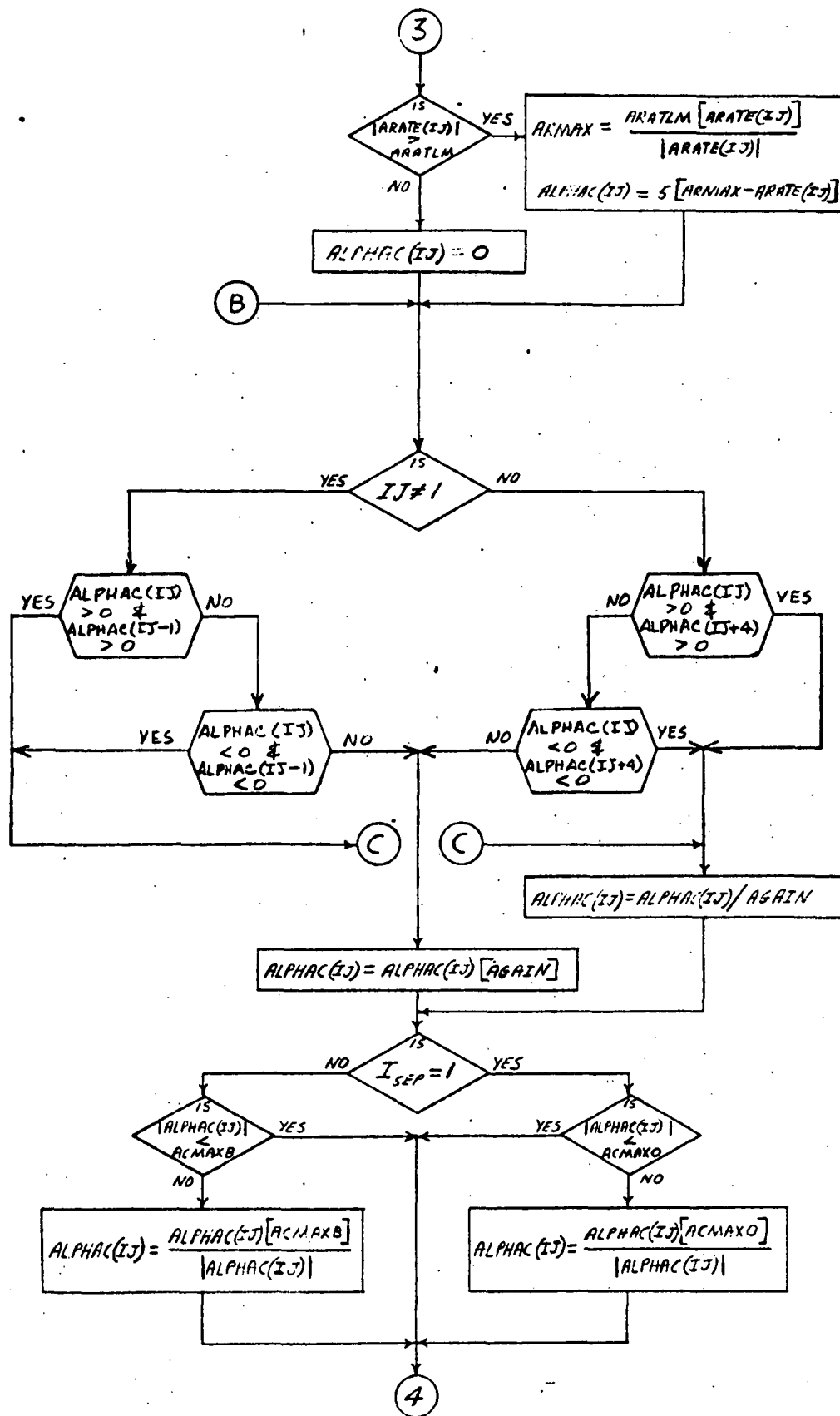


FIGURE 6 (CONT'D)

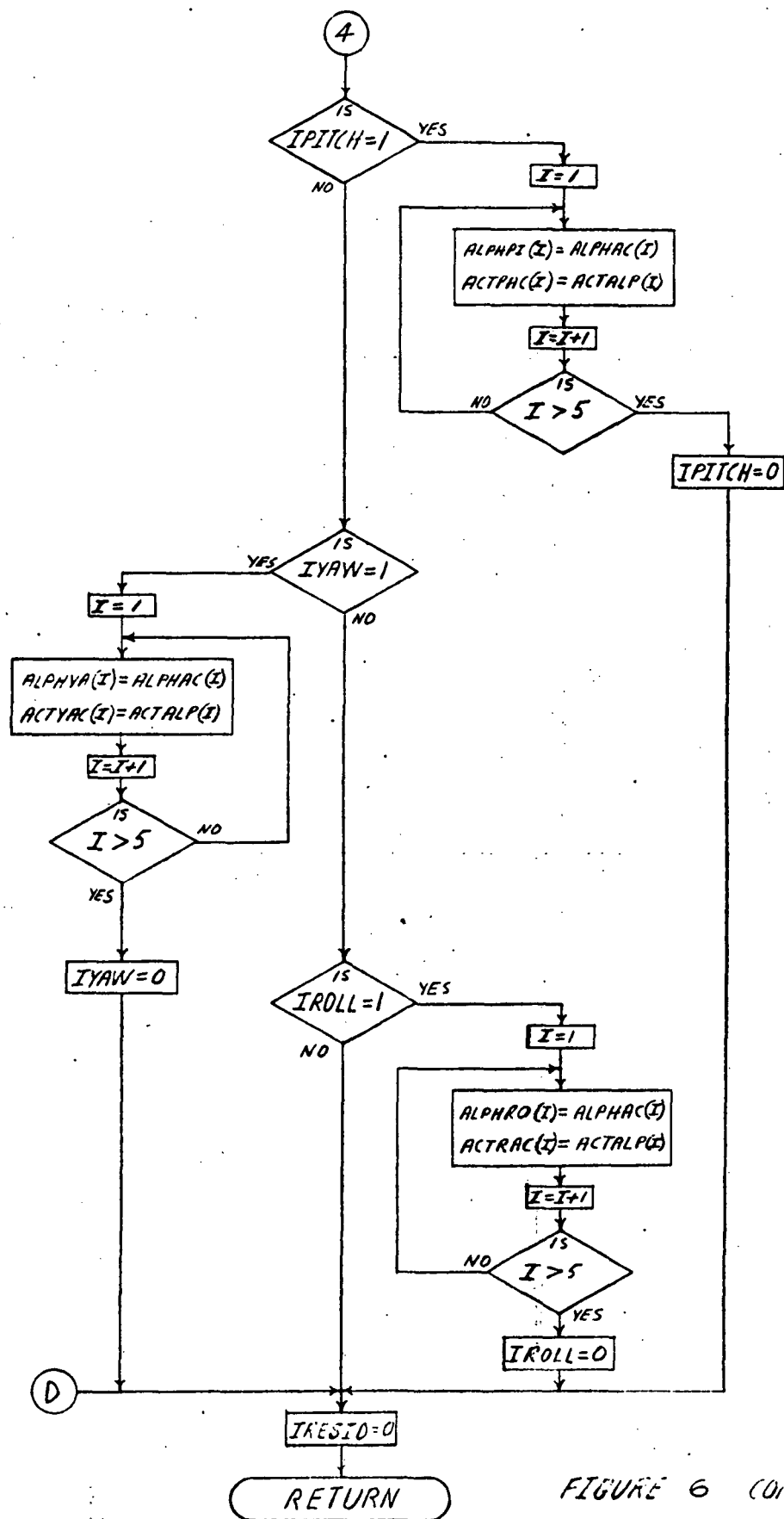


FIGURE 6 CONTD.

TABLE XIX SYMBOL DEFINITION FOR ACC SUBROUTINE

CODED SYM.	ENGR. SYM	SYMBOL DEFINITION OR USE	UNITS
ACCLIM	α_{LIM}	Angular acceleration limit; 2.268928 E-1	rad/sec ²
ACMAXB	α_{MAXB}	Maximum orbiter plus tank angular acceleration	rad/sec ²
ACMAXO	α_{MAXO}	Maximum orbiter angular acceleration	rad/sec ²
ACOMSM	α_{CSM}	Constant for angular acceleration commanded equal to zero test; 1.745329E-7	rad/sec ²
ACTALP (5)	α_{ACT}	Actual angular acceleration experienced	rad/sec ²
ACTPAC (5)	$\alpha_{\theta ACT}$	Actual pitch angular acceleration experienced	rad/sec ²
ACTRAC (5)	$\alpha_{\phi ACT}$	Actual roll angular acceleration experienced	rad/sec ²
ACTYAC (5)	$\alpha_{\psi ACT}$	Actual yaw angular acceleration experienced	rad/sec ²
ADDES	Δ_D	Desired change in body angle ($\Delta\theta_D$, $\Delta\psi_D$, $\Delta\phi_D$)	rad
ADEND	Δ_{END}	Total angle accumulated ($\Delta\theta_{END}$, $\Delta\psi_{END}$, $\Delta\phi_{END}$) if vehicle rate is stopped at the end of the present minor cycle	rad
ADINC	Δ	Impending incremental angle ($\Delta\theta$, $\Delta\psi$, $\Delta\phi$) due to body rate on first pass	rad
ADTOT	Δ_{TOT}	Total angle accumulated ($\Delta\theta_{TOT}$, $\Delta\psi_{TOT}$, $\Delta\phi_{TOT}$) since the start of the major cycle	rad
AGAIN	G	Desired or computed system gain (G_p , G_R , G_Y)	unitless
AGAIN 1	G_1	Desired acceleration system gain; 0.9	unitless
AGAIN 2	G_2	Desired acceleration system gain; 0.7	unitless
ALPHAC (5)	α_{COM}	Angular acceleration commanded	rad/sec ²
ALPHPI (5)	$\alpha_{\theta COM}$	Pitch angular acceleration commanded	rad/sec ²
ALPHRO (5)	$\alpha_{\phi COM}$	Roll angular acceleration commanded	rad/sec ²
ALPHYA (5)	$\alpha_{\psi COM}$	Yaw angular acceleration commanded	rad/sec ²
A _{MAXGA}	G_{MAX}	Upper limit of AGAIN; 1.3	unitless
A _{MINGA}	G_{MIN}	Lower limit of AGAIN; 0.35	unitless

TABLE XIX (Continued)

CODED SYM.	ENGR. SYM	SYMBOL DEFINITION OR USE	UNITS
AMINOM	C_{ω}	Minimum percent of desired rotational rate; 0.99	unitless
ANGMAX	$C_{\Delta MAX}$	Upper limit of percent desired angle change; 1.05	unitless
ANGMIN	$C_{\Delta MIN}$	Lower limit of percent desired angle change; 0.95	unitless
ANOAER	C_P	Percent of max acceleration with no aerodynamics 0.7	unitless
AOMEGA	ω	Desired body rotational rate ($\omega_p, \omega_R, \omega_Y$)	rad/sec
APRATE (5)	$\dot{\theta}_B$	Body pitch rate	rad/sec
ARATE (5)	$\dot{\Delta}$	Rotational rate ($\dot{\theta}, \dot{\psi}, \dot{\phi}$)	rad/sec
ARATLM	ω_{LIM}	Angular rate limit; 1.04719 E-1	rad/sec
AREVRS	$C_{\Delta OS}$	Percent reversal of existing rotational rate; 1.20	unitless
ARMAX	ω_{MAX}	Maximum allowable rotational rate	
ARRATE (5)	$\dot{\phi}_B$	Body roll rate	rad/sec
AYRATE (5)	$\dot{\psi}_B$	Body yaw rate	rad/sec
I	I	Do loop counter	
IJ	IJ	Autopilot pass counter	
IPITCH	I_{θ}	Pitch acceleration calculation flag	discrete
IRESID	I_R	Residual rate calculation	discrete
IROLL	I_{ϕ}	Roll acceleration calculation discrete	discrete
ISEP	I_{SEP}	Vehicle separation flag	discrete
IYAW	I_{ψ}	Yaw acceleration calculation flag	discrete
J	J	Pass counter	1-5
P	P	Atmospheric pressure	