

# Orbit Attitude Processor

## STS-1 Bench Program Verification Test Plan

(JSC-16386) ORBIT ATTITUDE PROCESSOR.  
STS-1 BENCH PROGRAM VERIFICATION TEST PLAN  
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SHUTTLE PROGRAM

ORBIT ATTITUDE PROCESSOR

STS-1 BENCH PROGRAM VERIFICATION TEST PLAN

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## 1.0 SUMMARY

This paper presents a plan for the static verification of the STS-1 ATT\_PROC\_ORBIT software requirements as given in Appendix A of the Level C Onorbit Flight Control FSSR. The orbit version of the SAPIENS bench program will be used to generate the verification data. A brief discussion of the simulation software and flight software modules is presented along with a description of the test cases.

## 2.0 INTRODUCTION

In general, verification testing insures that the coded requirements satisfy their original intent and serves as an indicator of software performance constraints. With the aid of a bench program model of the requirements, verification testing consists of two modes: static and dynamic. This paper presents plans for static verification testing of the Level C Onorbit Attitude Processor requirements. Static verification testing: (1) insures that all equations in the requirements are coded correctly, and (2) insures that all logic paths given in the requirements have been exercised.

Dynamic verification will be performed once static verification has been completed. This type of testing involves overall subsystem performance over mission phases, for nominal and off-nominal conditions (with and without sensor errors).

Section 3.0 contains a discussion of the SAPIENS/ORBIT module rate structure and a description of both the simulation software and flight software modules which comprise the SAPIENS/ORBIT bench program. Section 4.0 contains a description of the static verification test cases for each flight software module.



### 3.0 DISCUSSION

The orbit version of the SAPIENS bench program contains a FORTRAN simulation of the STS-1 onorbit attitude processor software requirements. These requirements are specified by the Level C Functional Subsystems Software Requirements (FSSR) Document (Reference 1) and all associated change requests dated up to May 1979. The static verification testing utilizes a single-shot onorbit simulated trajectory of approximately 2.0 seconds to cover major modes 201, 202, and 801 with error free IMU sensors. All logic paths of the ATT\_PROC\_ORBIT modules are exercised in order to check the code. A discussion of the rate structure of the modules is given in section 3.1 and a description of the simulation modules and the flight software modules are presented in sections 3.2 and 3.3.

#### 3.1 MODULES RATE STRUCTURE

The rate structure for the modules which comprise the orbit version of the SAPIENS bench program are presented in Table 1.0. The simulation software modules PMTG, CALLER and ORBSEN are executed at 6.25 Hz rate (minor cycle interval is 0.16 seconds). The flight software modules ATT\_PROC\_ORBIT\_INIT, ATT\_PROC\_ORBIT\_LOOP and ATT\_PROC\_ORBIT\_DISP are also executed at 6.25 Hz to support user principal function requirements. Even though all three ATT\_PROC modules are running at the 160 millisecond rate, the calculation of certain parameters occur at different rates which are dependent on the setting of certain flags and the value of certain internal counters. The detailed explanation of this is given in section 3.3.

#### 3.2 DESCRIPTION OF THE SIMULATION SOFTWARE MODULES

The FORTRAN modules which comprise the simulation software used in the onorbit version of the SAPIENS bench program are described in the following paragraphs (Figure 1.0).

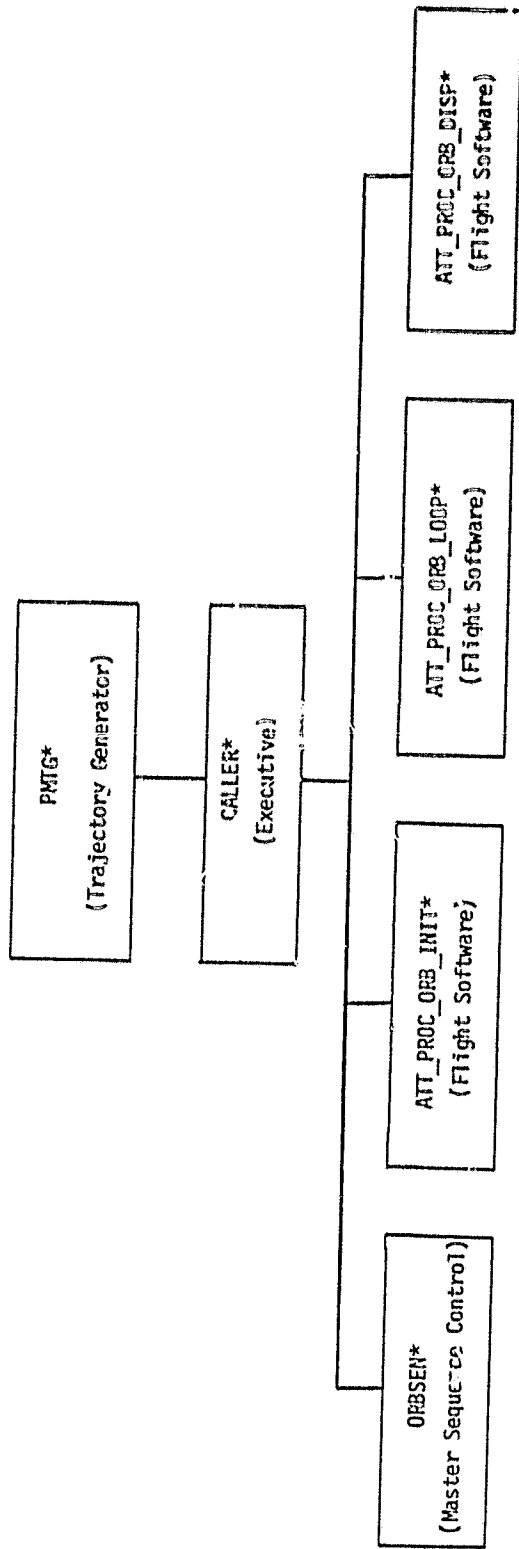
##### 3.2.1 PMTG (Main Program)

The PMTG (Point Mass Trajectory Generator) module is used as the environment generator for the SAPIENS bench program. This module consists of a single vehicle motion simulator which uses a simplified earth shape model (Fischer Ellipsoid), a 1962 standard atmospheric density model and a simplified gravity model (J2 and J3) with a 4th order Runge-Kutta-Gill integration routine. The PMTG module computes IMU gimbal angles for a single IMU, the M50-to-stable member matrix (REFSMMAT), and the position and velocity vectors  $\vec{R}_{AVGG}$  and  $\vec{V}_{AVGG}$  for input to the flight software modules ATT\_PROC\_ORBIT\_INIT and ATT\_PROC\_ORBIT\_LOOP; then, it calls the dispatcher module CALLER.

SIMULATION MODULES*		TIME OF FLIGHT (SEC)												
		0.0	0.16	0.32	0.48	0.64	0.80	0.96	1.12	1.28	1.44	1.60	1.76	1.92
1. PMTG		X	X	X	X	X	X	X	X	X	X	X	X	X
2. CALLER		X	X	X	X	X	X	X	X	X	X	X	X	X
3. ORBSEV		X	X	X	X	X	X	X	X	X	X	X	X	X
1. ATT_PROC_ORBIT_INIT		X	X	X	X	X	X	X	X	X	X	X	X	X
2. ATT_PROC_ORBIT_LOOP		X	X	X	X	X	X	X	X	X	X	X	X	X
• Inner Loop (Approximate Sines and Cosines Calculations)														
• Outer Loop (Exact Sines and Cosines Calculations)														
• Payload Functions														
3. ATT_PROC_ORBIT_DISP														
• ADI Functions														

\* The block data module is called COMINIT

TABLE 1.0 SAPIENS/ORBIT MODULE RATE STRUCTURE



\*The block data module COMMIT initializes common blocks for these modules

FIGURE 1.0 SIMULATION AND FLIGHT SOFTWARE MODULES

### 3.2.2 CALLER (Subroutine)

The CALLER module is used to simulate the IBM Frequency Dispatcher Queue. It controls the queuing of the simulation software module ORBSEN and the three flight software modules ATT\_PROC\_ORBIT\_INIT, ATT\_PROC\_ORBIT\_LOOP and ATT\_PROC\_ORBIT\_DISP. Each of these four modules are called by this module.

### 3.2.3 ORBSEN (Subroutine)

The ORBSEN module simulates the setting of flags, the manual controlling of switches, and crew inputs for the three flight software modules. It corresponds to a master sequencer controller.

### 3.2.4 COMINIT (Block Data)

The COMINIT module simulates the initialization and carryover requirements performed on transition from OPS 1 to OPS 2; also, it initializes all variables in each common block using the block data concept.

## 3.3 DESCRIPTION OF THE ATT\_PROC\_ORBIT FLIGHT SOFTWARE MODULES

The function of the onorbit attitude processor is to provide attitude information for user functions such as flight control, navigation, and displays during OPS 2 and 8. The three modules which comprise the onorbit attitude processor flight software are described in the following sections.

### 3.3.1 ATT\_PROC\_ORBIT\_INIT (Subroutine)

The function of the ATT\_PROC\_ORBIT\_INIT module is to compute the stable member wrt M50 quaternion after the completion of onorbit IMU alignments for each type of alignment option 1, 2, or 3. It is active in major modes 201, 202, and 801. The flow diagram representing the logic paths and relevant equations for this module is given in Figure 2.0. This module calculates a stable member wrt M50 quaternion for each IMU using as input the T\_CLUSTERM50<sub>k</sub> matrices (REFSMMAT) from the IMU ORB A/CAL principal function. The logic paths through this module are controlled by the external flag IMU\_QUAT\_UPD\_REQ which is set by the IMU ORB A/CAL principal function (4.208).

### 3.3.2 ATT\_PROC\_ORBIT\_LOOP (Subroutine)

The main function of the ATT\_PROC\_ORBIT\_LOOP module is to calculate attitude quaternions and the associated Euler angles to support 6.25, 1.04, and 0.52 Hz processing of user principal functions. It is active in major modes 201, 202, and 801. The flow diagram representing the logic paths and relevant equations of this module is given in Figure 3.0. \*

\*The value of the parameter CONSTANT = RAD\_PER\_DEG/2

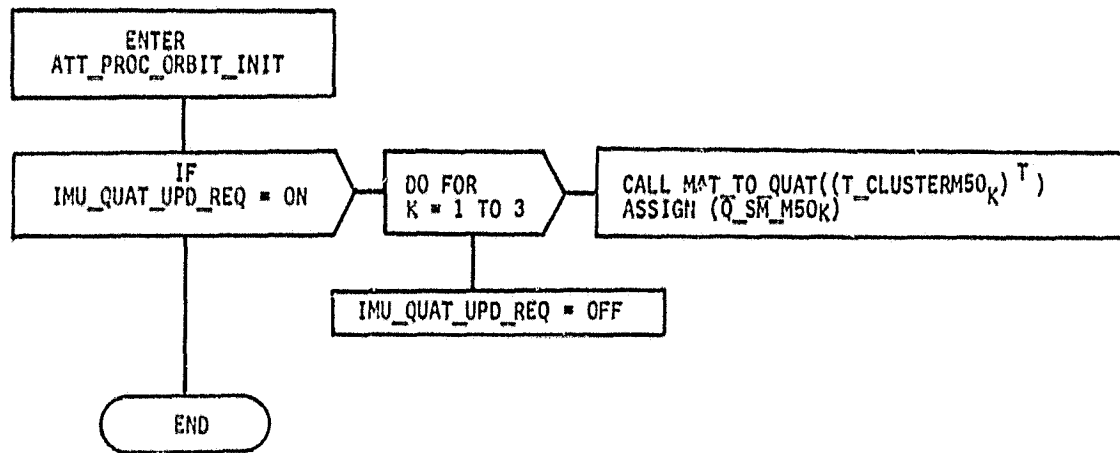


FIGURE 2.0 ATT\_PROC\_ORBIT\_INIT FLOW DIAGRAM

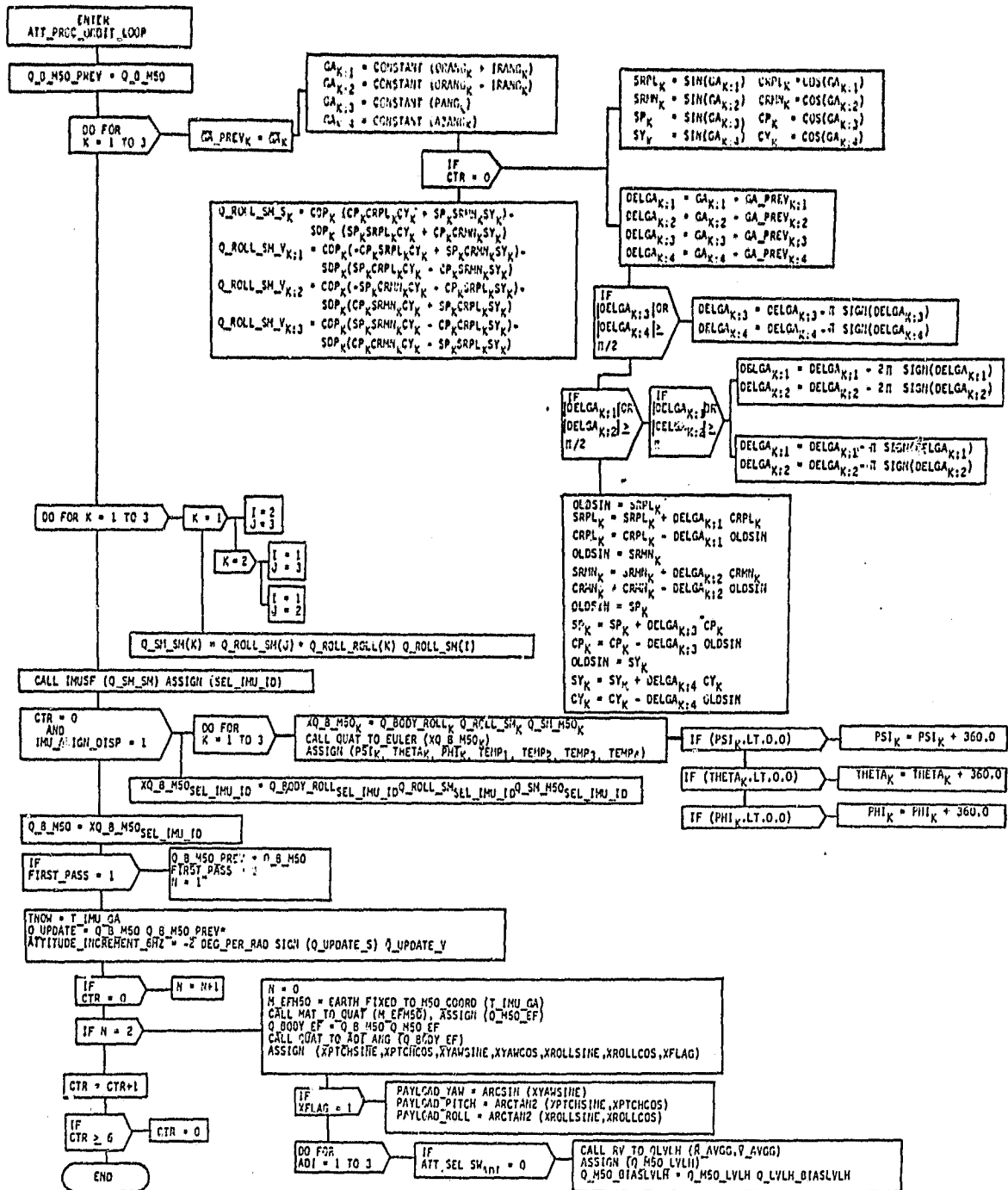


FIGURE 3.0 ATT\_PROC\_ORBIT\_LOOP FLOW DIAGRAM

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The basic attitude input variables for this module are the gimbal angles which are supplied by the IMU SOP at 6.25 Hz. The attitude quaternion associated with these gimbal angles is the roll with respect to stable member quaternion. In computing this quaternion, half gimbal angles are used for the arguments of the trigonometric functions. Furthermore, simplifications in the equations are achieved if the sum and difference of the outer and inner roll half angles are used. This new set of angles  $GA(I), I=1, 2, 3, 4$  will be denoted by the terminology modified gimbal angles.

Since processing in this module occurs at three different rates, there are several flags and counters used to control flow through the various logic paths. These parameters can be classified as internal and external. The three internal flags and counters CTR, FIRST PASS and N are defined as following: (1) CTR denotes a counter which distinguishes between exact and approximate trigonometric function calculations, (2) FIRST PASS denotes a first pass flag and (3) N denotes a 0.52 Hz processing counter. The three external flags and counters SEL IMU ID, IMU ALIGN DISP, and ATT SEL SW<sub>ADI</sub> are defined as: (1) SEL IMU ID denotes the IMU RM selected IMU, (2) IMU ALIGN DISP denotes that the alignment display is active and (3) ATT SEL SW<sub>ADI</sub> denotes the position of the ADI reference quaternion select switch. A discussion of the parameters which are computed by this module is presented according to their processing rate.

#### 3.3.2.1 Parameters Computed at 6.25 Hz

There are five parameters which are required at 6.25 Hz: (1) Q<sub>ROLL SM(K)</sub>, the roll wrt stable member quaternion for IMU<sub>K</sub> (K=1,2,3) which is used for other internal calculations, (2) Q<sub>SM SM(K)</sub>, the stable member wrt stable member quaternion for IMU<sub>K</sub> which is used by IMU RM to determine the selected IMU, (3) Q<sub>B M50</sub>, the body wrt M50 quaternion (always associated with the selected IMU) which is used by the software community as the basic attitude information, (4) T<sub>NOW</sub>, the time tag associated with Q<sub>B M50</sub> and (5) ATTITUDE\_INCREMENT\_6HZ a quantity proportional to the average angular velocity of the body over the current minor cycle and used by the ORB DAP flight control principal function.

In the computation of the first parameter Q<sub>ROLL SM(K)</sub>, there exist two different methods of computing the sines and cosines of the modified gimbal angles: exact and approximate. The first method computes the exact values of these trigonometric functions while the second method uses a Taylor series expansion to first order. Since the first method is more time consuming than the second, the first method is used once every six minor cycles. The other five minor cycles use the second method. The switching from one method to the other is handled by means of the counter CTR.

#### 3.3.2.2 Parameters Computed at 1.04 Hz

There is a set of Euler angles which is required at 1.04 Hz: (1) PSI(K), THETA(K), PHI(K), the Euler angles associated with IMU<sub>K</sub> which are extracted from XQ<sub>B M50(K)</sub> in a yaw, pitch, roll sequence and are used by the IMU alignment display. Since the required rate is 1.04 Hz, this particular calculation is made during the minor cycle when the exact sines and

cosines of the modified gimbal angles are used (CTR=0); furthermore, the calculation is done only when the alignment display is active (IMU\_ALIGN\_DISP=1).

### 3.3.2.3 Parameters Computed at 0.52 Hz

There are four parameters which are required at 0.52 Hz; (1) PAYLOAD\_YAW, PAYLOAD\_PITCH, PAYLOAD\_ROLL, the set of Euler angles associated with the body wrt EF (Earth Fixed) quaternion which are extracted in a pitch, yaw, roll sequence and used by GN&C/SM-PL IF principal function, (2) Q\_M50\_LVLH, the M50 wrt LVLH quaternion, (3) Q\_LVLH\_BIASLVLH, the LVLH wrt BIASLVLH quaternion and (4) Q\_M50\_BIASLVLH, the M50 wrt BIASLVLH quaternion. The last three parameters are used by the Display module in ATT\_PROC. Since the processing rate is 0.52 Hz, the counter N is used to control the computation rate (N=2).

### 3.3.3 ATT\_PROC\_ORBIT\_DISP (Subroutine)

The function of the ATT\_PROC\_ORBIT\_DISP module is to compute body attitude error angles and Attitude Director Indicator (ADI) ball driver functions to support 6.25 and 3.125 Hz processing for the principal function ORB ADI PROC (4.169). ATT\_PROC\_ORBIT\_DISP is active in major modes 201, 202, and 801. The flow diagram representing the logic paths and relevant equations of this module is given in Figure 4.0. ADI ball driver functions are derived for each of the three crew station ADI's. The two forward ADI's function as +X ADI's and the aft ADI functions as -X or -Z ADI. Associated with the aft ADI is a two-position sense switch (SENSE\_SW) which is used to correct for the -X or -Z mounting of the aft ADI. Both the forward and aft ADI's have attitude reference pushbuttons (FWD\_ATT\_REF\_PB, AFT\_ATT\_REF\_PB) which are used to update the reference quaternion (Q\_M50\_REF) with the conjugate of the current attitude quaternion (Q\_B\_M50). Each ADI has an attitude select switch setting which is used to indicate a reference coordinate system defined by quaternions. The three reference frame settings are 'INRTL', 'LVLH' and 'REF'.

The 'INRTL' coordinate system is defined by an I-LOAD quaternion (Q\_M50\_INRTL) which represents an in-plane LVLH attitude configuration at a specified time. This I-LOAD quaternion is formed from the RELMAT matrix which is computed by using the position and velocity vectors  $\bar{R}_{AVGG}$  and  $\bar{V}_{AVGG}$  defined at the orbital noon time which is closest to the midway Mission Elapsed Time between TIG (Time of Ignition) for nominal OMS 2 and TIG for nominal deorbit burn.

The 'LVLH' coordinate system is defined by a quaternion (Q\_M50\_BIASLVLH) which represents an unbiased LVLH attitude configuration. The quaternion Q\_M50\_BIASLVLH is formed by the quaternion product of Q\_M50\_LVLH (formed by a call to the utility routine RV\_TO\_QLVLH given the position and velocity vectors  $\bar{R}_{AVGG}$  and  $\bar{V}_{AVGG}$  at that instant of time) and the I-LOAD identity quaternion Q\_LVLH\_BIASLVLH.



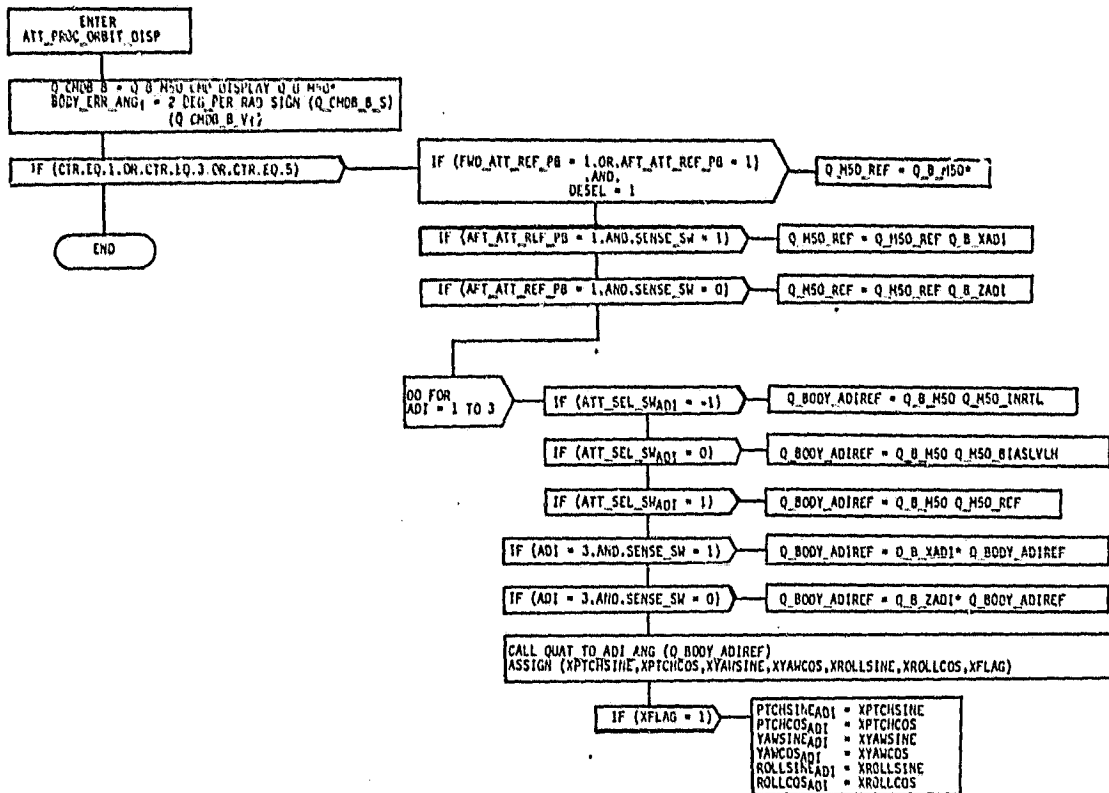


FIGURE 4.0 ATT\_PROC\_ORBIT\_DISP FLOW DIAGRAM

The 'REF' coordinate system is defined by a quaternion ( $Q_{M50\_REF}$ ) which represents a PTC (Passive Thermal Control) attitude configuration. This I-LOAD quaternion  $Q_{M50\_REF}$  is formed from the RELMAT matrix which is computed by using the SUN vector and angular momentum vector H defined at the orbital noon time which is closest to the midway mission elapsed time between TIG for nominal OMS 2 and TIG for nominal deorbit burn.

Since processing in this module occurs at two different rates, there are several flags and a single counter used to control flow through the various logic paths. These parameters can be classified as internal and external. The internal counter CTR denotes a 3.125 Hz processing counter. The five external flags FWD\_ATT\_REF\_PB, AFT\_ATT\_REF\_PB, DESEL, SENSE\_SW, and ATT\_SEL\_SW<sub>ADI</sub> are defined as: (1) FWD\_ATT\_REF\_PB denotes the forward ADI's attitude reference pushbutton which is used to update the 'REF' coordinate system, (2) AFT\_ATT\_REF\_PB denotes the aft ADI's attitude reference pushbutton which is used to update the 'REF' coordinate system, (3) DESEL denotes the COAS deselect command, (4) SENSE\_SW denotes the position of the aft ADI sense switch, (5) ATT\_SEL\_SW<sub>ADI</sub> denotes the position of the ADI reference quaternion select switch. A discussion of the parameters which are computed by this module is presented according to their processing rate.

### 3.3.3.1 Parameters Computed at 6.25 Hz

There is a set of body attitude error angles which are required at 6.25 Hz to drive the ADI error needles: (1) BODY\_ERR\_ANG is derived from an error quaternion formed by the quaternion product of the commanded quaternion ( $Q_{B\_M50\_CMD\_DISPLAY}$ ) and the conjugate of the current attitude quaternion ( $Q_{B\_M50}$ ).

### 3.3.3.2 Parameters Computed at 3.125 Hz

There are three sets of ball driver functions which are required at 3.125 Hz to drive the three ADI's: (1) PTCHSINE<sub>ADI</sub>, PTCHCOS<sub>ADI</sub>, YAWSINE<sub>ADI</sub>, YAWCOS<sub>ADI</sub>, ROLLSINE<sub>ADI</sub> and ROLLCOS<sub>ADI</sub>, the six trigonometric functions associated with a particular ADI which are extracted from  $Q_{BODY\_ADIREF}$  in a pitch, yaw, roll sequence. The calculation of the quaternion  $Q_{BODY\_ADIREF}$  for a particular ADI is dependent on the position of the select switch ATT\_SEL\_SW<sub>ADI</sub> and, in addition, for the aft ADI, the position of the sense switch SENSE\_SW.

#### 4.0 DESCRIPTION OF THE TEST CASES

The test cases which will be simulated for static verification of the onorbit attitude processor software requirements are described in the following sections. A summary of the test case flag settings and counters is given in Table 2.0 as a function of time of flight and major mode over the 2.0 second simulated trajectory. A summary of the various flag settings and counters for each module ATT\_PROC\_ORBIT\_INIT, ATT\_PROC\_ORBIT\_LOOP, and ATT\_PROC\_ORBIT\_DISP is presented in the corresponding test case description subsection. In addition, for each test case description, a flow diagram of the module is given on which arrows are used to denote the test case path taken through the module.

#### 4.1 ATT\_PROC\_ORBIT\_INIT TEST CASES

Test case 1 verifies the logic paths in the ATT\_PROC\_ORBIT\_INIT module. The logic paths in this module are controlled by the flag IMU\_QUAT\_UPD\_REQ (Table 3) which is set by the IMU ORB A/CAL principal function (4.208). Test case 1 consists of two subcases, 1.1 and 1.2 and are presented in Figures 5.0 and 6.0.

##### 4.1.1 Test Case 1.1

Test case 1.1 simulates an onorbit profile during major mode 201 at a time of 0.0 seconds where the IMU\_QUAT\_UPD\_REQ flag is OFF indicating no IMU alignment has occurred. Therefore, there is no computation of Q\_SM\_M50K.

##### 4.1.2 Test Case 1.2

Test case 1.2 simulates major mode 201 operation at a time of 1.2 seconds where the IMU\_QUAT\_UPD\_REQ flag has been set ON indicating the completion of an IMU alignment; therefore, the stable member wrt M50 quaternion is calculated for each IMU and the control flag reset OFF.

#### 4.2 ATT\_PROC\_ORBIT\_LOOP TEST CASES

Test case 2 verifies all logic paths in the ATT\_PROC\_ORBIT\_LOOP module. The logic paths are controlled by the following flags: CTR, SEL\_IMU\_ID, IMU\_ALIGN\_DISP, FIRST\_PASS, N and ATT\_SEL\_SWADI (Table 4.0). Test case 2 consists of six subcases 2.1 through 2.6 and are presented in Figures 7.0 through 12.0.

MEMORY CONFIGURATION	2		2										
	201		201										
	0.0	0.16	0.32	0.48	0.64	0.80	0.96	1.12	1.28	1.44	1.60	1.76	1.92
1. IMU_QUAT_UPD_REQ	0	0	0	0	0	0	1	0	0	0	0	0	0
2. CTR (when entering ATT_PROC_ORB_LOOP)*	0	1	2	3	4	5	0	1	2	3	4	5	0
3. SEL_IMU_ID	1	1	1	1	2	2	2	2	3	3	3	3	3
4. IMU_ALIGN_DISP	0	0	0	0	0	1	1	0	0	0	0	0	0
5. FIRST_PASS	1	0	0	0	0	0	0	0	0	0	0	0	0
6. N	2	0	0	0	0	0	1	1	1	1	1	1	2
7. ATT_SEL_SW_ADI      AUJ=1,2,3	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	0
8. FWD_ATT_REF_PB	0	0	0	0	0	0	1	0	0	0	0	0	0
9. AFT_ATT_REF_PB	0	0	0	0	0	0	0	0	1	0	1	0	0
10. DESEL	1	1	1	1	1	1	1	1	1	1	1	1	1
11. SENSE_SW	0	0	0	0	0	0	0	0	1	1	1	0	1

\*The value of this counter is modified at the end of ATT\_PROC\_ORB\_LOOP.

TABLE 2.0 ATT\_PROC\_ORBIT TEST CASE FLAG SETTINGS

TEST CASE NUMBER	NONE												
	1.1	NONE					1.2	NONE					
TIME OF FLIGHT (SEC)	0.0	0.16	0.32	0.48	0.64	0.80	0.96	1.12	1.28	1.44	1.60	1.76	1.92
1. IMU_QUAT_UPD_REQ	0	0	0	0	0	0	1	0	0	0	0	0	0

TABLE 3.0 ATT\_PROC\_ORBIT\_INIT FLAG SETTINGS AND COUNTERS  
VERSUS TIME AND TEST CASE NUMBERS

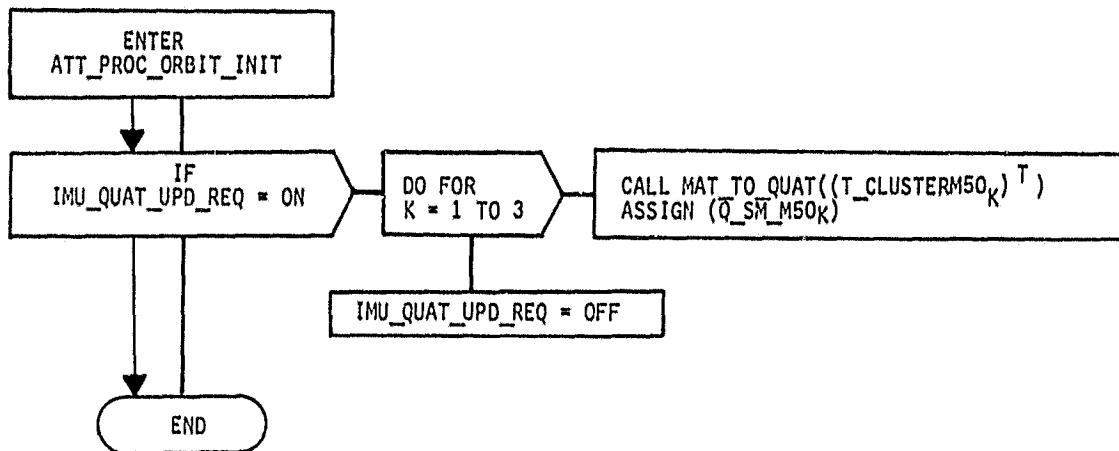


FIGURE 5.0 TEST CASE 1.1 LOGIC PATHS THROUGH ATT\_PROC\_ORBIT\_INIT

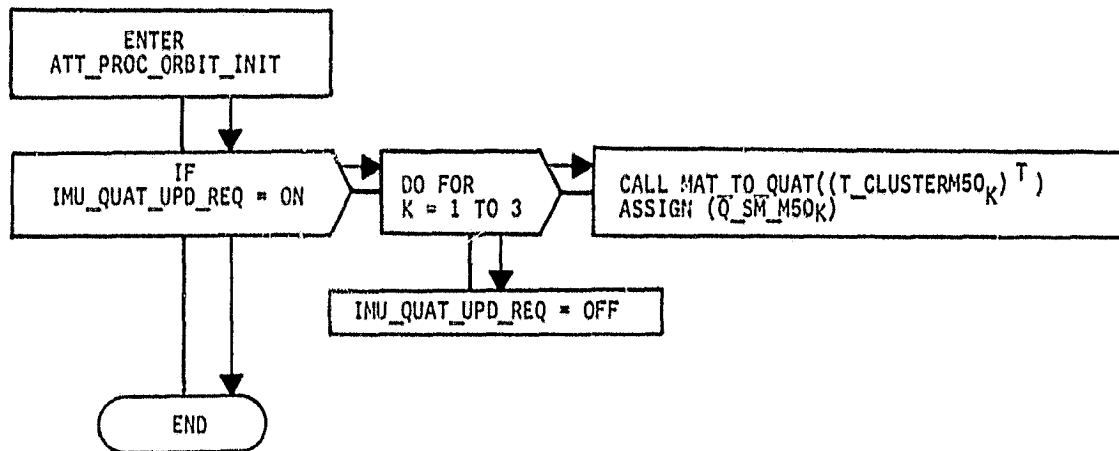


FIGURE 6.0 TEST CASE 1.2 LOGIC PATHS THROUGH ATT\_PROC\_ORBIT\_INIT

TEST CASE NUMBER	2.1	2.5	2.4	NONE			2.2	NONE			2.3	
	2.6	2.6	2.4	0.48	0.64	0.80	0.96	1.12	1.28	1.44	1.60	1.76
TIME OF FLIGHT (SEC)	0.0	0.16	0.32	0.48	0.64	0.80	0.96	1.12	1.28	1.44	1.60	1.76
1. CTR (when entering ATT_PROC_ORB_LOOP)	0	1	2	3	4	5	6	1	2	3	4	5
2. SEL_IMU_ID	1	1	1	1	2	2	2	2	3	3	3	3
3. IMU_ALIGN_DISP	0	0	0	0	0	1	1	0	0	0	0	0
4. FIRST_PASS	1	0	0	0	0	0	0	0	0	0	0	0
5. N	2	0	0	0	0	0	1	1	1	1	1	2
6. ATT_SEL_SW_ADI	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1

TABLE 4.0 ATT\_PROC\_ORBIT\_LOOP FLAG SETTINGS AND COUNTERS VERSUS TIME AND TEST CASE NUMBERS



#### 4.2.1 Test Case 2.1

Test case 2.1 simulates major mode 201 operation at a time of 0.0 seconds (Table 4). For this test case (Figure 7), outer loop processing (CTR=0) of exact sines and cosines of the modified gimbal angles is verified. Next,  $Q_{SM\_SM}(K)$  are computed and sent to the IMU selection filter (IMU\_SFT). The selected IMU as determined by the IMU selection filter is assumed to be IMU1 (SEL\_IMU\_ID=1). Since the IMU alignment display is inactive (IMU\_ALIGN\_DISP=0), no computation of Euler angles is done. Furthermore, since this is the first pass through the module (FIRST\_PASS=1), payload attitude data calculations are supported (N=2); however, no LVLH frame calculations are done since the attitude select switch for each ADI is in the 'INRTL' position (ATT\_SEL\_SWADI≠0).

#### 4.2.2 Test Case 2.2

Test case 2.2 simulates major mode 201 operation at a time of 0.96 seconds (Table 4). For this case (Figure 8), it is assumed that an IMU alignment has occurred on the previous cycle (0.80 seconds) so that the IMU\_ALIGN\_DISP flag is set. Also, since this is an outer loop cycle (CTR=0), Euler angle computations for the IMU alignment display are performed.\* The selected IMU for computation of the attitude quaternion  $Q_{B\_M50}$  is assumed to be IMU 2 (SEL\_IMU\_ID=2). No 0.52 Hz processing of payload attitude data or LVLH frame calculations are supported (N≠2) for this case.

#### 4.2.3 Test Case 2.3

Test case 2.3 simulates major mode 202 operation at a time of 1.92 seconds (Table 4). For this case (Figure 9), outer loop processing is again supported (CTR=0) and the selected IMU for attitude purposes is assumed to be IMU 3 (SEL\_IMU\_ID=3). The IMU alignment display is inactive (IMU\_ALIGN\_DISP=0) so that no Euler angle computations are done. Since this test case represents a 0.52 Hz pass through this module (N=2), payload attitude calculations are performed; also, the quaternion  $Q_{M50\_BIASLVLH}$  is computed since the attitude select switch is in the 'LVLH' position (all three ADI's have ATT\_SEL\_SWADI=0 in this particular case).

#### 4.2.4 Test Case 2.4

Test case 2.4 simulates major mode 801 operation at a time of 0.32 seconds (Table 4). For this case (Figure 10), inner loop processing (CTR≠0) of the approximate sines and cosines of the modified gimbal angles is verified. The selected IMU for computation of the attitude quaternion ( $Q_{B\_M50}$ ) is assumed to be IMU1 (SEL\_IMU\_ID=1). During major mode 801, the IMU alignment display is not supported so that the IMU\_ALIGN\_DISP flag is set to OFF for this test case.

\* In order to test modulo  $2\pi$  calculations, Euler angles computed for IMU3 will be overwritten with negative values

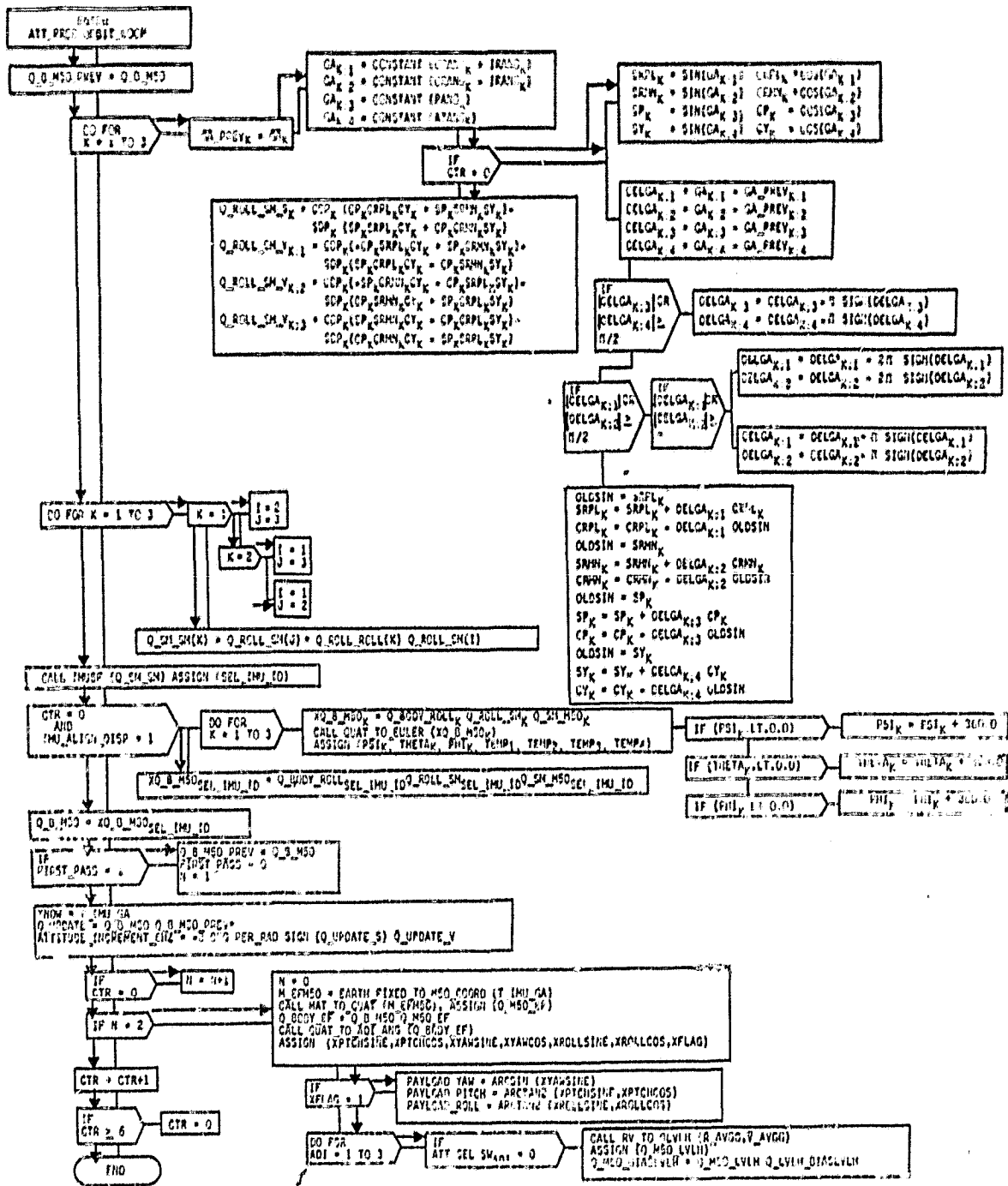


FIGURE 7.0 TEST CASE 2.1 LOGIC PATHS THROUGH ATT\_PROC\_ORBIT\_LOOP

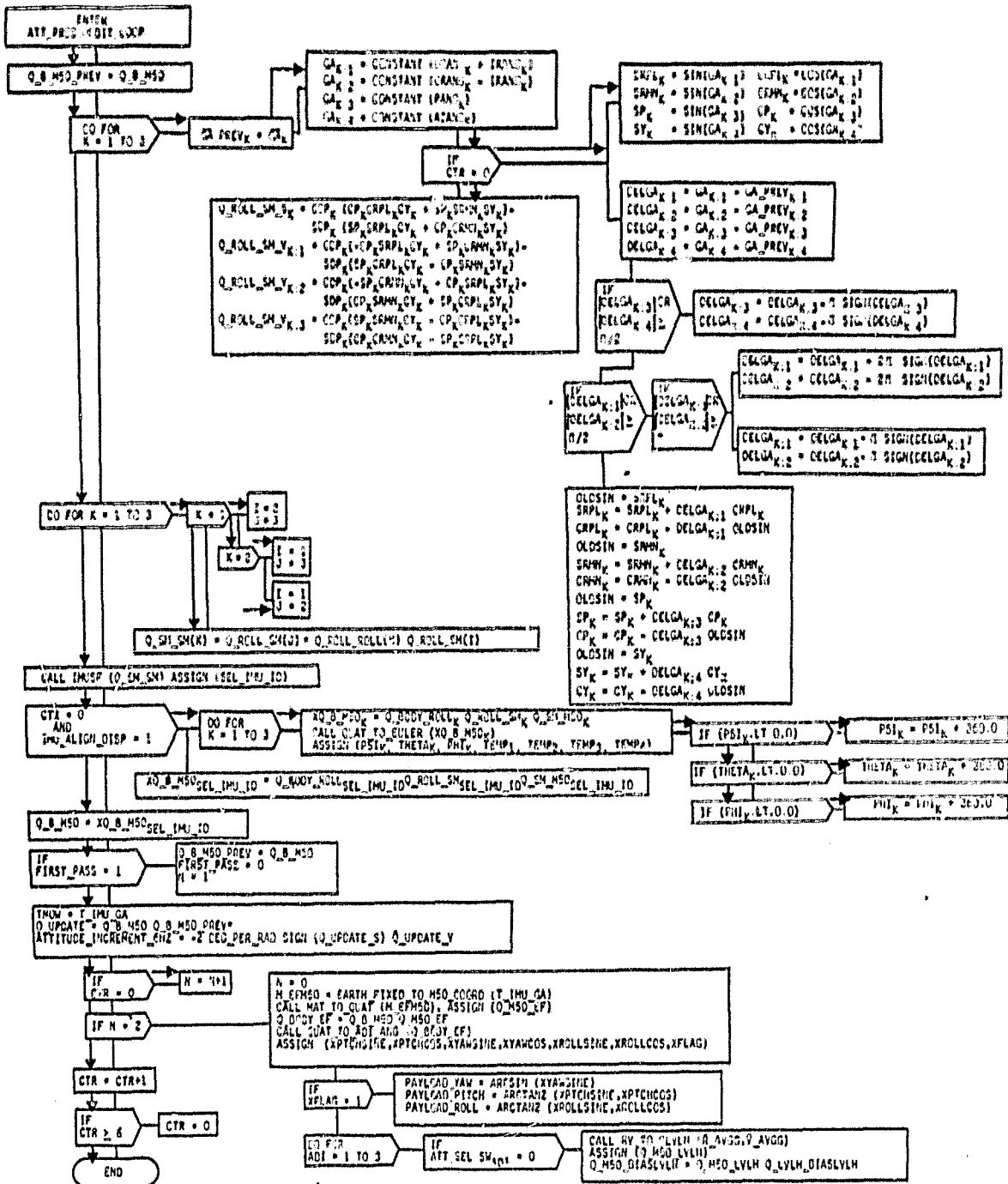


FIGURE 8.0 TEST CASE 2.2 LOGIC PATHS THROUGH ATT\_PROC\_ORBIT\_LOOP

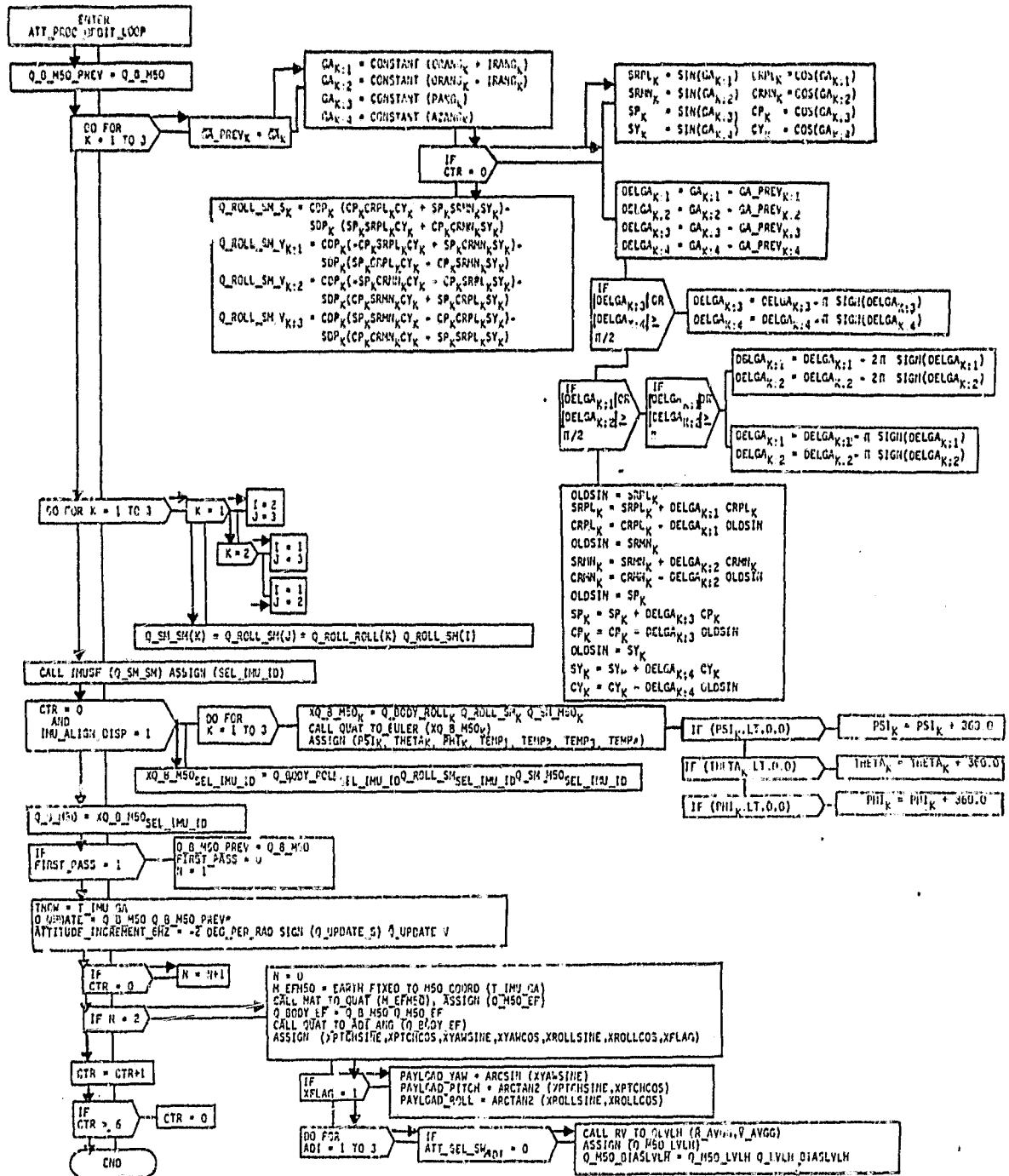
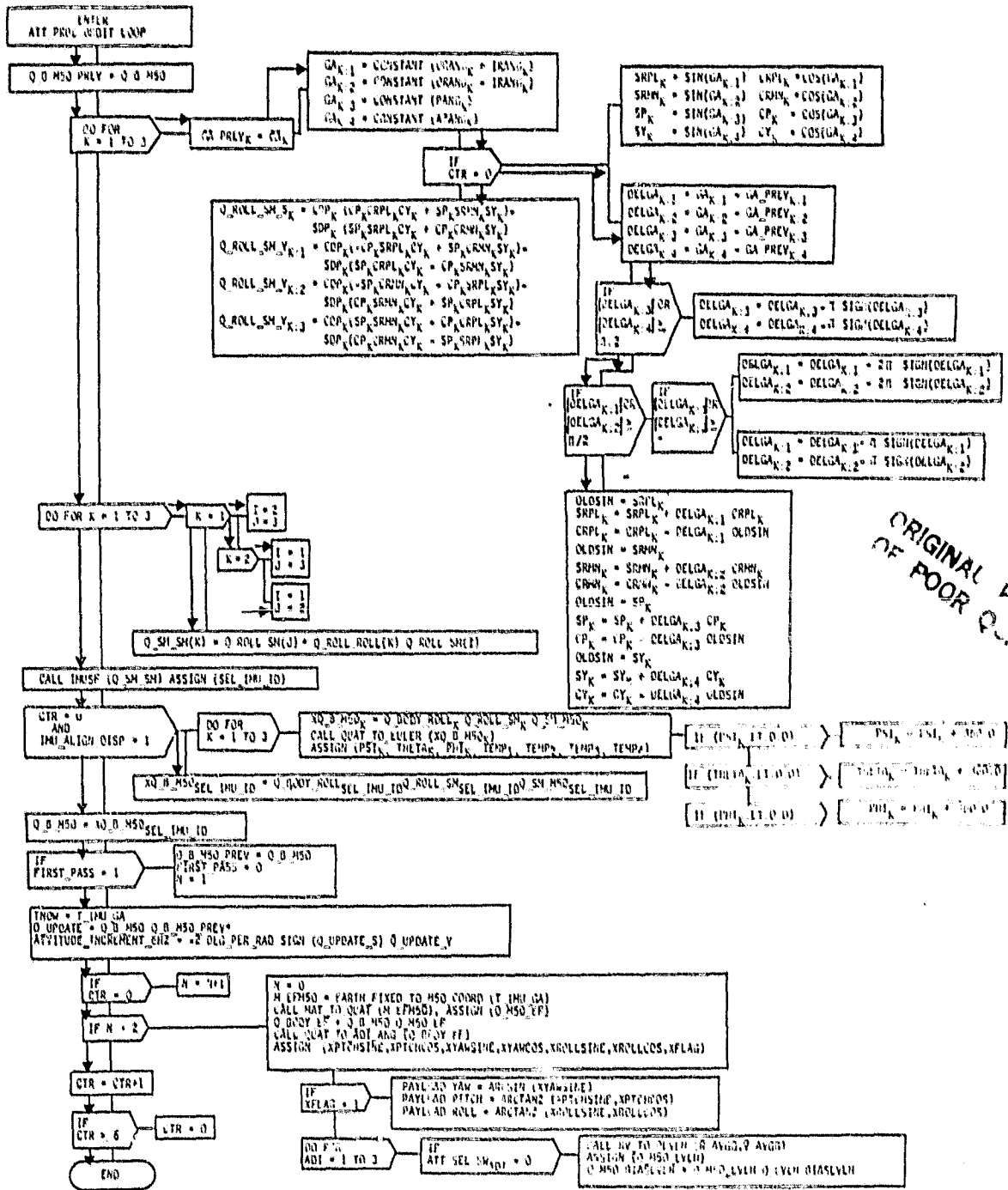


FIGURE 9.0 TEST CASE 2.3 LOGIC PATHS THROUGH ATT\_PROC\_ORBIT\_LOOP



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FIGURE 10.0 TEST CASE 2.4 LOGIC PATHS THROUGH ATT PROC ORBIT LOOP

#### 4.2.5 Test Case 2.5

Test case 2.5 represents a special test case (Table 4) for verifying inner loop processing (CTR≠0) within the ATT\_PROC\_ORBIT\_LOOP module. This case (Figure 11) verifies the logic paths for the outer roll and inner roll delta modified gimbal angles (DELGA<sub>1</sub> and DELGA<sub>2</sub>) with values greater than 90 degrees but less than 180 degrees. Also, the logic paths for the pitch and azimuth delta modified gimbal angles (DELGA<sub>3</sub> and DELGA<sub>4</sub>) with values greater than 90 degrees are verified. For this case, the IMU alignment display is inactive and the selected IMU is assumed to be IMU1 (SEL\_IMU\_ID=1).

#### 4.2.6 Test Case 2.6

Test case 2.6 also represents a special test case (Table 4) for verifying inner loop processing (CTR≠0) within the ATT\_PROC\_ORBIT\_LOOP module. This case (Figure 12) verifies the logic paths for the outer roll and inner roll (DELGA<sub>1</sub> and DELGA<sub>2</sub>) delta modified gimbal angles with values greater than 180 degrees but less than 360 degrees. As with the previous case, the IMU alignment display is inactive (IMU\_ALIGN\_DISP=0) and the selected IMU is assumed to be IMU1 (SEL\_IMU\_ID=1).

### 4.3 ATT\_PROC\_ORBIT\_DISP TEST CASES

Test case 3 verifies all logic paths in the ATT\_PROC\_ORBIT\_DISP module. The logic paths in this module are controlled by the following flags: CTR, FWD\_ATT\_REF\_PB, AFT\_ATT\_REF\_PB, DESEL, SENSE\_SW and ATT\_SEL\_SW<sub>ADI</sub> (Table 5). Test case 3 is composed of five subcases 3.1 through 3.5 and are presented in Figures 13.0 through 17.0.

#### 4.3.1 Test Case 3.1

Test case 3.1 simulates major mode 201 operation at a time of 0.0 seconds (Table 5). This test case (Figure 13) verifies the computation of the body attitude error angles which are required to drive the ADI error needles. Also for this test case, ADI ball driver functions are computed for the 'INRTL' reference frame setting (ATT\_SEL\_SW<sub>ADI</sub>=-1). Thus the vehicle's reference attitude configuration represents an in-plane LVLH attitude. Since the aft ADI is oriented in the -Z direction (SENSE\_SW=0), the logic path used to correct for the mounting of the aft ADI is also verified.

#### 4.3.2 Test Case 3.2

Test case 3.2 simulates major mode 201 operation at a time of 0.96 seconds (Table 5). For this case (Figure 14), the logic path associated with the crewman depressing the forward attitude reference pushbutton (FWD\_ATT\_REF\_PB=1) in combination with the COAS not selected (DESEL=1) is verified. The depressing of the pushbutton results in the update

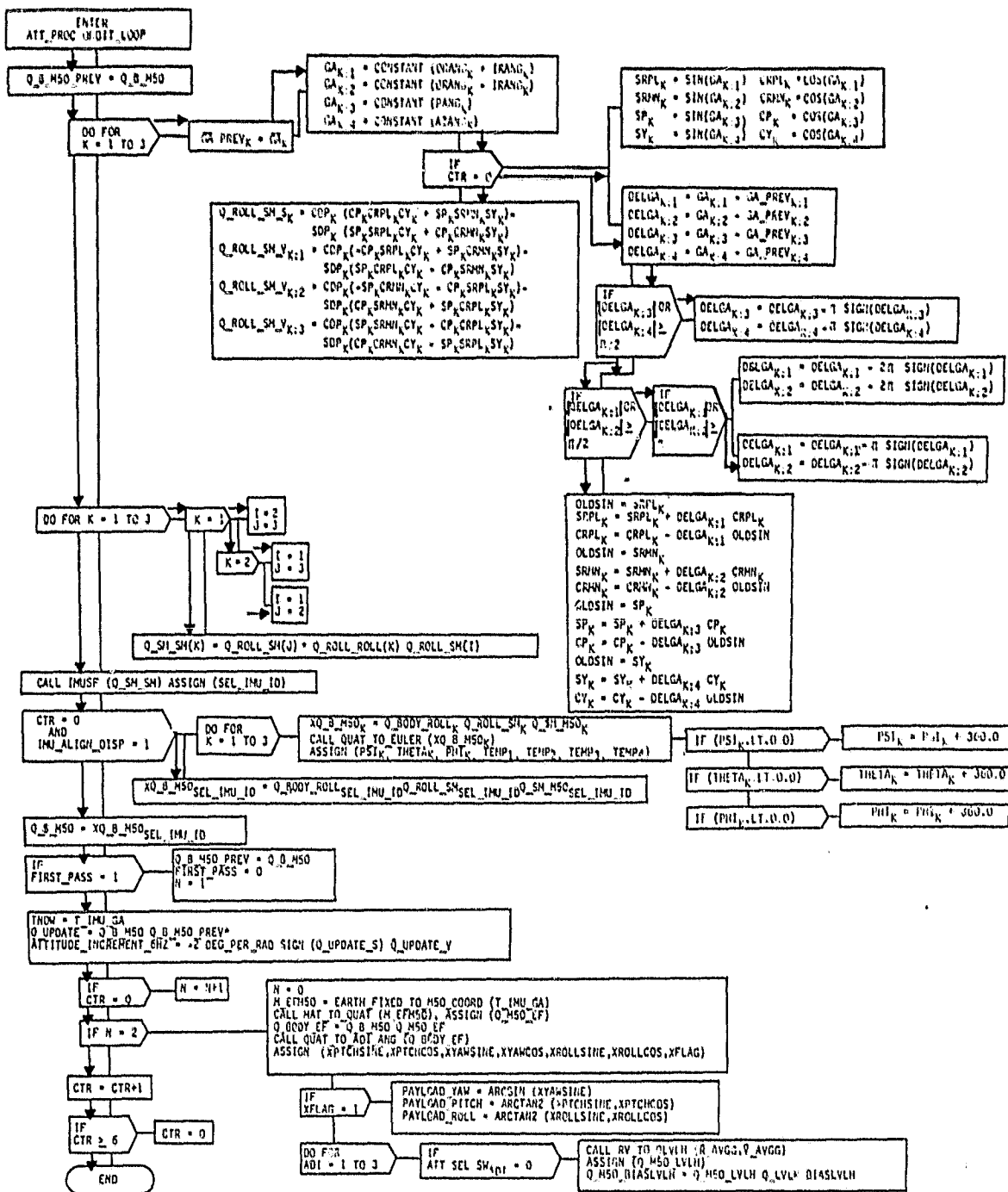


FIGURE 11.0 TEST CASE 2.5 LOGIC PATHS THROUGH ATT\_PROC\_ORBIT\_LOOP

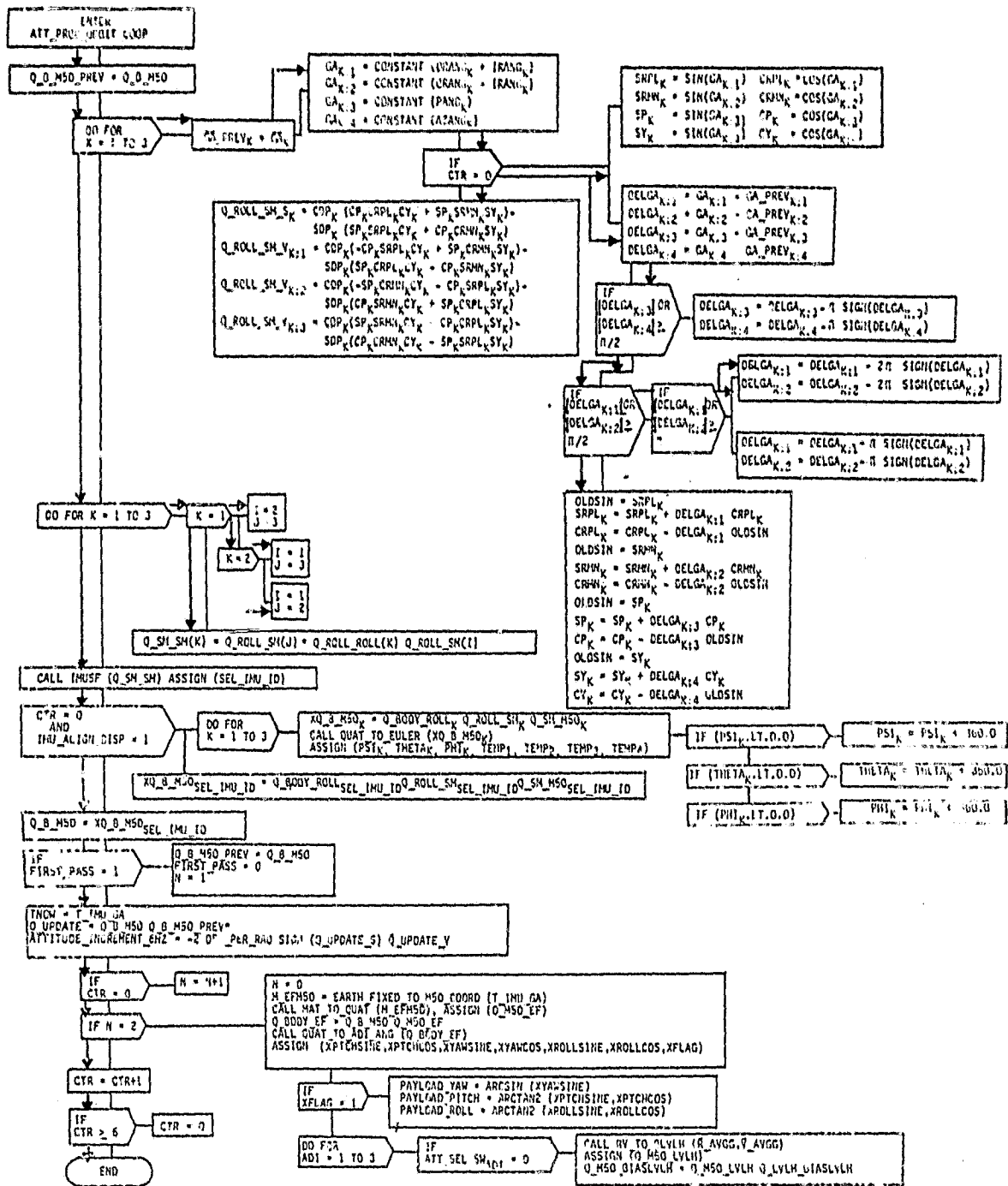


FIGURE 12.0 TEST CASE 2.6 LOGIC PATHS THROUGH ATT\_PROC\_ORBIT\_LOOP



TEST CASE NUMBER	3.1						NOISE						3.2	3.3	3.4	3.5
	0.0	0.16	0.32	0.48	0.64	0.80	NOISE	NOISE	NOISE	NOISE	NOISE	NOISE	NOISE	NOISE	NOISE	NOISE
TIME OF FLIGHT (SEC)	0.0	0.16	0.32	0.48	0.64	0.80	0.96	1.12	1.28	1.44	1.60	1.76	1.92			
1. CTR *	1	2	3	4	5	0	1	2	3	4	5	0	1			
2. FWD_ATT_REF_PB	0	0	0	0	0	0	1	0	0	0	0	0	0			
3. AFT_ATT_REF_PB	0	0	0	0	0	0	0	0	1	0	1	0	0			
4. DESEL	1	1	1	1	1	1	1	1	1	1	1	1	1			
5. SENSE_SW	0	0	0	0	0	0	0	0	1	1	0	0	1			
6. ATT_SEL_SW_ADI ADI=1,2,3	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1			

\*The value of this counter has been modified at the end of ATT\_PROC\_ORB\_LOOP.

TABLE 5.0 ATT\_PROC\_ORBIT\_DISP\_FLAG\_SETTINGS\_AND\_COUNTERS  
VERSUS TIME AND TEST CASE NUMBERS

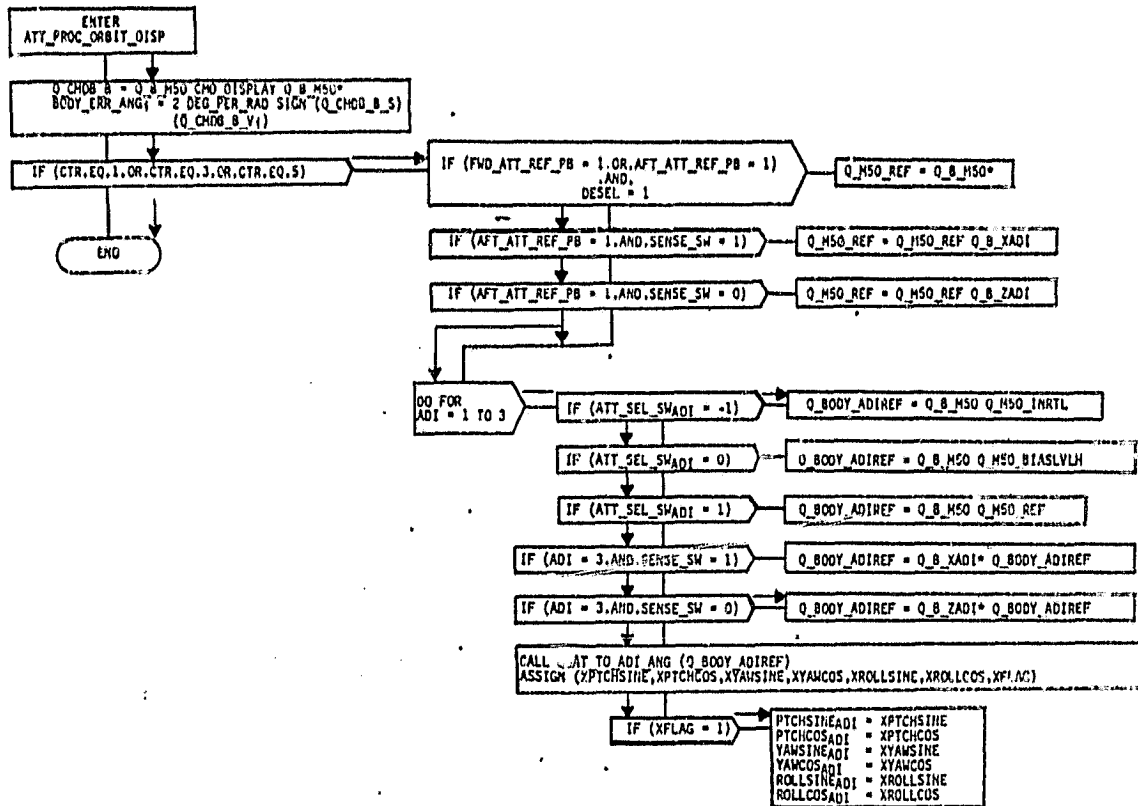


FIGURE 13.0 TEST CASE 3.1 LOGIC PATHS THROUGH ATT\_PROC\_ORBIT\_DISP

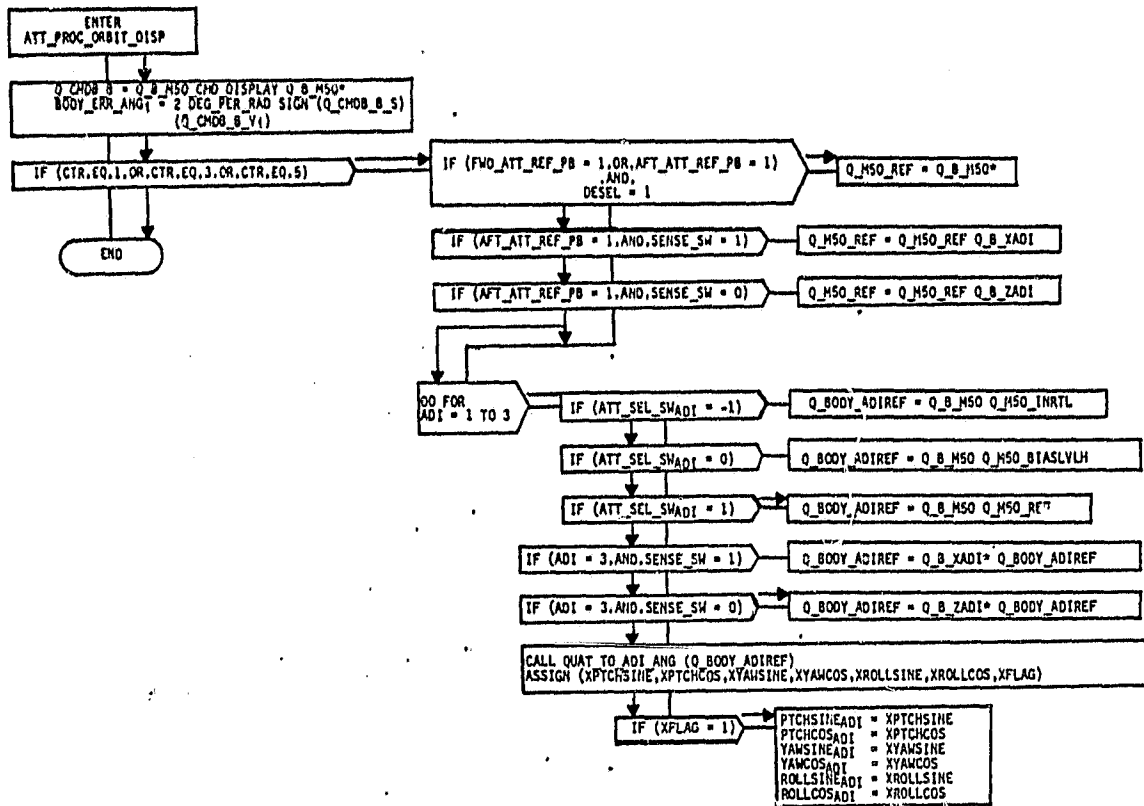


FIGURE 14.0 TEST CASE 3.2 LOGIC PATHS THROUGH ATT\_PROC\_ORBIT\_DISP

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of the 'REF' quaternion (Q\_M50\_REF) with the conjugate of the current Q\_B\_M50 quaternion. The attitude select switch is in the 'REF' position (ATT\_SEL\_SW<sub>ADI</sub>=1) and so the ADI ball driver functions are derived for this switch setting. For this test case, the forward ADI balls should read 0° pitch, 0° yaw, and 0° roll since the quaternion (Q\_BODY\_ADIREF) is an identity quaternion. The aft ADI is oriented in the -Z direction but angles associated with this ADI will be those extracted from Q\_B\_ZADI since the forward ADI's were selected for update.

#### 4.3.3 Test Case 3.3

Test case 3.3 simulates major mode 201 operation at a time of 1.28 seconds (Table 5). For this case (Figure 15), the logic paths associated with the crewman depressing the aft attitude reference pushbutton (AFT\_ATT\_REF\_PB=1) in combination with the COAS not selected (DESEL=1) and the aft ADI oriented in the -X direction (SENSE\_SW=1) are verified. The depression of the aft attitude reference pushbutton (AFT\_ATT\_REF\_PB=1) also results in the update of the 'REF' quaternion (Q\_M50\_REF) with the conjugate of the current Q\_B\_M50 quaternion. The attitude select switch is in the 'REF' position (ATT\_SEL\_SW<sub>ADI</sub>=1) and so the ADI ball driver functions are derived for this switch setting. The aft ADI ball should read 0° pitch, 0° yaw, and 0° roll since the quaternion (Q\_BODY\_ADIREF) is an identity quaternion for ADI=3.

#### 4.3.4 Test Case 3.4

Test case 3.4 simulates major mode 202 operation at a time of 1.60 seconds (Table 5). This case (Figure 16) is similar to the previous test case except that the logic paths for correcting the mounting of the aft ADI in the -Z direction (SENSE\_SW=0) are verified.

#### 4.3.5 Test Case 3.5

Test case 3.5 simulates major mode 202 operation at a time of 1.92 seconds (Table 5). For this case (Figure 17), the logic paths for the attitude select switch in the 'LVLH' position for each ADI (ATT\_SEL\_SW<sub>ADI</sub>=0) and the aft ADI oriented in the -X direction (SENSE\_SW=1) are verified. The ADI ball driver functions are computed for the 'LVLH' reference frame setting (ATT\_SEL\_SW<sub>ADI</sub>=0), thus the vehicle's reference attitude configuration represents an unbiased LVLH attitude.

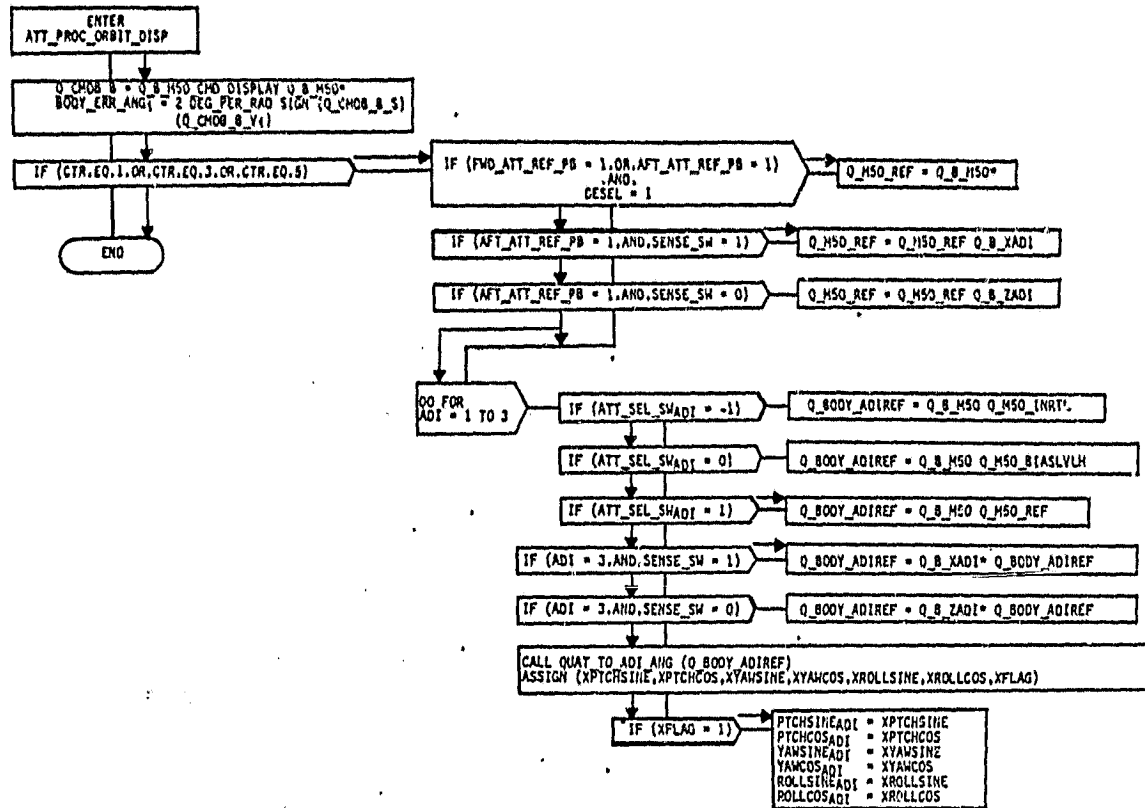


FIGURE 15.0 TEST CASE 3.3 LOGIC PATHS THROUGH ATT\_PROC\_ORBIT\_DISP

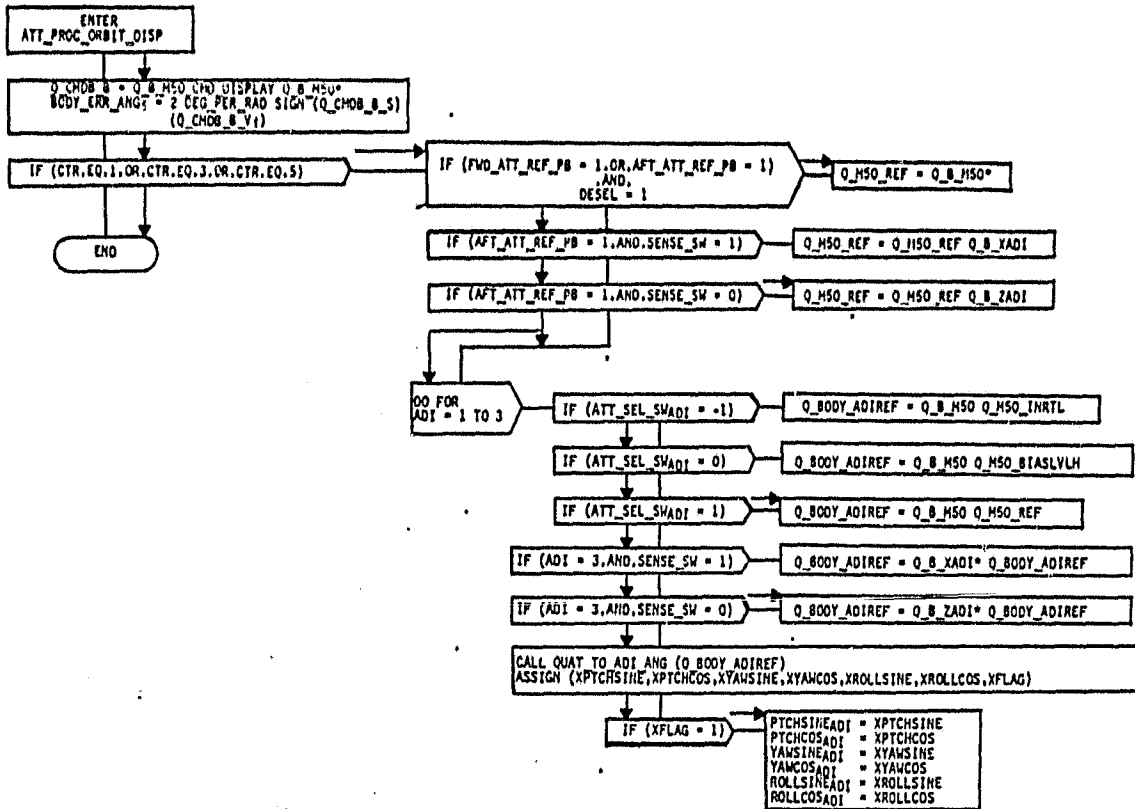
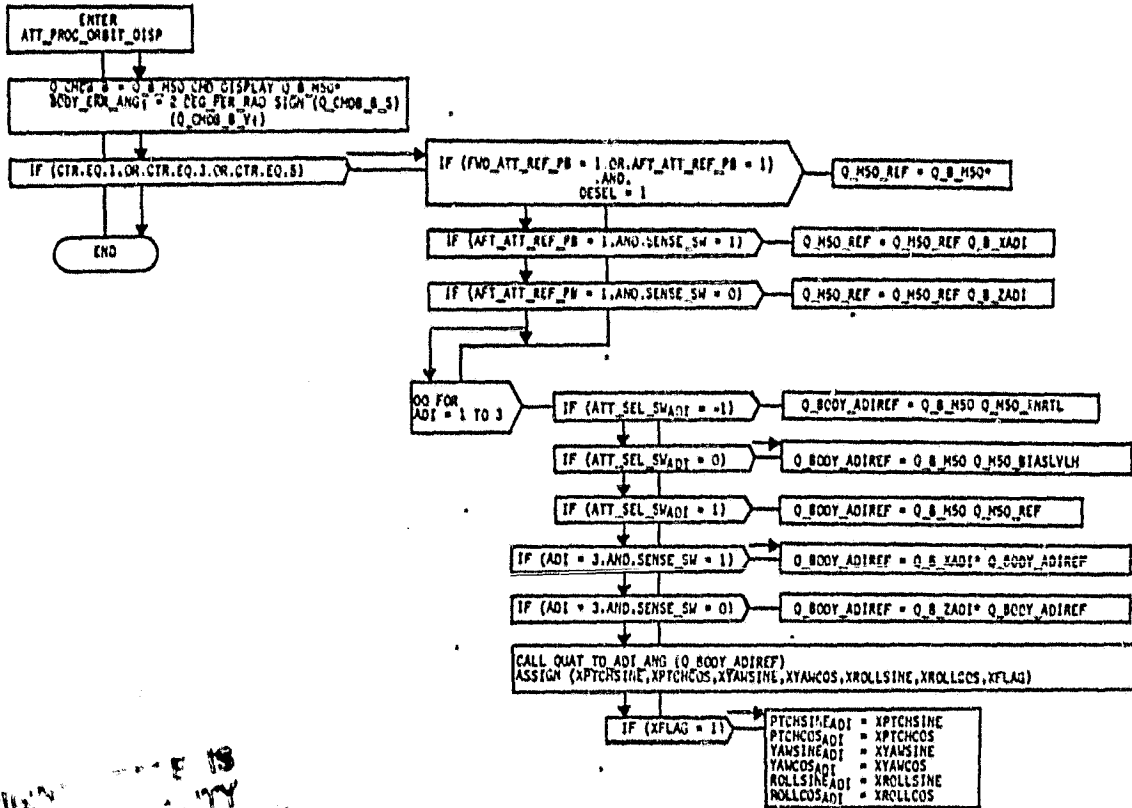


FIGURE 16.0 TEST CASE 3.4 LOGIC PATHS THROUGH ATT\_PROC\_ORBIT\_DISP



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FIGURE 17.0 TEST CASE 3.5 LOGIC PATHS THROUGH ATT\_PROC\_ORBIT\_DISP

## 5.0 CONCLUSIONS

The test cases defined for static verification of the onorbit Attitude Processor requirements will verify that all equations are coded correctly and will insure that all logic paths given in the requirements are exercised, and their output is reasonable.



## 6.0 REFERENCES

1. "Space Shuttle Orbital Flight Test - Level C FSSR-GN&C, Part C, Flight Control - ORBIT 2", Rockwell International Space Division, SD 76-SH-0009A, 15 April 1979.