

APOLLO GUIDANCE COMPUTER
BLOCK II - CMC DATA CARDS

Table of contents:

Table 1	Basic Instructions	Page 2
Table 2	Verb Codes	Page 4
Table 3	Noun Codes	Page 8
Table 4	Noun Storage Register Names	Page 15
Table 5	Check List Codes	Page 20
Table 6	Option Codes	Page 21
Table 7	Alarm Codes	Page 22
Table 8	Computer Programs	Page 25
Table 9	Computer Routines	Page 27
Table 10	Star / Planet List	Page 29
Table 11	Autopilot Configuration Data	Page 31
Table 12	CMC Programs Description (Colossus)	Page 32

DRAFT EDITION

Not to be used for operational purposes

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Table 1

BLOCK II - BASIC INSTRUCTIONS

<u>Instruction</u>	<u>Order_Code</u>	<u>Description</u>
AD K	06.	Add K
ADS E	02.6	Add to storage E
AUG E	12.4	Augment E
BZF F	11.2 11.4 11.6	Branch on zero to fixed F
BZMF F	16.2 16.4 16.6	Branch on zero or minus to fixed F
CA K	03.	Clear and add K
CAE E	03.	Clear and add E
CAF F	03.	Clear and add F
CCS E	01.0	Count, compare and skip on E
COM	04.0000	Complement A
CS K	04.	Clear and subtract K
CYL	.0022	Cycle left
CYR	.0020	Cycle right
DAS E	02.0	Double add to storage E
DCA K	13.	Double clear and add K
DCS K	14.	Double clear and subtract K
DCOM	14.0000	DP complement
DDOUBL	02.0000	DP double
DIM E	12.6	Diminish E
DOUBLE	06.0000	Double A
DTCB	05.2005	DP transfer control both banks
DV E	11.0	Divide by E
DXCH E	05.2	Double exchange A and E
EDOP	.0023	Edit operator
EXTEND	0.0006	Extend
INCR E	02.4	Increment E
INDEX E	05.0	Index next basic instruction with E
INHINT	00.0004	Inhibit interrupt
LXCH E	02.2	Exchange L and E
MASK K	07.	Mask with K

BLOCK II - BASIC INSTRUCTIONS

MP K	17.	Multiply K
MSK K	07.	Mask K
MSU E	12.0	Modular subtract E
NDX E	05.0	Index E
NDX K	15.	Index K
NOOP	03.0000	No operation (E)
NOOP	TCF I+1	No operation (F)
OVSF	05.4000	Overflow skip; TS A
QXCH E	12.2	Exchange Q and E
RAND H	10.2	Read and AND H
READ H	10.0	Read H
RELINT	00.0003	Release inhibit interrupt
RESUME	05.0017	Resume interrupted program
RETURN	00.00002	Return; TCQ
ROR H	10.4	Read and OR H
RXOR H	10.6	Read and Exclusive-OR H
SR	.0021	Shift right
SU E	16.0	Subtract E
TCAA	05.4005	Transfer control to address in A; TS Z
TC K	00.	Transfer control to K
TCF F	01.2 01.4 01.6	Transfer control to fixed F
TCR K	00.	TC K
TS E	05.4	Transfer control to storage E
WAND H	10.3	Write and AND H
WOR H	10.5	Write and OR H
WRITE H	10.1	Write H
XCH E	05.6	Exchange A and E
ZL	02.2007	Zero L; LXCH zero
ZQ	12.2007	Zero Q; QXCH zero

Table 2

BLOCK II - VERB CODESREGULAR VERBS

<u>Code</u>	<u>Description</u>
00	Not in use
01	Display Octal component 1 in R1
02	Display Octal component 2 in R1
03	Display Octal component 3 in R1
04	Display Octal components 1,2 in R1,R2
05	Display Octal components 1,2,3 in R1,R2,R3
06	Display Decimal in R1 or in R1,R2 or in R1,R2,R3
07	Display Double Precision Decimal in R1,R2 (test only)
08	
09	
10	
11	Monitor Octal component 1 in R1
12	Monitor Octal component 2 in R1
13	Monitor Octal component 3 in R1
14	Monitor Octal component 1,2 in R1,R2
15	Monitor Octal component 1,2,3 in R1,R2,R3
16	Monitor Decimal in R1 or R1,R2 or R1,R2,R3
17	Monitor Double Precision Decimal in R1,R2 (test only)
18	
19	
20	
21	Load component 1 into R1
22	Load component 2 into R2
23	Load component 3 into R3
24	Load component 1,2 into R1,R2
25	Load component 1,2,3 into R1,R2,R3
26	
27	Display fixed memory
28	
29	

BLOCK II - VERB CODES

30 Request executive
 31 Request waitlist
 32 Recycle program
 33 Proceed without DSKY inputs
 34 Terminate function
 35 Test lights
 36 Request fresh start
 37 Change program (Major Mode)
 38
 39

EXTENDED VERBS

Code	Description
40	Zero CDU's
41	Coarse align CDU's
42	Fine align IMU
43	Load IMU attitude error meters
44	Set surface flag
45	Reset surface flag
46	Establish G&C control
47	Move LM state vector into CM state vector
48	Request DAP data load (R03)
49	Request crew defined maneuver (R62)
50	Please perform
51	Please mark
52	Mark on offset landing site
53	Please perform alternate LOS mark
54	Request rendezvous backup sighting mark routine (R23)
55	Increment AGC time (decimal)
56	Terminate tracking (P20)
57	Display update state of FULTKFLG
58	Enable auto maneuver in P20
59	Please calibrate

BLOCK II - VERB CODES

60 Set astronaut total attitude (N17) to present attitude
61 Display DAP attitude error
62 Display total attitude error WRT N22
63 Display total astronaut attitude error WRT N17
64 Request S-Band antenna routine
65 Optical verification of prelaunch alignment
66 Vehicles attached, move this vehicle state vector to
other vehicle state vector
67 Display W Matrix
68
69 Cause restart

70 Update liftoff time
71 Universal update - block address
72 Universal update - single address
73 Update AGC time (octal)
74 Initialize erasable dump via downlink
75 Backup liftoff
76
77
78 Update prelaunch azimuth
79

80 Update LM state vector
81 Update CSM state vector
82 Request orbital paramters display (R30)
83 Request rendezvous paramter display (R31)
84
85 Request rendezvous paramter display no. 2 (R34)
86 Reject rendezvous backup sighting mark
87 Set VHF range flag
88 Reset VHF range flag
89 Request rendezvous final attitude (R63)

90 Request rendezvous out of plane display (R36)
91 Display bank sum

BLOCK II - VERB CODES

92	Operate IMU performance test (P07)
93	Enable W Matrix initialization
94	Perform cislunar attitude maneuver (P23)
95	
96	Terminate integration and go to P00
97	Perform engine fail procedure
98	
99	Please enable engine

Table 3

BLOCK II - NOUN CODESNORMAL NOUNS

Code	Comp	Scaling	Description
00			
01	3	.XXXXXX .XXXXXX .XXXXXX	Specify machine address (fractional)
02	3	XXXXXX. XXXXXX. XXXXXX.	Specify machine address (whole)
03	3	XXX.XX XXX.XX XXX.XX	Specify machine address (degrees)
04			
05	1	XXX.XX deg	Angular error/difference
06	2	Octal only Octal only	Option code
07	3	Octal only Octal only Octal only	ECADR of word to be modified Ones for bits to be modified 1 to set or 0 to reset selected bits (Loading Noun 07 will set or reset selected bits in any erasable location)
08	3	Octal only Octal only Octal only	Alarm data
09	3	Octal only Octal only Octal only	Alarm codes
10	1	Octal only	Channel to be specified
11	3	00XXX. hrs 000XX. min 0XX.XX sec	TIG of CSI
12	2	Octal only	Option code (used by extended verbs only)
13	3	00XXX. hrs 000XX. min 0XX.XX sec	TIG of CDH
14	1	XXXXXX. ft/sec	Inertial velocity magnitude at TLI cutoff

BLOCK II - NOUN CODES

15	1	Octal only	Increment machine address
16	3	00XXX. hrs 000XX. min 0XX.XX sec	Time of event (used by extended verbs only)
17	3	XXX.XX deg XXX.XX deg XXX.XX deg	Astronaut total attitude
18	3	XXX.XX deg XXX.XX deg XXX.XX deg	Auto maneuver ball angles
19			
20	3	XXX.XX deg XXX.XX deg XXX.XX deg	ICDU angles
21	3	XXXXX. pulses XXXXX. pulses XXXXX. pulses	PIPAs
22	3	XXX.XX deg XXX.XX deg XXX.XX deg	New ICDU angles
23			
24	3	00XXX. hrs 000XX. min 0XX.XX sec	Delta time for AGC clock
25	3	XXXXX. XXXXX. XXXXX.	Checklist (used with please perform only)
26	3	Octal only Octal only Octal only	Priority/dealy, ADRES, BBCON
27	1	XXXXX.	Self test on/off switch
28			
29	1	XXX.XX deg	XSM launch azimuth
30	3	XXXXX. XXXXX. XXXXX.	Target codes
31	3	00XXX. hrs 000XX. min 0XX.XX sec	Time of W initialization
32	3	00XXX. hrs 000XX. min 0XX.XX sec	Time from perigee

BLOCK II - NOUN CODES

33	3	00XXX. hrs 000XX. min 0XX.XX sec	Time of ignition
34	3	000XX. hrs 000XX. min 0XX.XX sec	Time of event
35	3	00XXX. hrs 000XX. min 0XX.XX sec	Time from event
36	3	00XXX. hrs 000XX. min 0XX.XX sec	Time of AGC clock
37	3	00XXX. hrs 000XX. min 0XX.XX sec	TIG of TPI
38	3	00XXX. hrs 000XX. min 0XX.XX sec	Time of state vector
39	3	00XXX. hrs 000XX. min 0XX.XX sec	Delta time for transfer

MIXED NOUNS

Code	Comp.	Scaling	Description
40	3	XXbXX min/sec XXXX.X ft/sec XXXX.X ft/sec	Time from ignition/cutoff VG Delta V (accumulated)
41	2	XXX.XX deg XX.XXX deg	Target azimuth Target elevation
42	3	XXXX.X nm XXXX.X nm XXXX.X ft/sec	Apogee Perigee Delta V (required)
43	3	XXX.XX deg XXX.XX deg XXXX.X nm	Latitude Longitude Altitude
44	3	XXXX.X nm XXXX.X nm XXbXX min/sec	Apogee Perigee TFF
45	3	+XXbXX XXbXX min/sec XXX.XX deg	Marks (VHF - Optics) TFI of next burn MGA

BLOCK II - NOUN CODES

46	2	Octal only Octal only	Autopilot configuration
47	2	XXXXX. lbs XXXXX. lbs	This vehicle weight Other vehicle weight
48	2	XXX.XX deg XXX.XX deg	Pitch trim Yaw trim
49	3	XXXX.X nm XXXX.X ft/sec XXXXX.	Delta R Delta V VHF or Optics code
50	3	XXXX.X nm XXXX.X nm XXbXX min/sec	Splash error Perigee TFF
51	2	XXX.XX deg XXX.XX deg	S-Band antenna angle pitch S-Band antenna angle yaw
52	1	XXX.XX deg	Central angle of active vehicle
53	3	XXX.XX nm XXXX.X ft/sec XXX.XX deg	Range Range rate Phi
54	3	XXX.XX nm XXXX.X ft/sec XXX.XX deg	Range Range rate Theta
55	3	XXXXX. XXX.XX deg XXX.XX deg	Perigee code Elevation angle Central angle of passive vehicle
56	2	XXX.XX deg XXXXX. ft/sec	Reentry angle Delta V
57			
58	3	XXXX.X nm XXXX.X ft/sec XXXX.X ft/sec	Perigee altitude (post TPI) Delta V TPI Delta V TPF
59	3	XXXX.X ft/sec XXXX.X ft/sec XXXX.X ft/sec	Delta velocity LOS
60	3	XXX.XX g XXXXX. ft/sec XXX.XX deg	G max V pred Gamma EI
61	3	XXX.XX deg XXX.XX deg +/-00001	Impact latitude Impact longitude Heads up/down
62	3	XXXXX. ft/sec XXXXX. ft/sec XXXX.X nm	Inertial velocity magnitude (VI) Altitude rate change (HDOT) Altitude above pad radius (H)

BLOCK II - NOUN CODES

63	3	XXXX.X nm	Range 297,431 to splash (RTGO)
		XXXXX. ft/sec	Predicted inertial velocity (VIO)
		XXbXX min/sec	Time from 297,431 (TFE)
64	3	XXX.XX g	Drag accelerator
		XXXXX. ft/sec	Inertial velocity (VI)
		XXXX.X nm	Range to splash
65	3	00XXX. hrs	Sampled AGC time (fetched in interrupt)
		000XX. min	
		0XX.XX sec	
66	3	XXX.XX deg	Command bank angle (BETA)
		XXXX.X nm	Cross range error
		XXXX.X nm	Down range error
67	3	XXXX.X nm	Range to target
		XXX.XX deg	Present latitude
		XXX.XX deg	Present longitude
68	3	XXX.XX deg	Command bank angle (BETA)
		XXXXX. ft/sec	Inertial velocity (VI)
		XXXXX. ft/sec	Altitude rate change (RDOT)
69	3	XXX.XX deg	BETA
		XXX.XX g	DL
		XXXXX. ft/sec	VL
70	3	Octal only	Star code
		Octal only	Landmark data
		Octal only	Horizon data
71	3	Octal only	Star code
		Octal only	Landmark data
		Octal only	Horizon data
72			
73	3	XXXXX. nm	Altitude
		XXXXX. ft/sec	Velocity
		XXX.XX deg	Flight path angle
74	3	XXXXX. deg	Command bank angle (BETA)
		XXXXX. ft/sec	Inertial velocity (VI)
		XXX.XX g	Drag acceleration
75	3	XXXX.X nm	Delta altitude CDH
		XXbXX min/sec	Delta time (CDH-CSI or TPI-CDH)
		XXbXX min/sec	Delta time (TPI-CDH or TPI-NOMTPI)
76			
77			
78	3	XXX.XX deg	Yaw angle for P20
		XXX.XX deg	Pitch angle for P20
		XXX.XX deg	Azimuth constraint for P20
79	2	X.XXXX deg/sec	P20 rotation rate
		XXX.XX deg	P20 rotation deadband

BLOCK II - NOUN CODES

80	3	XXbXX min/sec	Time from ignition/cutoff
		XXXXX. ft/sec	VG
		XXXXX. ft/sec	Delta V (accumulated)
81	3	XXXX.X ft/sec	Delta V (LV)
		XXXX.X ft/sec	
		XXXX.X ft/sec	
82	3	XXXX.X ft/sec	Delta V (LV)
		XXXX.X ft/sec	
		XXXX.X ft/sec	
83	3	XXXX.X ft/sec	Delta V (Body)
		XXXX.X ft/sec	
		XXXX.X ft/sec	
84	3	XXXX.X ft/sec	Delta V (Other vehicle)
		XXXX.X ft/sec	
		XXXX.X ft/sec	
85	3	XXXX.X ft/sec	VG (Body)
		XXXX.X ft/sec	
		XXXX.X ft/sec	
86	3	XXXXX. ft/sec	Delta V (LV)
		XXXXX. ft/sec	
		XXXXX. ft/sec	
87	2	XXX.XX deg	Mark data shaft
		XX.XXX deg	Mark data trunnion
88	3	.XXXXXX	Half unit Sun or Planet vector
		.XXXXXX	
		.XXXXXX	
89	3	XX.XXX deg	Landmark latitude
		XX.XXX deg	Longitude/2
		XXX.XX nm	Altitude
90	3	XXX.XX nm	Y active vehicle
		XXXX.X fps	Y Dot active vehicle
		XXXX.X fps	Y Dot passive vehicle
91	2	XXX.XX deg	OCDU angle shaft
		XX.XXX deg	OCDU angle trunnion
92	2	XXX.XX deg	New optics angle shaft
		XX.XXX deg	New optics angle trunnion
93	3	XX.XXX deg	Delta gyro angles
		XX.XXX deg	
		XX.XXX deg	
94	2	XXX.XX deg	New optics angle shaft
		XX.XXX deg	New optics angle trunnion
95	3	XXbXX min/sec	Time from ignition/cutoff
		XXXXX. ft/sec	VG
		XXXXX. ft/sec	Inertial velocity magnitude

BLOCK II - NOUN CODES

96	3	XXX.XX nm	Y CM
		XXXX.X ft/sec	Y Dot CM
		XXXX.X ft/sec	Y Dot LM
97	3	XXXXX.	System test inputs
		XXXXX.	
		XXXXX.	
98	3	XXXXX.	System test results and inputs
		.XXXXX	
		XXXXX.	
99	3	XXXXX. ft	RMS in position
		XXXX.X ft/sec	RMS in velocity
		XXXXX.	RMS option

Table 4

BLOCK II - NOUN STORAGE REGISTER NAMES

Code	Register(s)
00	
01	(Specify address)
02	(Specify address)
03	(Specify address)
04	
05	DSPTM1
06	OPTION1,+1
07	XREG YREG ZREG
08	ALMCADR,+1,+2
09	FAILREG,+1,+2
10	(Specify channel)
11	TCSI,+1
12	OPTIONX,+1
13	TCDH,+1
14	VC/O
15	(Increment address)
16	DSPTMX,+1
17	CPHIX,+1,+2
18	THETAD,+1,+2
19	
20	CDUX,Y,Z
21	PIPAX,Y,Z
22	THETAD,+1,+2
23	
24	DSPTM2,+1
25	DSPTM1,+1,+2
26	N26/PRI,+1,+2
27	SMODE
28	
29	DSPTM1

BLOCK II - NOUN STORAGE REGISTER NAMES

30 DSPTM1 ,+1 ,+2
31 AGEOFW ,+1
32 -TPER ,+1
33 TIG ,+1
34 DSPTM1 ,+1
35 TTOGO ,+1
36 TIME2 ,+1
37 TTP1 ,+1
38 TET ,+1
39 T3T0T4 ,+1

40 TTOGO
VGDISP
DVTOTAL
41 DSPTM1 ,+1
42 HAPO
HPER
VGDISP
43 LAT
LONG
ALT
44 HAPOX
HPERX
TFF
45 VHFCNT
TTOGO
+MGA
46 DAPDATR1
DAPDATR2
47 CSMMASS
LEMMASS
48 PACTOFF
YACTOFF
49 N49DISP ,+2 ,+4

50 RSP-RREC
HPERX
TFF
51 RHOSB
GAMMASB
52 ACTCENT

BLOCK II - NOUN STORAGE REGISTER NAMES

53	RANGE RRATE RTHETA (RPHI ?)
54	RANGE RRATE RTHETA
55	NNI ELEV CENTANG
56	RTEGAM2D RTEDVD
57	DELTAR
58	POSTTPI DELVTPI DELVTPIF
59	DVLOS , +2 , +4
60	GMAX VPRED GAMMAEI
61	LAT (SPL) LNG (SPL) HEADSUP
62	VMAGI HDOT ALT 1
63	RTGO VIO TTE
64	D VMAGI RTGON64
65	SAMPTIME , +1
66	ROLLC XRNGERR DNRNGERR
67	RTGON67 LAT LONG
68	ROLLC VMAGI RDOT
69	ROLLC Q7 VL

BLOCK II - NOUN STORAGE REGISTER NAMES

70	STARCODE LANDMARK HORIZON
71	STARCODE LANDMARK HORIZON
72	
73	P21ALT P21VEL P21GAM
74	ROLLC VMAGI D
75	DIFFALT T1TOT2 T2TOT3
76	
77	
78	UTAW UTPIT AZIMUTH
79	RATEPTC DBPTC
80	TTOGO VGDISP DVTOTAL
81	DELVLVC , +2 , +4
82	DELVLVC , +2 , +4
83	DELVIMU , +2 , +4
84	DELVOV , +2 , +4
85	VGBODY , +2 , +4
86	DELVLVC , +2 , +4
87	MRKBUFF1+3 , +5
88	STARSAV3 , +2 , +4
89	LANDLAT LANDLONG LANDALT
90	YCSM YDOTC YDOTL

BLOCK II - NOUN STORAGE REGISTER NAMES

91	CDUS CDUT
92	SAC PAC
93	OGC ,+2 ,+4
94	MRKBUFI+3 ,+5
95	TTOGO VGTLI VNOW
96	RANGE RRATE RRATE2
97	DSPTM1 ,+1 ,+2
98	DSPTM2 ,+1 ,+2
99	WWPOS WWVEL WWOPT

Table 5

BLOCK II - CHECK LIST CODES

<u>R1 Code</u>		<u>Action to be effected</u>
00014	KEY IN	Fine alignment option
00015	PERFORM	Celestial body acquisition
00016	KEY IN	Terminate mark sequence
00017	PERFORM	MINKEY rendezvous
00020	PERFORM	MINKEY plane change pulse torquing
00041	SWITCH	CS/SM speration to up
00062	SWITCH	AGC power down
00202	PERFORM	GNCS automatic maneuver
00203	SWITCH	To CMC-AUTO
00204	PERFORM	SPS gimbal trim
00409	SWITCH	Optics to manual or zero

Note: SWITCH denotes: change position of a console switch
PERFORM denotes: start or end of a task
KEY IN denotes: key in or data thru the DSKY

Table 6

BLOCK II - OPTION CODES

Code	Purpose	Input for components
00001	Specify IMU orientation	1 = PREF 2 = NOM 3 = REFSMMAT
00002	Specify vehicle	1 = THIS 2 = OTHER
00003	Specify tracking attitude	1 = PREFERRED 2 = OTHER
00004	Specify state of tracking (= FULTKFLAG)	0 = FULL 1 = PARTIAL
00007	Specify propulsion	1 = SPS 2 = RCS
00024	Specify tracking option	0 = RENDEZVOUS, VECPOINT 1 = CELESTIAL BODY, VECPOINT 2 = ROTATION 4 = RENDEZVOUS, 3-AXIS 5 = CELESTIAL BODY, 3-AXIS

The specified option code will be flashed in component R1 in conjunction with Verb 04 Noun 06 to request the astronaut to load into component R2 the option he desires.

Table 7

BLOCK II - ALARM CODES

Code	Type	Set by
00110	No mark since last mark reject	SEXTMARK
00113	No inbits	SEXTMARK
00114	Mark made but not desired	SEXTMARK
00115	Optics torque request with switch not at CMC	EXT VERB OPT CDU
00116	Optics switch altered before 15 sec zero time elapsed	T4RUPT
00117	Optics torque request with optics not available (OPTIND = -0)	EXT VERB OPT CDU
00120	Optics torque request with optics not zeroed	T4RUPT
00121	CDUs no good at time of mark	SXTMARK
00205	Bad PIPA reading	SERVICER
00206	ICDU zero not allowed with coarse align + gimbal lock	IMU MODE SWITCH
00207	ISS turn-on request not present for 90 sec	T4RUPT
00210	IMU not operating	IMU MODE SWITCH, IMU-2, R02, P51
00211	Coarse align error > 2 degrees	IMU MODE SWITCH
00212	PIPA fail but PIPA in not being used	IMU MODE SWITCH, T4RUPT
00213	IMU not operating with turn-on request	T4RUPT
00214	Program using IMU when turned off	T4RUPT
00217	Bad return from stall routines	CURTAINS
00220	IMU not aligned - no REFSMMAT	R02, P51
00401	Desired gimbal angles yield gimbal lock	IMF ALIGN, IMU-2
00402	Crew must honor 2nd MINKEY torque request	P52
00404	Target out of view - trunnion angle > 90 degrees	R52
00405	Two stars not available	P52, P54
00406	Rendezvous navigation not operating	R21, R23
00421	W-Matrix overflow	INTEGRV
00600	Imaginary roots on first iteration	P32, P72
00601	Post CSI perigee altitude low	P32, P72

BLOCK II - ALARM CODES

00602	Post CDH perigee altitude low	P32, P72
00603	CSI to CDH time less than 10 minutes	P32, P72, P33, P73
00604	CDH to TPI time less than 10 minutes	P32, P72
00605	Number of iterations exceed loop maximum	P32, P72, P37
00606	DV exceeds 1000 fps	P32, P72
00611	No TIG for given elevation angle	P34, P74
00612	State vector in wrong sphere of influence	P37
00613	Re-entry angle out of limits	P37
00777	PIPA fail caused ISS warning	T4RUPT
01102	AGC self test error	SELF CHECK
01105	Downlink too fast	T4RUPT
01106	Uplink too fast	T4RUPT
01107	Phase table failure, assume erasable memory destroyed	RESTART
01301	ARCSIN-ARCCOS argument too large	INTERPRETER
01407	VG increasing	S40.8
01426	IMU unsatisfactory	P61, P62
01427	IMU reversed	P61, P62
01520	V37 request not permitted at this time	V37
01600	Overflow in drift test	OPT PRE ALIGN CALIB
01601	Bad IMU torque	OPT PRE ALIGN CALIB
01703	Insufficient time for integration, TIG was slipped	R41
03777	ICDU fail caused the ISS warning	T4RUPT
04777	ICDU, PIPA fails caused the ISS warning	T4RUPT
07777	IMU fail caused the ISS warning	T4RUPT

BLOCK II - ALARM CODES

10777	IMU, PIPA fails caused the ISS warning	T4RUPT
13777	IMU, ICDU, PIPA fails caused the ISS warning	T4RUPT
20430	* Integration abort due to sub-surface state vector	ALL CALLS TO INTEG.
20607	* No solution from TIME-THETA or TIME-RADIUS	TIMETHET, TIMERAD
20610	* LAMBDA less than unity	P37
21204	* Negative or zero waitlist call	WAITLIST
21206	* Second job attempts to go to sleep via keyboard and display program	PINBALL
21210	* Two programs using device at the same time	IMU MODE SWITCH
21302	* SQRT called with negative argument abort	INTERPRETER
21501	* Keyboard and display alarm during internal use (NVSUB), abort	PINBALL
21502	* Illegal flashing display	GOPLAY
21521	* P01 or P07 illegally selected	P01, P07
31104	** Delay routine busy	SERVICE ROUTINES
31201	** Executive overflow - no vacant areas	EXECUTIVE
31202	** Executive overflow - no core sets	EXECUTIVE
31203	** Waitlist overflow - too many tasks	WAITLIST
31211	** Illegal interrupt of extended verb	SEXTMARK

Notes: * POODOO abort, does software restart (ENEMA) and "GO TO POOH" (flashing Verb 37) unless "AVERAGE G" is running then only software restart

** Bailout abort, does software restart (ENEMA)

Table 8

BLOCK II - COMPUTER PROGRAMS

Phase	Program Number	Program title
PRE_LAUNCH	00	CMC idling
AND SERVICE	01	Prelaunch or service - initialization
	02	Prelaunch or service - gyro compassing
	03	Prelaunch or service - optical verification of gyro compassing
	06	GNCS power down
	07	Systems test
BOOST	11	Earth orbit insertion monitor (EOI)
	15	TLI initiate/cutoff
COAST	20	Universal tracking
	21	Ground track determination
	22	Orbital navigation
	23	Cislunar midcourse navigation
	24	Rate-aided optics (landmark tracking)
	27	CMC update
	29	Time to longitude
PRE-THRUST	30	External Delta V
TARGETING	31	Height Adjustment Maneuver (HAM)
	32	Co-elliptic Sequence Initiate (CSI)
	33	Constant Delta altitude (CDH)
	34	Transfer Phase Initiation (TPI)
	35	Transfer Phase (TPF)
	36	Plane Change (PCM)
	37	Return To Earth (RTE)
THRUSTING	40	SPS
	41	RCS
	47	Thrust monitor

BLOCK II - COMPUTER PROGRAMS

ALIGNMENT	51	IMU orientation determination
	52	IMU realign
	53	Back-up IMU orientation determination
	54	Back-up IMU realign
ENTRY	61	Entry - preparation
	62	Entry - CM/SM separation and pre-entry maneuver
	63	Entry - initialization
	64	Entry - post 0.05 g
	65	Entry - up control
	66	Entry - ballistic
	67	Entry - final phase
PRE-THRUSTING OTHER VEHICLE	72	LM Co-elliptic Sequence Initiation (CSI) targeting
	73	LM Constant Delta altitude (CDH) targeting
	74	LM Transfer Phase Initiation (TPI) targeting
	75	LM transfer phase (midcourse) targeting
	76	LM target Delta V
	77	CSM target Delta V
	79	Rendezvous final phase

Table 9

BLOCK II - COMPUTER ROUTINES

<u>Number</u>	<u>Name</u>	<u>Called/Initiated by</u>
R00	Final automatic request terminate	GO TO POOH
R01	Erasable and channel modification routine	V25N07
R02	IMU status check	P20, P22, P40, P47, P52, P54, P61, P62, R05, R63
R03	Digital autopilot data load	V48
R05	S-Band antenna angles	V64
R07	MINKEY Controller	<i>Not in A15 Cards</i>
R21	Rendezvous tracking sighting mark	V57
R22	Rendezvous tracking data processing	P20
R23	Backup rendezvous tracking and sighting mark	V54
R30	Orbit parameter display	V82
R31	Orbit parameter display number one	V83
R33	CMC/LGC clock synchronization	V06N65
R34	Rendezvous parameter display number two	V85
R36	Rendezvous out-of-plane display	V90
R40	SPS thrust fail	P40
R41	State vector integration (MID to AVE)	P40, P41, P47, P61
R50	Coarse align	P52, P54
R51	Fine align	P52, P54
R52	Automatic optics positioning	P20, P22, P23, R51
R53	Sighting mark	P23, P51, R52
R54	Sighting data display	P51, R51
R55	Gyro torquing	R51
R56	Alternate LOS sighting mark	P53, R51
R57	Optics calibration	P23
R60	Alternate LOS sighting mark	P23, P40, R61, R62, V89
R61	Tracking attitude	P20, R52

BLOCK II - COMPUTER ROUTINES

R62	Crew defined maneuver	V49
R63	Rendezvous final attitude	R61, V89
R64	Barbecue mode routine	V79
R67	Universal pointing	P20

Table 10

BLOCK II - STAR / PLANET LIST

Octal Star Code	Name	Vis. Mag.	Right Ascension (HR. MIN.)		Declination (HR. MIN.)	
1	Alpha Andromedae (Alpheratz)	2.1	0	06	+28	53
2	Beta Ceti (Diphda)	2.2	0	42	-18	11
3	Gamma Cassiopeiae (Navi)	2.2	0	54	+60	27
4	Alpha Eridani (Achernar)	0.6	1	36	-57	25
5	Alpha Ursae Minoris (Polaris)	2.1	1	58	+89	06
6	Theta Eridani (Acamar)	3.4	2	57	-40	26
7	Alpha Ceti (Menkar)	2.8	3	00	+03	56
10	Alpha Persei (Mirfak)	1.9	3	22	+49	44
11	Alpha Tauri (Aldebaran)	1.1	4	34	+16	26
12	Beta Orionis (Rigel)	0.3	5	12	-08	15
13	Alpha Aurigae (Capella)	0.2	5	13	+45	57
14	Alpha Carinae (Canopus)	-0.9	6	23	-52	40
15	Alpha Canis Majoris (Sirius)	-1.6	6	44	-16	40
16	Alpha Canis Minoris (Procyon)	0.5	7	37	+05	19
17	Gamma Velorum (Regor)	1.9	8	08	-47	14
20	Iota Ursae Majoris (Dnoces)	3.1	8	50	+48	30
21	Alpha Hydrae (Alphard)	2.2	9	26	-08	30
22	Alpha Leonis (Regulus)	1.3	10	06	+12	09
23	Beta Leonis (Denebola)	2.2	11	47	+14	46
24	Gamma Corvi (Gienah)	2.8	12	13	-17	20
25	Alpha Crucis (Acrux)	1.6	12	24	-62	49
26	Alpha Virginis (Spica)	1.2	13	23	-10	58
27	Eta Ursae Majoris (Alkaid)	1.9	13	46	+49	30
30	Theta Centauri (Menkent)	2.3	14	04	-36	11
31	Alpha Bootis (Arcturus)	0.2	14	14	+19	22
32	Alpha Corona Boreal. (Alphecca)	2.3	15	33	+26	50
33	Alpha Scorpii (Antares)	1.2	16	27	-26	21
34	Alpha Trianguli Austr. (Atria)	1.9	16	43	-68	56
35	Alpha Ophiuchi (Rasalhague)	2.1	17	33	+12	35

BLOCK II - STAR / PLANET LIST

36	Alpha Lyrae (Vega)	0.1	18	36	+38	45
37	Sigma Sagittarii (Nunki)	2.1	18	53	-26	20
40	Alpha Aquilae (Altair)	0.9	19	49	+08	46
41	Beta Capricorni (Dabih)	3.2	20	19	-14	54
42	Alpha Pavonis (Peacock)	2.1	20	23	-56	51
43	Alpha Cygni (Deneb)	1.3	20	40	+45	09
44	Epsilon Pegasi (Enip)	2.5	21	42	+09	42
45	Alpha Piscis Austr. (Fomalhaut)	1.3	22	56	-29	49
46	Sun					
47	Earth					
50	Moon					
00	Planet					

Star	No.	Star	No.	Star	No.
Acamar	6	Canopus	14	Mirfak	10
Achernar	4	Capella	13	Navi	3
Acrux	25	Dabih	41	Nunki	37
Aldebaran	11	Deneb	43	Peacock	42
Alkaid	27	Denebola	23	Procyon	16
Alphard	21	Diphda	2	Polaris	5
Alphecca	32	Dnoces	20	Rasalhague	35
Alpheratz	1	Enif	44	Regor	17
Altair	40	Fomalhaut	45	Regulus	22
Antares	33	Gienah	24	Rigel	12
Arcturus	31	Menkar	7	Sirius	15
Atria	34	Menkent	30	Spica	26
				Vega	36

Table 11

BLOCK II - AUTOPILOT CONFIGURATION DATA (Noun 46)

DAP data loaded into components R1 and R2 upon request by flashing V06N46.

R1 = ABCDE (DAPDATR1)

A	B	C	D	E
Vehicle Config.	X-transl for Quad A/C	X-transl for Quad B/D	Attitude Deadband	Maneuver Rate
0=No DAP	0=Disable A/C	0=Disable B/D	0=+/-0.5 deg	0=0.05 deg/s
1=CSM	1=Use A/C	1=Use B/D	1=+/-5.0 deg	1=0.2 deg/s
2=CSM & LM				2=0.5 deg/s
3=CSM & SIVB				3=2.0 deg/s
6=CSM & LM (ascent stage only)				

R2 = ABCDE (DAPDATR2)

A	B	C	D	E
Roll Quad Select	Quad A Status	Quad B Status	Quad C Status	Quad D Status
0=Use B/D	0=Disable	0=Disable	0=Disable	0=Disable
1=Use A/C	1=Use	1=Use	1=Use	1=Use

Table 12

BLOCK II - CMC PROGRAMS DESCRIPTIONS (COLOSSUS)**INTRODUCTION**

The Command Module Computer software, named Colossus, is a collection of Programs and Routines that can be executed automatically or by user command.

Programs are usually invoked explicitly by the user while Routines are often executed in background or as result of the execution of a Program. Programs are collected in Major Modes that corresponds with Guidance and Navigation mission phases:

- pre-launch and service
- boost (launch, EOI and TLI)
- coast (and navigation)
- pre-thrusting (orbital and rendezvous maneuvering)
- thrusting
- IMU alignment
- entry
- pre-thrusting other vehicle (rendezvous maneuvering)

This description will give a quick overview of the Major Modes and of the Programs available to the astronauts to accomplish the mission phases.

Astronauts' interaction with the CMC is by means of the DSKY (Display and Keyboard) whose use is detailed in another document (** REF **).

[0] PRE-LAUNCH AND SERVICE**P00 - CMC Idling**

P00 is the program that will be invoked after switching the CMC on, or where execution is brought after a 'reset' is commanded by the user or after a major software error. From P00 the user can switch to any other mode while a background routine keeps propagating the state vector of both the CSM and the LM. The knowledge of the state vector for the second vehicle is needed to perform rendezvous calculations and target tracking functions.

P01 - Initialization

P01 is used to initialize the inertial platform before launch, orientating its members in the best position to better measure attitudes and accelerations during the boost phase. After the initialization is accomplished the CMC transitions automatically to

BLOCK II - CMC PROGRAMS DESCRIPTIONS (COLOSSUS)**P02 - Gyrocompassing**

P02 where the inertial platform orientation is maintained against Earth rotation (gyrocompassing). User can here change launch azimuth orientation for last minute corrections (mainly due to launch delays). This program will wait the enabling of the Lift-off Discrete to automatically transition to P11 for the boost phase. While waiting the user can select

P03 - Optical Verification of Gyrocompassing

P03 to perform an optical verification of gyrocompassing by means of sighting two different targets with the optical subsystems. Any sighting error can be used to torque one platform gyro and correct the azimuth error.

P06 - CMC Power Down

P06 is used to put the CMC in Stand-By and, eventually, to switch it off. While in Stand-By mode the CMC will only update the Ground Elapsed Time. From this state, the CMC can be brought to Operate and P00 can then be selected.

[1] BOOST (LAUNCH, EOI AND TLI)**P11 - Earth Orbit Insertion Monitor**

P11 is automatically activated after P02 sense that the Lift-off Discrete has been enabled by first motion detectors on the launch vehicle. From that moment on, the CMC will compute the roll and pitch attitude errors comparing the actual values with those stored in a programmed profile. In case the Saturn Inertial Platform should fail the CMC can be commanded to provide the Saturn Instrument Unit attitude information. In other cases the user can select manual operations and command Saturn steering by means of the control stick. Trajectory parameters are also available by means of dedicated displays, while acceleration forces are integrated with the Average G algorithm. As soon as orbit is achieved the user will transition the CMC to P00.

P15 - Trans Lunar Injection Initiate/Cutoff

P15 is selected to monitor initiation and termination (or Cutoff) of the Trans-Lunar Injection burn which is controlled by the Saturn Instrument Unit. In case of need the CMC can be selected to command the TLI burn and steer the Saturn.

BLOCK II - CMC PROGRAMS DESCRIPTIONS (COLOSSUS)**[2] Coast and Navigation****P20 - Universal Tracking**

P20 is the main program to manage attitude and attitude rates of the CSM. Managing attitude means selecting a target and pointing an arbitrary line of sight to it (and keeping it pointed, that is tracking it). Managing attitude rates means selecting the rate of change of attitude during pointing maneuvers or defining a constant rotation rate about an arbitrary spacecraft axis. This program is therefore used also to point optics to requested targets such as a celestial body or even another vehicle such as the LM.

P21 - Ground Track Determination

P21 is used to obtain data on the ground track of either the CSM or the LM. Ground track is the path of the vehicle projected on the surface of the celestial body around which the orbit develops. The user can monitor geographic coordinates, altitude and attitude data referred to the local vertical.

P22 - Orbital Navigation

P22 is the main navigation program for the CSM and enables the user to update spacecraft position and velocity by means of optical sightings taken of selected landmarks on Earth or Moon. Final results are given as estimated difference between computed speed and velocity and actual stored state vector.

P23 - Cislunar Midcourse Navigation

P23 is like the previous one but enables position updates by means of sighting of stars and their elevation with respect of Earth, or Moon, horizon. Final results are given as estimated difference between computed speed and velocity and actual stored state vector.

P24 - Rate Aided Optics Tracking

P24 enables the user to locate and acquire a selected landmark on Earth or Moon surfaces and to continue tracking it letting the CMC drive the optics.

P27 - AGC Update

P27 enables the user to update memory locations inside the CMC. This program is often used on board to update/correct liftoff time and to read/write the state vector being integrated. Mission Control makes use of this program to also update CSM state vector from ground observations.

BLOCK II - CMC PROGRAMS DESCRIPTIONS (COLOSSUS)**P29 - Time Of Longitude**

P29 is used to compute the time of passage over a specified longitude with the assumption that no applications of thrust will be made.

[3] PRE-THRUSTING (ORBITAL AND RENDEZVOUS MANEUVERING)**P30 - External Delta-V**

P30 computes the total Delta-V and the Engine Gimbal angles for the burn targeting data provided by the user. Other parameters such as orbital ones that will be obtained after the maneuver are also computed.

P31 - Height Adjustment Maneuver (HAM)

P31 is the first of a series of programs used in sequence to compute burn parameters for the various rendezvous maneuvers. The Height Adjustment Maneuver is used to establish initial conditions for the successful completion of a standard rendezvous. Parameters calculated, and stored, are for an in-plane maneuver but out-of-plane status is also displayed.

P32 - CSM Coelliptic Sequence Initiation (CSI)

P32 is used to compute burn parameters to perform the beginning of the concentric rendezvous flight plan. This maneuver is mainly an apsidal line rotation maneuver. Parameters stored are for an in-plane burn but out-of-plane status is also shown.

P33 - CSM Constant Delta Altitude (CDH)

P33 is used to compute burn parameters for the rendezvous maneuver, which will establish a quasi-constant altitude difference between the participating spacecrafts. Again stored parameters are for an in-plane burn but out-of-plane status is also computed and shown.

P34 - CSM Transfer Phase Initiation (TPI) Targeting

P34 is used to compute a series of parameters to subsequently perform the burn, which will start bringing the two vehicles closer. This maneuver is performed under predetermined line-of-sight conditions.

BLOCK II - CMC PROGRAMS DESCRIPTIONS (COLOSSUS)**P35 - CSM Transfer Phase Midcourse (TPM) Targeting**

P35 is used to perform correction maneuvers after the execution of the previous maneuver therefore compensating deviation from the initial estimates. During previous rendezvous targeting programs the presence of P20 running in background to perform sighting marks was not explicitly required. In this case P20 will be automatically activated if not already running to perform attitude tracking of the target.

P36 - Plane Change (PC) Targeting

P36 is an additional rendezvous program used to compute parameters to correct out-of-plane conditions after CSI or, if needed, after CDH too.

P37 - Return To Earth

P37 is a burn targeting program used to compute burn parameters to establish the desired return to Earth trajectory outside the Moon's sphere of influence.

[4] THRUSTING**P40 - SPS Thrusting**

P40 is mainly used to automatically perform countdown, ignition, thrusting and shutdown for a previously targeted burn, which will employ the main SPS engine. After program activation a series of operations are also performed to align the IMU to the thrust vector, to align the gimballed engine and to orient the CSM to the burn attitude. Two different steering options are available: Delta-V steering and Lambert steering. Orbital and various other parameters are made available.

P41 - RCS Thrusting

P41 is mainly used in providing assistance to perform a manually controlled RCS only burn previously targeted. RCS burns are used mainly when required Delta-Vs are less than 7 fps. Other characteristics are similar to those of the previous program.

P47 - Thrust Monitor

P47 is used to monitor applied Delta-V during manual controlled burns. The program is mainly used during the final phases of a rendezvous and it makes available different displays to read the CSM status and its position and velocity in relation to that of the target vehicle. Generic orbital parameters are also available.

BLOCK II - CMC PROGRAMS DESCRIPTIONS (COLOSSUS)**[5] IMU ALIGNMENT****P51 - IMU Orientation Determination**

P51 is another of the most important AGC programs (together with the next one) and is used to measure the exact orientation of the Inertial Measurement Unit by means of sightings of two different celestial bodies. When IMU alignment is lost or need to be refined this program enables the user to restore its orientation, and that of the CSM, in space.

P52 - IMU Realign

P52 is used to change IMU orientation from one reference to another. Mission phases have the IMU oriented in the most convenient way depending on the kind of planned maneuvering. There are different orientations for the launch pad, the landing area and that calculated for a generic maneuver. The re-orientation will require sightings of two celestial bodies to complete the operation.

P53 - Backup IMU Orientation Determination

P53 is like P51 but requires the use of a backup optical device instead of the telescope or the sextant.

P54 - Backup IMU Realign

P54 is like P52 but requires the use of a backup optical device instead of the telescope or the sextant.

[6] ENTRY**P61 - Entry Preparation**

P61 is used to perform a series of initialization tasks to be accomplished before beginning the entry phase. The tasks include checking IMU alignment and the program is used to input splashdown coordinates and compute a series of parameters to be used for EMS (Entry Monitor System) initialization. After displaying the results the AGC transitions to

P62 - CM/SM Separation and Pre-Entry Manoeuver.

P62 is used to coordinate with the AGC the separation of the CM from the SM. After this event the entry DAP is activated and target data can be modified. Values to orient the CM to the right entry attitude are shown and when the attitude is within limits the AGC transitions to

BLOCK II - CMC PROGRAMS DESCRIPTIONS (COLOSSUS)**P63 - Entry Initialization**

P63 is used to display a series of parameters related to entry equations. The DAP (Digital Auto Pilot) is given control of the vehicle attitude and when a drag acceleration of 0.05 g is sensed the AGC transition to

P64 - Entry Post 0.05 G

P64 initiate entry guidance in terms of roll attitude, drag level and various thresholds. Entry displays are made available to the user. Depending on entry condition the AGC will automatically transition to P67 (Final Phase) or to P65 (Controlled Skip Phase).

P65 - Entry Upcontrol

P65 execute entry upcontrol guidance steering the CM for a controlled exit and successive re-entry (never used after Earth orbit missions). Entry displays are made available to the user. If conditions during exit permit the AGC will transition automatically to P67 (Final Phase) otherwise it will transitions to

P66 - Entry Ballistic

P66 will maintain CM attitude before atmospheric reentry after the skip out. Desired attitude angles are shown as other entry displays are kept available. At reentry, or when 0.2 g of drag acceleration are sensed the AGC transitions to

P67 - Entry Final Phase

P67 continues entry guidance for target coordinates. Entry displays are kept available to the user. At a relative speed of 1000 fps (corresponding approximately to an altitude of 65.000 ft) the program terminates.

[7] PRE-THRUSTING OTHER VEHICLE**P72 - LM Coelliptic Sequence Initiation (CSI) Targeting**

P72 is used to perform LM active rendezvous targeting calculations in the AGC. Results regarding the CSI maneuver will then be transmitted to the LM for execution of the respective burn. The type of computation is identical to that performed under P32 (targeting only) for a CSM active rendezvous.

BLOCK II - CMC PROGRAMS DESCRIPTIONS (COLOSSUS)**P73 - LM Constant Delta Altitude (CDH) Targeting**

P73 is used to perform LM active rendezvous targeting calculations in the AGC. Results regarding the CDH maneuver will then be transmitted to the LM for execution of the respective burn. The type of computation is identical to that performed under P33 (targeting only) for a CSM active rendezvous.

P74 - LM Transfer Phase Initiation (TPI) Targeting

P74 is used to perform LM active rendezvous targeting calculations in the AGC. Results regarding the TPI maneuver will then be transmitted to the LM for execution of the respective burn. The type of computation is identical to that performed under P34 (targeting only) for a CSM active rendezvous.

P75 - LM Transfer Phase Midcourse (TPM) Targeting

P75 is used to perform LM active rendezvous targeting calculations in the AGC. Results regarding the TPM maneuver will then be transmitted to the LM for execution of the respective burn. The type of computation is identical to that performed under P35 (targeting only) for a CSM active rendezvous.

P76 - Target Delta V

P76 is used to notify the AGC that the target vehicle (LM) has executed an orbital maneuver of a determined Delta V. This will permit the AGC to update the target vehicle state vector. Delta V values in local vertical coordinates shown are those from the last LM targeting calculation performed (see P72 ... P75).

P77 - CSM Target Delta V

P77 is used to notify the AGC that the CSM has executed (or will execute) an orbital maneuver of a determined Delta V. This will permit the AGC to update the CSM state vector without need to measure thrusting accelerations. Delta V values in local vertical coordinates shown are those from the last CSM targeting calculation performed (see P32 ... P35).

P79 - Final Rendezvous

P79 is used to perform the final X-axis orientation for the final phase of the rendezvous (braking phase) and to compute and display rendezvous parameters including range to target and relative speed (range rate).

BLOCK II - CMC PROGRAMS DESCRIPTIONS (COLOSSUS)**THE MINKEY CONTROLLER ROUTINE**

To reduce the amount of DSKY operations that the user has to perform while accomplishing a partial or full rendezvous a special routine, named MINKEY (for MINimum KEYing), has been included in Colossus. This routine will automatically sequence the rendezvous maneuvers targeting programs and will also handle execution of P20 for tracking purposes and of P40 or P41 for execution of the burn. P76 can also be automatically invoked to update the AGC after each LM burn. (In nominal operations the CSM is passive during the rendezvous and keeps computing LM targeting burns to follow its approach).

The MINKEY controller will also automatically determine if multiple CSI maneuvers are needed, if the Plane Change maneuver is to be performed, and will perform two P35 calculations for two MCC (Mid Course Correction) burns. The sequence ends with execution of P79.

The MINKEY controller can be activated at any of six different points in the rendezvous sequence. After selecting any of the rendezvous maneuver programs (P31 ... P36) the AGC will permit a choice between using the MINKEY controller or the manual procedure.

NOTES**General considerations**

AGC programs are run in a very closed environment where single memory locations are accounted for some peculiar significance. Therefore, most of them perform computations whose results are both showed to the user, and stored in predetermined memory locations. In fact, computations results presented to the user are exactly the display of those locations, which are identified by DSKY Noun codes. Linking programs one after another is easily possible because specific programs look for data in locations where other programs, previously run, or running in background, leave results.

When more than one program are running users can interact directly with only one, the foreground program. Background programs, which requires user attention, use the KEY REL indicator to request user intervention. Generally speaking, users at any time can recall the display associated with certain memory locations and therefore monitor the status of a background program. Even background programs routines can be executed because each AGC routine is assigned a different code.

Closing remarks

Learning to use the AGC, with both the CSM software (Colossus) or the LM one (Luminary) is not too hard if one has the knowledge of the practical problems that can be solved with it.

BLOCK II - CMC PROGRAMS DESCRIPTIONS (COLOSSUS)

In fact, it is not much different than operating in any technical profession with an old programmable pocket calculator (such as the first generation HPs or TIIs) with scores of short programs than had to be loaded one after another to accomplish a complex task.

Today Colossus or Luminary functions can be implemented in a modern pocket calculator, such as the HP38/48, with the only limitation that the control functions would be lost due to the "limited capabilities" in direct interfacing offered by such consumer products.

Engineers usually experience pleasure when good design choices are propagated in future developments of a project or are even inherited by new projects. Some of our readers can therefore enjoy the knowledge that some numbering of CMC Programs, and the notion of Major Modes, have been propagated in the Space Shuttle software. In fact the Shuttle software (both the redundant set PASS and the backup BFS) is divided in Major Modes as follows:

MM 000	Pre-launch and maintenance
MM 100	Ascent
MM 200	Coasting and maneuvering
MM 300	Entry
MM 600	Launch aborts
MM 800	Systems checkout

In MM 200 the main program is called Universal Pointing and performs the same tasks, and some others, of the Apollo Universal Tracking program.

Apart from the more evident differences between the two environments, one less noticeable is that switching between Major Modes in the CMC is practically immediate since all the programs are stored in the core memory, while switching Major Modes in the Shuttle PASS (Primary Avionics System Software) is a slow process since the programs for the selected modes must be read by a tape device. Only MM 100 and MM 600 are loaded at the same time in the GPCs memories.