

UNITED STATES GOVERNMENT

Memorandum

RECEIVED

AUG 2 1968

AIN LAATS

DATE: JUL 17 1968

TO : See list attached

FROM : FS/Chief, Flight Support Division

SUBJECT: Minutes of the MIT presentation on checkout of the Apollo Guidance and Control System

1. On June 20, 1968, MIT/IL gave a presentation on checkout of the Apollo Guidance and Control System. The following MIT/IL personnel gave the described presentation.

a. Mr. D. G. Hoag - Philosophy which is followed in G&N checkout. Slides one and two of enclosure one (slides presented) detail that philosophy.

b. Mr. J. D. Fleming, Jr. - A picture of checkout plans and operations (enclosure two) covering objectives, test flow, and document flow. He also stressed the point that there is a significant interaction in this flow with flight program development.

c. Mr. G. L. Silver - Presented KSC checkout operations. He stated that a major rope change, say from SUNDANCE to LUMINARY, would cause an impact to KSC operations while the impact resulting from a change to level V ropes from level IV would depend upon the changes made to the ropes following the level IV release. Slide 15 of enclosure one describes the impact on specific tests.

d. Mr. A. Laats - Described G&N system testing. It was here that Mr. C. C. Kraft requested that the effect that a PCR had on E-memory programs be added to the impact time consideration. Mr. Kraft also stated that there was a real need to know from a flight standpoint where a system will deteriorate completely and not just when a certain black box will fail.

e. Mr. M. M. Sullivan - Discussed interface testing with an emphasis on the use of E-memory programs.

f. Mr. M. Johnston - Described SIMFLIGHT, covering its design philosophy, use, and problems uncovered as a result of its use.

g. Mr. W. F. Marscher - Detailed software testing at MIT using the SUNDANCE program as a specific example.

h. Mr. Hoag - Concluded by showing the interaction between software and hardware verification. He also detailed the verification done during manufacture of the ropes.

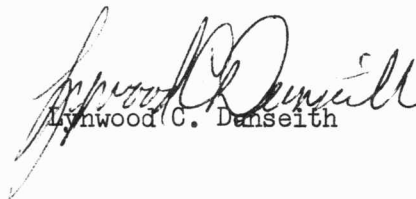


5010-108

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2. An action item was given to MIT/IL to investigate problems arising from the installation of flight ropes at the CDDT. This investigation was to cover the need and procedures necessary to keep KSC informed of changes to the ropes following the level IV release, procedures for the recommendation on the need for KSC retesting and the feasibility of using the MIT/IL digital and hybrid simulators for level V release interface compatibility verification.

3. Enclosure one contains the slides presented, enclosure two covers Mr. Fleming's presentation, enclosure three is a handout on the flight program testing philosophy, and enclosure four is the list of attendees.


Lynwood C. Danseith

Enclosures 4

cc:
All attendees

FS55:FJKastelic:jrv

CHECKOUT OF THE APOLLO GUIDANCE AND CONTROL SYSTEM
IN THE SPACECRAFT AT KSC (WITH MISSION PROGRAMS)

PRESENTATION GIVEN AT NASA SPACEFLIGHT CENTER

20 JUNE 1968

Channel

MEETING AGENDA

SUBJECT: MIT Presentation on Checkout
TIME: June 20th 1968, 9 A. M.
LOCATION: NASA Manned Spacecraft Center
Building 2, Room 716

A. Introduction	D. Hoag
B. Outline of Test and Checkout Operations	J. Fleming
C. Checkout at KSC	G. Silver
D. G&N System Testing	A. Laats
E. Interface Testing	M. Sullivan
F. Sim Flight	M. Johnston
G. Software Testing at MIT	W. Marscher
H. Interaction between Software and Hardware Verification and Conclusion	D. Hoag



HARDWARE AND SOFTWARE VERIFICATION TEST "PHILOSOPHY"

PROBLEM

- DEFINITIONS, REQUIREMENTS, AND SPECS LATE AND CHANGEABLE
- VERIFICATION TESTING MUST OCCUR SIMULTANEOUSLY WITH DESIGN, CHANGE, DEVELOPMENT, & TROUBLESHOOTING
- SPACECRAFT HARDWARE AND SPACE ENVIRONMENT MATH MODELS ARE OFTEN INACCURATE, UNAVAILABLE, LATE, AND CHANGING DURING TEST VERIFICATION
- LIMITS ON FACILITY AND MAN-HOUR RESOURCES

SOLUTION BY COMPROMISE

- OPTIMIZE CONFIDENCE IN SYSTEM INTEGRITY WITHIN EXISTING CONSTRAINTS
- CONFIGURE TEST APPROACH UNDER GROUND RULES AND DETAILS DETERMINED BY CAREFUL JUDGMENT, SKILL, & DEDICATION OF QUALIFIED ENGINEERS
- COMPROMISE GROUND RULES EMBODIED IN TEST "PHILOSOPHY"

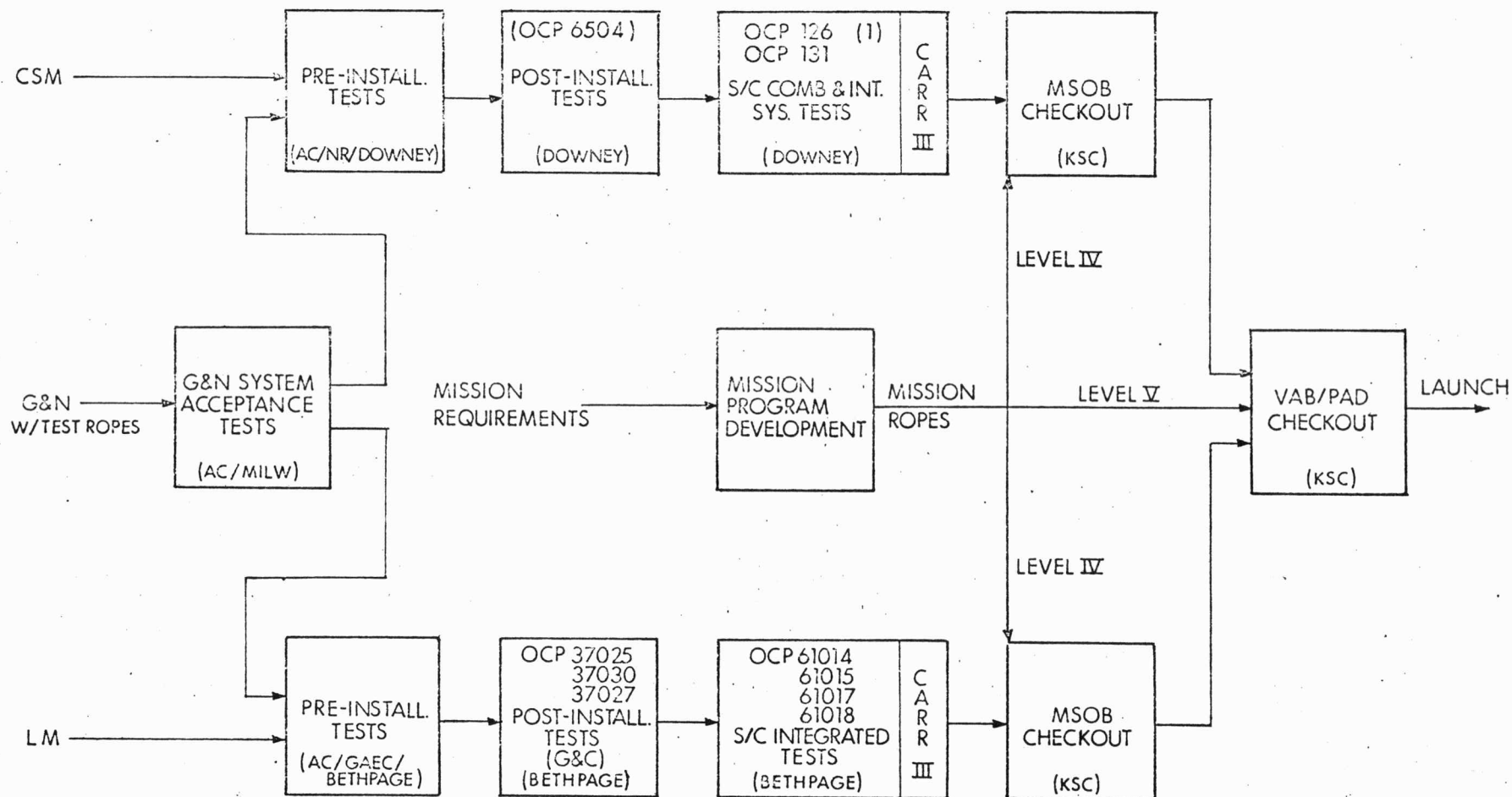
HARDWARE AND SOFTWARE VERIFICATION TEST "PHILOSOPHY" (CONT.)

"PHILOSOPHY" - REQUIREMENTS AND GUIDELINES

1. CONFIGURE TESTS TO OPTIMIZE SUBJECTIVE INCREMENT IN CONFIDENCE
2. COMPREHENSIVE TEST PLAN BEFORE START
3. PLAN TO PROCEED FROM DETAIL ELEMENTAL TESTS TOWARDS OVERALL END TO END TESTING
4. EXERCISE EVERY NOMINAL MISSION AND ABORT PATH
5. EXERCISE ABNORMAL RATIONAL PATHS
6. AS MUCH AS PRACTICAL STRESS TEST WITH WIDE RANGES OF PARAMETER VARIATION
7. INCORPORATE CHANGES WITH RESTRAINT TO DESIGN WHICH ALREADY SUPPORTS MISSION
8. INCORPORATE CHANGES WITH RESTRAINT TO MATH MODELS ALREADY HAVING SUFFICIENT FIDELITY
9. RETEST LOCAL AREA AND INTERFACES OF CHANGE
10. CAREFULLY EXAMINE TEST RESULTS AGAINST PLAN, SPEC, & UNUSUAL OPERATION
11. KEEP LOG OF ANOMOLIES, DISCREPANCIES, & CURIOSITIES
12. ENCOURAGE INDEPENDENT REVIEW AND INDEPENDENT TEST

Fig. 1

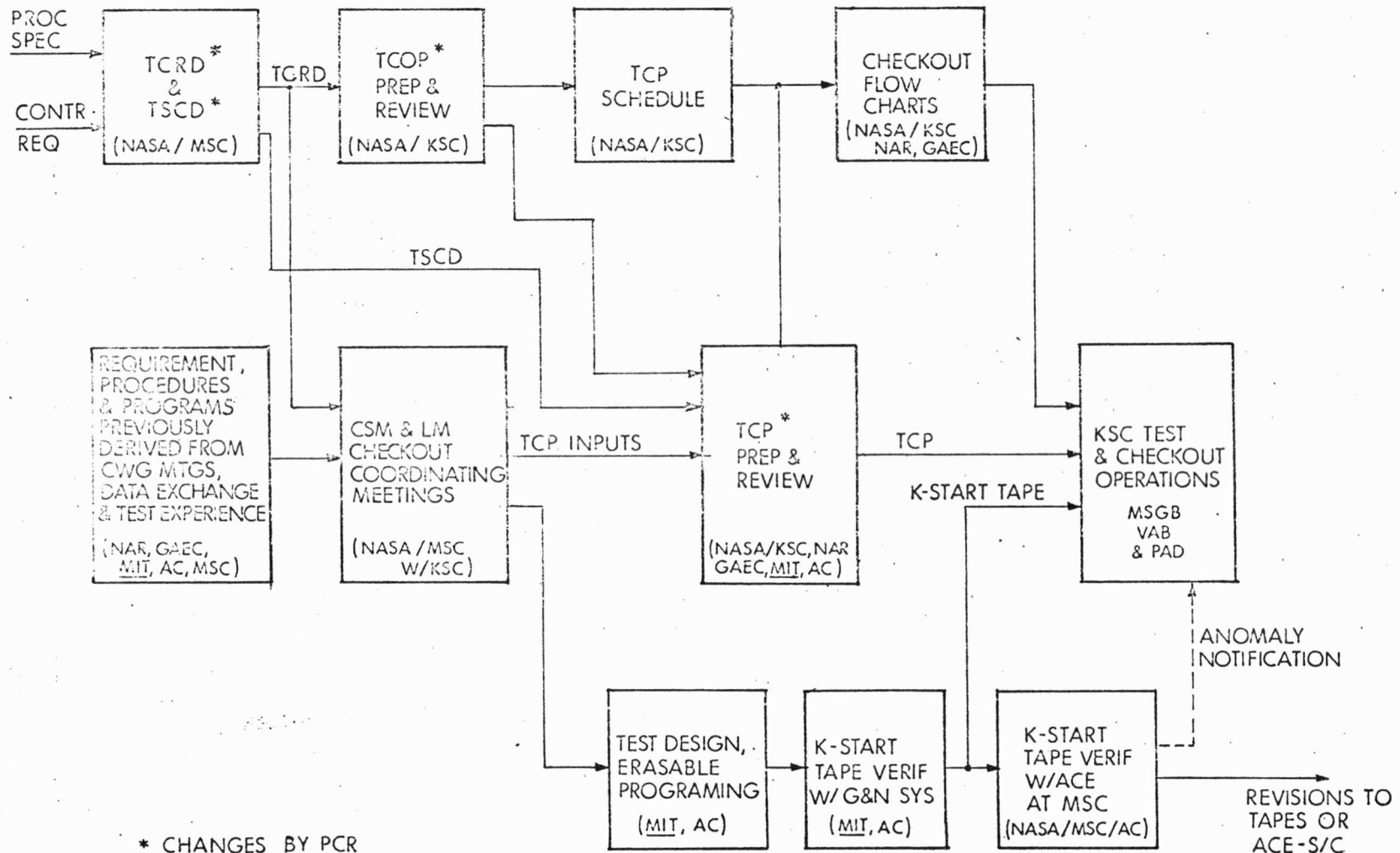
ILLUSTRATION OF TYPICAL OVERALL G&N ASSOCIATED TEST AND CHECKOUT FLOW



Notes:

(1) CARR, PHASE II, OCCURS AFTER OCP 126, COMBINED SYSTEMS TEST.

ILLUSTRATION OF CHECKOUT DOCUMENTATION FLOW AND RELATED ACTIVITIES



A. OBJECTIVES OF CHECKOUT (G & N)

DOCUMENTED IN

1. STG MEMOS
2. PROCESS SPECS
3. TEST AND CHECKOUT OPERATIONAL PLAN (TCOP)
4. TEST AND CHECKOUT PROCEDURES (TCP)

B. TEST FLOW AND G & N PARTICIPATION

1. PRESENT VEHICLES
2. FUTURE VEHICLES

C. IMPACT ON OBJECTIVES IF FLIGHT ROPES ARRIVE LATE IN THE FLOW

1. CONFIGURATION
2. PROCEDURES
3. CONFIDENCE LEVELS

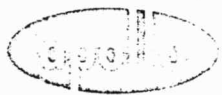
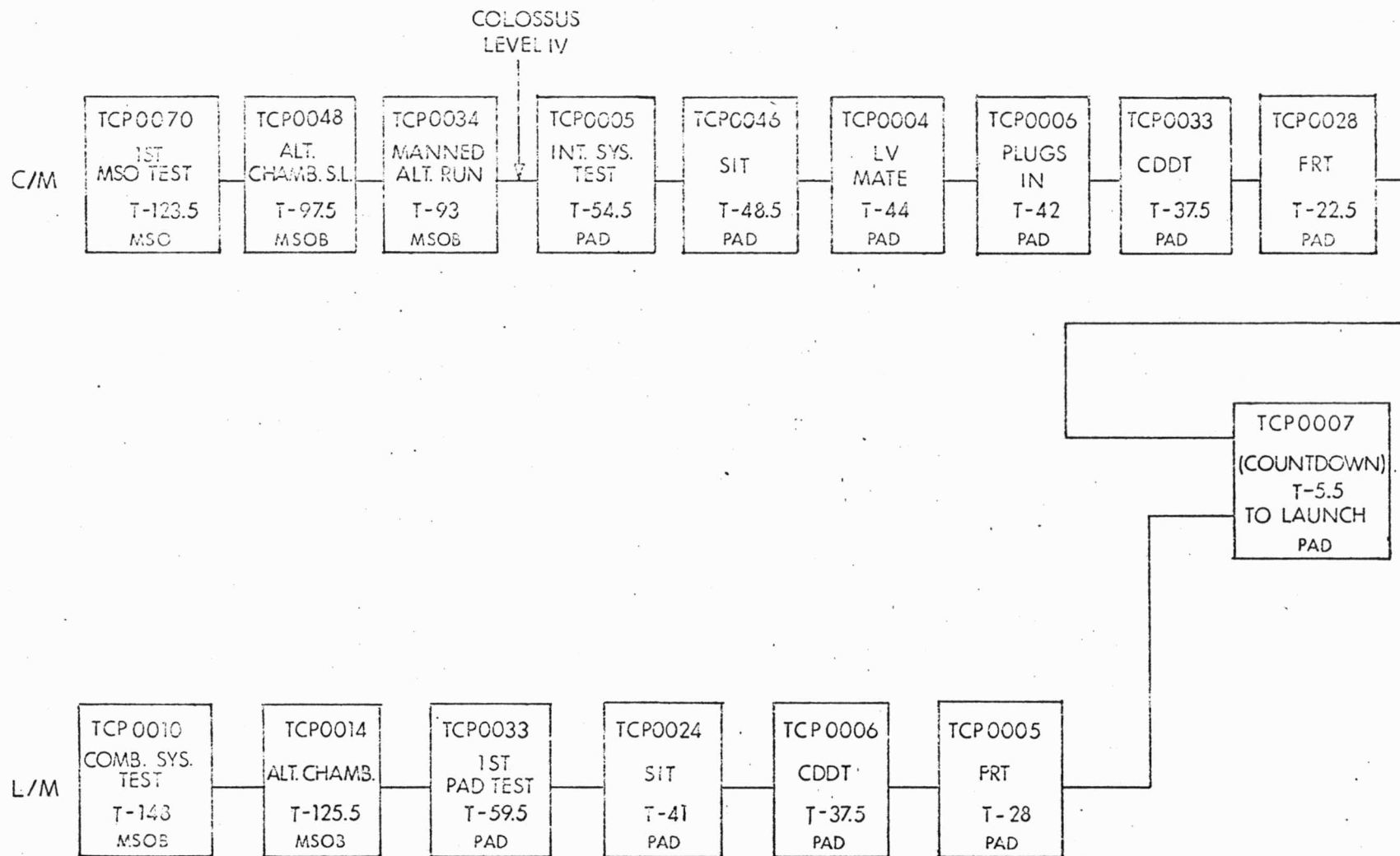
GENERAL OBJECTIVES

KSC TESTING TO INSURE THAT

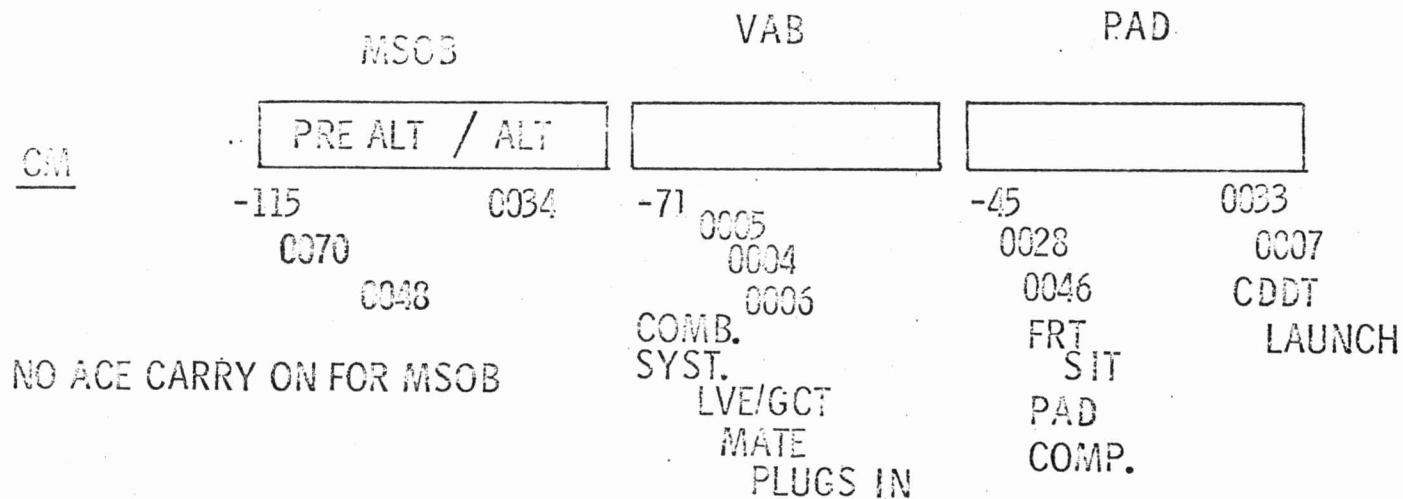
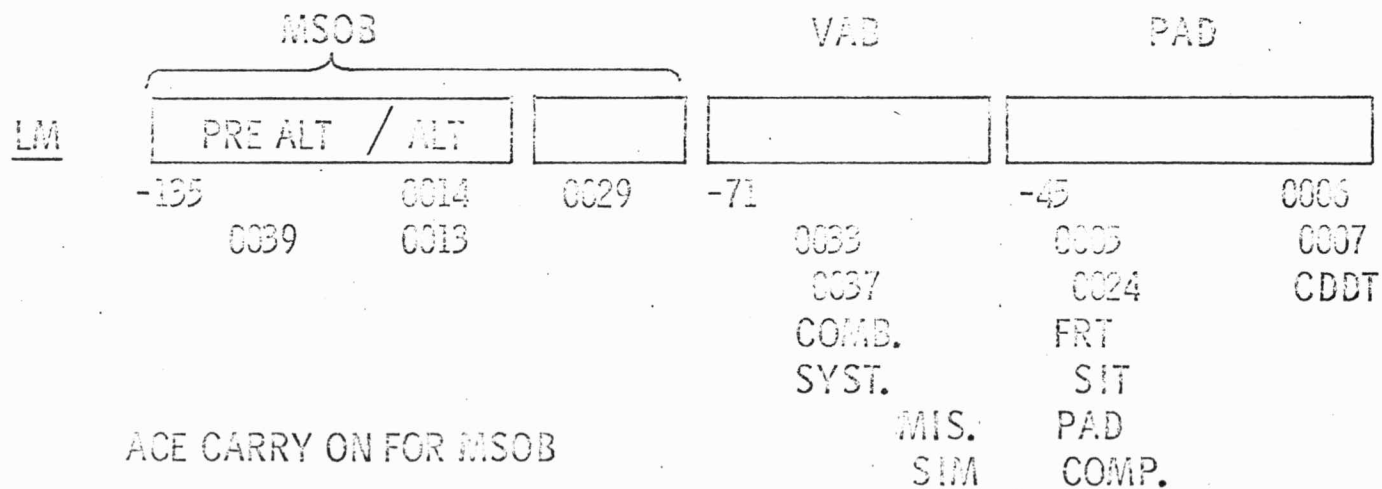
1. SYSTEM IS FUNCTIONING PROPERLY.
2. INTERFACES TO OTHER SYSTEMS ARE CORRECT.
3. MEASUREMENT POINTS ARE FUNCTIONAL.
4. ACE GSE IS CONNECTED PROPERLY.
5. ACE PROCESSING IS CORRECT.
6. DYNAMIC SIGNAL SEQUENCING IS POSSIBLE.
7. PROCEDURES ARE APPLICABLE.
8. CAN SUPPORT OTHER INTERFACE TESTS (ie: LV & MCCH).
9. EXPERIENCE IN SPECIFIC SPACECRAFT AND G&N IS SUFFICIENT FOR LAUNCH AND MISSION SUPPORT.

Fig. 4B

TYPICAL EARLY BLOCK II CHECKOUT FLOW AT KSC



TYPICAL FLOW (FUTURE VEHICLES)
(AS 504)



10 MAY 1968

SC - 101

A P O L L O

14
K-0203-A

G AND N SYSTEM TEST

RAD

MSOB			VAR			PAD		
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
7	4	3	0	0	0	3	2	4
0	8	4	5	4	5	3	8	6

1. GENERAL TURN ON AND TURN OFF SHORT G + N ACTIVATION (3) ABBREVIATED G + N ACTIVATION (3) G + N DEACTIVATION STANDBY POWER ON (3) CMC OPERATIONAL TEST OPERATE POWER ON (3.6.4.A + B + C)		2	2	-	X	X	X	-	X	X
2. G AND N PANEL BRIGHTNESS (3.6.4.D)	X	X	X	X	X	X	X	X	X	X
3. G AND N OPERATIONAL (3.6.4.F)	X	X	X	X	X	X	X	X	X	X
4. GIMBAL FRICTION (3.6.4.G)	2	X	-	-	X	-	-	-	X	-
5. CMC VOLTAGE MARGIN (3.6.4.H)	X	X	-	-	X	-	-	-	X	X
6. SEMI-AUTOMATIC MODE CTL (3.6.4.I)	2	X	-	-	X	-	-	-	X	-
7. OPTICS COORD. X FORMATION (3.6.4.J)	X	X	-	-	X	-	-	-	X	-
8. ZERO OPTICS (3.6.4.K)	2	X	-	-	X	-	-	-	X	-
9. OPTICS POSITIONAL ACCURACY (3.6.4.L)	-	X	-	-	X	-	-	-	1	-
10. OPTICS SLEW RATE (3.6.4.M)	2	X	-	-	X	-	-	-	X	-
11. IRIG SCALE FACTOR (3.6.4.N)	X	X	-	-	X	-	-	-	X	-
12. IMU PERFORMANCE (3.6.4.O)	X	X	-	-	X	-	-	-	X	X
13. FINE ALIGNMENT (3.6.4.X)	-	-	-	-	X	-	-	-	-	-
14. GYRO COMPASSING W/OPT VERIF (3.6.4.Q + R)	-	X	-	-	X	-	-	-	X	X
15. CMC CLOCK FREQUENCY (3.6.4.S)	-	X	-	-	X	-	-	-	X	X
16. TEMP CLOSURE (3.6.4.V)	X	X	-	-	X	-	-	-	-	-

10 MAY 1968
SC - 101

A P O L L O

PAD

15
K-0203 -A

MSOB	VAB				PAD			
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
7	4	3	0	0	3	2	0	4
0	8	4	5	4	3	8	7	7
17. E-MEMORY VERIFICATION (3.6.4.W)	X	X	-	-	X	-	X	-
18. IMU CAGE (3.6.3.M)	-	-	-	X	-	-	-	-
19. MIN IMP TEST (TO CMC) (3.6.3.J)	X	X	-	-	-	-	-	-
20. CMC CLOCK ALIGN (3.6.4.P)	X	X	-	X	X	X	X	-
21. TEMPERATURE CHECK	-	-	-	X	-	X	-	-

NOTES

- PARTIAL TEST
- TEST LIMITED DUE TO CARRY-ON NOT CONNECTED.
- A. STANDBY POWER ON..

CMC POWER APPLICATION,
RECORDING OF POWER
SUPPLY OUTPUTS, AND BUS
CONTINUITY CHECKS.
IMU STANDBY POWER
APPLICATION, RECORDING
OF POWER SUPPLY
OUTPUTS, AND BUS
CONTINUITY CHECKS.
IMU STANDBY TEMPERATURE
CHECKS.
OPTICS EYEPiece HEATER
CHECKS.
CMC SELF TEST.

- B. SHORT G + N ACTIVATION INCLUDES..

CMC POWER APPLICATION
AND RECORDING OF POWER
SUPPLY OUTPUTS.
IMU STANDBY POWER
APPLICATION AND
RECORDING OF POWER
SUPPLY OUTPUTS, CMC

17
K-0203-A

104

P - INDICATES PARTIAL

1. MANUAL CONTROL & POLARITY TEST
(3.6.3.A)
2. CMC INPUT/OUTPUT DISCRETES
(3.6.3.B)
3. FDAI TOTAL ATTITUDE/BACKUP
ATTITUDE ERROR DISPLAY
(3.6.3.C)
4. FDAI TOTAL ATTITUDE/ATT ERROR
(COUNT)
(3.6.3.C)
5. CDC RATES TO CMC
(3.6.3.D)
6. ATTITUDE ERROR DISPLAY
(3.6.3.E)
7. CMC GIMBAL COMMANDS (MOTORS OFF)
(3.6.3.G)
8. G+N THRUST ON
(3.6.3.F)
9. TVC DAP & POLARITY TEST
(3.6.3.H)
10. RCS DAP TEST & POLARITY TEST
(3.6.3.I)
11. MINIMUM IMPULSE TEST ⁴
(3.6.3.J)
12. I.O. INTERFACE TEST & POLARITY TEST
(3.6.3.K + 3.6.4.U + 3.10.5.A.10)
13. ENTRY DAP TEST
(3.6.3.L)
14. ORDEAL
(3.6.3.Q)
15. G+N DOWNLINK
(3.6.3.P)
16. RAMP SPS RESPONSE
(3.6.3.R)
17. G AND N/TVC TEST
(3.6.3.N)
18. UDL TEST
(3.6.3.O)
19. FLIGHT PROGRAM EXERCISE
(3.13)
20. DAP RATE COMMAND
(3.6.3.S)
21. SIM FLIGHT

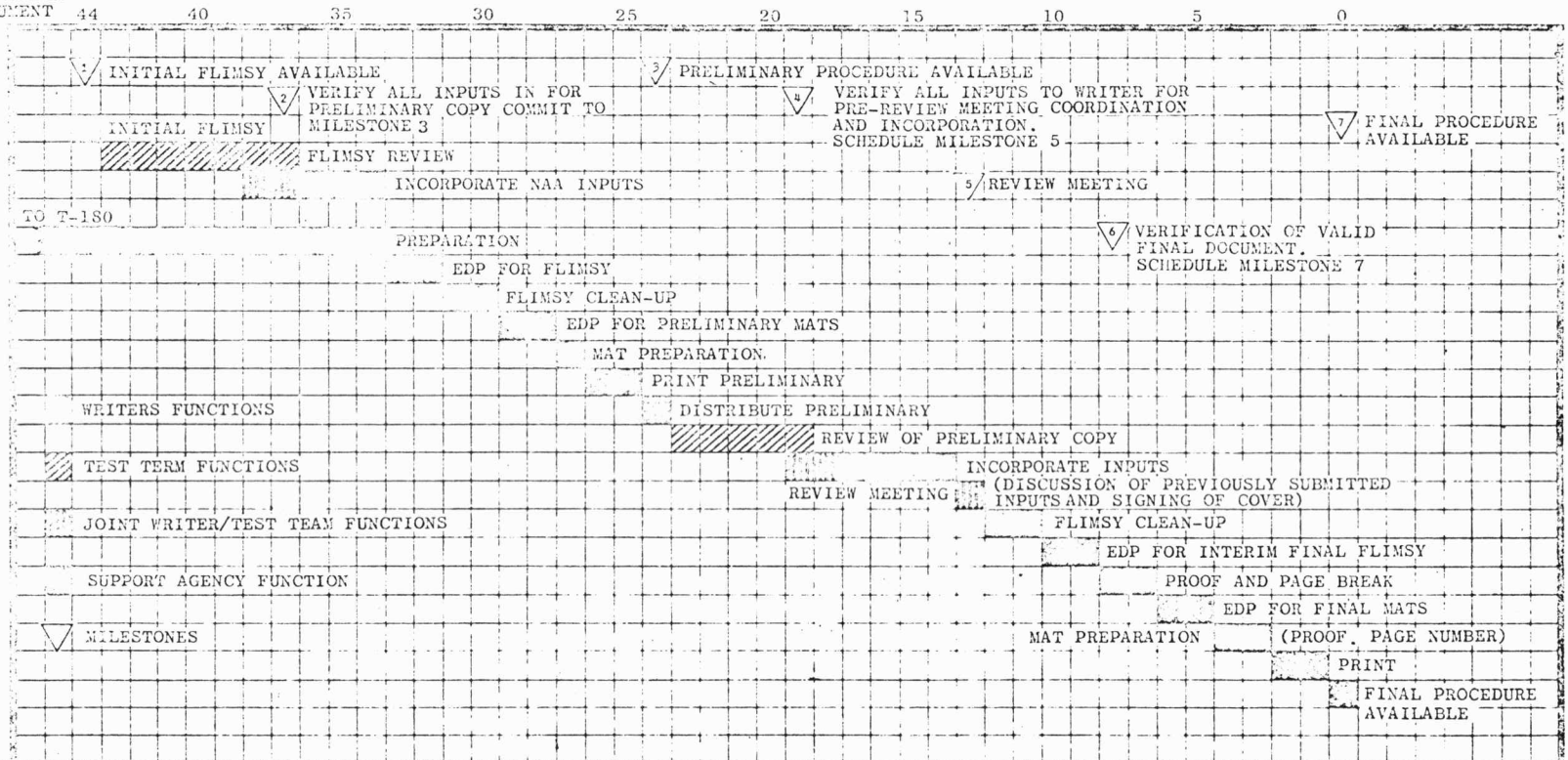
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
7	4	3	0	4	0	0	3	2	0
0	8	4	5	6	4	6	3	8	7
(X)							[P]		
X			X				X		
			X				X		
							X		X
			X						
X			X						
X			X						
			(X)				[]		
			(X)				[]		
X	P	P	X				X		
X	P	P	(X)	(X)			[]		
			(X)				[]		
X	P	P	X				X		
			X						
			X						
			X				X		
			X				P		
			X						
			X						
			(X)	(X)			[X]		


⊗ TESTS TO BE DONE ☐ IF FINAL ROPES
INSTALLED AT FRT/CDDT.

TCP DEVELOPMENT CYCLE
6 DEC 1967

APPROVED TCP CONTROL BOARD 12/6/67

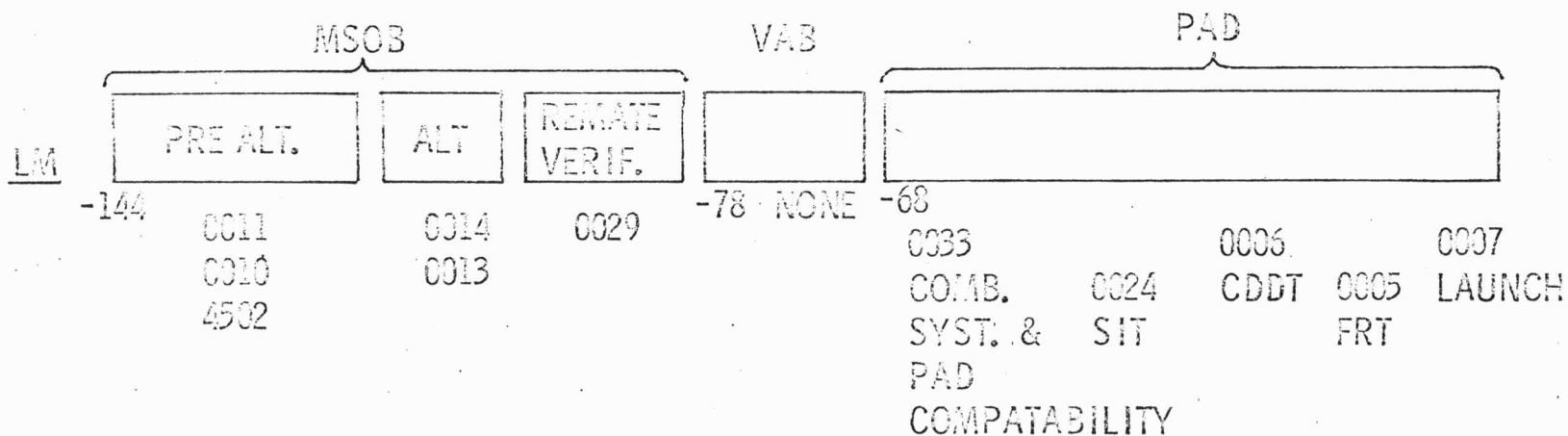
WORKING DAYS PRIOR
TO FINAL DOCUMENT



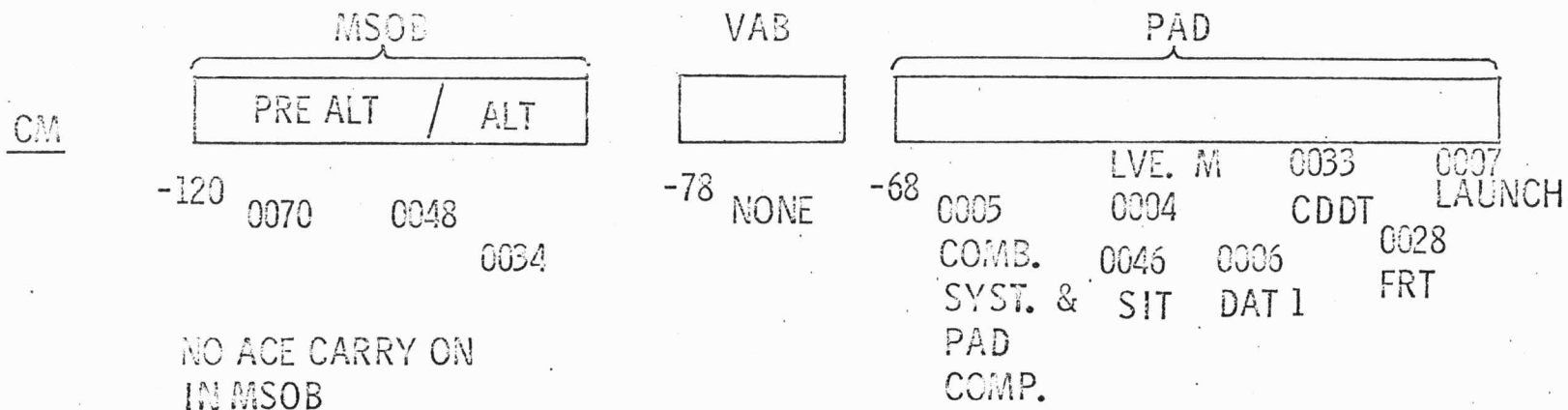
STEP	0	1	2	3	4	5	6	7	8	9		T
DESCRIPTION	NOT STARTED	PREP & INITIAL FLIMSY	FLIMSY REVIEW	DEVELOP PRELIMINARY MATS	PRINT & DIST. PRELIM COPIES	ENGR REVIEW	INCRP ENGR COMMENTS	REVIEW & SIGN	FINAL MAT PREPARATION	PRINT HARD COPIES	AVAIL FOR TEST	
DAYS PRIOR TO TEST		180 ↔ 74	73 ↔ 67	66 ↔ 57	56 ↔ 54	53 ↔ 48	47 ↔ 44	43 ↔ 42	33 ↔ 32	31 ↔ 30	29 ↔ 1	0

TYPICAL FLOW (PRESENT VEHICLES)

503 EXAMPLE



LM HAS ACE CARRY ON FOR PRE ALT TESTS AND AT PAD



MSUB	PAD	
0 4 0 0 0	0 0 0	0 0
0 5 0 0 0	0 0 0	0 0
1 0 1 1 2	3 2 0	0 0
1 2,4 3 9	3 4 6	5,7

AUT FUNCTIONAL PERF.
(3.4.14)

X - - - - - - - - - -

E MEMORY RETENTION

X - - - - - - - - - -

E MEMORY FLT LOAD/VER-AGE

- - - - - - - X - - X

G AND N INTERFACE/INTEGRATED CHECKOUT

PGNS/CES INTERFACE
(3.4.16)

X - P P P X - X X X

PGNS POLARITY (RCS/TVC)

(X) - - - - - - - - - -

PGNS/RADAR INTERFACE
(3.5.4)

X - - - P - - - - -

SIN. FLIGHT
(3.15)

(X) - - - - - - - - - -

PGNS MATED SYSTEMS C/O

X - - - - X - - X -

PGNS STAGED SYSTEMS C/O

X - - - - X - - X -

PGNS/CWEA JET LOGIC C/O
(3.12.4)

- X - - - X - - X -

PGNS/DISPLAYS INTERFACE C/O
(3.4.16)

X - P P - X - - X -

PGNS/AGNCS INTERFACE CHECKS
(3.7.4)

X - P P - X - X X X

DEA/LCC INTERFACE C/O
(3.11.4)

X - X X - X - X X X

G AND N SUPPORT

VALVE SIGNATURE SUPPORT
(3.8.2)

- X - - - - - - - X -

RADAR SUPPORT

X - X X X X - X X X

ALTITUDE CHANGER SUPPORT
(3.4.17)

- - X X - X - - - -

MATRIX 4
PGNCS TEST MATRIX

MSOB	VAB		PAD	
	PAD			
0 4 0 0 0	0 0 0	0 0	0 0	
0 5 0 0 0	0 0 0	0 0	0 0	
1 0 1 1 2	3 2 0	0 0	0 0	
1 2 4 3 9	3 4 6	5 7		

G AND N S/S FUNCTIONAL TEST SEQ.

GENERAL TURN-ON
IHU STANDBY
(3.4.1)

- X X X X - X X - X
X - X - - X - X X X

ALARMS AND INTERRUPTS
(3.4.2)

X - - - - X - X X X

IHU OPERATE
(3.4.3)

X - - - - X - X X X

TEMP CONTROL VERIF
(3.4.3)

X - - - - X - P X P

POWER SUPPLIES CHECK
(3.4.4)

X - P P X - X X X X

G AND N OPERATIONAL TEST
(3.4.5)

X - X - X X X X X X

SEMI AUTO MODE
(3.4.6)

X - - - - X - - X -

IRIG SCALE FACTOR
(3.4.7)

X - - - - X - - X -

IHU PERFORMANCE
(3.4.8)

X - - - X X - X X X

LGC VOLTAGE MARGIN
(3.4.9)

X - - - - X - - X -

LGC CLOCK FREQ.
(3.4.10)

X - - - - X - X X X

GIMBAL FRICTION
(3.4.11)

X - - - - - - - X -

STAB LOOP RESPONSE
(3.4.12)

X - - - - X - - X -

FINE ALIGNMENT TEST
(3.4.13)

X - - - - X - - - -

Rope Change Impact on Spacecraft Tests

A. GEN System tests

1. Small Procedural changes
2. Reassembly of K's & E Memory PROG
3. Rope Change not cause of Rerun

B. Interface & Integrated Tests

1. Can cause large procedural changes
2. " " Redesign of Sim Flight
3. New K's tapes Required
4. Some Retests Required (Polarity)?

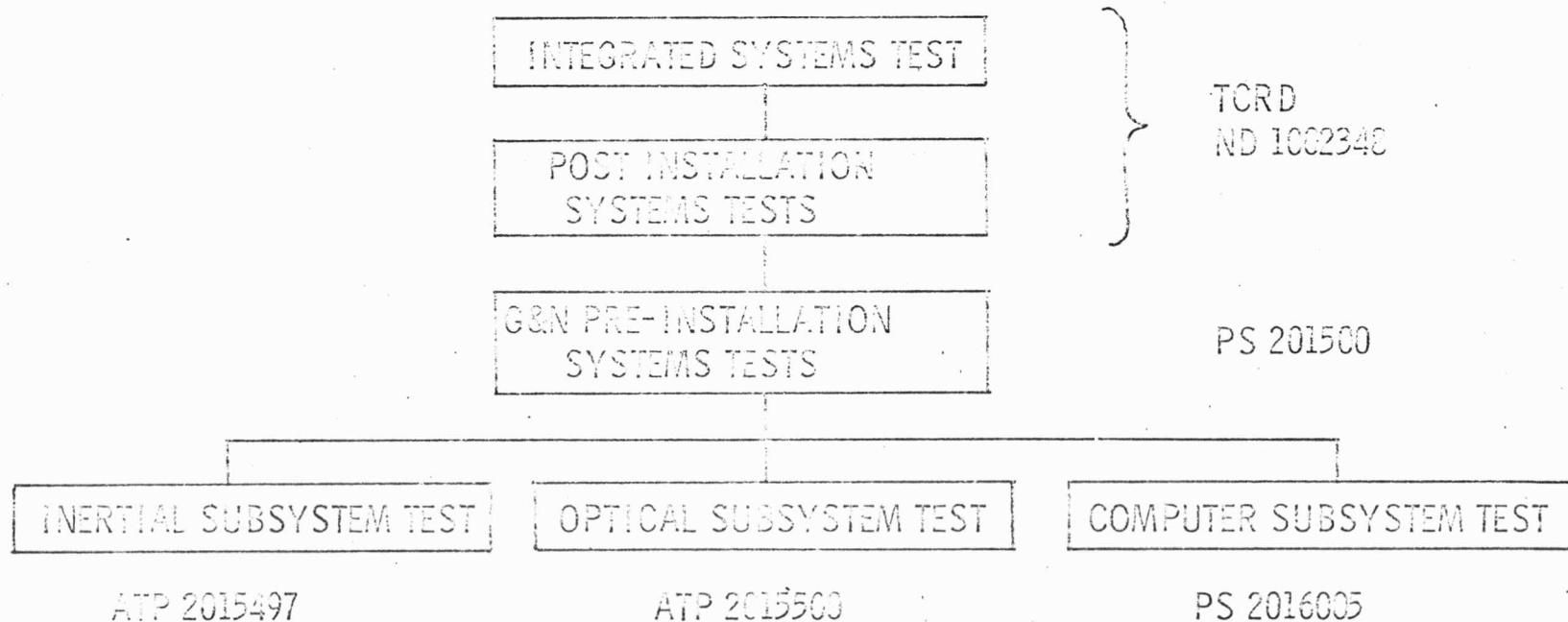
C. Software Integration Tests

1. Retest Required

D. ACE PROGRAMS

1. Downlink.

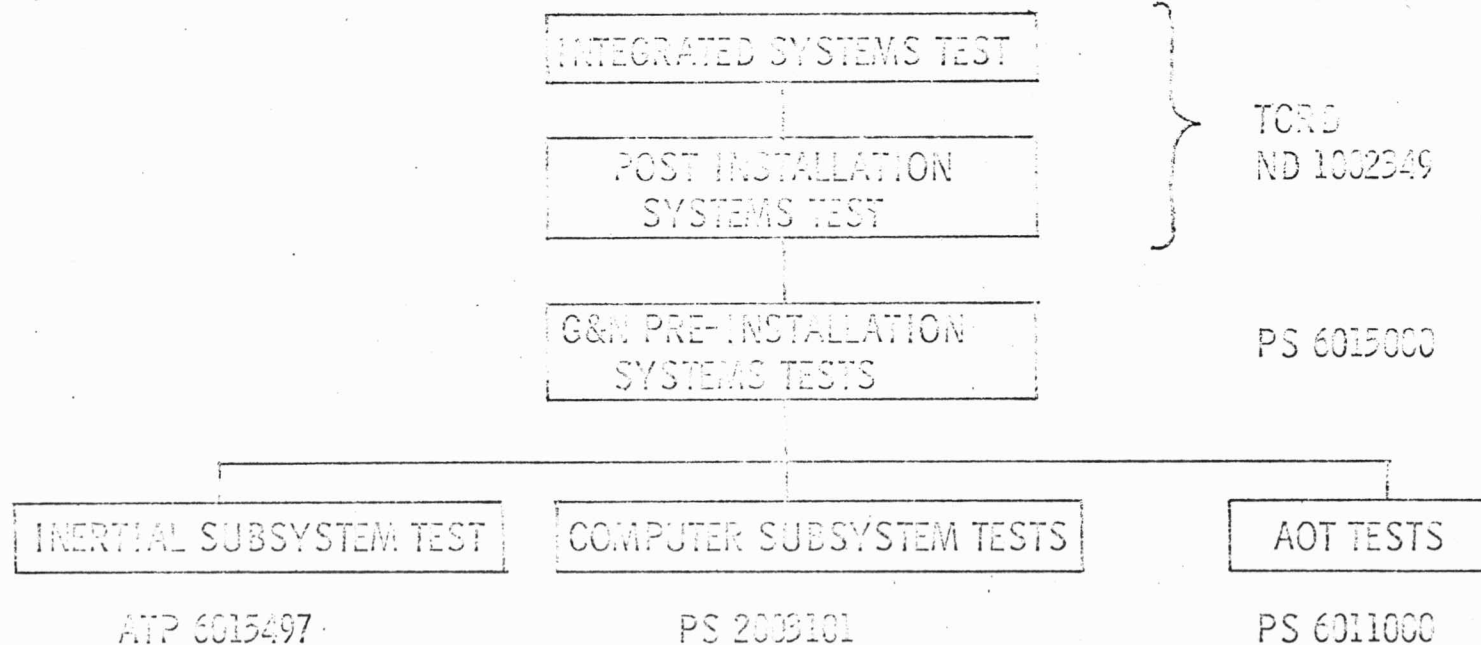
TEST SPECIFICATIONS - CM



THE G&N SYSTEM TEST SPECIFICATION IS THE MEI - MASTER END ITEM DETAIL SPECIFICATION.

PART 2 OF THE MEI ESTABLISHES DETAILED TEST REQUIREMENTS, ESTABLISHES TOLERANCES AND SPECIFIES TEST PROCEDURES.

TEST SPECIFICATIONS - LM



THE PGNC'S SYSTEM TEST SPECIFICATION IS THE
MEI - MASTER END ITEM DETAIL SPECIFICATION.

PART 2 OF THE MEI ESTABLISHES DETAILED REQUIRE-
MENTS, ESTABLISHES TOLERANCES AND SPECIFIES
TEST PROCEDURES.

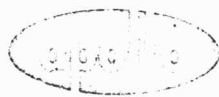
TEST METHOD DESIGN OBJECTIVES

1. DEPEND ON FEW EXTERNAL STIMULI.
2. SIMPLIFY PROCEDURES.
3. REDUCE TEST TIME.



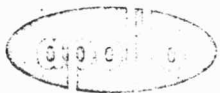
TEST METHODS

1. USE GRAVITY REACTION ACCELERATION AS REFERENCE FOR INERTIAL PLATFORM AND ACCELEROMETER CALIBRATION AND END TO END SYSTEM TESTS.
2. USE PRE-DETERMINED AUTOMATIC COMMAND SEQUENCES UTILIZING ACE UPLINK COMMAND CAPABILITY.
3. USE AGC/LGC CAPABILITIES FOR SYSTEM MODING AND IMU DATA PROCESSING UNDER AGC/LGC PROGRAM CONTROL.
4. SEQUENCE TESTS TO MINIMIZE RE-TEST TIME.

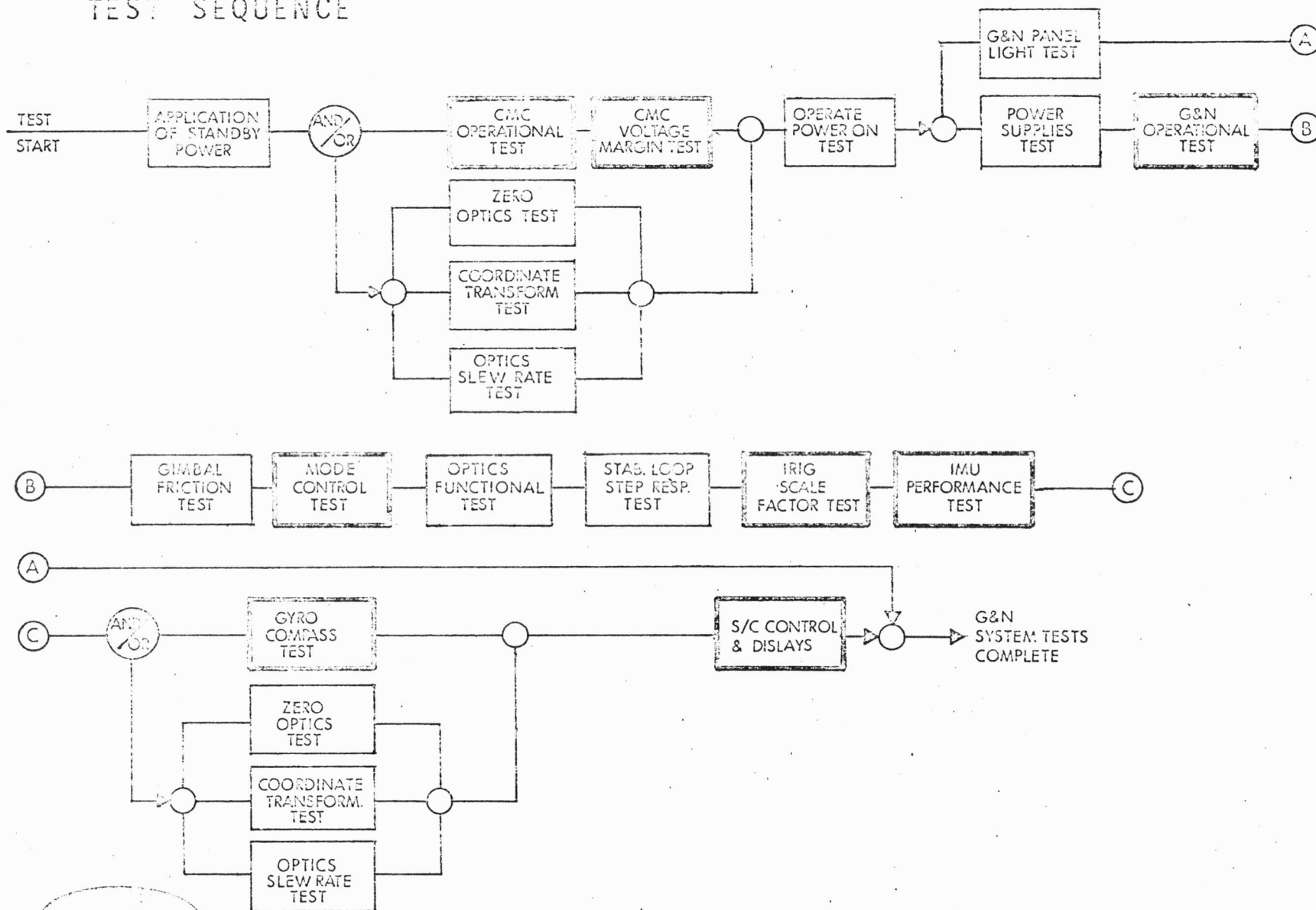


SYSTEM TEST CATEGORIES

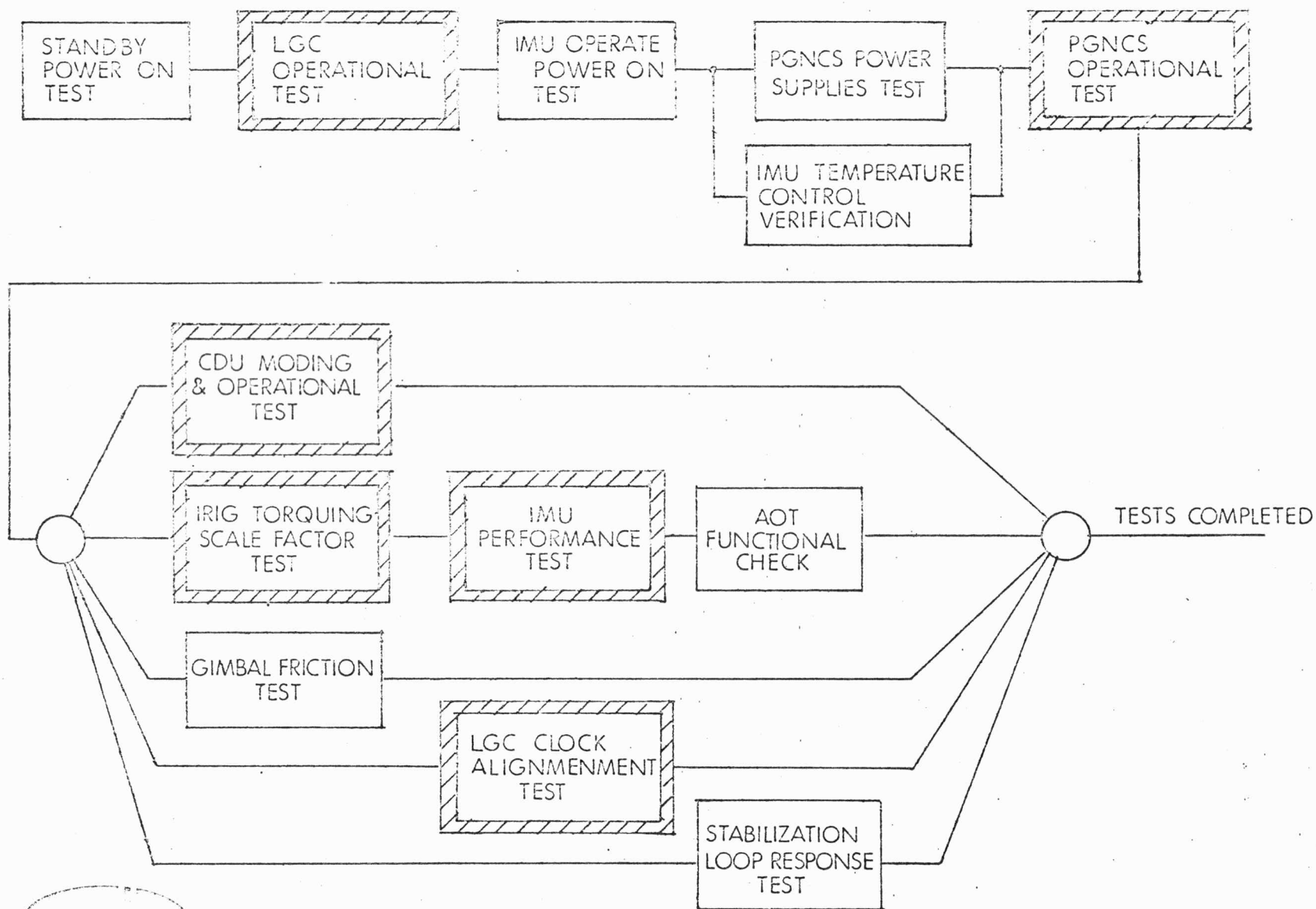
1. INTERFACE SIGNAL TESTS FOR S/C INTERFACES.
2. FUNCTIONAL TEST OF G&N SUBSYSTEM INTERFACES.
3. FUNCTIONAL TEST OF G&N OPERATIONAL MODES.
4. TEST FOR DEGRADATION, WEAR AND PERFORMANCE UNDER VOLTAGE MARGINS.
5. PERFORMANCE TESTS.



CM. G&N INDIVIDUAL SYSTEMS TEST SEQUENCE



TEST PROCEDURE FLOW - LM PGNC



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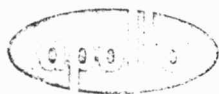
DETAILED AGC/LGC PROGRAM REQUIREMENTS FOR G&N SYSTEM TESTS

<u>TEST</u>	<u>TYPE OF PROGRAM</u>	<u>TEST PROCEDURE</u>
1. AGC/LGC fixed and erasable memory test	Fixed memory, flyable	Manual
2. AGC/LGC instruction check	Erasable memory loaded, nonflyable	K-START controlled K-START tape by ACE
3. AGC/LGC DSKY check	Erasable memory loaded, nonflyable	K-START controlled K-START tape by ACE
4. IRIG torquing scale factor	Erasable memory loaded, nonflyable	K-START controlled K-START tape by MIT
5. Gyro drift and accelerometer error measurement	Partially fixed memory, partially erasable.	K-START controlled Tape by MIT
6. CDU operational modes check	Erasable memory program by ACE nonflyable	K-START controlled Tape by ACE
7. IMU operational test	Erasable memory program by ACE	K-START controlled Tape by ACE
8. Semi-automatic interface and display test	Erasable memory program by ACE	K-START controlled Tape by ACE
9. AGS-IMU mechanical alignment test LM only.	Partially fixed memory, partially erasable.	K-START controlled Tape by MIT

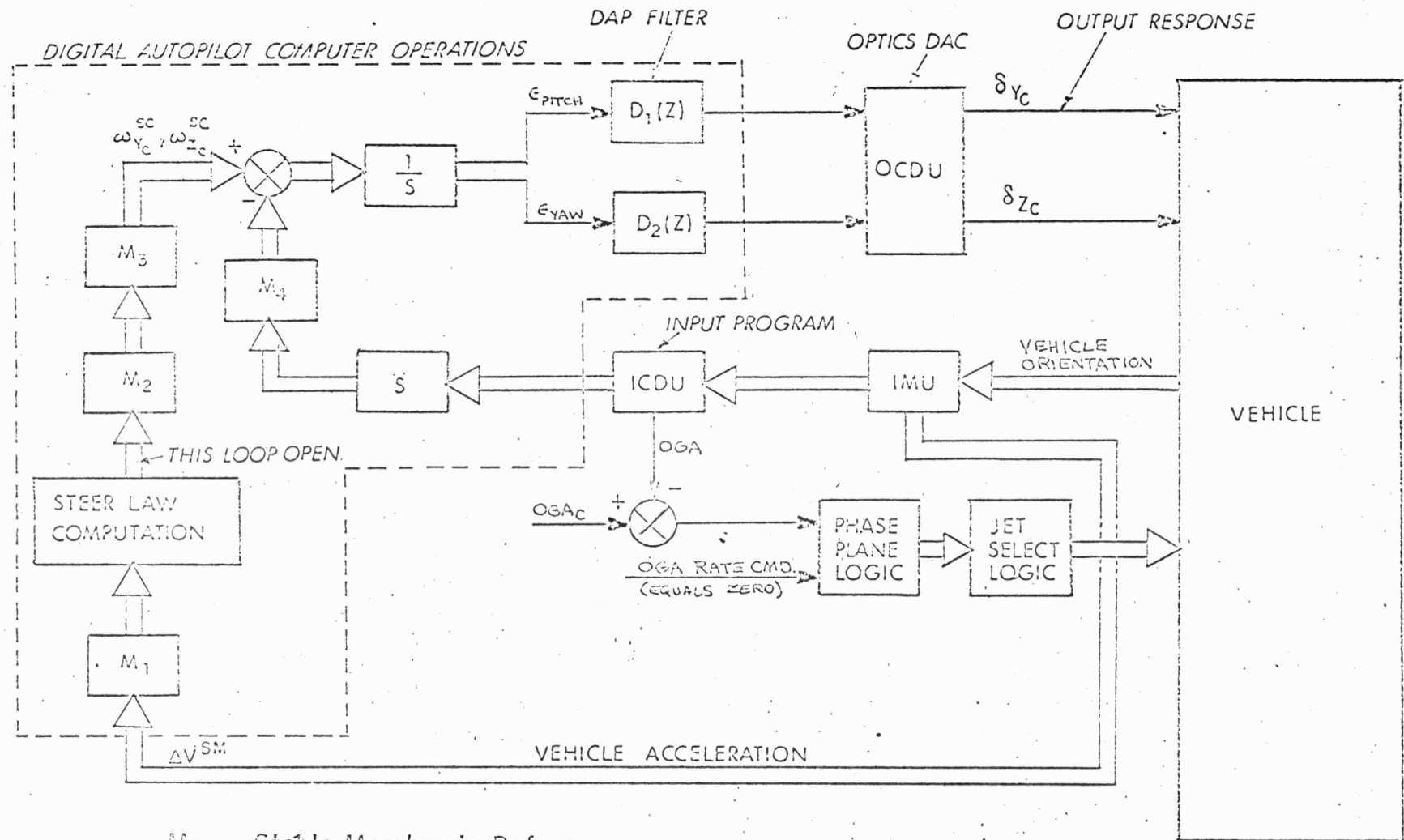


COMPROMISES AND TRADEOFFS AFFECTING SYSTEM TESTING

1. COMPROMISES AND TRADEOFFS MADE IN GENERATING THE SPECIFICATION.
2. NOMINAL VOLTAGE AND NOISE ENVIRONMENT CHOSEN FOR MOST TESTING EVEN THOUGH SPECIFICATION TOLERANCES COVER A RANGE OF VOLTAGES.
3. PERFORMANCE PARAMETERS FOR IN-FLIGHT COMPENSATION MEASURED IN THE SPACECRAFT WITH DEGRADED ACCURACY INSTEAD OF CONDUCTING LABORATORY TESTS IMPLYING REMOVAL OF IMU.
4. SYSTEM TESTS LIMITED TO END TO END TYPE TESTING AND SINGLE POINT SIGNAL CHECKS.
5. LOWER LEVEL SUBSYSTEM TESTS ARE DEPENDED UPON FOR EXACT IDENTIFICATION OF DEGRADATION OR FAILURE. LOWER LEVEL TESTS REQUIRED FOR TROUBLESHOOTING.



BLOCK DIAGRAM OF TVC DIGITAL AUTOPILOT



- M₁ : Stable Member to Reference
- M₂ : Reference to Stable Member
- M₃ : Stable Member to Spacecraft
- M₄ : Gimbal to Spacecraft

RESPONSIBLE CONTRACTOR	TEST NAME	S/C 101													
		EARTH RATE TO IMU-CDU'S	GRAVITY TO PIPA'S	CMC TO RCS JETS	CMC TO SPS SERV AMP'S	CMC TO SLVS IU	CMC I/O DISCRETES	RHC THC MIC	HAND CONTROLLERS	GDC RATES TO CMC	FDAI TOTAL ATTITUDE	UPLINK	DOWNLINK	VHF RANGING (NOT FOR SC101)	
(MIT)	TVC DAP TEST	X	X		X		X				X	X			
(MIT)	RCS DAP TEST	X		X		X		X			X	X			
(MIT)	RAMP SPS RESPONSE TEST		X		X		X				X	X			
(MIT)	DAP RATE COMMAND TEST			X		X		X			X	X			
(MIT)	SIMFLITE	X	X	X	X	X	X	X	X	X	X	X			
(NR)	MANUAL CONTROL TEST			X		X		X	X		X	X			
(NR)	CMC INPUT / OUTPUT DISCRETES TEST					X					X				
(NR)	FDAI TOTAL ATTITUDE / BACKUP ATTIT. ERROR DISPLAY TEST					X				X	X				
(NR)	GDC RATES TO CMC TEST					X				X	X				
(NR)	ATTITUDE ERROR DISPLAY TEST					X	X				X				
(NR)	CMC GIMBAL COMMANDS (MOTORS OFF) TEST			X		X					X				
(NR)	G&N THRUST ON TEST					X					X				
(NR)	MINIMUM IMPULSE TEST		X			X			X		X				
(NR)	G&N TVC TEST					X					X				
(NR)	ORDEAL TEST					X					X				
(NR)	IU INTERFACE TEST				X	X	X				X				
(NR)	FDAI TOTAL ATTITUDE / ATTIT. ERROR DISPLAY TEST					X	X			X	X				

RESPONSIBLE CONTRACTOR	S/C 101 TEST NAME	MSOB		PAD 34						
		0048	0034	0005	0004	0006	0021	0033	0028	0007
(MIT)	TVC DAP TEST		X							
(MIT)	RCS DAP TEST		X							
(MIT)	RAMP SPS RESPONSE TEST		X							
(MIT)	DAP RATE COMMAND TEST		X							
(MIT)	SIMFLITE		X		X	X		X		
(NR)	MANUAL CONTROL TEST	X	X					X		
(NR)	CMC INPUT/OUTPUT DISCRETES TEST	X	X					X		
(NR)	FDIA TOTAL ATTITUDE/EACKUP ATTIT. ERROR DISP. TEST	X	X					X		
(NR)	GDC RATES TO CMC TEST	X	X					X		
(NR)	ATTITUDE ERROR DISPLAY TEST	X	X					X		
(NR)	CMC GIMBAL COMMANDS (MOTORS OFF) TEST	X	X					X		
(NR)	G&N THRUST ON TEST	X	X					X		
(NR)	MINIMUM IMPULSE TEST	X	X					X		
(NR)	G&N TVC TEST	X	X					X		
(NR)	ORDEAL TEST	X	X					X		
(NR)	IU INTERFACE TEST	X	X	X	X					
(NR)	FDAI TOTAL ATTIT./ATTIT. ERROR DISPLAY TEST						X		X	

"SIM FLIGHT"

INTRODUCTION

BACKGROUND

GROUND RULES

TYPICAL MISSION PROFILE

LAUNCH PAD ENVIRONMENT

"COAXING" PHILOSOPHY

HISTORY

OBJECTIVES

CONTROL SYSTEM TESTING

DATA LINK EXERCISES

INTERFACE EXERCISES

SUPPORT/IDENTIFY OTHER TESTS

SUMMARY

APPENDIX

APPENDIX

PRIMARY OBJECTIVES

ADDITIONAL OBJECTIVES

GROUND RULES

PRESENT "COAXING" CAPABILITIES

PRESENT "COAXING" TECHNIQUES

ALTERNATE "COAXING" TECHNIQUES

RE-EVALUATION

PROGRAM SUMMARY - COLOSSUS (SUNDISK)/LUMINARY (SUNDANCE)

ROUTINE SUMMARY - COLOSSUS (SUNDISK)/LUMINARY (SUNDANCE)

SUNDISK PROGRAM/INTERFACE RELATIONSHIPS

SIM. FLIGHT PROGRAM SUMMARY - SUNDISK

PRIMARY OBJECTIVES

AT KSC

SOFTWARE/HARDWARE COMPATIBILITY VERIFICATION
(FLIGHT SOFTWARE/FLIGHT CREW/G&N/SPACECRAFT/
BOOSTER/GROUND)

Engine throttle & gimbal activity (DAP)
RCS Jet Activity (DAP)
FDAI Attitude and attitude error displays (DAP)
S4B Steering Signals when applicable (DAP)

Normal ground updates & fails
Real time commands
Aborts
Normal downlink

In bits (Liftoff, S4B sep., Ullage, Stage Verify, etc.)
Out bits (Engine ON/OFF, CM/SM Sep., etc.)
Alarms (Caution & Warning, Program)
S/C Switch Activity (G&N, SCS, etc.)
Astronaut Interfaces (DSKY, Hand Controllers, mark, etc.)
Inertial (Discrete & Analog)
Optics (Discrete & Analog)
Radar (Discrete & Analog)
S/C Power
EMC

SUPPORT/IDENTIFY OTHER FLIGHT ROPE CONTROLLED
TESTS

Integrated Flight Control Tests
Polarity Tests
MSC/Spacecraft Interface Tests

MACROSCOPIC VERIFICATION OF SYSTEM OPERATION &
MODING, PROCEDURES, TIMING, DISPLAYS, SIMULATIONS,
CONVENTIONS, MODELS, ETC.

ENHANCE GENERAL UNDERSTANDING OF FLIGHT SOFTWARE
AND ITS INTERACTION WITH FLIGHT CREW/G&N/SPACECRAFT/
BOOSTER/GROUND

ADDITIONAL OBJECTIVES

AT MIT

SOFTWARE/HARDWARE COMPATIBILITY VERIFICATION (FLIGHT SOFTWARE/FLIGHT CREW/G&N)

System/Flight Software Operations and Moding

System and Flight Software Alarms

System and Flight Software Polarities

Ground Updates, RTCs, and Aborts

DSKY Displays and Operations

Signal Interfaces (Discrete and Analog)

Restart Protection, G&N fails, Off-nominal
Options

Symptomatic Problem Diagnosis via CRS

GSOP/FLIGHT CREW CHECKLIST/ERASABLE LOAD VERI- FICATION

AT NAR/GAEC

SOFTWARE/HARDWARE COMPATIBILITY VERIFICATION (FLIGHT SOFTWARE/G&N/SPACECRAFT)

AT MSC

SOFTWARE/HARDWARE COMPATIBILITY VERIFICATION (FLIGHT SOFTWARE/FLIGHT CREW/G&N/GROUND)

GROUND RULES

EXERCISE ACTUAL FLIGHT SOFTWARE/HARDWARE VIA
NOMINAL CREW CHECKLIST

PRESERVE NOMINAL FLIGHT SOFTWARE/HARDWARE
ACTIVITY PATTERNS

UTILIZE SENSED ACCELERATION (1G) IN STEER LOOPS

REQUIRE NO CHANGES TO FLIGHT SOFTWARE

REQUIRE NO INTERFERENCE WITH FLIGHT HARDWARE

OPERATE TEST VIA DSKY AND UP AND DOWNLINKS ONLY

PROVIDE FLEXIBLE KSC/MSD TEST PROCEDURES

AVOID TESTING OF A SOFTWARE VERIFICATION, HARD-
WARE CALIBRATION, OR CREW TRAINING NATURE

PRESENT "COAXING" CAPABILITIES

DO:

Satisfy the Objectives and Ground Rules Previously Delineated

Provide Predictable Acceleration Profiles

Provide Predictable Attitude Profiles

Provide Periods With Predictable, Unsaturated Attitude (Error) Signals

Provide Nominal Discrete Displays (Spacecraft and Ground)

Provide Nominal Star, Landmark, LM, and CSM Optical/Radar Acquisition

Generally Avoid Sensitivity to Operational Timeline Changes

DO NOT:

Provide Nominal Acceleration Profiles

Provide Nominal Attitude Profiles

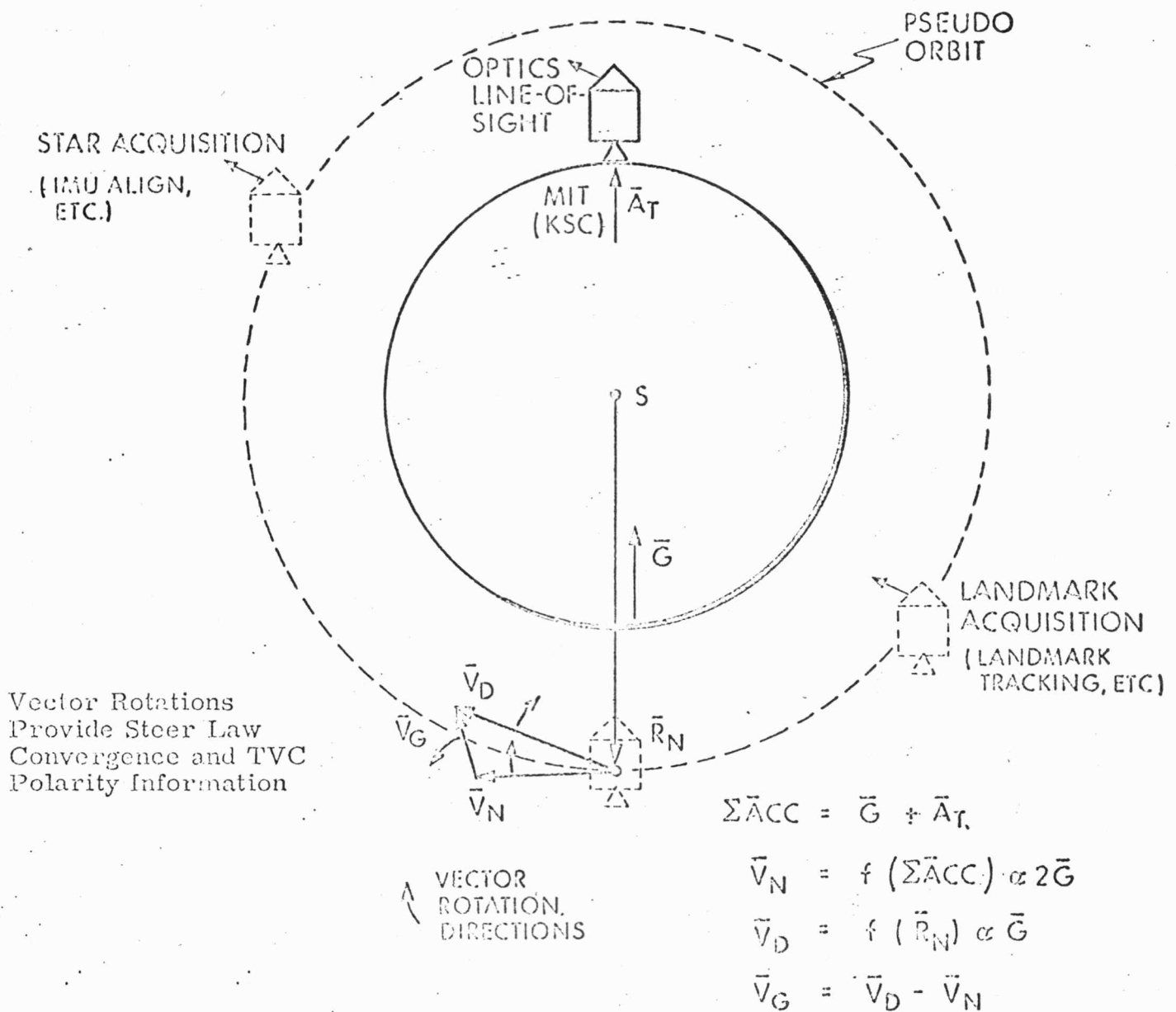
Always Avoid Saturated Attitude (Error) Signals

Provide Nominal Analog Displays (Spacecraft Or Ground)

Provide Nominal Star, Landmark, LM, and CSM Optical/Radar Tracking

Always Avoid Sensitivity to Operational Timeline Changes

PRESENT "COAXING" TECHNIQUES



ALTERNATE "COAXING" TECHNIQUES

PROVIDE NOMINAL ACCELERATION PROFILES

- Vary IMU Compensation Parameters
- Load PIPA Counter Registers with Acceleration Profiles
- Torque Gyros And/Or Gimbals and Above
- Vary NBSM Transformation Matrix and Above

PROVIDE NOMINAL ATTITUDE PROFILES

- Torque Gyros And/Or Gimbals
- Vary NBSM Transformation Matrix
- Load DAP Source of Attitude Error

ALWAYS AVOID SATURATED ATTITUDE (ERROR) SIGNALS

- Satisfy Acceleration and Attitude Profiles
- Intercept Signals Before DAP, Output Channels, or Jets/Gimbals
- Adjust Erasable Initialization (Wts, DAP Configuration, Etc.)

PROVIDE NOMINAL ANALOG DISPLAYS (SPACECRAFT OR GROUND)

- Satisfy Acceleration and Attitude Profiles

PROVIDE NOMINAL STAR, LANDMARK, LM, AND CSM OPTICAL/ RADAR TRACKING

- Provide Moving External Targets

ALWAYS AVOID SENSITIVITY TO OPERATIONAL TIMELINE CHANGES

- Satisfy Acceleration and Attitude Profiles
- Provide Real Time Retargeting
- Rotate Platform
- Rotate Refsmmat
- Use Table of State Vectors, Targets, Etc.
- Adjust Computer Clock

RE-EVALUATION

INDICATION OF A SINGLE SOURCE OF DIRECTION

REVIEW AND AGREEMENT ON GROUND RULES AND OBJECTIVES AMONG NASA/NAR/GAEC/MIT AT MSC/KSC/MSFC/DOWNEY/BETHPAGE/CAMBRIDGE

INDICATION OF RESULTANT TEST REQUIREMENTS BY ABOVE SOURCE OF DIRECTION

INDICATION OF ALTERNATIVE METHODS OF IMPLEMENTING TEST REQUIREMENTS; RELATIVE COMPLEXITY, COST, ETC. BY THOSE RESPONSIBLE FOR DETAILED TEST DESIGN

REVIEW OF TEST REQUIREMENTS AND ALTERNATE METHODS OF IMPLEMENTATION AND DIRECTION FROM ABOVE SOURCE

PROGRAM SUMMARY

COLOSSUS

*00 CMC Idling
 *01 Prelaunch Initialization
 *02 Gyro Compassing
 *03 Optical Verification of Gyrocompass
 **05 GNCS Start Up
 *06 GNCS Power Down

 *11 Earth Orbit Insertion (EOI) Monitor
 15 Translunar Injection (TLI)
 17 Transfer Phase Initiation (TPI) Search

 *20 Rendezvous Navigation
 *21 Ground Track Determination
 *22 Orbital Navigation
 *23 Cis Lunar Midcourse Navigation
 *27 CMC Update

 *30 External ΔV
 31 General Lambert Maneuver
 *34 Transfer Phase Initiation (TPI)
 *35 Transfer Phase Midcourse (TPM)
 37 Return to Earth (RTE)
 38 Stable Orbit Rendezvous (SOR)
 39 Stable Orbit Midcourse (SOM)

 *40 SPS
 *41 RCS
 *47 Thrust Monitor

 *51 IMU Orientation Determination
 *52 IMU Realign
 *53 Backup IMU Orientation Determination
 *54 Backup IMU Realign

 *61 Maneuver to CM/SM Separation Attitude
 *62 CM/SM Separation & Pre-Entry Maneuver
 *63 Entry-Initialization
 *64 Entry-Post 0.05 G
 65 Entry-Up Control
 66 Entry-Ballistic
 *67 Entry-Final

 *74 LM TPI Targeting
 *75 LM TPM Targeting
 77 LM TPI Search
 78 LM SOR Targeting
 79 LM SOM Targeting

LUMINARY

*00 LGC Idling
 *06 PGNCS Power Down

 10 Predicted Launch Time (CFP)
 11 Predicted Launch Time (DT)
 12 Powered Ascent Guidance

 *20 Rendezvous Navigation
 *21 Ground Track Determination
 22 Lunar Surface Navigation
 *25 Preferred Tracking Attitude
 *27 LGC Update

 *30 External ΔV
 31 General Lambert Maneuver
 *32 Co-Elliptic Sequence Initiation (CSI)
 *33 Constant Delta Altitude (CDH)
 *34 Transfer Phase Initiation (TPI)
 *35 Transfer Phase Midcourse (TPM)
 38 Stable Orbit Rendezvous (SOR)
 39 Stable Orbit Midcourse (SOM)

 *40 DPS
 *41 RCS
 *42 APS
 46 LM/CSM Separation Monitor
 *47 Thrust Monitor

 *51 IMU Orientation Determination
 *52 IMU Realign
 57 Lunar Surface Align

 63 Landing - Braking
 64 Landing - Approach
 65 Landing - Automatic
 66 Landing - Rate of Descent (ROD)
 67 Landing - Manual

 70 DPS Abort
 71 APS Abort
 *72 CSM CSI Targeting
 *73 CSM CDH Targeting
 *74 CSM TPI Targeting
 *75 CSM TPM Targeting
 78 CSM SOR Targeting
 79 CSM SOM Targeting

*SUNDISK

**SUNDISK only

*SUNDANCE

ROUTINE SUMMARY

COLOSSUS

*00 Final Automatic Request Terminate
*02 IMU Status Check
*03 Digital Autopilot Data Load
05 S-Band Antenna

*21 Rendezvous Tracking Sighting Mark
*22 Rendezvous Tracking Data Processing
23 Backup Rend. Track. Sighting Mark
24 Backup Rend. Track. Data Processing

*30 Orbit Parameter Display
*31 Rendezvous Parameter Display #1
*32 Target Delta V
33 CMC/LGC Clock Synchronization
*34 Rendezvous Parameter Display #2
35 Lunar Landmark Selection
36 Out of Plane Rendezvous Display

*50 Coarse Align
**51 Fine Align
*52 Automatic Optics Positioning
*53 Sighting Mark
*54 Star Data Test
*55 Gyro Torquing
*56 Alternate LOS Sighting Mark
57 Optics Calibration

*60 Attitude Maneuver
*61 Preferred Tracking Attitude
*62 Crew-Defined Maneuver
*63 Rendezvous Final Attitude

LUMINARY

*00 Final Automatic Request Terminate
*02 IMU Status Check
*03 Digital Autopilot Data Load
*04 RR/LR Self-Test
05 S-Band Antenna

10 Landing Analog Displays
11 Abort Discretes Monitor
12 LR Data Read
13 Landing Auto Modes Monitor

*21 RR Designate
*22 RR Data Read
*23 RR Manual Acquisition
*24 RR Search
*25 RR Monitor

*30 Orbit Parameter Display
*31 Rendezvous Parameter Display
*32 Target Delta V
*33 CMC/LGC Clock Synchronization
*36 Out of Plane Rendezvous Display

*47 AGS Initialization

*50 Coarse Align
*51 Inflight Fine Align
*52 Automatic Optics Positioning
*53 Inflight Sighting Mark
*54 Star Data Test
*55 Gyro Torquing
59 Lunar Surface Sighting Mark

*60 Attitude Maneuver
*61 Preferred Tracking Attitude
*62 Crew-Defined Maneuver
*63 Rendezvous Final Attitude

*77 Landing Radar Spurious Test

* SUNDISK

* SUNDANCE

** SUNDISK only

SUNDISK PROGRAM/INTERFACE RELATIONSHIPS

FLIGHT SOFTWARE/FLIGHT CREW/G&N/SPACECRAFT/
BOOSTER/GROUND

(None)

FLIGHT SOFTWARE/FLIGHT CREW/G&N/SPACECRAFT/
BOOSTER

(P11)

FLIGHT SOFTWARE/FLIGHT CREW/G&N/SPACECRAFT/
GROUND

(P27)

FLIGHT SOFTWARE/FLIGHT CREW/G&N/SPACECRAFT

(P05, 06, 20, 40, 41, 61, 62, 63, 64, 67)

FLIGHT SOFTWARE/FLIGHT CREW/G&N

(P01, 02, 03, 22, 23, 47, 51, 52, 53, 54)

FLIGHT SOFTWARE/FLIGHT CREW

(P00, 21, 30, 34, 35, 74, 75)

NOTES:

- 1) Ground (Above) Does Not Include Receipt and Handling of Downlink As This Always Is Available
- 2) Switch Settings, S/C Power, and Clock Settings Are Not Considered Under Spacecraft (Above) As These Are Always Obtainable.

--SIM.FLIGHT PROGRAM SUMMARY--

PRELAUNCH (15 MIN)

01 - PRELAUNCH INITIALIZATION

02 - GYROCOMPASSING

03 - OPTICAL VERIFICATION OF GYROCOMPASSING

BOOST (10 MIN)

11 - EARTH ORBIT INSERTION MONITOR

* INERTIALIZATION (20 MIN)

06 - GNCS POWER DOWN

05 - GNCS START UP

51(53) - IMU (BACKUP) ORIENTATION DETERMINATION

52(54) - IMU (BACKUP) REALIGN

ORBITAL UPDATE (10 MIN)

27 - CMC UPDATE

21 - GROUND TRACK DETERMINATION

00 - CMC IDLING

* NAVIGATION (15 MIN)

22 - ORBITAL NAVIGATION

23 - CISELUNAR MIDCOURSE NAVIGATION

* RENDEZVOUS (20 MIN)

20 - RENDEZVOUS NAVIGATION

34(74) - CM(LM) TRANSFER PHASE INITIATION TARGETING

35(75) - CM(LM) TRANSFER PHASE MIDCOURSE TARGETING

THRUST (15 MIN)

30 - EXTERNAL DELTA V TARGETING

40(41) - SPS(RCS)

47 - THRUST MONITOR (SCS)

ENTRY (10 MIN)

61 - MANEUVER TO CM/SM SEPARATION ATTITUDE

62 - CM/SM SEPARATION AND PRE-ENTRY MANEUVER

63 - ENTRY - INITIALIZATION

64 - ENTRY - POST 0.05G

67 - ENTRY - FINAL

* OPTIONAL

Software Test Facilities

Test Facility	Guidance Programs	ENVIRONMENT	Use
Engineering Simulations (360)	<ul style="list-style-type: none"> • MAC Language • Developmental 	<ul style="list-style-type: none"> • Engineering Judgement 	<ul style="list-style-type: none"> • Develop Theory and Algorithms
Engineering Simulation System ($\frac{1}{10}$ - 2 Real Time -360)	<ul style="list-style-type: none"> • MAC Language • Based on GSOP • Sequence as in AGC 	<ul style="list-style-type: none"> • Complete ENVIRONMENT • High Fidelity MAC Model • Analog Interfaces 	<ul style="list-style-type: none"> • Development • Test Criteria • Mission Analysis • Post Flight Analysis
BIT/BIT Simulation System (2 - 15 Real Time -360)	<ul style="list-style-type: none"> • AGC Language • BIT/BIT Simulated AGC 	<ul style="list-style-type: none"> • Complete ENVIRONMENT • Very High Fidelity MAC Model • Exact Interfaces 	<ul style="list-style-type: none"> • Primary AGC Language dev. facility
Hybrid Simulation System (Real Time-Digital/Analog)	<ul style="list-style-type: none"> • AGC Language • Real AGC with CRS 	<ul style="list-style-type: none"> • Complete ENVIRONMENT • High Fidelity Analog/Digital/Model • Real DSKY, Displays and Operating Controls 	<ul style="list-style-type: none"> • Rapid Program Check-Out • Mission procedures Development • Man/Machine Dev..
System Test Lab. (Real Time-Real Hdw)	<ul style="list-style-type: none"> • AGC Language • Real AGC with CRS 	<ul style="list-style-type: none"> • Real G&N Hardware only 	<ul style="list-style-type: none"> • G&N Hardware Compatibility Testing

Software Testing

Introduction

- Software / Hardware
- At MIT / GA NAR NASA / Redundancy
- Evolving Procedures ---- { mission complexity
 desire to improve
- Facilities, Level Testing, Summary

Facilities

- Description
- Models

Level Testing

- Level Testing
- Objectives

Summary

ENVIRONMENT Models

- Sources of data
 - Mission Module Data Book
 - Interface Specs.
 - NASA Hdq. Specs.
 - Miscellaneous Documents
 - Direct Contact with responsible people
- GSOP Chapter
 - 3 (Autopilots)
 - 5 (Guidance Equations)
 - 6 (ENVIRONMENT)
- Internal Control
 - ENVIRONMENT at Level 4
 - AGC Programs after Level 4

Level Testing Objectives

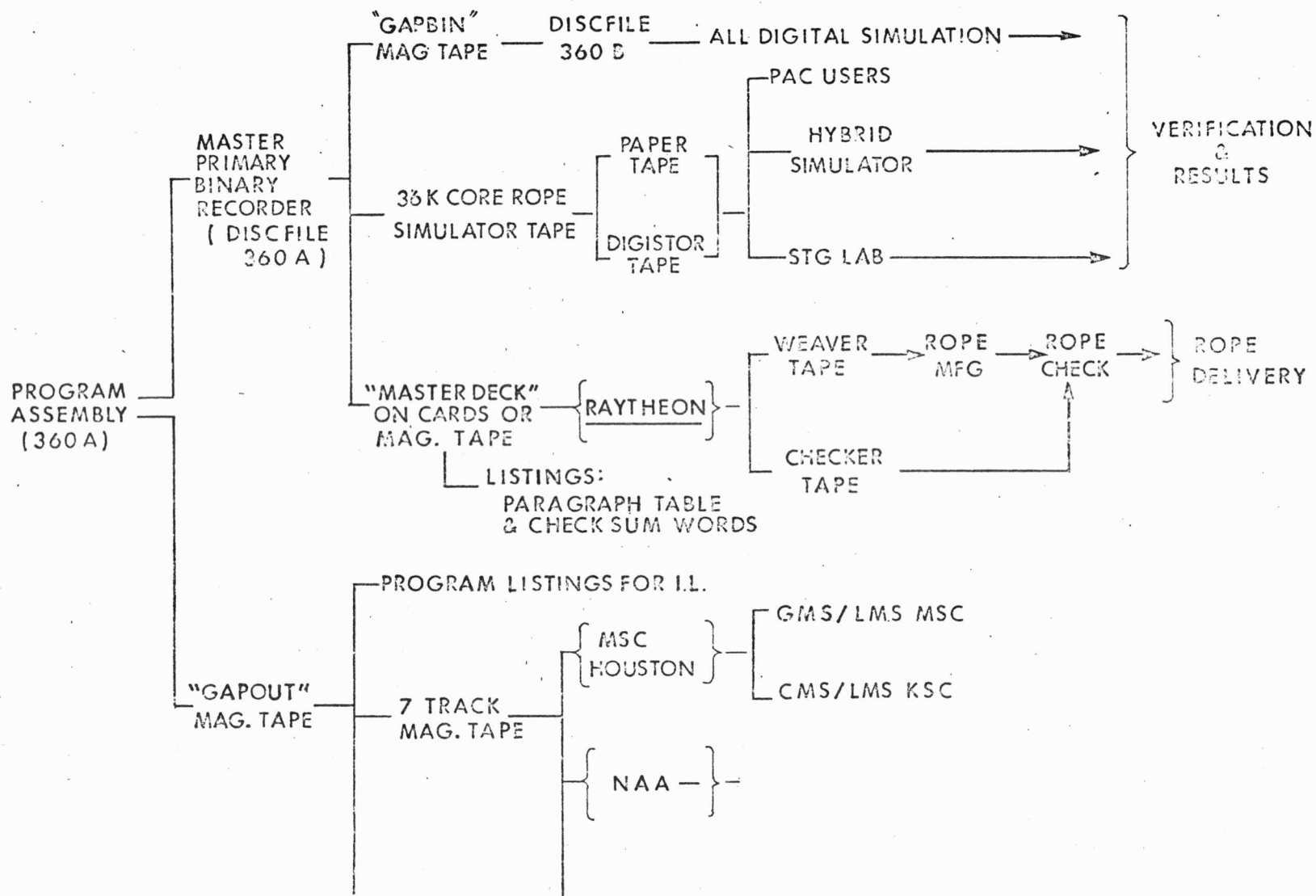
Level		Objective	Facility
Design Testing		<ul style="list-style-type: none"> Design and develop mission programs and algorithms 	Engr.
Level 1	// // // //	<ul style="list-style-type: none"> Verify program units as defined in GSOP Define Level 2 tests 	Engr. Sim.
Level 2	// // // //	<ul style="list-style-type: none"> Test unit level of AGC Program <ul style="list-style-type: none"> - Accuracy - Scaling 	BIT/BIT
Program Testing	// // // //	<ul style="list-style-type: none"> Verify programs as defined in GSOP Define Level 3 tests 	Engr. Sim.
Level 3 Testing	// // // //	<ul style="list-style-type: none"> Test program level of AGC Program (both w/wo ENVIRONMENT) Limited Stress Testing 	BIT/BIT and Limited Hybrid
Sequence Testing	// // // //	<ul style="list-style-type: none"> Verify programs can carry out <u>typical</u> mission phases Define Level 4 tests 	Engr. Sim.
Level 4 Testing	// // // //	<ul style="list-style-type: none"> Test Sequences of AGC Program <ul style="list-style-type: none"> - Erasable - Ability to run together - Margin 	BIT/BIT and Hybrid
Performance Testing		<ul style="list-style-type: none"> Verify ability to carry out mission "What if" testing Develop mission procedures & rules 	Engr. Engr. Sim.
Level 5		<ul style="list-style-type: none"> Reaffirm Level 3 and 4 Find procedural and operational faults Wire trace Stress test 	BIT/BIT Hybrid

Level Testing Objectives
(continued)

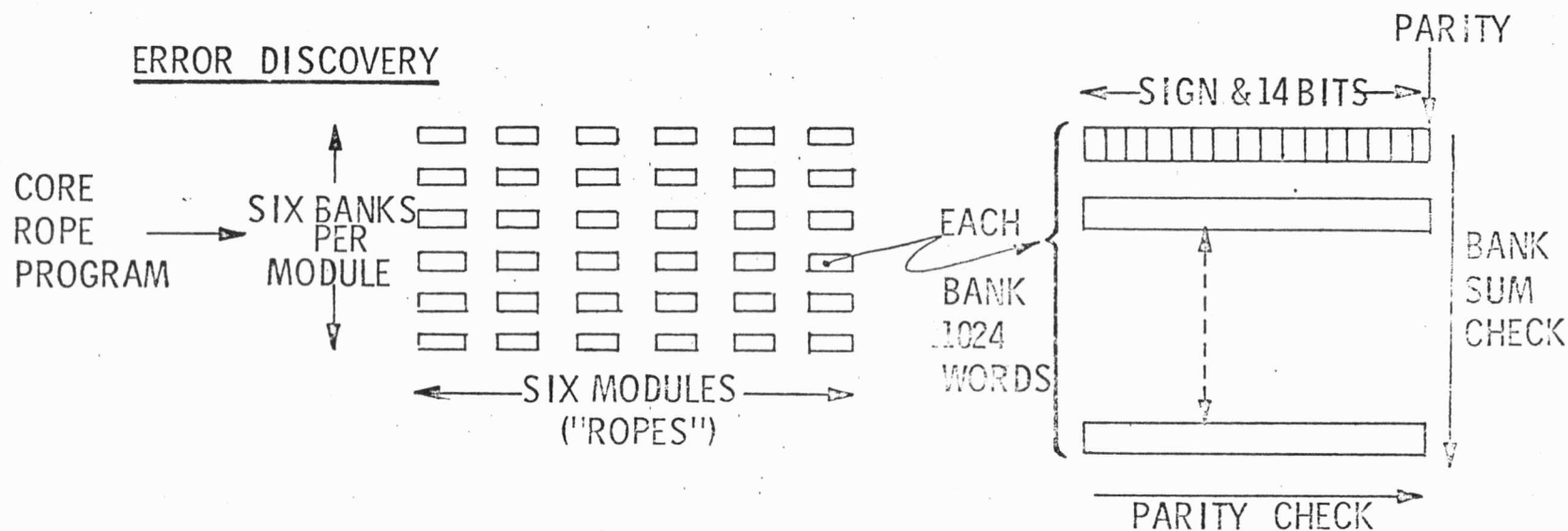
Level	Objective	Facility
Mission Verification	<ul style="list-style-type: none">• Verify man/machine interface• Verify that program can carry out mission	Hybrid
Post Flight Testing	<ul style="list-style-type: none">• Establish reasons for visable malfunction• Search for design weakness• Confirm assumptions	Engr. Sim. BIT/BIT Hybrid

HARDWARE & SOFTWARE VERIFICATION

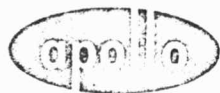
FACILITIES → (PARTIAL)										
	ENGINEERING SIMULATIONS	"ALL DIGITAL"	HYBRID	STG LAB	CMS & LMS	NAR/GAEC CHECKOUT	KSC CHECKOUT	KSC SIMPLITE	MISSION	
TEST	FORMULATION & PERFORMANCE	ALL PHASES COMPLETE	ALL PHASES COMPLETE	GN & C PERFORMANCE & PRELAUNCH	CREW VERIF. & TRAINING	SPACECRAFT CHECKOUT	SPACECRAFT CHECKOUT & HARD-SOFT- WARE INTERFACES	MOST PHASES OPERATIONAL COMPAT- ABILITY	ALL PHASES	
AGC HARDWARE	×	BASIC 360 / 75 BIT BY BIT SIM	REAL	REAL	DIGITAL INTERPRE- TIVE SIM	REAL	REAL	REAL	REAL	
AGC PROGRAM	DIGITAL NOT IN AGC CODE		CORE ROPE SIM	CORE ROPE SIM		TEST ROPES	REAL	REAL	REAL	
OTHER GN & C HARDWARE	DIGITAL SIM	DIGITAL SIM	REAL CDU & HYBRID SIM	REAL & RADAR SIM	DIGITAL SIM	REAL	REAL	REAL	REAL	
CREW INTERFACE	×	×	REAL & SIMULATED	NAV PANEL & DSKY ONLY	REALISTIC	REAL	REAL	REAL	REAL	
SPACECRAFT	DIGITAL SIM	DIGITAL SIM	HYBRID SIM	×	DIGITAL SIM	REAL	REAL	REAL	REAL	
SPACE ENVIRONMT	DIGITAL SIM	DIGITAL SIM	HYBRID SIM	×	DIGITAL SIM	×	LAUNCH PAD	LAUNCH PAD	REAL	



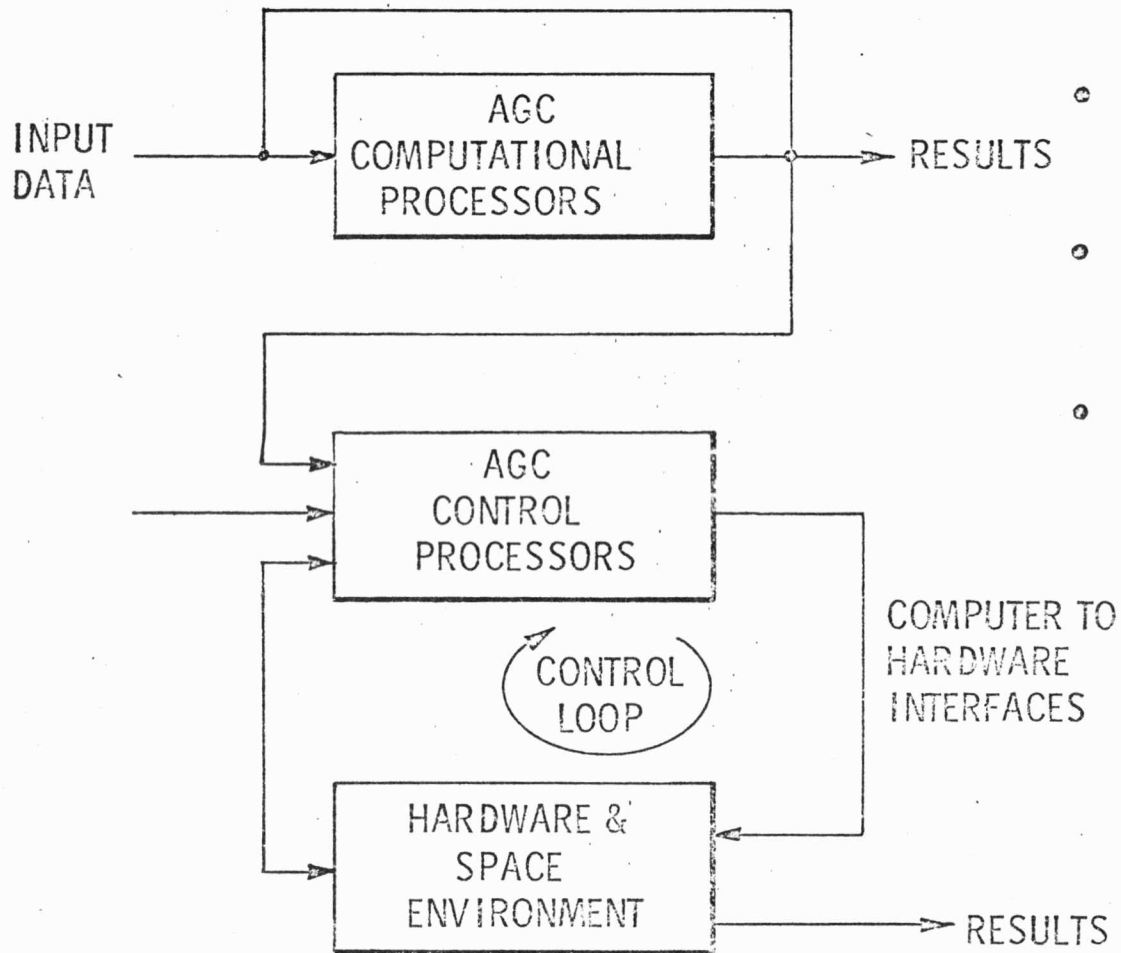
ARE ROPES IDENTICAL BIT FOR BIT WITH PROGRAM AS VERIFIED ?



IF PROBABILITY OF A BAD BIT ANYWHERE IN THE PROGRAM IS 0.5 . . .
 THEN PROBABILITY THAT THE COMBINATION OF PARITY CHECK AND BANKSUM CHECK
 WILL NOT REVEAL A BAD PROGRAM IS $\cong 0.5 \times 10^{-13}$.



HARDWARE & SOFTWARE RELATIONSHIP



- INCORPORATION OF MARK DATA INTO STATE VECTOR

- INTEGRATING STATE VECTOR FORWARD IN TIME

- RENDEZVOUS TARGETING

- RR DESIGNATE & SEARCH

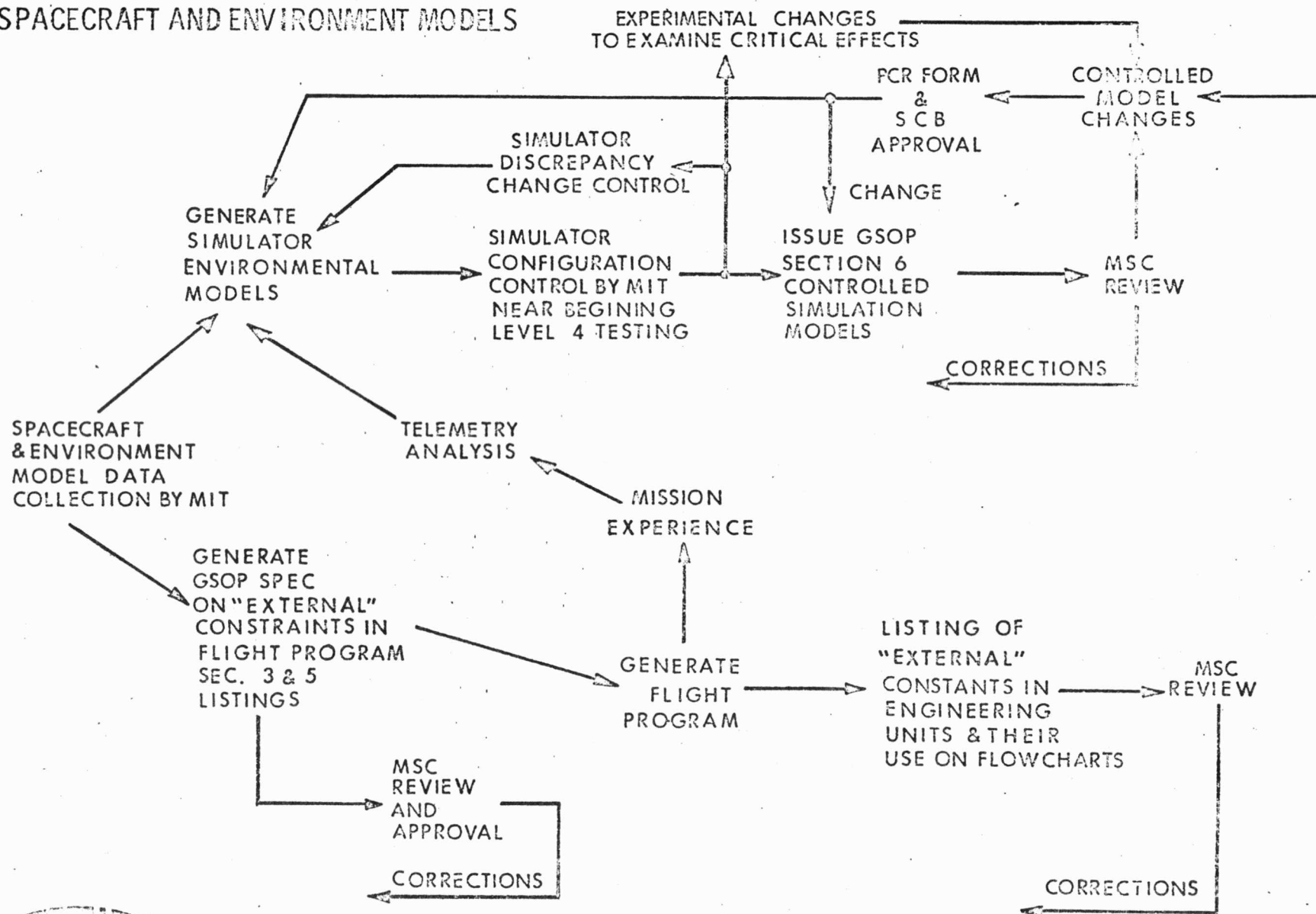
- POWERED STEERING

- DIGITAL AUTOPILOT

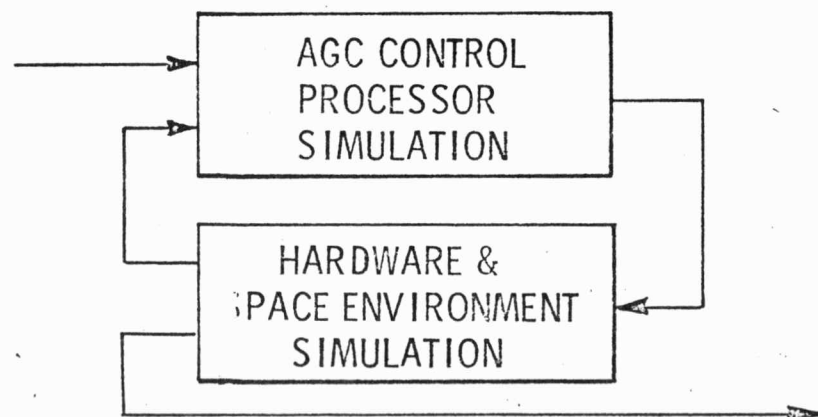


SIMULATOR AND PROGRAM CONTROL OF SPACECRAFT AND ENVIRONMENT MODELS

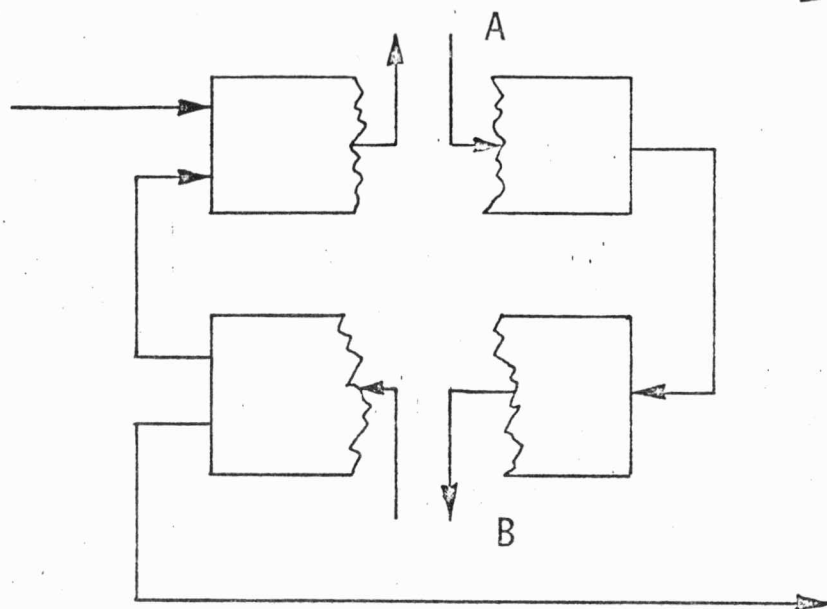
SIMULATOR AND PROGRAM CONTROL OF SPACECRAFT AND ENVIRONMENT MODELS



RELATIONSHIP BETWEEN ALL DIGITAL & KSC REAL SPACECRAFT TESTS



ALL DIGITAL
SIMULATION



KSC
CHECKOUT
TESTS

A → B PER CHARACTERISTIC
DETERMINED AT MIT

OUTLINE OF TEST AND CHECKOUT

PLANS AND OPERATIONS

Joseph D. Fleming, Jr.

OBJECTIVES

In order to support the overall checkout goal of providing a flight ready spacecraft to enable the crew and ground to perform each mission, certain intermediate objectives have been established. These include checking:

(a) Proper function of the Guidance and Control System (G&C) as a Spacecraft sub-system, maintaining continuity of significant data from the various levels of factory testing to launch.

(b) Capability of the G&C to communicate with all interfacing systems aboard and to operate as an integral part of the spacecraft.

(c) Operation in realistic simulations of the entire mission including ground and crew functions.

BASIC PLAN

Over a period of more than five years, MIT has worked in close association with ACED, NAR, GAEC, and NASA in establishing and revising basic plans, test requirements, detailed procedures, and computer programs relative to the three objectives above. These general checkout plans include the NASA/KSC Prelaunch Operations Document (POD-2) prepared in 1963 and, subsequently, the NASA/MSC Ground Operational Requirements Plans (GORP). In addition, MIT has provided comprehensive base plans in a test plan (R434, dated August 1965), a test data plan (R494, dated July 1965), and a Contingency test plan (E1801, dated Feb. 1966). This basic advance planning has provided a "backbone" for the design of tests and supporting facilities. As more experience is obtained new methods for planning are employed and new factors are introduced to modify original plans. Tests involving the G&C developed to add substance to the basic "backbone" have been used to check four unmanned spacecraft which have flown successfully. Although this constitutes a "proving-out" of the G&C related tests, willingness to make changes in order to improve checkout is necessary and, fortunately, is evident.

FLOW OF OPERATIONS

As a result of the basic planning effort, a flow plan for all CSM and LM tests has evolved. A representative flow of the test and checkout operations is shown in Figure 1, which indicates the sequence of major operations from the early factory testing (including component, sub-assembly, sub-system, and G&C system tests) through the Spacecraft contractor plants and on through KSC. The flow shown is typical of early Block II missions and is based on Mission D (CSM103/LM-3). The major categories of tests which comprise the flow correspond to the three objectives given earlier and are termed:

- a. G and C System Tests
- b. Interface/Integrated Tests
- c. Simulated Missions

These categories will be discussed in detail subsequently. In general, the G & C System tests are designed to verify operation within specified tolerances under nominal conditions. For the verification of interfaces and proper

Continued

integration, dual or multiple verification is used, ranging from the checking of all conductive paths to the exercise of software with hardware to the extent that certain functional aspects, including polarity, are demonstrated. The Simulated Missions are comprehensive tests to provide confidence that the entire Mission sequence can be completed as planned. In the actual flow, certain tests under these categories are selected for each phase of the checkout sequence, with consideration given to the nature of the facility used and the level of assembly. The direction anticipated for changes in the flow shown in Figure 1 for late missions is toward:

- a. decreasing "power-up" testing in the MSOB
- b. testing in the VAB with a greatly reduced number of monitoring points in active use.
- c. comprehensive PAD tests including all monitoring points available through ground computers and culminating in simulated missions prior to launch.

GENERAL CHARACTERIZATION OF TESTS

Taken as a whole, the tests have been designed and sequenced in order to obtain identical (or similar) procedures for running each test no matter where or how many times it may be used in order to facilitate the comparison of data. Also, identical (or similar) computer programs have been developed for the ground checkout system at each site. Extensive effort has gone toward reaching reasonable compromises on such considerations as: redundant tests, time allowed for testing, test complexity, and contingencies. In general, the tests are less than end-to-end, but where an end-to-end test is impractical, the end-to-end function is established by the assembly and comparison of data from two (or more) tests.

CURRENT TEST PLANNING AND CONTROL

All tests at some point are visible as a requirement. From time to time, the method of controlling requirements has changed. Currently, the sequence of activities associated with requirements and procedures may be viewed broadly as shown in Figure 2. This illustration is applicable to test and checkout requirements, for lunar missions (i.e. COLOSSUS and LUMINARY programs) for which certain fixed memory test programs used in Block I and early Block II (SUNDISK) were removed. G&N CSM and LM work Groups have been established by MSC to coordinate intercenter and intercontractor problems. Both MSC and KSC participate. These groups work directly with the G&N and PGNS Steering Committees at KSC which meet weekly.

INTERACTION BETWEEN TCP AND MISSION PROGRAM DEVELOPMENT

Mission software schedules directly effect the development of the KSC test procedures now called TCP's. Their relationship is particularly noticable in the development of those portions of test procedures which involve the use of flight computer erasable memory programs or erasable memory initialization in that these must be verified with the mission program assembly which is released for rope manufacture. Also, the same facilities at MIT, such as the System Test Lab, are used in both the Verification of Mission Programs and the Verification of Erasable Memory Program for KSC checkout.

As an example, let us consider the group of CSM tests labeled TCP 0005, and assume that this TCP must be run starting 45 to 60 working days before launch. Now add 75 to 90 more days prior to the TCP run date for starting the preparation of the TCP. Since the content of the mission program effects the content of the TCP, the mission program must be well established 4 to 5 months prior to launch in case of TCP 0005 or the TCP will not be done on time. If

mission ropes are to be used in tests prior to TCP 0005, still greater lead times are needed. Also, it may be assumed that if major changes in the content of the ropes (or in S/C hardware) occur late in the KSC flow, such as between TCP 0005 and the countdown demonstration (CDDT), KSC will probably insist on cycling back for a rerun of, at least, portions of previous test sequence. In order to avoid this type of problem, and the consequent delays, the approach being used is to strictly limit the extent of changes in hardware and software which would impact KSC. As of now, and starting as long ago as the initial tests on Boilerplate 14 at Downey, MIT and ACED in conjunction with the Spacecraft Controller have been able to provide the test software for all spacecraft at all locations in sufficient time to avoid delays in the test schedule.

ENDING

The two illustrations given and the previous discussions are relatively broad and general. The discussion which follows on "Checkout at KSC" is designed to expand and detail the KSC operations in order to provide a basis for discussing questions such as the need dates for mission ropes. Also, some of the problems in complementing an "ideal" or entirely consistent checkout philosophy will be made evident.

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Apollo Project Memorandum #1923

TO: J. C. Stokes
FROM: R. H. Battin and D. Hoag
DATE: 17 June 1968
SUBJECT: Apollo Flight Computer Program Testing Philosophy

The Apollo flight computer program exists as hardware in the pattern of wire threading the 36,000 word rope memory and the pattern of magnetic polarity of that portion of the 2000 erasable core memory loaded at liftoff. At the Flight Readiness Review this program must be certified as capable of performing the mission and must be sufficiently tested to commit for launch. Herein is described the philosophy and method of program testing from which the test results are available to aid in the decision for launch.

In its simplest form, the sequence of flow for computer program development may be considered as follows:

Requirements → Specification →
Design → Coding → Test Plan →
Testing → Examination → Documentation →
Review → Approval → Flight Use →
Post Use Analysis → Report

This simple flow is only a basic pattern of a more complex network of parallel paths and feedback to earlier steps. Here we consider the aspects of test planning, test execution, and test reporting.

The Apollo flight computer program testing is an exceedingly exacting task. Obviously, computer programs cannot be "debugged" in flight and the consequences of errors manifesting themselves in flight can be most serious. On the other hand, design constraints and the technological state of the art have led to the development of a flight computer not easy to code or test. Thus, the careful develop-

ment of a rigorous test plan to guarantee the discovery of program faults, together with a sufficient period of time available to execute these tests with the completed program, is essential.

Unavoidably, the Apollo spacecraft and mission development precludes the optimum circumstances within which to do the "best" job of computer program verification testing. Compromises must be made for some of the following reasons:

1. The definition of the requirements and functions desired of the computer program are not known in reasonable detail until less than a year before the program is planned to be used in flight.
2. During the period of program development and verification testing there will be a large number of candidate changes to the requirement proposed, many of which must be incorporated to assure mission success.
3. The data representing the environment of the spacecraft for program test simulation will not be available with needed accuracy during the program design and verification. New and better data will arrive after verification testing is well underway.
4. The resources in qualified manpower, in simulation facilities, and in financial support are realistically limited.

The Apollo flight computer program test philosophy is evolutionary and today differs markedly from that of a few years ago. It is expressed below as a list of requirements and guidelines:

1. Verification testing is configured so that the greatest subjective increment in confidence in the program's integrity is obtained for the most efficient expenditure of resources.
2. For each level of testing, a carefully considered test plan is formulated before committing the test activity. The plan is devised by personnel who understand the idiosyncrasies of the computer and its program, the interfacing hardware, and the operational use of the system. The plan details the tests to be run, specifies the initial and

environmental conditions to be used, and provides the success criteria for the tests. The plan is examined and approved by a competent reviewing board.

3. Test planning proceeds from tests of small program elements, through testing of combinations of elements and regions, to the tests of full mission programs.

4. The tests are designed to demonstrate performance of every operational path through the program which will be used in the nominal mission and the planned abort paths.

5. To the greatest extent possible, the tests will exercise the computer program through non-nominal paths which could arise from rational keyboard activity by the crew, unplanned maneuvers, or unanticipated but rational abort paths.

6. To the greatest extent practical the testing exercises the program with expected variations in flight conditions and hardware. The test planners deliberately seek out those variations which have a high probability of occurrence and include them in the plan.

7. After verification testing is in progress, every proposed program change should be considered with restraint and avoided whenever the existing program can support the mission.

8. After verification testing is in progress, every proposed change to the mathematical models in the simulator test environment should be considered with restraint and avoided whenever the existing test models are of sufficient fidelity to support test objectives with confidence.

9. After verification testing is in progress, every change in the program code is tested at least in the local area of the change and its interfaces with other programs. Whenever possible, other program regions are retested since changes can introduce unexpected errors.

10. All test results are examined against the test plan criteria, documented and reviewed by a competent board.

Constant awareness for unusual operation over and above the test plan criteria and formal program specifications is maintained.

11. All anomalies, discrepancies, unexpected properties, and unusual attributes which are discovered and left in the program are identified and documented in an appropriate log. Those judged to be of significance to the proper and safe use of the system are advertised in an accepted set of operational notes.

12. To the greatest extent practical, independent review of test results and independent testing using independently derived test design, facilities, criteria, and personnel are encouraged. Independent and redundant examination of the program is essential to ferret out the repeatedly unnoticed error which can plague the most conscientious and dedicated team.

In summary, no absolute rules are possible or are any absolute scales available for measuring the relative effectiveness of different test philosophies. Like the laws and courts of society, the test philosophy and its execution depends on the judgement and wisdom of the best engineers available.

ATTENDANCE LIST FOR G&N CHECKOUT MEETING
June 20, 1968

<u>Name</u>	<u>Organization</u>
J. J. Tadich	KSC
P. C. Heinemann	MIT/IL
M. W. Johnston	MIT/IL
W. F. Marscher	MIT/IL
J. D. Fleming, Jr.	MIT/IL
M. M. Sullivan	MIT/IL
D. G. Hoag	MIT/IL
A. Laats	MIT/IL
R. R. Ragan	MIT/IL
R. C. Millard	MIT/IL
J. E. Miller	MIT/IL
G. L. Silver	MIT/IL/KSC
T. M. Lawton	MIT/IL/EG
W. O. Covington	Bellcomm
J. L. Norton	TRW
E. L. Chastant	Boeing
V. R. Dahlmann	AC/MKE
D. A. Ziemer	AC/MKE
F. A. Dasse	AC/KSC
K. G. Korth	AC/MSc
T. F. Gibson, Jr.	MSC/FS5
S. E. Snipes	MSC/EG42
L. C. Dunseith	MSC/FS
G. L. Doerre	MSC/CF
J. E. Williams, Jr.	MSC/FS55
J. C. Stokes, Jr.	MSC/FS5
J. W. Dodson	MSC/PT2
R. D. Hicks	MSC/PE6
W. B. Goeckler	MSC/PD8
S. M. Blackmer	MSC/PD6
R. E. Lewis	MSC/EG43
C. C. Kraft, Jr.	MSC/FA
F. J. Kastelic	MSC/FS55
R. C. White	MSC/FC7
R. A. Gardiner	MSC/EG
R. A. Thorson	MSC/FC4