Massachusetts Institute of Technology
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1068

COLOSSUS MEMO # 170

TO: Distribution
FROM: Saydean Zeldin
DATE: 4 April 1969
SUBJECT: MIT Review of Boeing-Houston (MSC) Information Package on CMC Boost Takeover

MIT has recently been assigned the task of reviewing the Boeing-Houston analysis of the CMC boost takeover characteristics. The first part of this task was to comment upon the attached information package

1. The text and block diagrams are essentially correct and accurately depict the information flow in Colossus 2 and Colossus 2A. (More functional descriptions are available in the Colossus 2 GSOP, Sections 3 and 5. An exact flow chart of the coding has recently become available as part of the MIT Flow Chart Effort.)

2. As a point of information, the maximum time and minimum time between takeover and ladder update, as described in the package, is in close agreement with that obtained by MIT simulated results. However, it should be pointed out that the flow chart on p. 16 means to convey that a .25 sec delay is built in between calls to ATERJOB. ATERJOB is a CMC low priority job. The variability of cycle time is a function of the number and duration of each higher priority job or clock. The effect of such interruptions on the cycle time is shown below.

Sampling frequency (sec)	Probability of Occurance Before & After Polynomial	During Polynomial
.35	.85	0
.45	0	.008
.55	0	.73
.65	.15	.126
.8	0	.126
.9	0	.0042

3. Certain minor discrepancies within the package are noted below:

   a. page 14:

      The computation of attitude errors for display on FDAI transforms attitude errors from gimbal axes to S/C axes (not SIC axes).

   b. "ATERTASK" (p. 11) disconnects the IMU error counters. This important for restart protection. In the event of a restart, "ATERTASK" is called, the error counters are disenabled, and S/C takeover is reinitialized.

Informal Boeing Data Package

Prepared by MSC and Given to MSFC

GENERAL DESCRIPTION OF SC BACKUP GUIDANCE MODES OPERATION

1. AUTOMATIC MODE - Operates from liftoff through translunar injection, unless terminated by DSKY entry (see Manual Mode).

   A. Guidance - Normally provided from CMC to monitor the LV flight unless SC guidance takeover is initiated.

      (1) 0 to 11.851 *seconds - Maintain liftoff attitude.

      (2) 11.851 *seconds - Start roll to 180 degrees gimbal angle at a roll rate of plus or minus one degree/second* and start pitch polynomial.

      (3) 157.101 *seconds - Stop pitch polynomial calculations and maintain attitude at final polynomial calculation.

      * Erasable Constant.

   B. Spacecraft takeover initiation requires two signals (not necessarily in this order):

      (1) LVDC signals failure and enables LV takeover relay.

      (2) LV Guidance switch placed in the CMC position, provides power to takeover relays in LV and SC, and starts the CMC takeover sequence.

   C. CMC Takeover Sequence (Automatic)

      (1) Zero attitude error output channels.

      (2) Enable SC takeover relay (transfers interface wires from ground to CMC error counter output).

      (3) Store bias constants equal to existing errors.

      (4) Subtract bias constants from attitude errors.

      **(5) Output biased errors to LV Flight Control Computer and FDAI attitude error needles.

      ** Note that FCC acceptance of SC generated attitude error signals requires that the LVDC has enabled the LV takeover relay.

GENERAL DESCRIPTION OF SC BACKUP GUIDANCE MODES OPERATION

2. MANUAL MODE - Available at any time during mission by entering VERB 46 when CONFIG octal window of NOUN 46 R1 has been set to 3 using VERB 48 (R03).

   A. Spacecraft takeover initiation requires three signals (not necessarily in this order):

      (1) VERB 46 entered in DSKY. Starts CMC takeover sequence.

      (2) LV Guidance switch placed in CMC position provides power to takeover relays in SC and LV.

      (3) LVDC signals failure and enables LV takeover relay (not needed for TB5 and TB7).

   B. CMC Takeover Sequence

      (1) Zero attitude error output channels.

      (2) Enable SC takeover relay (if not already enabled by Automatic Mode).

      (3) Interrogate stick every 0.1 second.

      (4) Transmit on/off error signals to LV Flight Control Computer (if the LVDC has enabled the LV takeover relay).

   C. Guidance

      Provided through astronaut by comparison of information obtained from the FDAI and DSKY with a trajectory card.

   D. Operation

      (1) Stick deflected - Fixed error signal.

      (2) Stick not deflected - Zero error signal.

3. S-IVB ENGINE SHUTDOWN

   A. The S-IVB is <u>not</u> shut down automatically following platform failure.

   B. S-IVB engine shutdown is accomplished <u>only</u> by operation of the S-II/S-IVB staging switch.

4. S-IVB REIGNITION

   A. Normal LVDC initiation exists.

   B. Present planning provides capability for initiation from spacecraft effective SA 507 and subs.

S/C BACKUP GUIDANCE SYSTEM IMPLEMENTATION PARAMETERS

A. Approximate Command Module Computer attitude error output times for Automatic Mode simulation are shown in Table I on page 7. The attitude errors are calculated 0.08 seconds before they are output.

B. Switchover Delay Time

During the time required to accomplish the switchover events listed in Backup System Description, the error signal is either held constant at a non-zero value or is zero. This time of no control is composed of three elements listed below and illustrated in Figure 1.

	Minimum	Maximum
LVDC Response		
a) Pre-IGM (Automatic Mode)	0.6 sec.	1.7 sec.
b) During IGM (Manual Mode)	1.2	3.5
Crew Response		
a) S-1C (Automatic Mode)	0.3	1.0
b) S-II, S-IVB (Manual Mode)	0.3	5.0
CMC Response		
a) Automatic Mode	0.7	1.9
b) Manual Mode	0.2	0.2

C. Quantization: 0.013 volts/bit.

D. Maximum attitude error voltage range: ± 5 volts.

E. Maximum rate of change of attitude error: not limited.

F. Transport Lag: 0.08 seconds.

G. Scale Factors:

1. Automatic Mode may be any specified value up to 1.2 volts/degree in pitch or yaw; roll scaling is always 1/4 of pitch or yaw; e.g., normal CM scaling is 0.3 volts/degree in pitch and yaw which would give 0.075 volt/degree in roll. At S/C takeover the FCC scaling is changed from 0.8 volt/degree to 0.3 volt/degree.

2. Manual Mode may be any specified value up to 15 degrees. (Recommended value is 2.5 degrees attitude error.) Fixed output is identical for all axes in the Manual Mode.

H. CMC Guidance

1. CMC pitch attitude command polynomial coefficients for AS-505 flight (erasable load):

TSTART = 11.851 seconds after liftoff.
TSTOP = 157.101 seconds after liftoff.

S/C BACKUP GUIDANCE SYSTEM IMPLEMENTATION PARAMETERS

H.1. (CONT)

$$\text{Pitch Gimbal Command} = 90° - \sum_{i=0}^{6} A_i\, t^i;\ 0 \le t \le (\text{TSTOP-TSTART}).$$

t = time from liftoff - TSTART.

A0 = +0.2466154 deg.
A1 = +0.4515752 X 10^{-1} deg/sec.
A2 = +0.8524913 X 10^{-2} deg/sec^2.
A3 = +0.9802650 X 10^{-4} deg/sec^3.
A4 = -0.2881423 X 10^{-5} deg/sec^4.
A5 = +0.2008589 X 10^{-7} deg/sec^5.
A6 = -0.4632108 X 10^{-10} deg/sec^6.

Reference: Saturn V AS-505 Launch Vehicle Operational Flight Trajectory - Preliminary Report, February 17, 1969.

2. Roll Guidance - CMC commands roll angle to 180°. The initial body roll command varies according to the launch azimuth.

   Roll Gimbal Command = launch azimuth + 90° + t (roll rate).

3. Yaw Guidance - CMC commands zero degrees yaw gimbal at all times.

I. Table II lists the Manual Mode vehicle attitude rate capabilities for a 1° error signal stick gain. For stick gain producing other than 1° attitude error, the vehicle rates can be scaled in proportion to the error signal. Also listed are the uncertainties due to 3σ thrust vector misalignments and the error signal required to null the moment produced by the uncertainty.

TABLE II

STAGE	AXIS	TIME(SEC)	a_0	a_1	VEHICLE RATE FOR 1.0° ERROR $\dot{\phi}$(DEG/SEC)	THRUST MISALIGNMENT, β_m (DEGREES)	ERROR DUE TO β_m, $\Delta\psi_m$ (DEGREES)
S-II	P, Y	0-60	1.12	1.89	.593	.47°	.42°
		60-190	.65	1.10	.591	.47°	.72°
		190-C.O.	.44	.74	.594	.47°	1.07°
	R	0-C.O.	.25	.20	1.25	.56°	2.24°
S-IVB	P, Y	First Burn	.81	.97	.835	1.12°	1.38°

S/C BACKUP GUIDANCE SYSTEM IMPLEMENTATION PARAMETERS

I. Table II (CONT)

Where $\dot{\phi}$ and $\Delta\psi_m$ are defined by the following relations:

$$\beta = a_0 \psi + a_1 \dot{\phi}$$

β = engine deflection

ψ = attitude error

$\dot{\phi}$ = vehicle attitude rate

a_0, a_1 = gains

If $\beta = 0$ and $\psi = 1°$, $\dot{\phi} = a_0/a_1$.

The error required to null the vehicle rates due to thrust misalignment is similarly done.

$$\beta_m = a_0 \Delta\psi_m + a_1 \dot{\phi}$$

But $\dot{\phi} = 0$; therefore, $\Delta\psi_m = \beta_m/a_0$.

J. S/C backup guidance CMC flow diagram for the Automatic Mode is presented in Figure 2 on pages 11 through 17.

K. S/C backup guidance CMC flow diagram for the Manual Mode is presented in Figure 3 on pages 18 and 19.

L. Schematic diagrams, spacecraft oriented (Figure 4) and Launch Vehicle oriented (Figure 5) show the interface functions related to S/C backup guidance.

M. IMU Alignment Errors:

Refer to Classified NASA Document

MIE No. 2015000 Part I
Airborne Guidance and Navigation Equipment
Block II for Apollo Command Module
Spec. No. PS 2015000

It contains:

(1) Stable member alignment uncertainties.

(2) Gyro drift.

(3) Accelerometer uncertainties.

TABLE I

CMC ATTITUDE ERROR OUTPUT CYCLE TIME HISTORY

FROM MIT/IL SIMULATION

	SECONDS FROM LIFTOFF		SECONDS FROM LIFTOFF		SECONDS FROM LIFTOFF		SECONDS FROM LIFTOFF
1	.991	25	9.708	49	22.988	73	36.617
2	1.328	26	10.049	50	23.511	74	37.118
3	1.668	27	10.436	51	24.029	75	37.628
4	2.005	28	10.948	52	24.623	76	38.425
5	2.444	29	11.469	53	25.139	77	38.927
6	2.779	30	11.990	54	25.660	78	39.430
7	3.119	31	12.625	55	26.465	79	39.938
8	3.456	32	13.139	56	26.978	80	40.413
9	3.786	33	13.660	57	27.498	81	40.919
10	4.395	34	14.460	58	28.018	82	41.432
11	4.727	35	14.978	59	28.627	83	41.940
12	5.059	36	15.498	60	29.141	84	42.617
13	5.396	37	16.018	61	29.649	85	43.123
14	5.726	38	16.623	62	30.447	86	43.631
15	6.057	39	17.141	63	30.956	87	44.427
16	6.435	40	17.659	64	31.458	88	44.939
17	6.767	41	18.464	65	31.967	89	45.452
18	7.099	42	18.976	66	32.614	90	45.961
19	7.437	43	19.489	67	33.119	91	46.617
20	7.766	44	20.010	68	33.629	92	47.123
21	8.374	45	20.629	69	34.422	93	47.631
22	8.706	46	21.151	70	34.927	94	48.423
23	9.036	47	21.670	71	35.429	95	48.931
24	9.368	48	22.475	72	35.938	96	49.444

	SECONDS FROM LIFTOFF		SECONDS FROM LIFTOFF		SECONDS FROM LIFTOFF		SECONDS FROM LIFTOFF
97	49.951	123	64.939	149	79.643	175	94.622
98	50.622	124	65.451	150	80.437	176	95.136
99	51.131	125	65.961	151	80.950	177	95.645
100	51.642	126	66.623	152	81.464	178	96.443
101	52.434	127	67.132	153	81.972	179	96.952
102	52.939	128	67.643	154	82.620	180	97.465
103	53.450	129	68.437	155	83.134	181	97.973
104	53.961	130	68.941	156	83.643	182	98.625
105	54.623	131	69.453	157	84.439	183	99.134
106	55.132	132	69.962	158	84.951	184	99.645
107	55.643	133	70.622	159	85.463	185	100.438
108	56.437	134	71.134	160	85.972	186	100.952
109	56.939	135	71.643	161	86.624	187	101.464
110	57.452	136	72.441	162	87.132	188	101.941
111	57.962	137	72.950	163	87.643	189	102.628
112	58.616	138	73.463	164	88.436	190	103.146
113	59.123	139	73.972	165	88.941	191	103.656
114	59.631	140	74.622	166	89.452	192	104.452
115	60.424	141	75.132	167	89.962	193	104.963
116	60.931	142	75.643	168	90.624	194	105.474
117	61.444	143	76.436	169	91.133	195	105.984
118	61.951	144	76.941	170	91.644	196	106.624
119	62.622	145	77.451	171	92.439	197	107.136
120	63.132	146	77.962	172	92.952	198	107.645
121	63.642	147	78.624	173	93.466	199	108.444
122	64.435	148	79.133	174	93.973	200	108.953
						201	109.465

	SECONDS FROM LIFTOFF		SECONDS FROM LIFTOFF		SECONDS FROM LIFTOFF		SECONDS FROM LIFTOFF
202	109.974	228	124.952	254	139.656	280	151.779
203	110.626	229	125.464	255	140.452	281	152.406
204	111.134	230	125.974	256	140.963	282	152.750
205	111.645	231	126.626	257	141.474	283	153.094
206	112.439	232	127.135	258	141.985	284	153.430
207	112.952	233	127.645	259	142.626	285	153.770
208	113.465	234	128.439	260	143.136	286	154.395
209	113.975	235	128.952	261	143.645	287	154.730
210	114.626	236	129.466	262	144.444	288	155.073
211	115.135	237	129.974	263	144.953	289	155.414
212	115.646	238	130.624	264	145.466	290	155.750
213	116.441	239	131.136	265	145.974	291	156.373
214	116.952	240	131.645	266	146.627	292	156.710
215	117.466	241	132.444	267	146.958	293	157.052
216	117.974	242	132.952	268	147.299	294	157.389
217	118.625	243	133.465	269	147.642	295	157.730
218	119.136	244	133.974	270	147.979	296	158.345
219	119.645	245	134.625	271	148.443	297	158.679
220	120.444	246	135.135	272	148.779	298	159.018
221	120.953	247	135.645	273	149.122	299	159.359
222	121.465	248	136.438	274	149.459	300	159.700
223	121.974	249	136.952	275	149.800	301	160.037
224	122.626	250	137.464	276	150.423	302	160.407
225	123.135	251	137.975	277	150.760		
226	123.645	252	138.627	278	151.104		
227	124.438	253	139.146	279	151.442		

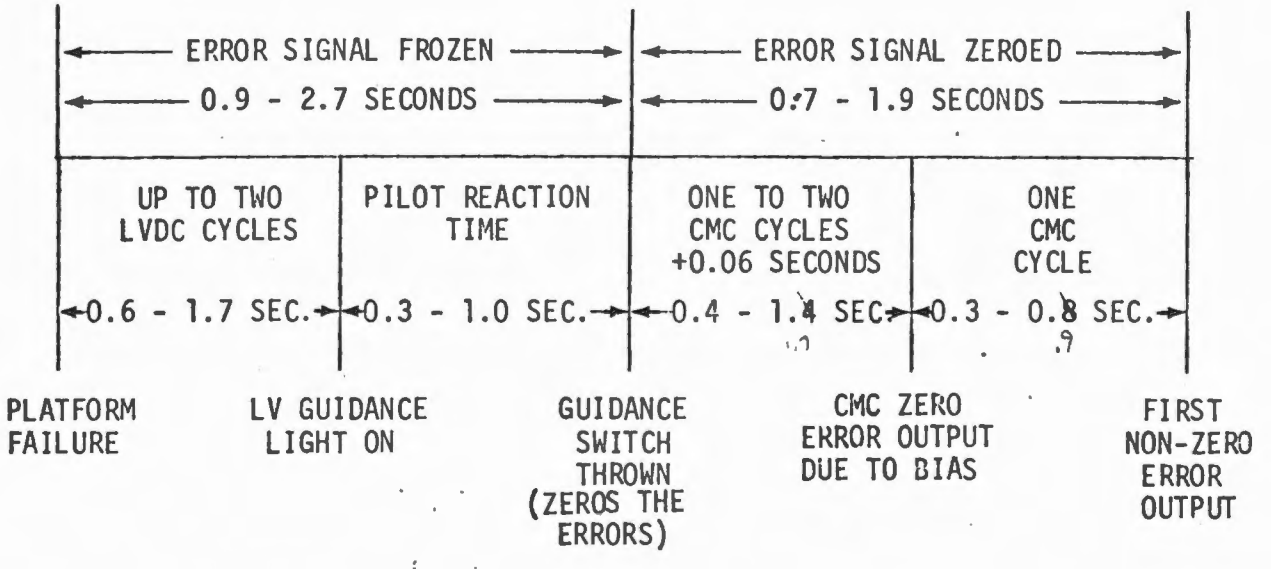


FIGURE 1 - AUTOMATIC GUIDANCE MODE - SWITCHOVER TIMING

FIGURE 2

S/C BACKUP GUIDANCE SYSTEM FLOW DIAGRAM FOR THE AUTOMATIC MODE

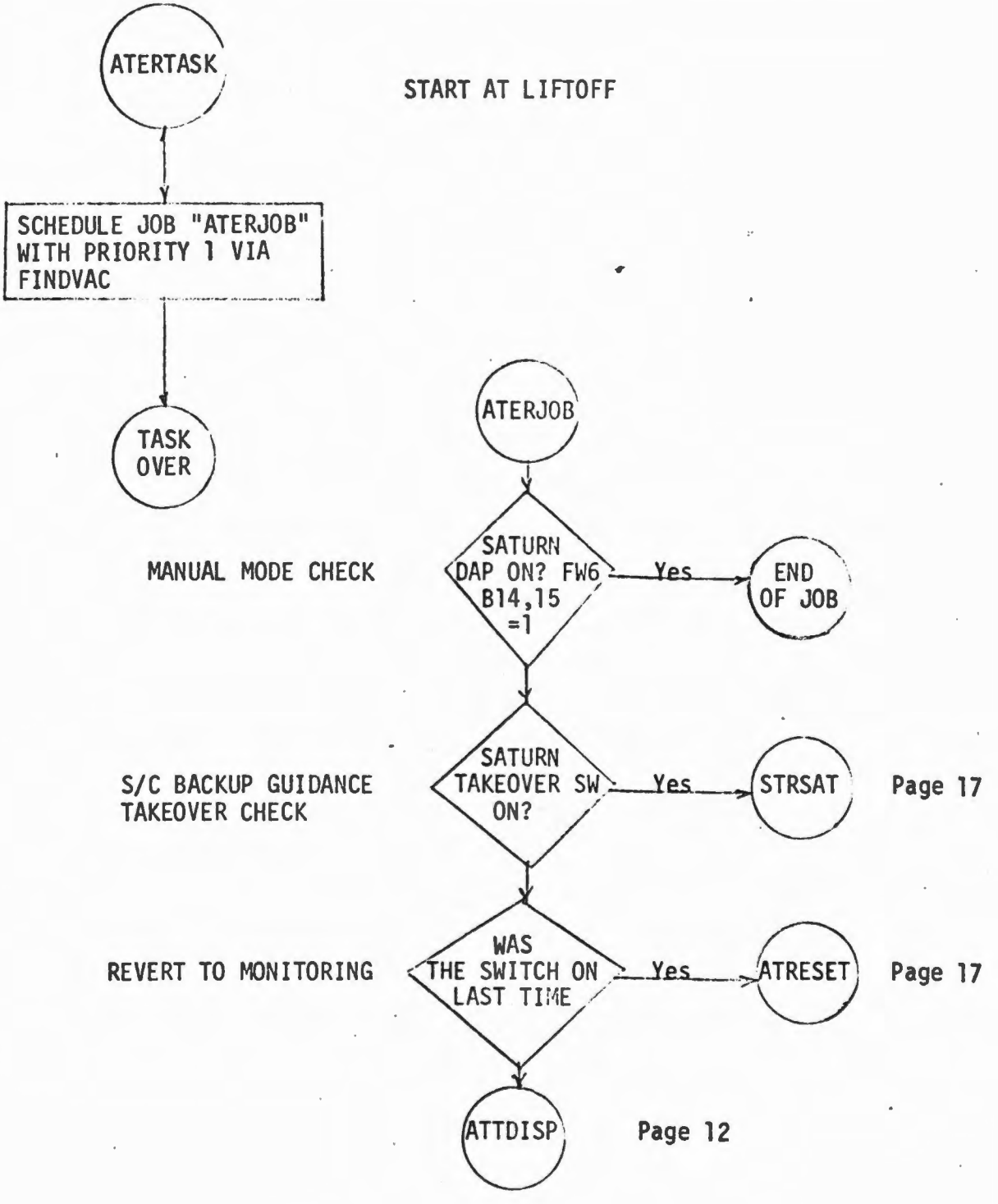


FIGURE 2 (CONT)

S/C BACKUP GUIDANCE SYSTEM FLOW DIAGRAM FOR THE AUTOMATIC MODE (CONT)

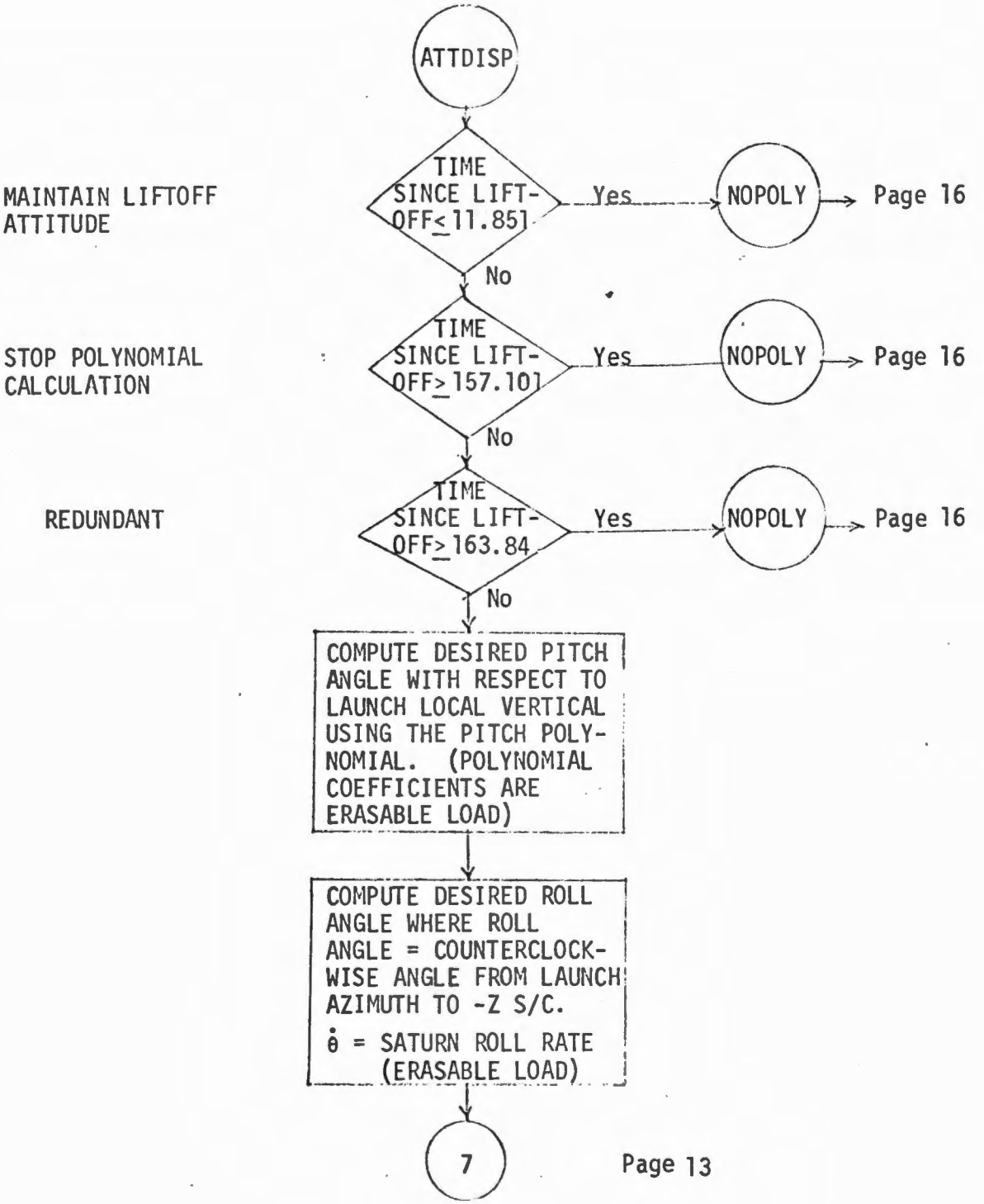
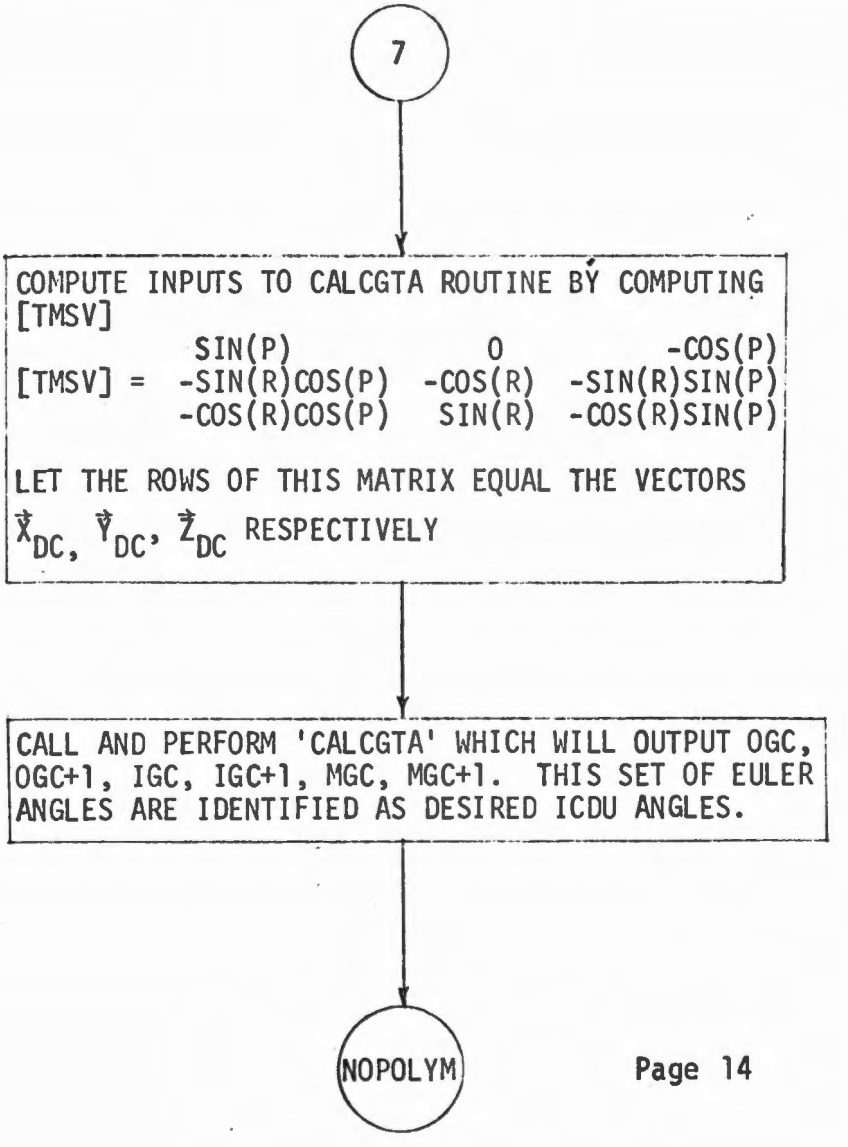


FIGURE 2 (CONT)

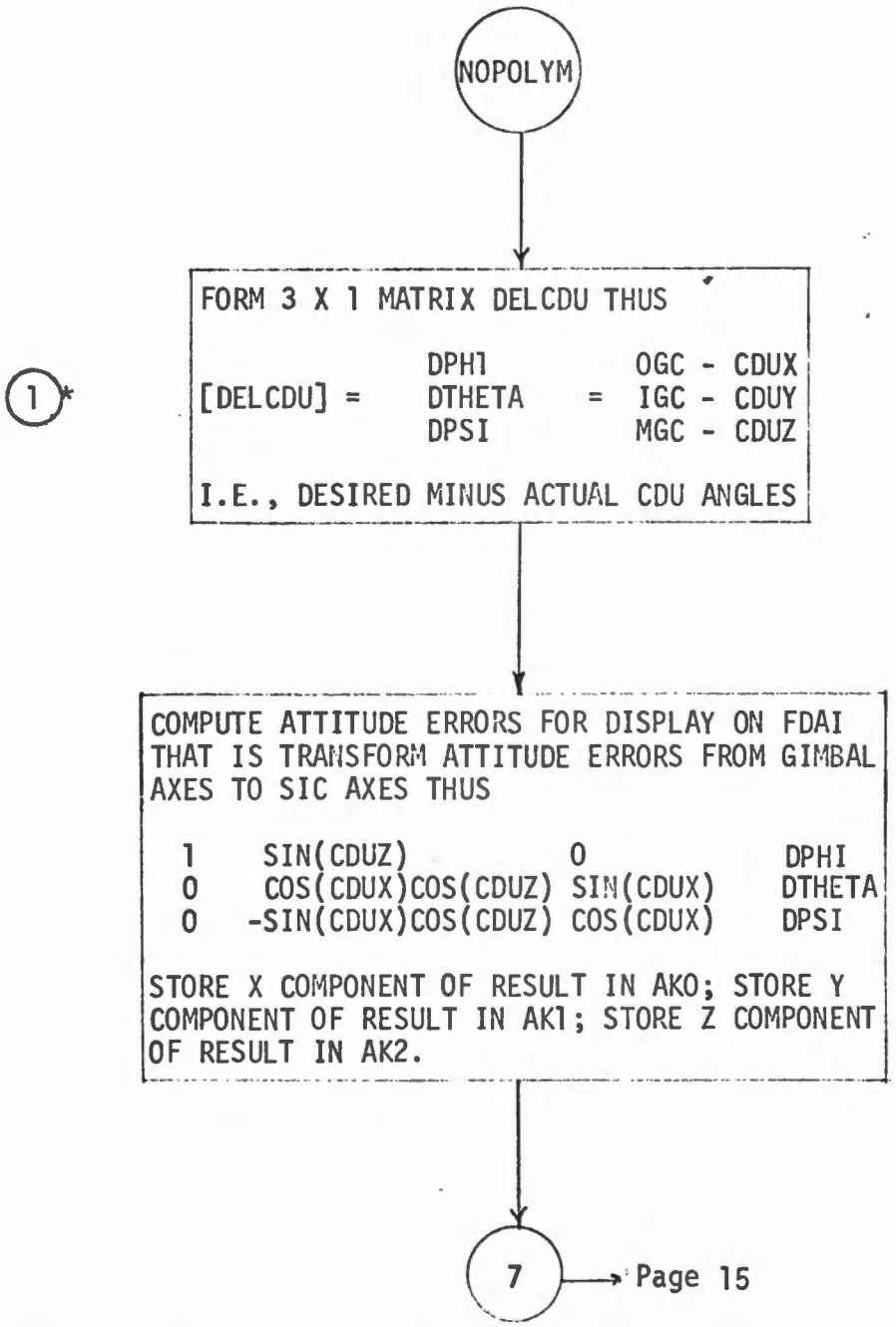
S/C BACKUP GUIDANCE SYSTEM FLOW DIAGRAM FOR THE AUTOMATIC MODE (CONT)



Page 14

FIGURE 2 (CONT)

S/C BACKUP GUIDANCE SYSTEM FLOW DIAGRAM FOR THE AUTOMATIC MODE (CONT)



* Transport delay of 0.08 seconds is defined between the computation of the attitude error, ①, and the output of the attitude errors to the ICDU, ② (see page 16 for location of ②).

FIGURE 2 (CONT)

S/C BACKUP GUIDANCE SYSTEM FLOW DIAGRAM FOR THE AUTOMATIC MODE (CONT)

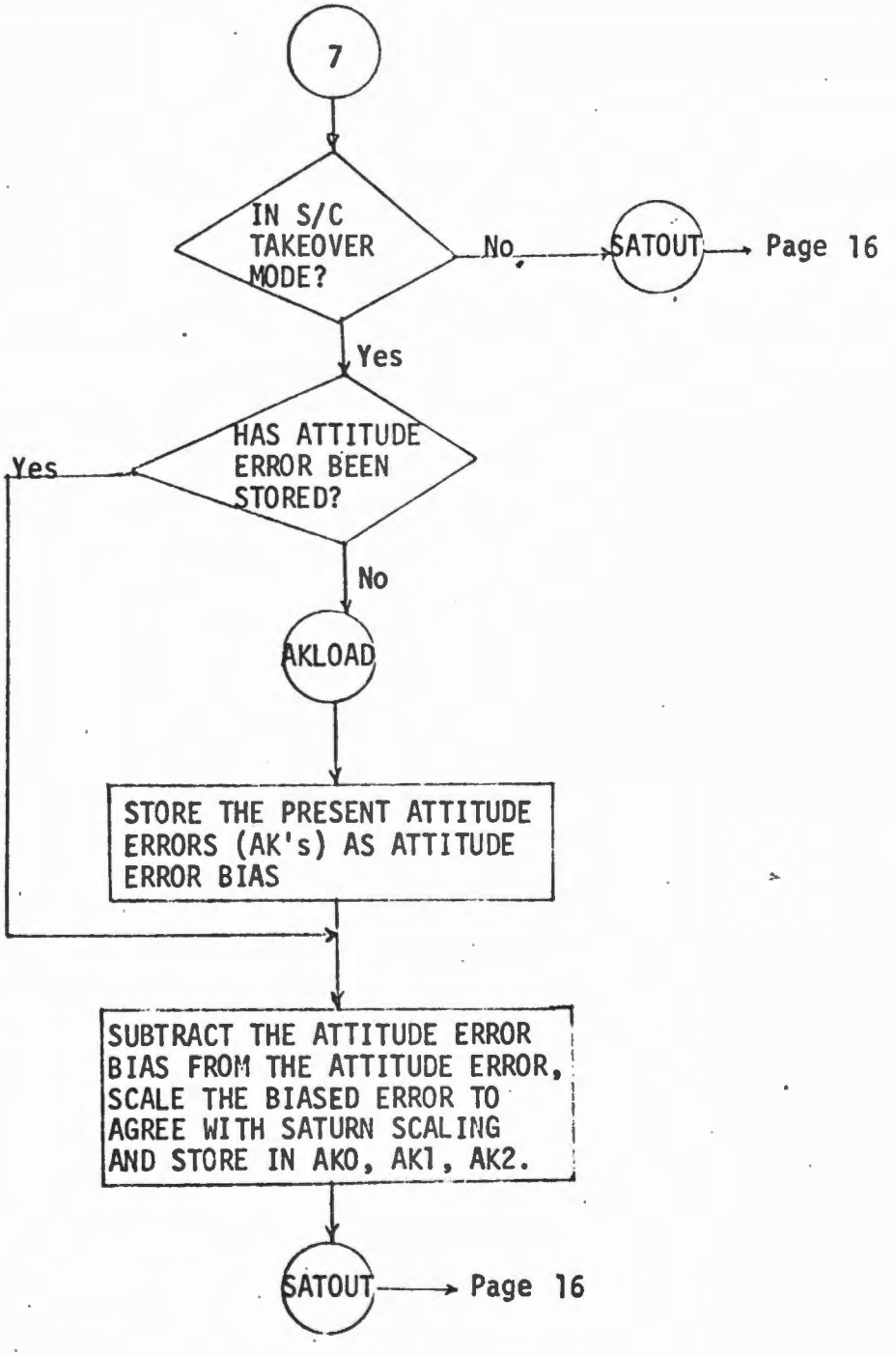


FIGURE 2 (CONT)

S/C BACKUP GUIDANCE SYSTEM FLOW DIAGRAM FOR THE AUTOMATIC MODE (CONT)

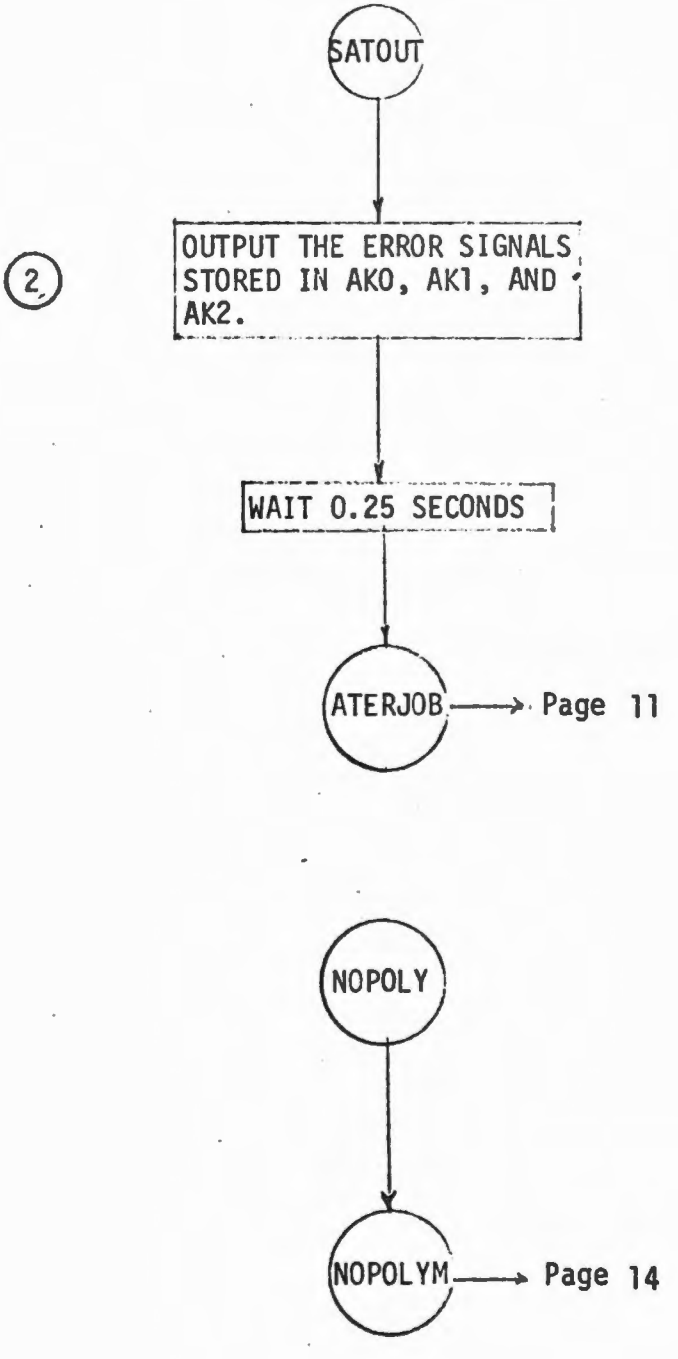


FIGURE 2 (CONT)

S/C BACKUP GUIDANCE SYSTEM FLOW DIAGRAM FOR THE AUTOMATIC MODE (CONT)

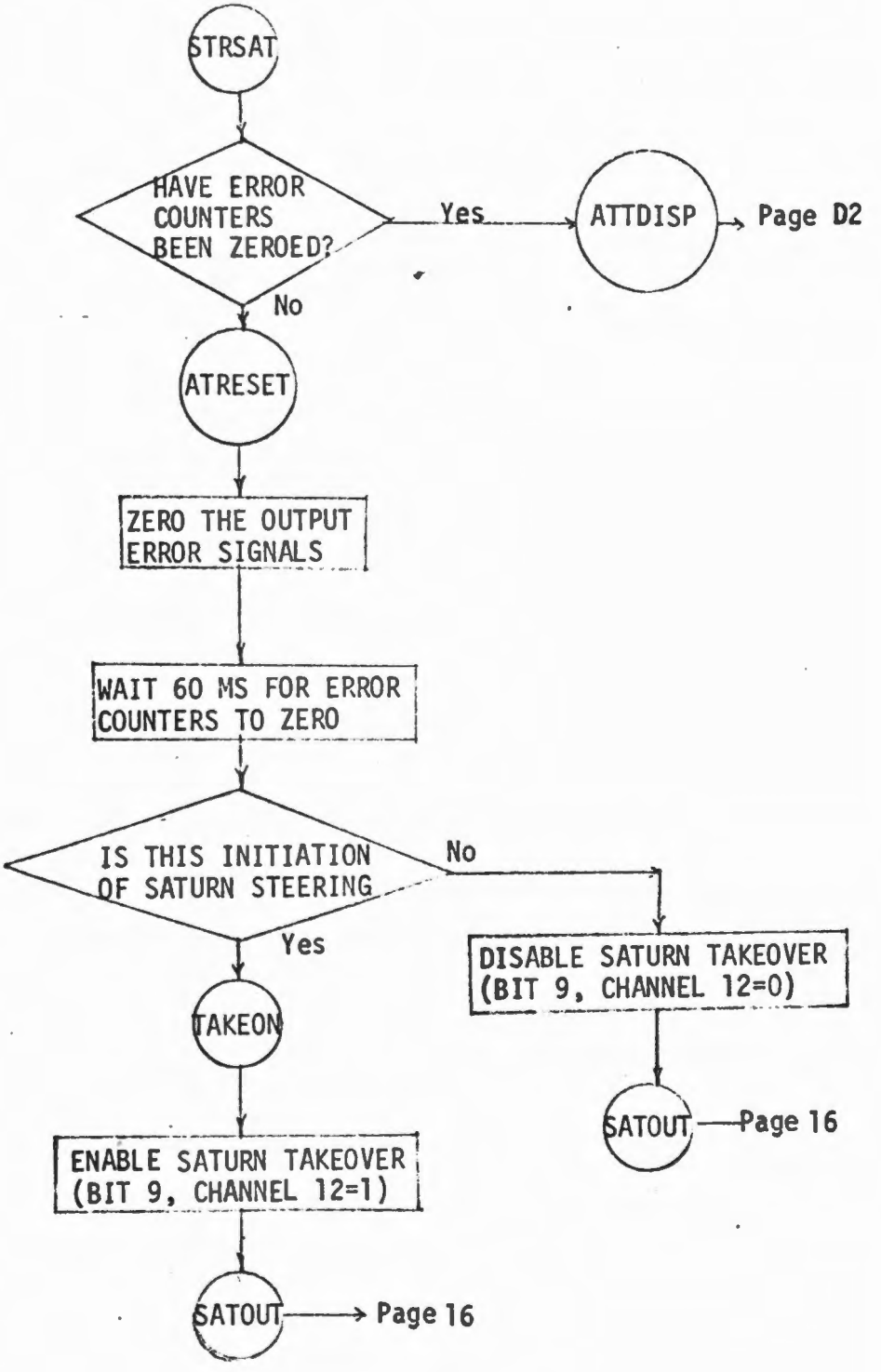


FIGURE 3

S/C BACKUP GUIDANCE SYSTEM FLOW DIAGRAM FOR THE MANUAL MODE

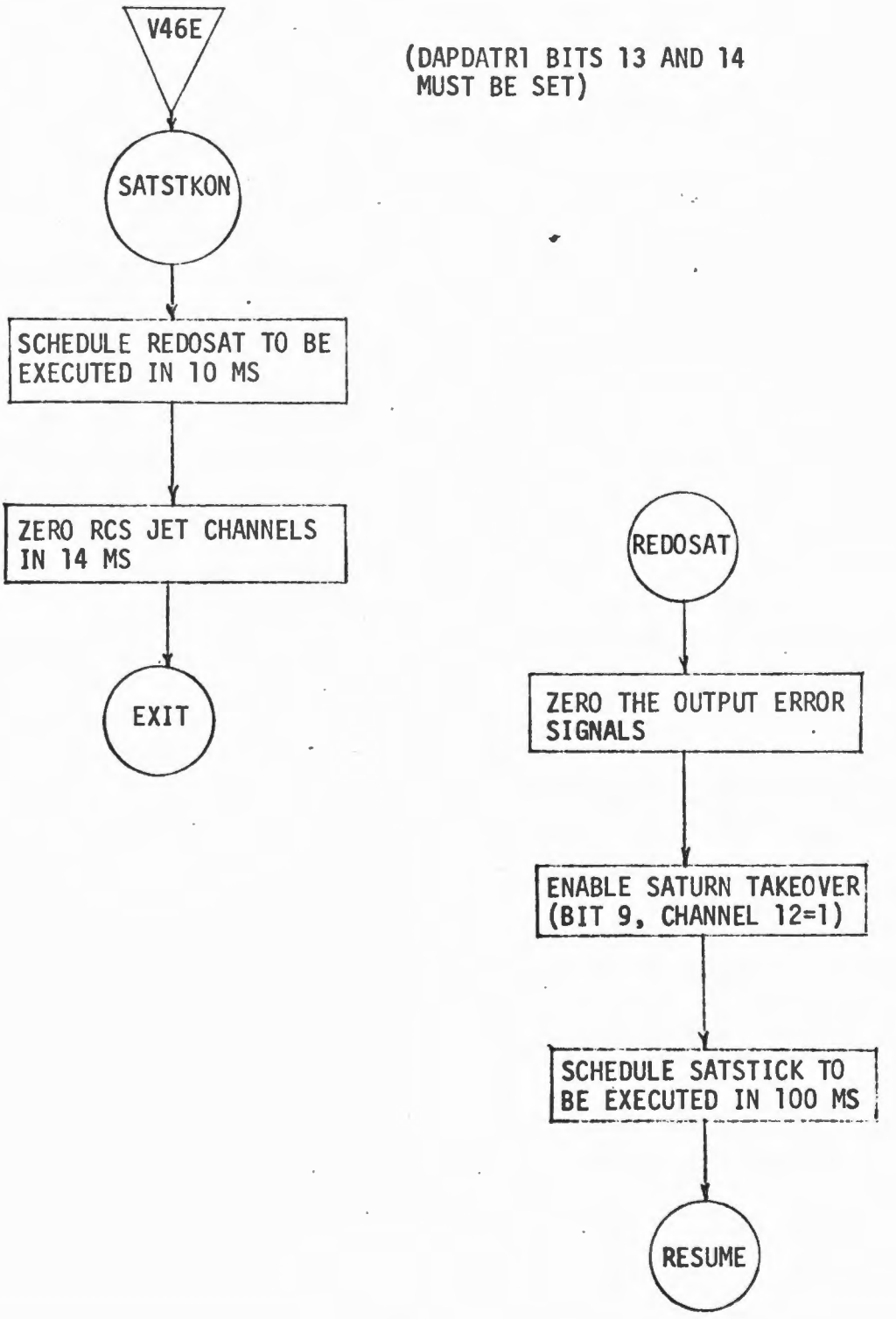
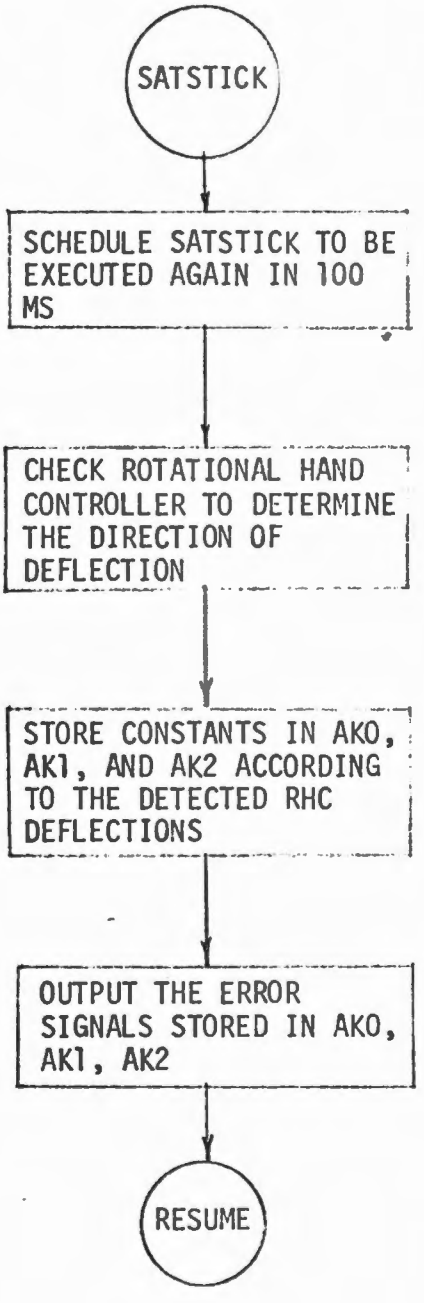
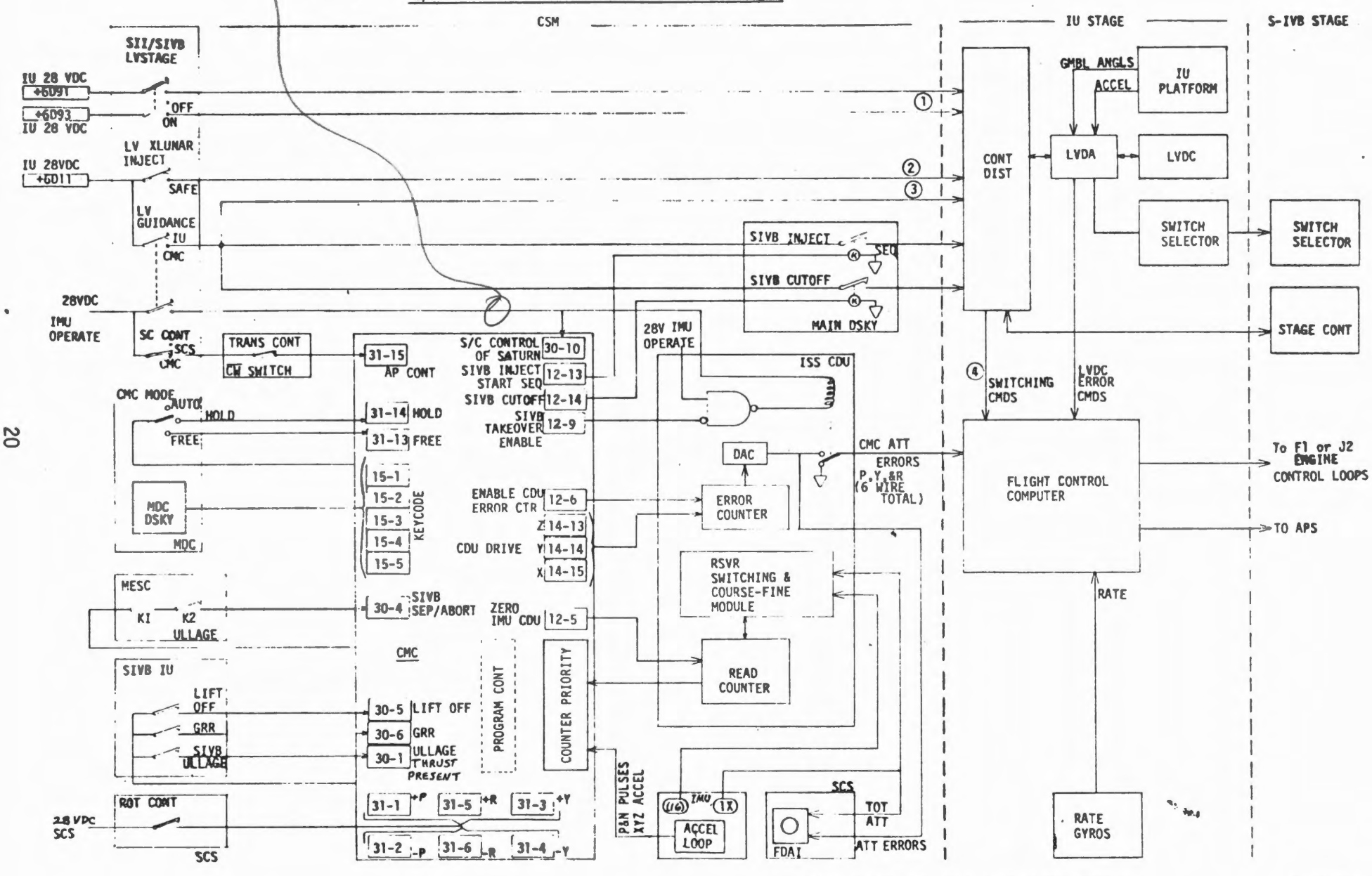


FIGURE 3 (CONT)

S/C BACKUP GUIDANCE SYSTEM FLOW DIAGRAM FOR THE MANUAL MODE (CONT)





SEE PAGE 21 FOR CIRCLED NOTES

FIGURE 4

NOTES FOR FIGURE 4 INTERFACE SCHEMATIC (CM)

(1)

(a) The SII/SIVB LV Stage Switch will be enabled from T3 +1.4 seconds on for up staging - for early stage it initiates T4a.

(b) During T4, T4a or T6 the signal will initiate SIVB cutoff if it has been off 5 seconds prior to activation.

(2)

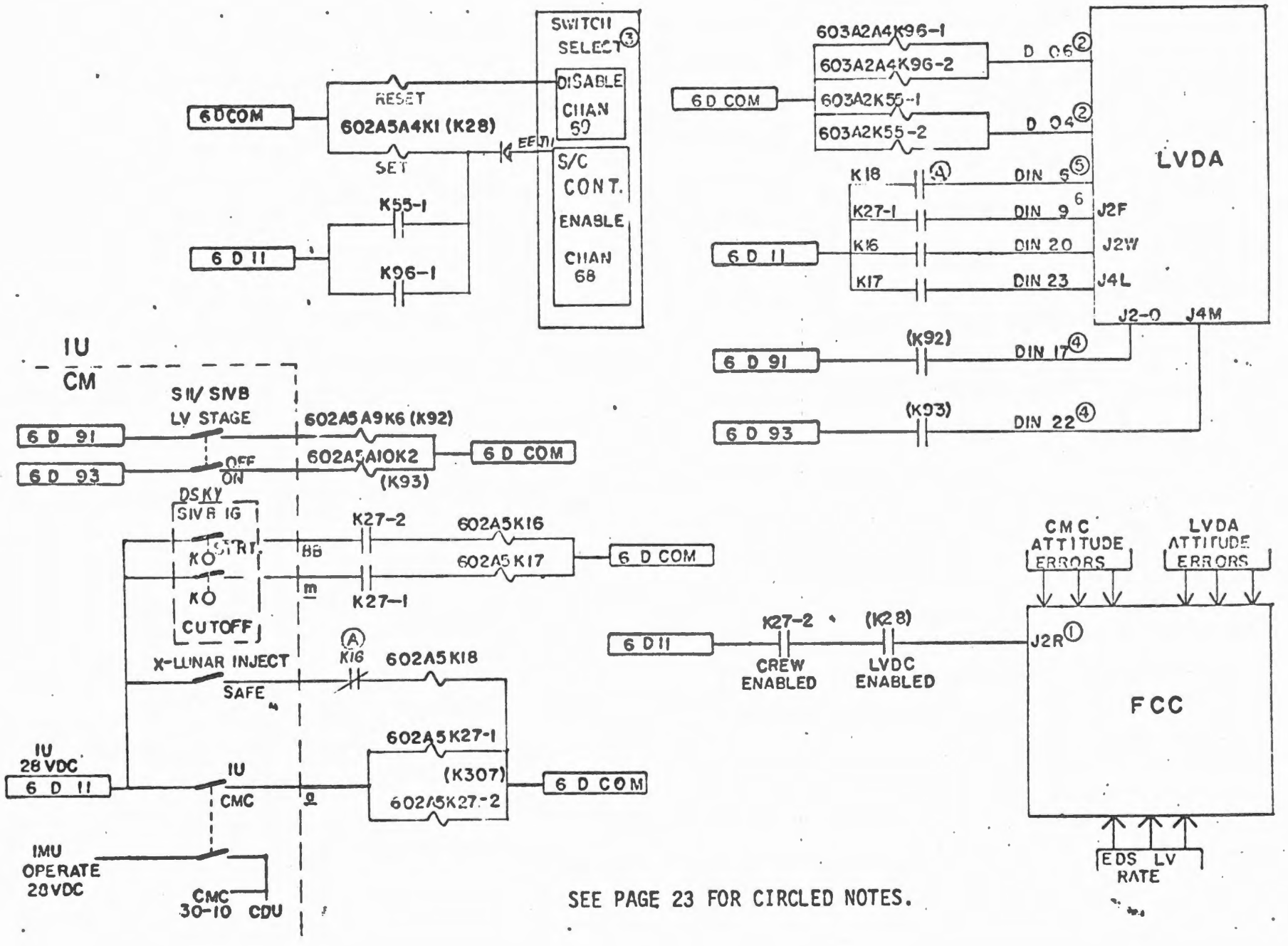
(a) Inhibits IU start of T6 only for the TLI injection sequence.

(b) CMC can initiate injection start sequence for the SIVB with LV X Lunar Injection Switch in SAFE position (unless blocked in LVDC).

(3) LV Guidance by CMC will be recognized in conjunction with a IU guidance fail light for all time basis except T5; T5 is initiated by orbit insertion and terminated at start of T6 which is TLI injection sequence start.

(4) The Control Distributor must initiate the switching command to the Flight Control Computer to permit the CMC Attitude Errors to be used for control.

FIGURE 5 - S/C BACKUP GUIDANCE SYSTEM INTERFACE SCHEMATIC (IU)



SEE PAGE 23 FOR CIRCLED NOTES.

NOTES FOR FIGURE 5 - INTERFACE SCHEMATIC (IU)

1. 28 volts on J2R of FCC will switch error signals used from LVDA errors to CMC generated errors.

2. DO4 and DO6 are set internally by the Flight Program. There are two ways these discretes can be set.

   (a) Total counter failure of the duplexed COD Counters.

   (b) Gimbal angle reasonableness test failures of both fine and backup gimbal angle readings.

3. Switch selector permits enabling S/C control if T5 is in progress (parking orbit).

4. LVDA will not accept DIN 17 or 22 until T3 +1.4 seconds. LVDA requires absence of DIN 17 and 22 for 5 seconds before either will terminate S-IVB thrusting.

5. DIN 6 is a signal from the S/C to enhibit S-IVB restart. This discrete is checked just prior to the start of T6, at T6 +85 seconds and once per computation cycle from T6 to 379.6 seconds until T6 + 440 seconds.

   (a) If the discrete is on prior to T6 start, the initiation of T6 is inhibited and T5 continues. The program logic is set up for a second restart opportunity. If the second restart is inhibited by DIN 6, no further restart attempts will be made without a target update.

   (b) If discrete is on at T6 + 85 seconds, T6c is executed after T6c is completed, T5 is resumed. The program logic is again set up for the next opportunity. All the T6 switch selectors will be issued during the next execution of T6.

   (c) The discrete is checked once per computation cycle during the interval from T6 + 379.6 until T6 + 440 seconds. If it appears during this interval, T6c, followed by T5, will be executed. The program logic is set up for next opportunity. The O_2H_2 burner switch selector, as well as T6a and T6b will be inhibited during the next execution of T6.

6. DIN 9 zeroes LVDA error output.