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SURVEY OF SATURN/APOLLO CHECKOUT AUTOMATION, SPRING, 1965: DETAILED DESCRIPTION

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PREFACE

This Memorandum is a review of the status of automation in Saturn/Apollo Checkout, undertaken at the request of Headquarters, National Aeronautics and Space Administration. It provides detailed support for its companion piece, RM-4784-NASA, Survey of Saturn/Apollo Checkout Automation, Spring, 1965: Summary. Besides providing a description of the prime system and test sequence for each checkout system, the Memorandum is designed to provide comparative information on stages and launch vehicles and a reasonably detailed description of the test planning, checkout equipment, and programming involved in the Saturn/Apollo program.

This Memorandum is part of a continuing study of the Apollo Checkout System conducted by The RAND Corporation under Contract NASr-21(08) with the National Aeronautics and Space Administration.

SUMMARY

This Memorandum describes the prime system and test sequences for each part of the Saturn/Apollo checkout system. It examines organization, communication flow, system analysis, standardization, and man-machine relationships for their effects upon the efficiency with which automation can be integrated into the checkout process. Appended to each section are descriptions of the hardware and the software in each checkout system.

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ACKNOWLEDGMENTS

Much of the material in this Memorandum and its companion piece was gathered during visits to the Saturn/Apollo checkout facilities listed below. The number of individuals who cooperated in providing pertinent information is too large to permit individual mention, but the authors specifically acknowledge and are grateful for the assistance of the personnel with whom they talked at the following facilities:

NASA

Office of Manned Space Flight	Washington, D.C.
Marshall Space Flight Center	Huntsville, Ala.
John F. Kennedy Space Center	Cocoa Beach, Fla.
Manned Spacecraft Center	Houston, Tex.

Stage Contractors

S-I/IB stage

Chrysler Corporation Space Division	New Orleans, La.

S-IV/IVB stage

Douglas Aircraft Company, Missile & Space Systems Division	
Space Systems Center	Huntington Beach, Calif.
Test Station	Sacramento, Calif.

S-IC stage

The Boeing Company, Aerospace Division	
Saturn Booster Branch	Huntsville, Ala. New Orleans, La.

S-II stage

North American Aviation, Space & Information Systems Division	
S-II Engineering, Test & Operations	Downey, Calif.
S-II Manufacturing	Seal Beach, Calif.

Command Module, Service Module, Launch Escape System

North American Aviation, Space & Information Systems Division	
Apollo Engineering, Tests & Operations	Downey, Calif.

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Lunar Excursion Module	
Grumman Aircraft Engineering Corp.	Bethpage, N.Y.
Support Contractors	
International Business Machines Corporation	Huntsville, Ala.
General Electric Company	
Apollo Support Department	Cocoa Beach, Fla.
Mesa Scientific Corporation	Huntsville, Ala.
Sanders Associates	Nashua, N.H.

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ABBREVIATIONS

ACE	Acceptance Checkout Equipment
ACE-S/C	Acceptance Checkout Equipment-Spacecraft
ACS	Automatic Checkout System
AGCS	Automatic Ground Control System
APS	Auxiliary Propulsion System
AT&O	Apollo Test & Operations
BHC	Blockhouse Computer
BP	Boiler Plate
CCSD	Chrysler Corporation Space Division
CIF	Central Instrumentation Facility
CIU	Computer Interface Unit
CM	Command Module
CPDF	Computer Program Development Facility
CRT	Cathode-ray Tube
CUE	Communications Unit Executor
D/A	Digital to Analog
DAC	Douglas Aircraft Company
DCCU	Digital Communication Control Unit
DDAS	Digital Data Acquisition System
DDP-224	Computer Model Number
DEE	Digital Events Evaluator
DISO	An ATOLL Operator
DTVC	Data Transmission and Verification Converter

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EBW	Exploding Bridge Wire
ECS	Environmental Control System
EDS	Emergency Detection System
EMM	Electro-mechanical Mockup
ESDU	Event Storage and Distribution Unit
ESE	Electrical Support Equipment
FCV	Facilities Checkout Vehicle
GAEC	Grumman A/C Engineering Corporation
GETS	Ground Equipment Test Set
GHe_2	Gaseous Helium
GN_2	Gaseous Nitrogen
GORP	Ground Operational Requirements Plan
IODC	Input/Output Data Channel
I&T	Instrumentation & Telemetry
KSC	Kennedy Space Center
LCC	Launch Control Center
LH_2	Liquid Hydrogen
LOX	Liquid Oxygen
LTA-1	Grumman "House S/C"
LUT	Launch Umbilical Tower
LVDC	Launch Vehicle Digital Computer
MILA	Merritt Island Launch Area
MSE	Mechanical Support Equipment
NAA	North American Aviation
OCP	Operation Checkout Procedure
OLSTOL	On-line STOL

PAM	Pulse Amplitude Modulation
PCM	Pulse Code Modulation
PDD	Program Description Document
PRD	Program Requirements Document
QC	Quality Control
Q&RA	Quality & Reliability Assurance
RACS	Remote Automatic Calibration System
RCS	Reaction Control System
RFI	Radio Frequency Interference
SGS	Symbol Generator and Storage
SIL	Systems Integration Laboratory
SLAP	Assembly Program for RCA-110A
SLCC	Saturn Launch Control Center
SM	Service Module
SPS	Service (Module) Propulsion System
SSB	Single Side Band
SSFL	Santa Susana Flight Laboratory
T/M	Telemetry
T&O	Test & Operations
T.O.	Test Operator
TRD	Test Requirement Document
VAB	Vehicle Assembly Building
VTS	Vehicle Test Station

I. INTRODUCTION

This Memorandum reviews the various stages in the factory-to-launch sequence of checkout in the Saturn/Apollo program in order to determine the state of automation as of the spring of 1965. Its companion piece, RM-4784-NASA, Survey of Saturn/Apollo Checkout Automation, Spring, 1965: Summary, discusses the present and projected status of automation and makes suggestions for future developments. In addition, the summary Memorandum discusses such technical aspects as the definition and control of system analysis, the efficient introduction of automation, problems of standardization, and man-machine relationships.

In the present Memorandum, particular emphasis was laid upon the following:

(a) percentage of automation achieved to date, and comparison with initial plans

(b) percentage of automation projected for the future

(c) suggested automation levels, and factors that influence those levels.

"Percentage" was taken to mean the estimated fraction of tests or test steps that are automated. A "test step" is defined as an operation comparable to issuing a single stimulus, measuring a single response, and checking the response against fixed tolerance limits. The "level" of automation refers only to the automatic fraction of the testing and expresses the complexity of the decisions in this automatic fraction. A higher level indicates increased amounts of decision-making by the computer, and therefore increased difficulty in planning and programming.

In each annex that follows is a description of the particular element in the checkout, including test sequences and estimates of both present and future status. Hardware and software are described in the appendixes to each annex.

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S-I/IB STAGE CHECKOUT

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CHECKOUT CONCEPT AND OBJECTIVES

BACKGROUND DATA

The S-I/IB Automatic Checkout system in factory use by Chrysler is the first computer controlled Saturn checkout system developed by MSFC. Equipment and initial computer programs were government furnished equipment from MSFC to Chrysler, with subsequent modification and expansion performed by Chrysler.

Checkout system development at MSFC was gradually phased into an existing manual checkout capability over a total of eight S-I flight vehicles. Commencing with the last two S-I stages (SA-8 and SA-10) and continuing into the S-IB program, Chrysler assumed manufacturing and checkout responsibility.

Factory acceptance (in this case synonymous with pre-static checkout) and post-static checkout are conducted at Chrysler's manufacturing facility at the NASA Michoud plant, New Orleans, La. Static testing is accomplished at the East Area test stands of MSFC's Test Laboratory facility in Huntsville by Chrysler and MSFC personnel. The factory checkout system, both hardware and software, differs from the MSFC Test Lab. static checkout system, which utilizes an RCA-110A computer as a monitoring and control element.

STAGE DESCRIPTION

The S-I and S-IB booster stages are the first stages of the Saturn I and IB launch vehicles, respectively. Since the Saturn I program is complete, the major attention will be focused on the S-IB.

The S-IB stage is approximately 80 ft long and 21 ft in diameter with a main stage propellant capacity of 900,000 lb and a rated thrust of 1,600,000 lb.

The major S-IB systems are:

1. Structure System--This includes four subsystems, the Tail Assembly, Propellant Tanks (fuel and LOX oxidizer), Second Stage Adapter, and Fins.

2. Propulsion System--This includes the eight H-1 engines and necessary support equipment. The engines use a bi-propellant system with LOX as the oxidizer and RP-1 as the fuel. Support equipment includes the Control Pressure, Fuel Tank Pressurization, and LOX Tank Pressurization subsystems.

3. Staging System--This separates the S-IB from the S-IVB in flight under sequenced commands. Included are two parallel EBW Firing Unit Squib subsystems, which detonate the linear shaped charges. The latter split the stages and ignite the S-IB retrorockets for the reverse thrust for separation.

4. Instrumentation and Telemetry System--This includes the sensors, transducers, signal conditioning and telemetry equipment provided to transmit information on the functioning of stage systems and associated environmental conditions. Telemetry includes PAM/FM/FM, PCM/FM, and SSB/FM, used during both ground checkout and flight, and DDAS for use only in ground checkout.

5. Control System--This system is directed by signals from the IU, and provides control actuation for the S-IB engines. Included are the Yaw and Pitch Control Accelerometers, the Pitch and Yaw Control Rate Gyro Package, the Control Signal Processor, and the Hydraulic Control Activators.

6. Electrical System--This includes the 28 volt and 5 volt DC, and 400 cps stage power supplies, distribution busses and networks, and stage sequences that provide sequenced command signals for timing system functions.

7. Range Safety Command System--This includes dual range safety command-destruct capability for redundancy, each unit of the pair having its own antenna, command receiver, Destruct System Controller, EBW Firing Unit and Detonator, Safe and Arm Unit, and explosive shaped charges. Flight termination by ground command also provides engine shutdown before detonation and propellant dispersion.

8. Tracking Systems--Offset DOPler (ODOP).

DESCRIPTION OF TESTS

A normal complete checkout for an S-IB stage at Michoud occupies about 10 weeks of two-shift testing. Since the Michoud checkout system is not used for static testing, a pre-static checkout sequence (for S-IB vehicle 203),* equivalent to a factory acceptance test, is

*For static testing at MSFC, propellant loading and captive firing would be added to the sequence, plus those tests necessary to check site facilities and monitor hazardous conditions. Propellant loading and captive firing are initially planned to be performed on a manual basis.

reviewed below to estimate the degree of automation achieved. This particular sequence is considered as representative. Stage tests are shown here as an integral sequence.

A full checkout would include verification of the automatic checkout and other GSE equipment prior to the stage checkout, and data evaluation and removal for shipment after testing. Although these are not strictly stage tests, they are included in the listing.

Test	Description
GSE Verification	
G-1	Computer Complex Self-test--to verify proper computer operation before checkout
G-2	Ground Equipment Test Set (GETS) Test--to verify overall checkout system and GSE operation and GSE/stage compatibility. Provides functional responses to checkout system and simulated stage interface.
Stage Verification	
Pre-test	Stage Installation--positioning at checkout station, connecting cabling
Test Preparation	Inspection--visual inspection of tanks, structure, and wiring for damage, and to establish correct configuration
1 (CCSD Tests 1.1, 1.2, 1.3)	Antenna System Test--checks for proper connection and operation of antennas and lines for Range Safety Command, and Telemetry systems. Includes pre-installation cable phasing, voltage standing wave ratio and insertion loss measurements.
Test	
2	Continuity Compatibility--Resistance check of vehicle interface and umbilical connections to assure absence of short circuits and stage readiness for power

Test	Description
3	Power Distribution Subsystem Check-out--a series of tests to verify correct operation of the Power Distribution Subsystem prior to extensive power-on testing; includes:
(CCSD Tests A2.0,	(a) Power Distribution
A2.1,	(b) Power Up
A2.2)	(c) Power Down
4 (CCSD Test A3.0)	Universal Measurement Adapter Scan and Calibrate--sequentially inserts calibration signals and scans the outputs of all instrumentation channels, comparing responses against preset limits
5	Signal Conditioning Calibration--adjusts as necessary the calibration of stage signal conditioners such as bias and gain settings of amplifiers, bridges, etc.; includes the following signal conditioner groups:
(CCSD Tests) 3.1	(a) Acceleration
3.2	(b) Acoustics
3.3	(c) Temperature
3.4	(d) Pressure (See A3.4 below)
3.5	(e) Vibration
3.8	(f) Hydraulic Oil Level
3.10	(g) Signals
3.11	(h) Liquid Level
3.12	(i) Voltage and Current
3.15	(j) Strain
3.16	(k) RPM
3.19	(l) Dynamic Pressure
6 (CCSD Test A3.4)	Pressure Calibration and Functional Test--the I&T Test Station commands calibrated pressure levels from a servo pressure generator into various vehicle pneumatic subsystems and monitors transducer responses.

Test	Description
7 (CCSD Test A3.17)	Sensor Identification--identifies sensor channel location and monitors ambient responses.
8 (CCSD Test A3.18)	Digital Data Acquisition System (DDAS) Calibration Verification--a test for end-to-end verification of DDAS channels, including a remote calibration sequence
9	Propulsion System Test--a series of tests of the propulsion and related subsystems and major components, including component operation and leak testing, as follows:
(CCSD Tests) 4.1	(a) Pressure Switches--verify switching levels
4.2	(b) GN_2 Control Pressure System--verify proper operation from high pressure spheres through manifold and valves to tanks
4.3	(c) H-1 Engine System--functional integrity and swing capability
4.4	(d) Fuel System--verify that control valves provide proper pressure level, test full vent and safety valves, and check leaks in tank and fittings
4.5	(e) Instrument Compartment--check proper operation
4.6	(f) LOX Tank Pressurizing System--verify pressure capability level and correct operation of LOX relief and vent valves
4.7	(g) LOX System--check leaks in tank and fittings
4.9	(h) LOX Seal Cavity--check seal cavity integrity
4.10	(i) Camera eject--check eject control operation

Test	Description
10 (CCSD Test A4.8)	Vehicle Heater System--checks out the stage heaters through the Vehicle Test Station
11 (CCSD Test A5.0)	General Networks Malfunction Cutoff Test No. 1--generates simulated cutoff conditions and verifies functioning of cut off control components monitoring rough combustion, voltage failure, manual cutoff, command receiver cutoff, low thrust and abortive firing sequences
12 (CCSD Test A6.0)	Components Test--to assure proper interface between electrical and mechanical systems; verifies operation of electrical-mechanical devices of networks and propulsion systems, including valve timing checks
13 (CCSD Test 7.1)	Range Safety Command System Test-- a series of tests (with special purpose test equipment) to verify operation of the Exploding Bridge Wire and Range Safety Command Receiver System; includes: (a) EBW Firing Simulation--with simulating pulse sensors in place of EBW detonators, a test to ensure detonation capability (b) Receiver Input--to verify ability of receiver to accept and decode command RF signals (c) Receiver Operation--tests threshold deviation, sensitivity, channel operation, command response, automatic gain control, and immunity to incorrect sequences; tests performed for both Safe-and-arm and External-internal power conditions
14 (CCSD Tests 7.2 7.3	Telemetry System Test--a checkout of stage telemetry systems, including end-to-end verification and adjustment of signal conditioners, multiplexers, modulator and transmitter
7.4)	Tracking System Test--a checkout of the Doppler repeater

Test	Description
15 (CCSD Test 8.1)	Radiated Compatibility Interference Test--a series of internal and external (to stage) measurements of radiated electromagnetic energy from stage equipment to determine whether level of radiation is high enough to cause interference with anticipated prelaunch, launch, and flight environments
16 (CCSD Test 9.0)	Control System Test--checks compatibility with simulated Instrument Unit commands, verifies proper response of engine movements to hydraulic actuation, and checks to see that movement to maximum extreme does not interfere with other stage hardware
17 (CCSD Test A9.4)	Actuator Linearity Test--checks engine actuator linearity to verify engine position accuracy when gimbaling to specified electrical control system command; includes a simulated flight condition routine
18 (CCSD Test A10.0)	Instrumentation Compatibility Test--checks accuracy of telemetered signals (including the RF loop) against duplicate hardwire signals and against predicted values (theoretical outputs for a given calibrated input), for those signals under automatic control
19 (CCSD Test 10.0)	Instrumentation Compatibility Test--similar to 18, but conducted manually for those channels under manual control
20	Telemetry Ground Station Calibration--a series of tests to set up, adjust, and calibrate the ground station telemetry equipment; including:
(CCSD Tests) 10.1	(a) Telemetry Calibrator Test
10.2	(b) FM Discriminator and Subcarrier Oscillator Adjustment (see also A10.2 below)
10.3	(c) Ground Station and Airborne Pre-emphasis Procedures
10.4	(d) SSB/FM Ground Station Setup

Test	Description
10.5	(e) PCM Ground Station Setup
10.6	(f) RF Compatibility
10.7	(g) DDAS Functional Check
21 (CCSD Test A10.2)	FM Discriminator and Subcarrier Oscillator Adjustment--performed in conjunction with 20 (b) above to introduce calibrated inputs in sequence and check subcarrier oscillator frequency deviation, discriminator linearity, overall accuracy, etc.
22 (CCSD Test A11.0)	Overall Systems Test (Simulated "Plug Drop" with Umbilicals Out)--verifies complete stage operation: stage power-up, firing sequence preparation, firing command, power transfer, engine ignition sequence, lift off with a simulated umbilical retraction, and a program for a full duration flight sequence; hydraulic system activated and engine gimbaled; cutoff sequence and command system verification included
23 (CCSD Test A21.0)	General Networks Malfunction Cutoff Test No. 2--similar to 11, repeated for verification before stage shipment
24 (CCSD Test TPEE-65-2)	Electromagnetic Compatibility--checks for compliance to MIL-E-6051C with level of detail specified by Q&RA representatives
25	Data Evaluation--final evaluation of test data before removal of stage
Post-test	Removal for Shipment--removal of Stage, preparation for shipment to static test site.

Static firing is not included in this sequence. It is performed by Chrysler at MSFC with different computer equipment, and is conducted manually at present.

CHECKOUT SYSTEM APPLICATION

The Chrysler factory checkout system was manufactured by Packard Bell in 1961-62 in accordance with MSFC performance specifications. The system utilizes a master-slave computer concept, with one computer acting as a command and communications center for a number of slave computers. The slave computers are linked to satellite test stations, each of which is designed to check out a major S-I/IB subsystem or group of subsystems. The equipment now in use by Chrysler at Michoud is limited to three, (a) Network Test, (b) Instrumentation and Telemetry Test, and (c) Vehicle Test.

The Network Test Station checks out such areas as the electrical power distribution subsystem, relay functions, GSE and vehicle networks, patch panel and junction box connections.

The Instrumentation and Telemetry Test Station checks out vehicle transducers, signal conditioning equipment, telemetry subsystems, and the Digital Data Acquisition System.

The Vehicle Test Station checks out vehicle electrical heaters and a number of discrete events such as valve closures. The Digital Events Evaluator operates in conjunction with the VTS.

With these stations, the checkout system is estimated to have the capability of performing almost all network tests and a majority of I&T tests automatically. The I&T station also acts as a control station for an automatic pressure calibration and functional test and an engine actuator test. For these it commands a servo pressure generator "manifolded" into the vehicle pneumatic and hydraulic subsystems. This is the extent of automation so far as mechanical tests are concerned.

Full capability for running automatic tests in a manual mode is provided. Normally, for manual testing, a switch control bypasses the computer and satellite test station complex and energizes directly the same ESE unit controlled by the computer in the automatic mode.

The system in use by Chrysler, with its prior development history at MSFC, is the checkout complex in the Saturn/Apollo program that has had the most use in stage checkout to date, and to some extent may be considered also as a "proving ground" for more recently developed automatic checkout systems.

DEVELOPMENT OF TEST REQUIREMENTS AND PROCEDURES

Checkout responsibility at CCSD-Michoud is delegated to the Quality Control Department for hardware and software modifications and for upgrading the checkout system. Within QC, this is concentrated in the QC Engineering branch, with Electrical Systems and Programming sections responsible for detailed system development.

Although technically receiving a government furnished "package" from MSFC, some considerable expansion by CCSD was involved. CCSD received the basic computer complex and Network Station, with corresponding automatic test programs, plus NASA manual test procedures for the I&T area. System expansion by CCSD included acquisition of the I&T and Vehicle Test Stations and preparation of these computer programs, plus some extension of GSE self-test programming. Because the stage and checkout system had evolved from MSFC designs and test requirements had already been frozen (except for R&D modifications of each successive vehicle), CCSD did not prepare the bulk of the manual test procedures that normally form the basis for subsequent automatic test programs.

With 100 per cent manual backup, there are contingency manual test procedures for each automatic test. CCSD is presently combining automatic and manual test procedures into a single document suitable for either type of test. There is no one-for-one correlation, however, since the automatic tests accomplish substantially more in the way of data checking, safety routines, etc., than the equivalent manual tests. The automatic tests are therefore preferred, and represent the "buy-off" procedures to CCSD and NASA. After increased experience with and confidence in the automatic equipment, CCSD anticipates deleting the backup manual procedures entirely.

Most of the automatic programs received by CCSD were based on semi-specialized machine-language programs prepared by Packard Bell. Data for a specific system were entered in tabular form for processing by these programs. Specialized machine-language programs were also used. At present, ATOLL is being superimposed for any new programming effort and is expected to phase in beginning with S-IB Vehicle SA-201. ATOLL is contemplated for network tests only, dealing mostly with simple, non-time-critical, discrete sequences.

Program documentation is in the form of coarse and detailed flow diagrams, plus machine-language coding sheets and data-entry tables. Flow diagrams are prepared by test engineer-programmer teams. Any required data from stage design groups are normally furnished on request, basically as one-way communications. There is relatively little feedback from the checkout group to the stage designers, since the stage design is considered too firm to vary to accommodate the checkout system.

PRESENT AUTOMATION LEVEL

To arrive at a quantitative value for the degree of automation achieved to date with the Chrysler checkout system, the list of tests outlined on pp. A-3 to A-9 is used as a base. "Degree of automation," is taken to mean the percentage of tests, or test steps, under automatic program control.

Neglecting pre-test and post-test procedures and GSE self-test routines, we estimate the automation to be 60 to 70 per cent. This estimate includes a weighting for the increase in the number of test steps due to automation. It is assumed that when a test is automated, three to four automated test steps result on the average from one manual test step. This is due to a number of factors; measurements are more often performed several times and averaged, test sequences are more often repeated, or more combinations are checked automatically than would be checked manually.

For the criterion of complexity of the kind (rather than quantity) of decisions under automatic program control, Fig. A-1 illustrates the present status. The Chrysler system communicates, processes data, compares limits, and sequences simple tests fully. Depending on the test station, groups of simple tests are partly or completely automatically sequenced. Emergency and backup or restart sequences are programmed as part of a semi-specialized or specialized program. There is no general-purpose provision for such sequences. Little or no fault isolation is deliberately performed, either in the GSE or the vehicle, but some direct fault isolation is derived from the test results. No contingency routine or adaptive testing is programmed.

REVIEW OF PRESENT STATUS

With the GSE checkout system received from MSFC, Chrysler assumed implementation responsibility for the last two S-I stages (SA-8 and SA-10) and the full complement of S-IB stages (excluding static testing).

For SA-8, post-static tests were conducted with automation at the planned level. There was an average time lag of 2-3 months between pre-static and post-static tests, with static firing at MSFC in the interim.

Comparing the manual pre-static against the more automatic post-static checkout on SA-8 is enlightening. Chrysler personnel estimate that total checkout time was cut by about 30 per cent in post-static, partly by reducing testing time but at least equally because of the greater ease in evaluating test data, which automatic equipment records in more convenient form.

In addition, tolerances on measurements were tightened because the automatic system could make tolerance judgments to closer levels than is possible when chart data must be visually interpreted.

Experience to date, therefore, with the computer-controlled check-out system has been good, with equipment and programs essentially performing as planned. This is to be expected, of course, with the prior development and operating experience at MSFC.

Of all the tests in the checkout sequence, almost all electrical network tests, approximately half the instrumentation and telemetry tests, and only one mechanical test (Test A3.4) are automated. Within these defined limits the checkout system is meeting established goals. The system accuracy is estimated at 1 per cent on DDAS measurement and 3 per cent on analog telemetry signals, equivalent to 50 and 150 millivolts respectively for 0-5 volt levels.

The chief benefits that Chrysler personnel have derived from computer-controlled checkout include:

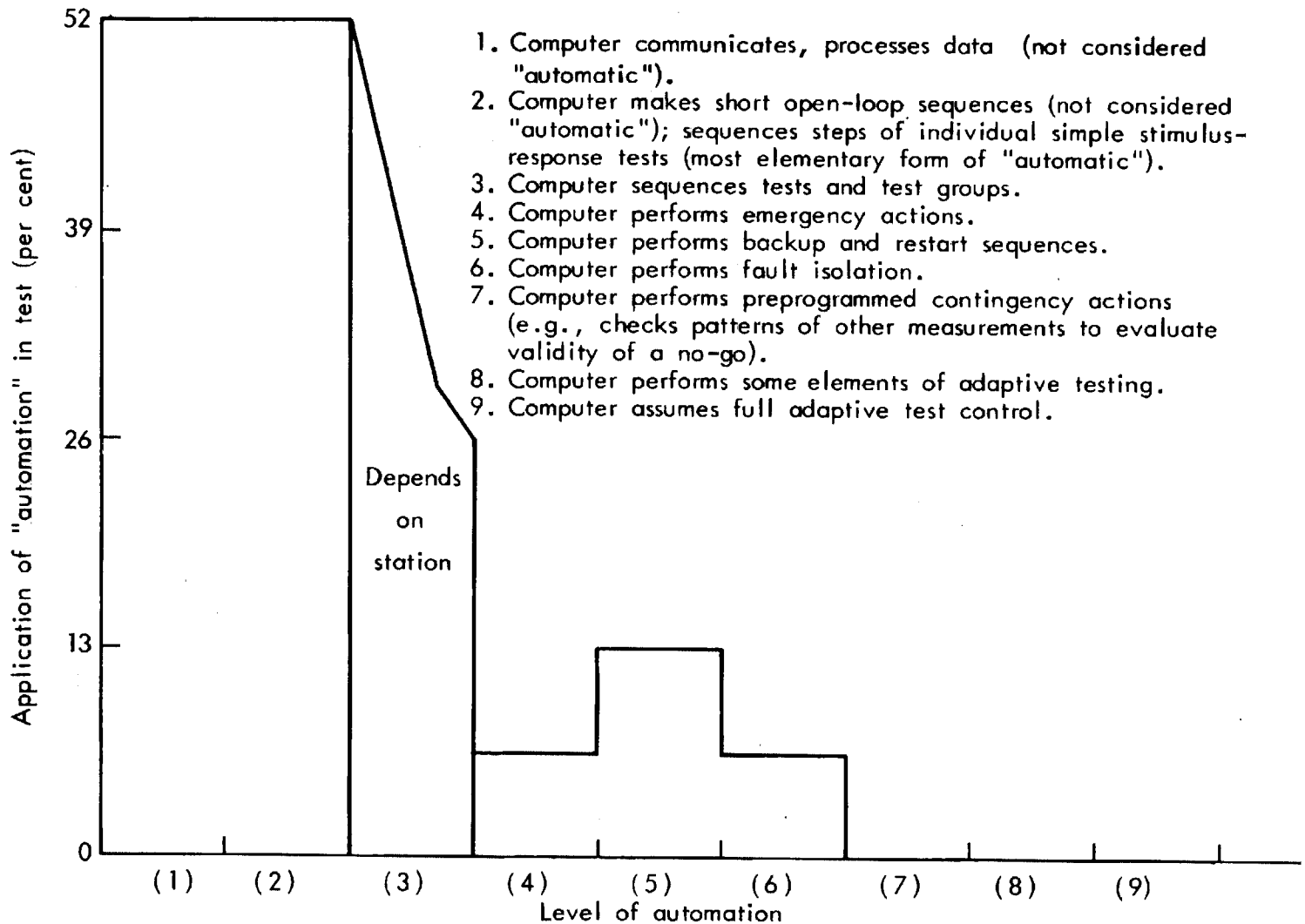
(1) better test quality (reproducibility of results) and more thorough individual tests

(2) faster and more convenient data analysis

(3) ease of test reruns when necessary

(4) failure trend data, in elementary form at least

(5) some decrease in total test time.



1. Computer communicates, processes data (not considered "automatic").
2. Computer makes short open-loop sequences (not considered "automatic"); sequences steps of individual simple stimulus-response tests (most elementary form of "automatic").
3. Computer sequences tests and test groups.
4. Computer performs emergency actions.
5. Computer performs backup and restart sequences.
6. Computer performs fault isolation.
7. Computer performs preprogrammed contingency actions (e.g., checks patterns of other measurements to evaluate validity of a no-go).
8. Computer performs some elements of adaptive testing.
9. Computer assumes full adaptive test control.

Fig. A-1—Automation level, S-IB

Balanced against these are the increase in cost, at least through the initial program phases resulting from:

(1) requirement for new skilled personnel, such as programmers, and for extensive re-training of other personnel, such as test, QC and system engineers, computer analysts, etc.

(2) dependence upon new and unstandardized sources of checkout control, such as computer software.

Apart from these general considerations, some specific features of the Chrysler system merit brief comment, and may assist a qualitative review.

(1) Some network discrete signals on the DDAS train had to be scanned by the computer and GSE at times when it was inconvenient to await the value of that signal coming in as part of the next DDAS frame (that is, the DDAS was essentially unbuffered). Because of this, Chrysler constructed a buffer storage register as additional memory for up to 112 selected discrete channels. This can be considered as a system capability modification.

(2) There is practically no feedback from the checkout system engineers to the stage design groups in terms of suggested improvements since the stage design is basically frozen except for mission requirements modifications.

(3) Reliability of the checkout system hardware, including the computer complex and GSE, has been sufficiently high so as not to affect checkout schedules. About 60-70 per cent of automatic equipment failures have been reported to be in the computer and magnetic tape handlers. (The Packard Bell computers and peripheral equipment are designed to commercial practices of several years ago.) Some grounding and noise problems still remain.

(4) The 100 per cent manual backup capability permits redundancy in testing and guarantees minimum disturbance of test schedules because of malfunctioning GSE. The duplication in equipment is, however, cumbersome (numerous racks, plus special manual/automatic switching) and costly. To date, malfunctioning in automatic GSE has been reported as not presenting a serious problem.

FUTURE AUTOMATION

Because Chrysler received its basic automatic checkout system as government furnished equipment from MSFC, and contract costs allocated to checkout are primarily for operational use rather than system improvement, the projected increase in degree of automation for the future, which is defined primarily by the design, is extremely limited. Since in addition, the equipment is accomplishing its goal in S-I/IB checkout, and since use of the S-IB stage in the Saturn/Apollo program is limited to the Saturn IB launch vehicle, the priority for expanding or upgrading the checkout system is low.

Within the present contractual limitations, it is anticipated that the following will be accomplished:

Expansion of DDAS. The DDAS can monitor all networks and instrumentation channels, but to date not all test points have been incorporated. A number of present hardwire connections through the umbilicals are to be deleted as these channels are added to DDAS. In addition, more reliance will be placed upon DDAS data as primary test information. In the first few S-IB stages, essentially duplicate hardwire instrumentation is still to be relied upon, since familiarization with and confidence in DDAS has not fully been achieved.

Use of ATOLL. The original programs for the Packard Bell computers utilized a special-purpose language that incorporated both problem-oriented and machine-language features. Chrysler now has contractual authority to reprogram all networks tests in ATOLL, to be phased into the program starting with Vehicle 201 post-static tests. Chrysler has also proposed to NASA that instrumentation and telemetry tests now automated be programmed in ATOLL. An SDS-920 computer was procured recently for support activity and will be used for ATOLL compilation.

Incorporation of Digital Events Evaluator. A DEE unit (SDS-910) is being integrated into each of the two checkout stations. The DEE will scan all discrete signals and record changes and out-of-tolerance conditions, with time correlation.

The use of ATOLL is basically a language standardization process, and adding a DEE unit would contribute to data monitoring and recording. Both may well save time during checkout, but neither would affect

the percentage of tests automated or the kind of decisions the computer makes. Expansion of the DDAS would mean that additional test points are monitored solely through the DDAS and utilized for computer accessing and evaluation. At present an overall increase of perhaps 5 per cent in automation appears reasonable.

It is also anticipated that some progressive programming efforts will result in more comprehensive tests and a minimal diagnostic ability, but these are considered normal evolutionary improvements.

* * *

Any attempt to expand further the degree of automation, assuming NASA authorization can be obtained, would imply major hardware revisions. The present system, while adequate to the presently assigned task, does not offer any margin of capability for expansion. In comparison with more recently available computers, the PB-250s are difficult to program.

Chrysler personnel are considering as a longer range possibility the use of the SDS-920 support computer as an on-line checkout control computer, possibly with active on-line communication from the DEE. This would permit more extensive on-line data evaluation and easier programming. Since, however, this is virtually a new system, its implementation is not expected.

ESTIMATE OF FUTURE STATUS

Even without those areas presently scheduled for expansion, the degree of automation provided by Chrysler checkout system appears to provide a more thorough and accurate stage checkout in less time than equivalent manual procedures.

So long as the assigned S-IB checkout task does not vary significantly, both GSE and software are adequate. If, however, the task magnitude increases (such as, for example, a hypothetical requirement to conduct propellant loading and static firing with the same system, or the checkout system is to be used on a more complex stage at the conclusion of the S-IB program), the somewhat marginal computer capability will force a system redesign in almost a step-function manner.

Chrysler personnel indicate that experience to date, if applied to the design of a new system, would call for the following approach:

Selection of a New Control Computer. This is simply a reflection of the fact that computers now available offer more capability, reliability and greater programming facility, and that these appear to be useful in the checkout task.

Elimination of the Master-slave Computer Concept. With greater computer capability, expandable memory, more use of DDAS for checkout, and more particularly the use of only a few satellite stations, the master-slave concept offers only the advantages of parallel testing, which may not be sufficient to justify the added cost.

Elimination of Redundant ESE. Because of the previous manual checkout capability, for networks there is in effect an ESE redundancy, with one set activated manually and an equivalent set under computer control. In addition, manual or semiautomatic control is possible through the station equipment. Experience with automatic checkout indicates that in a new design the independent, redundant, manual ESE portion of the Network Test Station might be eliminated, with some equipment reduction.

Standardized Design Techniques. Noise problems have not yet ben been overcome completely. More consistent grounding, shielding, isolation, filtering, and switching design standards, imposed at a systems level, are considered vital. These could be achieved by standardized design.

Appendixes

S-I/IB STAGE CHECKOUT SYSTEM DETAILS

A. FUNCTIONAL BLOCK DIAGRAM OF THE ON-LINE SYSTEM

Figure A-2 is a functional block diagram of the major on-line hardware components of the CCSD checkout system. In addition to the on-line equipment, a Scientific Data Systems 920 computer with peripheral equipment and two Packard Bell Computer PB-250 computers are used for off-line support, program preparation, and verification.

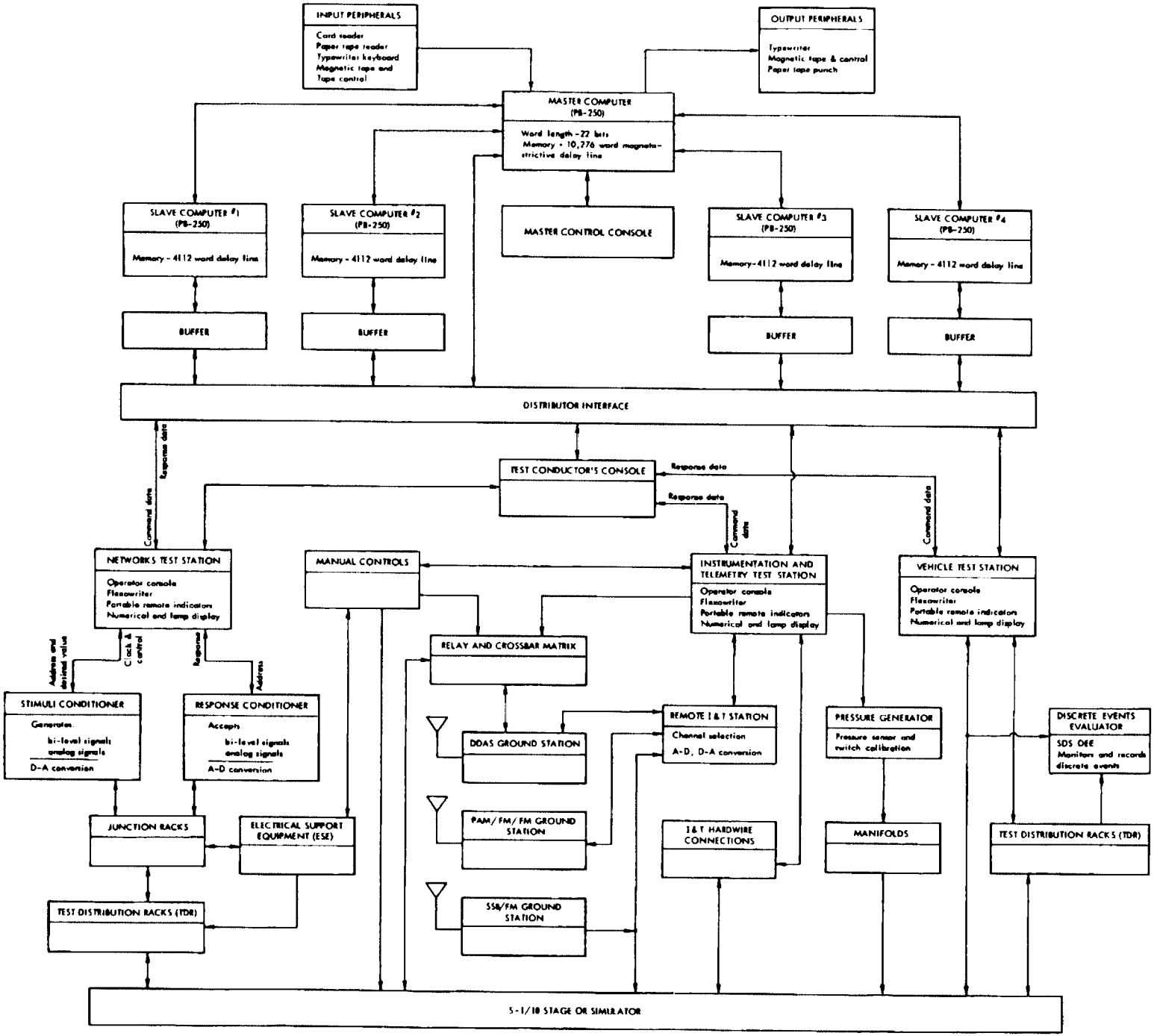


Fig. A-2—S-I/IB stage checkout system

B. DESCRIPTION--MAJOR COMPONENTS AND FUNCTIONS

(Chrysler Corporation Space Division)

MAJOR ON-LINE EQUIPMENT, COMPONENTS, AND FUNCTIONS

1. Checkout Computer Complex

(a) Master Computer - Packard Bell PB-250

Input - card reader, typewriter keyboard, paper tape reader, console

Output - typewriter, paper tape punch, console

Memory - 4,112 word (basic) magnetostrictive delay line, plus 6,164 word (extension) magnetostrictive delay line, 4 magnetic tape units

Word Length - 22 bits

Function - Serves as communication center between input-output equipment and slave computers

- Assigns checkout tasks to slave computers

(b) Slave Computers (4) - PB-250, similar to (a)

Function - Accepts test programs through master computer

- Executes program through satellite test station

- Receives test results and retransmits to output devices through master computer

- Permits communication, via test station keyboard, between Test Operator and Vehicle.

2. Distributor

Function - Interfaces computer complex with Test Conductor's Console and Test Stations

- Receives, stores, and transmits digital data from or to the slave computers, under master computer control

- Provides necessary level or signal conversion

- Controls timing and switching of communications

3. Test Conductor's Console

Function - Provides a centralized location for monitoring test sequencing and displayed results

- Enables individual Test Station to start and proceed with tests

- Provides communications among checkout complex, computer complex and telemetry ground stations

4. Test Stations

(a) Network Test Station

Function - Permits Network Test Operator to request, monitor, and control automatic tests of vehicle network subsystems via Operator Console, Flexowriter, numerical and lamp display, and portable remote indicators.

- Converts computer commands into control signals to stimuli conditions

- Converts response data from Response Conditioner into computer format

(b) Instrumentation and Telemetry Test Station

Function - Permits I&T Test Operator to request, monitor, and control automatic tests of I&T subsystems and some mechanical subsystems via Operator Console, Flexowriter, numerical and lamp display, and portable remote indicators

- Converts computer commands into control signals to remote I&T station, hardwire lines, or pressure generator

- Converts response data into computer format

(c) Vehicle Test Station

Function - Permits Vehicle Test Operator to request, monitor, and control automatic tests of vehicle heater subsystem and certain discrete events, via Operator Console, Flexowriter, numerical and lamp display, and portable remote indicators

- Converts computer commands into control signals

- Converts response data into computer format

5. Stimuli Conditioner

Function - Converts test commands into appropriate stimuli, either bi-level or analog, and routes stimuli to vehicle test points, either directly or, if required, through ESE

6. Response Conditioner

Function - Accepts command data, makes them accessible to the desired test points, converts the signal measurement into digital form, and relays data back through Test Station to Computer Complex

7. Electrical Support Equipment

Function - Provides alternative means to duplicate, via manual control, test signals to the vehicle, and to monitor response signals

8. Manual Controls

Function - Provides means to conduct all tests not under computer program control

- Provides alternative or backup means to conduct tests normally under automatic control

- Provides access capability, via relay-crossbar selector matrix, to critical vehicle data points for trouble-shooting and fault isolation

9. Remote I&T Station

Function - Serves as interface between I&T Test Station and Telemetry Ground Stations (normally located in separate area from checkout equipment)

- Converts command data into selection and accessing of telemetry channels

- Converts response data into computer format

10. Pressure Generator

Function - Provides means to generate calibrated pneumatic and hydraulic pressure levels in response to computer control

- Provides means, through manifold connections to vehicle, to establish calibrated pressure at selected vehicle test points

11. Telemetry Ground Stations

Function - Accepts telemetry data, either RF (through transmitter-receiver or via coaxial cable) or composite premodulated; demultiplexes, records and retransmits, if desired, selected data channels to I&T Test Station

(a) Digital Data Acquisition System Ground Station

Function - Accepts either PCM/FM RF data or 600KC FM DDAS signal; processes, records, and retransmits data to I&T Test Station

- Demultiplexes selected channels to analog form for display and recording

- Provides capability to adjust and calibrate transducers and signal conditioner

(b) Pulse Amplitude Modulated/FM/FM Ground Station

Function - Accepts PAM/FM/FM signals either in RF form or as composite subcarriers

- Demodulates data to a PAM pulse train for recording, display, or selected demultiplexing and digitizing channels

- Provides capability to adjust and calibrate transducers and signal conditioners

(c) Single Side-band/FM/Ground Station

Function - Accepts SSB/FM signals in RF or composite premodulated form from high frequency (to 3KC) vibration and acoustic channels

- Demodulates and demultiplexes data for recording and display

- Provides capability to adjust and calibrate transducers and signal conditioners

12. Discrete Events Evaluator

(Consists of a Scientific Data Systems 910 Computer with output typewriter and paper tape punch)

Function - Monitors and records discrete events (bi-level or "on-off" signals) together with reference time data so that a permanent record of time-critical test events is maintained.

C. BASIC SOFTWARE

GENERAL

Although the specific test programs used by Chrysler have received a good deal of modification from the original MSFC/Packard Bell programs, the basic software in current use is less modified. However, Chrysler is also implementing a restricted modification of ATOLL for Network programs, and has proposed expanding this to Instrumentation and Telemetry programs.

Basic software in the Chrysler system implements the master-slave computer relationship, including program requests and loading from tape, allows for starting, stopping, and sequencing slave programs from the operator controls, and permits logging program requests and other master operations. (The ATOLL software, when available, will also supply linkages to existing semi-specialized Network routines to permit coding those programs in ATOLL.) In addition, the station programs are coded mostly in a rather general-purpose way, so that they might be considered semi-specialized items of basic software.

The master programs occupy about 7,000 words of the master memory. The remainder of the master memory is taken up by common memory with the slave computers, and the space for tables, data to be transferred for slave-computer loading, and data to be logged on tape.

Information on the existing software is derived mainly from Refs. 1 and 2, and discussions with personnel.

Information on the Network ATOLL software is derived from Refs. 3-5 and discussions.

Existing software accepts input data off-line in tabular format, as long as the existing on-line semi-specialized programs are adequate to perform the on-line operations. For example, a timed sequence of discrete outputs, scans, and analog measurements is within the capability of the present semi-specialized Network program. For such a sequence, it is necessary only to prepare a manuscript table expressing the timing, reference data, and actions required. Off-line processing of this table, to produce a data table that can be used by the on-line Network program,

is performed on a PB-250 computer, which may either be one of those in the Computer Complex or a separate off-line machine.

ATOLL off-line pre-processing will be performed on an SDS-920, with magnetic and paper tape capability and a line printer. The SDS-920 has been considered for off-line analysis of test results, either from the computer complex or from the DEE, and for the off-line processing now being performed by the PB-250. ATOLL capability is expected to be available soon; first attempts at complete pre-processing on the SDS-920 were made at the end of March 1965.

A limited software simulation capability is included. The computer can be requested to type out (in octal only, not English or decimal) commands to the Test Station, instead of actually sending them. Similarly, responses to the commands may be typed in (in octal only) by the operator, to simulate station responses.

Figure A-3[1] shows schematically the master-slave communication software, including operator participation. Except for minor functions such as logging of program requests on tape at the Master Station, this constitutes most of the basic software in the existing configuration.

TEST PROGRAMS AND SLAVE-COMPUTER HOUSEKEEPING

Test programs generally are segmented to provide convenient breakpoints. (It was originally intended that this would also provide a way for master-controlled time-sharing to be implemented, but this is a minor factor in the present configuration.) By use of so-called breakpoint options within the semi-specialized programs, the operator may stop at the ends of segments, or may cause fully automatic sequencing.

A typical segment might be, for the Instrumentation and Telemetry Station, a check of a single instrumentation channel. For this station, the program might also permit a semiautomatic adjustment operation using the Remote Indicator unit, in which the computer continually monitors a channel, checks it for in-tolerance conditions, and if out of tolerance, informs the remote technician which side (high or low), and whether he is turning the adjustment in the correct direction.

The Flexowriter serves as both a control/display device and a visual logging device. Requests for operator participation are typed out by the computer automatically, as are log data, as specially programmed. Manual data and commands (other than those available with the standard controls, displays, and breakpoint options) are typed in manually. The display includes two single-purpose decimal displays, one for the current program step number, and one for the data output of the step (as programmed).

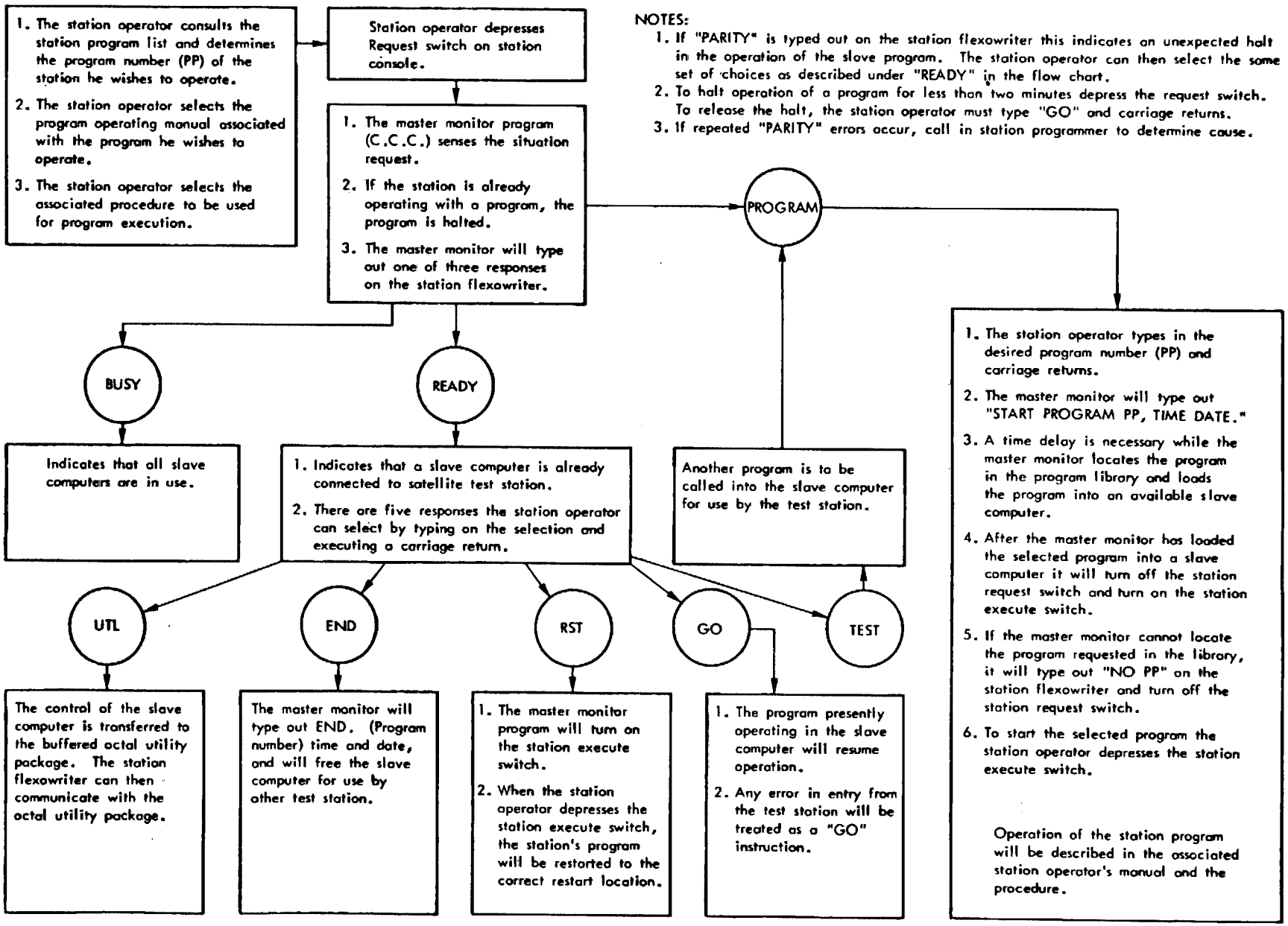
During running a of segment, no general purpose housekeeping loops are performed, although the semi-specialized programs may include monitoring and display functions. Between segments (if the breakpoint option so directs) or between computer commands in the single-step mode, the program cycles through an idle loop, checking for the presence of further manual or master-computer commands, and assembling input Flexowriter messages from the operator when necessary.

MANUAL CONTROL AND INTERRUPTS

A single interrupt exists in the computer, which may be entered by depression of two Flexowriter keys. This can be used to get the program out of a "hung-up" loop. Emergency shutdown is performed by the hardware reset button; no emergency shutdown sequences are included as parts of the general purpose software, although some emergency branches may be included in the specialized programs.

The operator may interrupt program operations by the request button, which causes the program to stop at the end of the current segment and enter the sequence of Fig. A-3. The slave computer scans for a request at the end of each segment. The software was originally intended to permit interrupting one station by a higher priority program request from another station, but this is not used at present.

Most of the detailed operator control, other than that of Fig. A-3, is contained in the semi-specialized programs for each test station. For example, the following listing of breakpoint control[1] shows the functions of the six general purpose breakpoint switches during operation of the Test Data Interpreter and Execution Program for the Network station.



NOTES:

1. If "PARITY" is typed out on the station flexowriter this indicates an unexpected halt in the operation of the slave program. The station operator can then select the same set of choices as described under "READY" in the flow chart.
2. To halt operation of a program for less than two minutes depress the request switch. To release the halt, the station operator must type "GO" and carriage returns.
3. If repeated "PARITY" errors occur, call in station programmer to determine cause.

Fig. A-3—Master control

No general purpose "continuous monitor" and check for limits routine is provided, although a program is provided that permits single display of an arbitrarily selected quantity (including scaling but not bias and linearization).

Breakpoint Control

1. Entry points under Master Monitor Control:

Starting the program is accomplished by depressing the Execute Switch after the test statements (data) and the program are loaded. Starting is also initiated by transferring to sector 001 of line 02. In either case, the actual profile and the reference profile are automatically cleared in the process. If clearing the maps is not desired, transfer to sector 002 of line 04 to start the program.

A restart of the program may be accomplished by using the Reset feature of the Master Monitor Program to turn on the Execute Switch, or by transferring to either of the entry points.

The breakpoint options permit a continuance of testing if a restart is not desired. A transfer to sector 304 of line 12 transfers the program to the breakpoint options.

2. Breakpoint options in this program can be selected at the following times: (At these times, the Execute Switch will be turned on by the program.)

A. After each segment, "I.D." (identification) is typed out on the station Flexowriter.

B. At a pause.

C. After a "no-go" is typed out on the station Flexowriter.

D. After transferring to sector 304 of line 12.

3. The breakpoint options are as follows:

A. With all breakpoints off, the program will continue to the next step, and the reference profile will automatically be updated from both the last actual profile formed in the previous step and from the test data in the current step. The update from the actual profile allows a

stray no-go to be accepted. In some cases, prior to step 1 the actual profile is blank, since no scanning cycle has been executed. Therefore, it might be beneficial to utilize breakpoint option 5 prior to initiation.

B. With breakpoint 1 on and all others off, the program will recycle the step just completed. The reference profile is updated from test data alone. This allows a no-go to be corrected, and then verified on a recycle.

C. With breakpoint 2 on and all others off, the program will go to the next segment. After all segments in the Segment Table are used, the program will type out "End Test."

D. With breakpoint 3 on and all others off, program control will be transferred to the Flexowriter, i.e., Buffered output (OUP).

E. With breakpoint 4 on and all others off, a programmed loop is initiated. This is sometimes necessary in the middle of a segment when another computer will use the Network Test Station. To resume testing, transfer to the breakpoint options.

F. With breakpoint 5 on and all others off, a scanning cycle is executed and an update is made from the resulting actual profile. This feature is used mainly when switching from manual control to computer control. By so doing, discretes which are ON due to previous manual operation will be accepted by the program, rather than being considered as stray no-go's in step 1. In some cases, this feature might also be utilized prior to a recycle, i.e., breakpoint option 1. Breakpoint option 5 also serves the purpose of resetting the program transfers resulting from a possible previous execution of breakpoint option 6.

G. With breakpoint 6 on and all others off, program transfers are set. This allows the program to check only those discretes listed in test data. This option would be used on segments on which many discrete status changes occur, but only a few key discretes are listed in test data. This option allows the test to progress, rather than to be hindered by the checking and subsequent no-go printout of insignificant strays.

Annex A

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Annex B

S-IVB STAGE CHECKOUT

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CHECKOUT CONCEPT AND OBJECTIVES

BACKGROUND DATA

Douglas Aircraft Company (DAC), as the contractor designing and manufacturing the S-IV, S-IVB/IB and S-IVB/V stages (for the Saturn I, IB, and V launch vehicles respectively), has stage checkout responsibility including factory acceptance, pre-static, static, and post-static testing.

At this writing, the S-IV program is complete at DAC, and manufacturing and testing for the initial S-IVB units are in process. The first flight version of the S-IVB is scheduled for incorporation in Saturn IB Vehicle SA-201, due to be launched from Complex 34 at KSC in early 1966.

A modified S-IVB, designated S-IVB/V, will be incorporated in the Saturn V vehicle, with the first launching scheduled from Complex 39 at KSC in early 1967.

STAGE DESCRIPTION

The S-IVB stage is the second stage of the Saturn IB launch vehicle, and the third stage of the Saturn V launch vehicle. It is approximately 58 ft long, 22 ft in diameter, with a main stage propellant capacity of 230,000 lb. Its main propulsion is provided by a single J-2 engine of 200,000-lb thrust, fueled by liquid hydrogen and liquid oxygen.

The S-IVB includes ten major systems:

Structure
Electrical
Hydraulic
Engine
Propellant Utilization
Chilldown

Main Propulsion
Auxiliary Propulsion
Ordnance
Instrumentation and Telemetry

The Structure System includes the passive structural elements. It is fabricated of aluminum alloys, and uses the propellant tanks as integral structural members. The forward and aft skirt portions serve as mounting areas for electrical and electronic equipment. The Saturn IB version has a cylindrical aft skirt to mate with the S-IB stage, while the Saturn V version has a conical aft skirt to mate with the S-II stage.

The Electrical System includes three 28 VDC and one 56 VDC power supplies, internal/external power transfer controls, power turn-on and distribution equipment, a switch selector for command decoding and four sets of silver oxide/zinc batteries, one for each supply.

The Hydraulic System provides actuation power for engine gimbals, which vary the direction of thrust (as controlled by the guidance equipment in the Instrument Unit). Its prime source is a main hydraulic pump driven by the turbine (that also drives the LOX pump) and that is actuated by the rocket engine. It also contains an auxiliary electrically driven pump, a reservoir-accumulator, servo control valves, engine actuators, and miscellaneous valves, filters, and piping.

The J-2 Engine is mounted on a thrust structure, and is gimbaled by the hydraulic actuators. It is self-contained, including fuel pumps, LOX pump, and valving, so that it requires only propellant, electrical power and signals, and gimbaling force from the remainder of the system.

The Propellant Utilization System senses the mass of LOX and liquid hydrogen in the tanks, to a nominal accuracy of 0.25 per cent. It includes capacitance probes in the tanks, capacitance-sensing servos, a fuel-mixture circuit, a drive amplifier for the mixture valve in the engine, and feedback and telemetry potentiometers.

The Chilldown System includes two electrically driven pumps, valves, and piping to chill the propellant feed system before starting. This guarantees the proper liquid head of propellant at the main pump inlets at starting.

The Main Propulsion System includes the valves and pressure tanks necessary to pre-pressurize the fuel and LOX tanks, and to excite the pneumatically operated valves in the system. Its subsystems include fuel tank pressurization, LOX tank pressurization, cold helium supply, ambient helium supply, and control helium supply.

The Auxiliary Propulsion System is used for roll control at all times and attitude control during orbital coast and before restart. For the Saturn V it includes ullage rockets, to provide positive "gravity" feed for priming the fuel and LOX pumps, orientation control rockets to pre-align the stage in the proper direction, self-contained tanks for the hypergolic propellants, and control circuits and valves.

The Ordnance System includes a shaped charge for separating the aft skirt to remove the spent S-II stage, solid rockets to decelerate the separated S-II, Exploding Bridge Wire (EBW) control circuits for activating these, and the Range Safety Subsystem, which includes the range-safety radio receivers, control circuits, EBW circuits, and shaped charges. Safety and Arming devices are provided for EBW circuits used in propellant dispersion; other EBW circuits do not contain S&A devices.

The Instrumentation and Telemetry System accepts signals from the transducers in the other systems. It includes all of the measurement transducers and signal conditioners, three FM/FM telemeters, three multiplexed PAM/FM/FM sequences using the 70-kc subcarrier of the FM/FM telemeters, a PCM/FM telemeter and a 15-channel SSB/FM telemeter. One PCM multiplexer, used for ground checkout only, is combined with the three PAM multiplexers and used to modulate a 600-kc carrier for a coaxial DDAS link. It is also transmitted as PCM.

DESCRIPTION OF TESTS

A checkout sequence for the factory, pre-static, static, and post-static testing of the S-IVB stage is shown below. It must be realized that with modifications in vehicle design the details of these individual tests may vary, but the sequence listed will serve the purpose of this study.

Operation	Description
Pre-test	Stage Installation--positioning at test stand, removal of environmental covers
Test Preparation	Inspection--visual inspection of tanks, structure, and wiring for damage, and to establish correct configuration
Test Preparation	Stage Preparation and Modification--connection of vehicle pneumatic pressure monitoring panel, completion of unfinished manufacturing assembly, and installation of modifications approved after manufacturing design freeze
GSE Verification	
G-1	Switch and Light Test--to determine operational integrity of all GSE switches, lights and meter indications, some manual switch operations included between automatic sequences
G-2	Auxiliary Distribution Unit Test--to verify the ability of the relay matrix in the ADU to transmit control and response signals between the mechanical GSE and the Response Conditioner or Stimuli Conditioner
G-3	Ground Equipment Test Set (GETS) Test--to verify overall GSE operation and GSE/stage compatibility by providing functional responses to the ACS output within the capability of hardwire connections through the umbilical and/or interface connectors. Verifies the following: (a) bi-level stimuli/response conditioning (b) analog stimuli/response conditioning (c) patching (d) signal distribution (e) external power distribution (f) cable/receptacle normal vehicle connections
G-4	GSE Certification--calibration against standards, to the extent necessary, of all ACS and GSE components

Test	Description
Stage Verif.	
1	Propellant Tank Inspection--ultrasonic test of full tank exterior to detect tank insulation debonding, internal inspection of full tank for insulation cracking or spalling; growler check of the forward surface of the common bulkhead
2	Forward and Aft Interface and Umbilical Impedence Compatibility--resistance check of forward and aft interface, and vehicle circuitry as seen through the umbilical pins, to assure absence of short circuits and stage readiness for power
3	Forward Skirt Thermal Conditioning Activation and Checkout--fill, leak check, flush, bleed, and thermal functioning checkout of thermal conditioning subsystem of forward skirt
4	Forward and Aft Skirt Purge Checkout--verification of operation of purge subsystems of forward and aft skirts
5	Power Distribution System Checkout--to verify correct operation of the power distribution subsystem prior to extensive power-on testing. Includes load evaluation on subsystem legs, checks of power switching functions, and set-up of initial conditions for each power turn-on
6	Signal Conditioning Calibration--adjustment of gain of DC amplifiers, expanded scale modules, temperature bridges, etc., on vehicle for compatibility with telemetry inputs
7	DDAS Checkout--end-to-end verification of DDAS channels, including a Remote Automatic Calibration Systems test. Includes ambient readouts from transducers and/or manual stimulation of inputs to transducers if necessary

Test	Description
Stage Verif.	
8	Propellant Utilization Subsystem Setup, Calibration and Checkout--manual setup and calibration of P.U. subsystem, followed by automatic checkout. Calibration includes LH_2 and LOX "bridge empty" calibrations, LH_2 and LOX "bridge full" calibration, data acquisition for LH_2 and LOX bridge slew, calibration of overfill sensor systems. Automatic P.U. Subsystem Checkout includes power test, servo balanced bridge test from the two mass sensors through the summation network, and valve movement tests from the slewing network through the P.U. valve positioner
Operation	
9	Range Safety Subsystem Tests--manual tests (with special-purpose test set) of range safety subsystem, plus automatic checkout of range safety receiver. Manual tests include: (a) EBW and Receiver External/Internal Power Transfer Test (b) Engine Cutoff Test (c) Pulse Sensor and Pulse Doppler Command Inhibit Test (d) In-flight Turn-off Command Test (e) Propellant Dispersion Command Test (f) Safe-and-arm Device Test. The automatic procedures include: (a) Automatic Gain Control calibration curves--three calibration curves run on each receiver to determine AGC calibration drift (b) Deviation sensitivity check--verification that receivers can receive signal deviated at minimum acceptable value (c) RF sensitivity checks--verification that receivers can receive signals at minimum power level

Operation	Description
10	Telemetry Checkout--turns on all T/M transmitters, first sequentially and then simultaneously, while verifying center frequency, modulation, calibration program steps, voltage standing wave ratio, and end-to-end operation (exception, Single Sideband/FM Telemetry and some other RF measurements checked manually)
11	EBW Subsystem Checkout--test to insure the capability of EBW subsystem to ignite and jettison ullage rockets, and to ignite retrorockets and stage separation primacord (electronic pulse sensors simulate EBW detonators, live ordnance devices not installed)
12	Hydraulic Subsystem Fill, Flush, Bleed and Fluid Sample Procedure--manual servicing of hydraulic system to verify fluid cleanliness and fill level
13	Hydraulic Subsystem Checkout--gimbals engines to measure actuator response to commands from Instrument Unit substitute
14	Auxiliary Propulsion System (APS) Circuitry Check--tests command signals routed from ACS through IU substitute to APS electrical interfaces (APS simulators substituted for hypergolic rockets)
15	J-2 Engine Leak and Functional Test--automatic, with self-interruptions for manual operations. Manual leak tests verify integrity of engine high and low pressure propellant ducting, of valves and valve seats, of main thrust chamber, of Engine Pneumatic Control Subsystem, and of Gas Generator Exhaust Subsystem. Automatic test verifies functional operation and timing of engine valves
16	Vehicle Control Pneumatic Leak and Functional Test--automatic program cycles pneumatic control valves and checks function and timing; manual interruptions include leak testing of vehicle control pneumatic components and fittings

Operation	Description
17	Cold Helium Subsystem Leak and Functional Test--automatic test verifies operation of ground and vehicle portions of cold helium subsystem of propulsion systems (has intermediate manual leak testing)
18	LH_2 Tank Pressurizing Subsystem Leak and Functional Test--automatic test verifies operation of vehicle and test stand pressurizing systems (has intermediate manual leak testing)
19	Propellant Tanks Leak and Functional Test--automatic test verifies operation of propellant tank valves (has intermediate manual leak testing)
20	Simulated Flight (Umbilicals Out)--to demonstrate normal operation of all electrical systems, with electrical umbilicals retracted at "time zero" to demonstrate stage control through IU interface
21	Weight and Center of Gravity Tests
Post-test	Evaluate test, prepare for shipment, ship to Sacramento
Pre-test	Receive, assemble into test stand, prepare for checkout
22	Inspect propellant tanks, using growler and ultrasonic tests, check engine alignment, install special instrumentation
23	Repeat tests 2 through 19 with minor variations for special facility and safety considerations
24	Hardwire Instrumentation Setup and Checkout--end-to-end verification of Ground Instrumentation System setup and patching

Test	Description
25	Integrated Systems Test--a rapid, sequential check of all vehicle and GSE functions that are computer controllable, to ensure that controls are in a ready condition and that functioning of vehicle and GSE components is normal prior to commitment of manpower and resources for a major test. Includes operating pneumatic components, valves and regulators, propellant transfer sleds, all stage valves in the pneumatic control, cold helium, fuel tank pressurization, engine controls, and propulsion subsystems, plus test turn-on and check of the DDAS, EBW, Range Safety, and Telemetry Systems and an end-to-end check of Hydraulic Subsystem functioning
26	Simulated Static Firing--simulates a static firing to demonstrate readiness to proceed into live propellant loading and hot firing. Utilizes the static firing countdown, but omits propellant loading, pressurization, and chilldown portions. It is conducted as a formal countdown with the stage exercised in a simulation of the static firing to follow. The test operates all electrical functions in normal sequence and stimulates all talkbacks insofar as possible to demonstrate functioning of all vehicle systems together (static firing automatic tapes used in this simulation)
27	Simulated Firing Data Evaluation--evaluation of data from (26) before commitment of stage to hot firing
28	Static Firing (Short Duration)--functions all systems of the stage in a captive simulation of actual launch, separation, engine start, attitude control, in-flight pressurization, and shutdown. Telemetry antennas radiate. No simulation of propellant inlet pressures due to acceleration is attempted. One Auxiliary Propulsion Unit* is simulated, installed, loaded with inert fluids, and pressurized. Control of vehicle systems from the start of loading through firing and detanking is by computer program through IU and

*Only one APS for Saturn I-B and one for Saturn V are installed, loaded with inert fluid, and pressurized. The APS for all other units will be simulated.

Test	Description
	umbilical paths. Telemeter data at the Test Control Center is demodulated and recorded on tape; DDAS data transmitted on coax through an umbilical connector to the DDAS ground station for access by the ACS computer
29	Integrated Systems Test--Test 25 repeated
30	Tests 25, 27, 28 (Full Duration), and 29 repeated
31	Static Firing Data Evaluation--similar to Test 26
32	LH_2 Tank Inspection--Test 1 repeated
33	DDAS Checkout--Test 7 repeated
34	Range Safety Subsystem Tests--automatic portion of Test 9 repeated
35	Telemetry Checkout--Tests 10, 11, 12, 13, and 14 repeated
36	Removal of Hardwire Instrumentation--stage returned to flight configuration by removal of hardwire instrumentation installed previously
37	Electromagnetic Compatibility Test--monitoring equipment connected to vehicle systems at points to be monitored for spurious electromagnetic signals and a simulated flight performed. Any interference problems noted are pursued by specific systems tests, and measurements of sources of incompatibility made
38	Repeat Tests 14 through 19
39	Simulated Flight (Umbilicals Out)--to demonstrate normal operation of all electrical systems, with electrical umbilicals retracted at "time zero" to demonstrate stage control through IU interface

Test	Description
40	Electromagnetic Interference Test--verification of conformance to MIL-E-6051C with the level of detail determined by QC representatives
41	Data Evaluation--final evaluation of test data before removal of stage from test stand
Post-test	Removal from Test Stand--includes all disconnections from stage, removal and installation of handling fixtures, lifting out of test stand, and installation on transporter
Post-test	Preparation for Shipment and Barge On-loading--all operations necessary prior to shipment, transport to docksite, on-loading and securing of vehicle.

CHECKOUT SYSTEM APPLICATION

The application of Douglas' Automatic Checkout System (ACS) in checkout began, to the extent permitted by available programs and equipment, with the first S-IVB Facilities Checkout Vehicles (FCVs) and SA-201s. (The battleship vehicle was checked out manually.) At present, the ACS uses a general purpose digital computer (Control Data 924A) as the central element. The computer is complemented by associated peripheral input-output equipment, special purpose test stations for major vehicle subsystems, and electrical and mechanical support equipment. Detailed hardware and software features of the ACS are described in the appendixes.

The ACS concept is that the automatic system will normally control as large a proportion of the total checkout sequence as is practicable. To permit operations outside the predetermined automatic program, the test operator may command semiautomatic actions (e.g., set output, read inputs, etc.), or delete steps from or add steps to the automatic program on-line. The capability is provided by the software and control-display console of the automatic system

Separate manual "local" controls are provided to the extent necessary for safing and shut-down contingency, but not to check out the stage.* Thus, it is not anticipated that the separate manual controls will be exercised during an automatic program except for safety. However, with care it is possible to return to automatic control without recycling to a start point in the test.

Douglas sees the ACS as basically an automatic system with emergency manual backup equipment, and not a parallel manual-automatic system with choices provided for forward-direction tests. However, there are still major subsystem test areas that are not directly compatible with computer-controlled checkout (primarily non-electrical tests and equipment adjustment or calibration). In these areas, checkout procedures vary from "full manual" tests to "hybrid" tests, which use both automatic and manual procedures.

DEVELOPMENT OF TEST REQUIREMENTS AND PROCEDURES

In response to the MSFC Automation Plan,(1) May 8, 1962, DAC developed the design concept for a computer-controlled checkout system (ACS) for use in the S-IVB program. The guideline ACS document is Ref. 2.

The S-IVB ACS,(3) with NASA coordination and authorization, was developed from this operating concept, resulting in ACS installations for factory acceptance at the Vehicle Checkout Laboratory (Huntington Beach) and pre-static, static, and post-static checkout at DAC's Test Station (Sacramento). In addition, an ACS installation at the System Integration Laboratory (SIL), Huntington Beach, serves as an R&D support, software verification and simulation facility.

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*It is possible to perform any control signal and read any static response that is normally performed automatically by using the manual inputs provided for ACS checkout and maintenance. However, these were not designed for operational use and would be very cumbersome to use in S-IVB checkout.

Responsibility for delineating checkout system requirements, ACS and GSE hardware design, ACS software preparation, R&D testing and end-item checkout operations for the S-IVB stage is assigned to the Saturn Engineering department, which also is responsible for stage design.

Checkout system requirements and the resulting ACS design were generated by combining input data from

(a) preliminary system and subsystem test requirements from the S-IVB stage design engineering groups

(b) the MSFC Automation Plan

(c) previous manual checkout experience on the S-IV (plus some related Thor and Skybolt test experience)

(d) automatic checkout on Skybolt and Nike-Zeus.

The individual test requirements that form the basis for the final automatic checkout programs originate from the vehicle design groups in general functional form. From these, the test engineers generate Test Requirement Documents (TRD) for those tests to be automated. Douglas stated that most test engineers who prepared TRDs were drawn from the appropriate vehicle design area. The test engineering group is in the same system organization as vehicle system design, facilitating feedback from test design to stage design. Tests for the S-IVB were developed primarily from S-IV experience, but are tailored to ACS capabilities. The resulting ACS tests usually accomplish substantially more in both self-check and data acquisition than the equivalent S-IV tests.

A TRD for a particular system or subsystem

(a) defines the test requirements

(b) includes applicable subsystem schematic diagrams

(c) includes detailed test flow diagrams in a form compatible with computer programming requirements

(d) lists stimuli, response points, and signal levels

(e) lists display indications desired.

The point is that the test engineers, who in many cases are also involved in the test operations, will carry the TRD through the logic

flow diagram. This requires their familiarization to a reasonably detailed degree with both the ACS equipment and the software.

With this assignment of responsibility, DAC claims benefits in:

(a) definition of test requirements and procedural steps with greater forethought and precision because of the detailed and unambiguous statements required by the computer program

(b) greater awareness by test engineers of the present and potential capability of the ACS, particularly in the programming area

(c) better interdisciplinary communication between the diverse design engineering groups such as propulsion, mechanical, electronic, etc., since they all work to a common test interface

(d) special attention to critical requirements; for example, the TRDs for the test programs peculiar to static firing, in which Sacramento facilities such as cryogenics and propellant loading are concerned, are prepared by Sacramento test engineers.

When the TRD has been completed for a particular automatic test, the ACS computer programming group, also a part of the engineering organization, prepares the computer test program. Use of a test language for most programming is planned, although certain areas must be in machine language for reasons of speed or program complexity. When approved by both DAC engineering management and NASA technical representatives, this test program forms part of the final Handling and Checkout Drawing, which is the document defining the specific test procedure for each subsystem. (Handling and Checkout Drawings are also prepared for all manual tests.) The full set of Handling and Checkout Drawings become, in effect, the governing test procedure for the complete checkout sequence.

So far, modification and updating have not caused serious problems, at least for Vehicle 201. Most of the modifications installed at Sacramento before static firing were the result of engineering that followed the basic manufacturing design "freeze," but preceded shipment to Sacramento. Most of the resulting program modifications had already been checked out on the simulator, before the programs were needed for the modified system. The SIL simulator was then converted

to the 202 configuration. Following this, a few more modifications were required due to further engineering (and perhaps a few more will be required as a result of static firing), but these have so far proven small enough that the resulting program changes can be checked out at Sacramento, on the S-IVB stage, without significant schedule delays.

PRESENT AUTOMATION LEVEL

With the test sequence beginning on p. B-5 as a basis, quantitative estimates of the degree of automation achieved to date may be made.

We estimate the automation to be 60 to 70 per cent. This estimate includes a weighting for the increase in the number of test steps due to automation. It is assumed that when a test is automated, three to four automated test steps result on the average from one manual test step. This is due to a number of factors; measurements are more often performed several times and averaged, test sequences are more often repeated, or more combinations are checked automatically than would be checked manually.

Another estimate of degree of automation is based upon the kind, rather than the quantity, of tests performed automatically. Considering only those portions of retesting that are performed automatically, the Douglas system achieves a "level" of automation shown in the profile of Fig. B-1. The more basic levels of automation--communication, processing data, and sequencing tests and test groups--are fully applied.

"Posting" of pre-chosen emergency-stop routines, as reactions to the Emergency Stop button, is applied to all areas. In addition, reactions to the Safety Item Monitor interrupts are mostly automatic in areas where such interrupts may reasonably be expected to occur. However, a manual decision area (with automatic visual warnings) is still present in Safety Item Monitor reactions because of the impracticality of preprogramming reactions to all possible (but very unlikely) interrupts from this source.

Posting of safe backup and restart routines is applied to all Douglas programs.

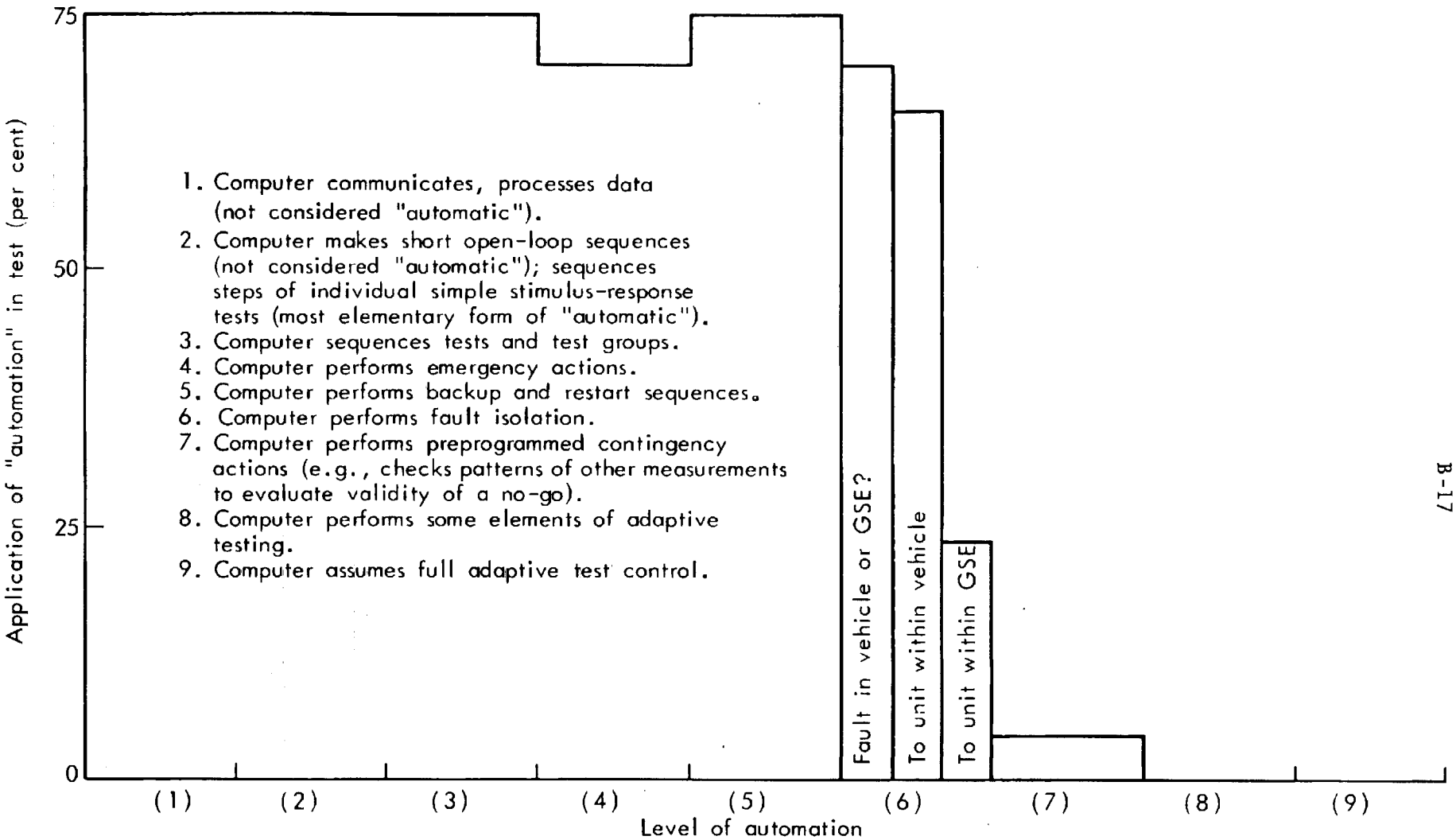

Fig. B-1—Automation level, S-IVB

Fault isolation to the replaceable unit (not including cabling) is applied to most of the Douglas programs for vehicle testing, and the GSE self-test distinguishes vehicle from GSE faults. However, the GSE self-tests do not include fault isolation, except perhaps to the major subsystem of the ground system.

Preprogrammed contingency routines and adaptive programming are absent from the Douglas system. Contingencies are met largely by semiautomatic actions using ACS (including basic software) as a manually directed device. (Since this does include a certain amount of automatic processing, display, and error-checking, the "contingency" bar is shown as having a slight degree of automation.)

REVIEW OF PRESENT STATUS

Normally an increase in degree of automation is accompanied by a decrease in flexibility. Any loss of flexibility is a consideration in an R&D program such as Saturn/Apollo, in which changes are the rule rather than the exception.

From a hardware point of view, the lack of 100 per cent backup manual checkout capability imposes some restrictions.

(a) In some cases, it is difficult to set up for testing more than one system or subsystem at a time. The semiautomatic on-line programming capabilities of the ACS (on-line STOL) and the manual hardwire controls permit a fair degree of parallel operations, especially during setup. However, independence is not complete, since the computer is involved in most cases and is not multiprogrammed among test stations. This has the converse advantage of ensuring that unwanted interaction between systems is minimized, but at the expense of setup time.

(b) If the ACS hardware is malfunctioning for an extensive time or the computer programs are not properly debugged, checkout becomes difficult.

Given the usual problems associated with program debugging on a flight stage (partly because of uncertainty as to whether the ACS or the new stage is the source of trouble, and partly because of the operating time and accessibility restrictions on the stage subsystems), the limitations on fall-back may cause delays. The desired approach,

of course, is to debug programs on the engineering breadboard facility (SIL in this case) in advance, but stage modifications and part shortages often make such advance simulation impossible. Also in static firing particularly, because of the site facilities involved it is in many cases impracticable to fully simulate these conditions, and the first vehicle static fired also serves to proof the ACS and software.

As an illustration, the SIL ACS is designed to verify programs for all automated electrical and pneumatic tests and to simulate mechanical and hydraulic tests. At the Vehicle Checkout Laboratory the real stage mechanical and hydraulic subsystems are checked out for the first time, while at the Sacramento Test Station the cryogenic, propellant loading, RF telemetry, and Ground Instrumentation Facility are involved in addition to the checkout.

The severest test of system flexibility occurs in the initial start-up, debugging, and familiarization period. Manual backup capability is of maximum benefit during this period. If many changes have to be introduced that were not checked out in SIL because of schedule pressure (and that cause extensive problems with ACS), manual backup may have to be added. However, if this phase is completed with the present characteristics of ACS, the ACS can be expected to permit planned automation to be achieved and maintained throughout the S-IVB program.

The SIL ACS facility, which includes an S-IVB simulator, appears to be serving its prime function of running, debugging, and verifying checkout computer programs, in addition to training test personnel.

The ACS System Status Display merits brief comment since it varies from the displays used in other Saturn facilities. (The project Saturn V display system at KSC also has slide projection capability, but this is expected to be a minor mode of operation.) The display system consists of a random-access slide projector, a source of alphanumeric display data, and means for mixing the two superimposed displays on a TV screen. The slide to be projected may be selected by the operator or the program, and contains a semi-pictorial block diagram of the equipment being tested. On each block of the diagram is an open space into which alphanumeric quantities are inserted by the ACS.

Thus the operator has a dynamic diagrammatic display of the instantaneous status of the system quantities of interest to him at the moment. This is more direct and less subject to human error than a purely alphanumeric "page" display.

There is also a flexibility disadvantage, however, in that the dynamic data values are limited to preprogrammed test points, and therefore for unexpected test situations the operator's ability to request information not on a slide is limited by the number of independent numerical indicators: two on the test station console, and eight more distributed among the subsystem consoles. In most cases, this will be adequate, but it does represent a potential display limitation. (Of course, these displays are augmented by conventional meters, lights, and strip charts.)

FUTURE AUTOMATION

Short Range

Aside from perturbations imposed by delivery schedule pressures and the start-up effort involved in assembling and checking out the ACS hardware, and verifying and debugging computer programs, the extent of automation in checkout was not planned to increase substantially throughout the Saturn IB and Saturn V Programs, and no development funds were contracted for this purpose.

Nevertheless, it is expected that using the ACS to the planned level of automation to check out several vehicles will familiarize test personnel much more intimately with the capabilities of ACS. This should generate proposed increases in computer usage, some of which no doubt will be added to the present checkout sequences. If proposed tests that would require substantial redesign of vehicle systems are ruled out (such as automated leak tests), the following areas offer reasonable prospects for future increase in automated checkout:

(1) The Digital Events Evaluator (DEE) function is to accept and record, with reference time history, the discrete (on-off) events

occurring during checkout. Consideration should be given to expansion of the DEE usage to include safety monitoring (possibly supplementing or replacing the Safety Item Monitor). A further possibility includes providing a feedback capability from the DEE to the ACS computer for on-line use of selected discrete events. A progressive valve actuation sequence, for example, with accurate timing data, could then be evaluated on-line as part of a more complex pneumatic system test.

(2) DDAS could be assigned more test points and greater checkout importance. Because of the inherent compatibility of DDAS data with the checkout computer format, its greater use would undeniably simplify ACE-stage interface requirements.

Any quantitative estimate of the increase in level of future automation by DAC is extremely hypothetical, but may nevertheless be of interest for planning purposes.

(3) Limit-checking Expansion. A desirable checkout feature (perhaps necessary in the future with increasing system complexity), if it can be achieved at reasonable cost, is the ability to perform 100 per cent limit-checking on all measurements. This includes (a) a synchronized limit comparison of each DDAS or PCM data value as received, (b) either a continuous parallel monitoring of all other analog and discrete channels, or, alternatively, a rapid repetitive scan.

The advantage of 100 per cent limit-checking is that it catches transient out-of-tolerance conditions in areas not under direct test observation.

(4) Multiprogramming. One of the present limits of the ACS is the fact that only one subsystem can be checked at a time, since power-up for another subsystem requires an interruption of the test program being run. To permit more parallel setup and testing, it is possible either to provide additional hardwire manual controls, or to multiprogram the ACS computer. The former is more straightforward. However, multiprogramming permits the user to retain the advantages of computer control in safety and in thoroughness of prechecks, and in addition permits checkout of more than one test program at a time.

Long Range

From the long range point of view, the use of the DAC ACS offers the possibility of benefits that, while not directly related to acceptance testing of a particular stage, nevertheless contributes to overall vehicle reliability. These benefits in many cases derive more from the convenient data format produced by the ACS than from any novel test concepts.

In this category, for example, is the possibility of using ACS test results to accumulate a "data library" from which component performance degradation trends can be evaluated. Apart from the obvious cases of replacing particular components whose performance has become marginal, these trends would establish reliability predictions to a much more precise quantitative level than presently possible.

Some potential ACS uses are limited by the stage design. When tradeoffs permit vehicle hardware modifications, the following examples illustrate the possible increased ACS usage:

(a) At the expense of increased weight and wiring complexity, the possibility exists, either through added junction boxes or parallel cabling in the vehicle, of having access to all electrical circuits for an automatic impedance test. End-to-end functioning is presently tested, but not internal branching continuity and resistance. (MSFC has already added such junction boxes on a temporary basis for manual and automatic testing.)

(b) DAC did propose the concept of automatic leak testing in the initial S-IVB design stages. This would involve double chambers for pressure components such as valves, regulators, etc., enabling critical pressure points to be monitored independently for changes in pressure. For a large fraction of the remaining manual tests, an undue weight and cost penalty would be imposed, but this remains a possibility to be reexamined in the future.

(c) With the growth of integrated microcircuits, many additional on-board functions can be added to assist automatic checkout without the previous weight penalties. DAC considers that if the present vehicle data multiplexer (Model 270), which weighs about 30 lb, could

be reduced to 1 or 2 lb, it is probable that extra multiplexers could be added in the S-IVB to provide more checkout data. The principal gain would be in the reduction of hardwire links and their associated connection time, rather than in increased automation per se.

A more peripheral trend noted at DAC is the extension of ACS use into DAC procedures not normally associated directly with checkout. As an example, there is a relation between wiring and termination data required by ACS programmers and the automated wiring lists prepared for GSE manufacturing. It is conceivable that future cooperative efforts may result in a single computer-generated table suitable for both purposes, and, going one step further, this may also be made acceptable to the customer as a contractual item replacing the more traditional wire tables and drawings.

Finally, the SIL* may in the future be used to research specific increases in automation. Its present prime function is to verify checkout hardware, procedures, and progress in support of stage testing, but as the program library becomes more complete and the number of changes from one vehicle configuration to the next begins to decrease, the SIL simulation capability could devote a larger proportion of time to optimizing the DAC checkout, diagnostic, and repair techniques.

ESTIMATE OF FUTURE STATUS

Any evaluation of the future capability of the ACS must depend necessarily upon which, if any, of the expansion possibilities discussed above are implemented and the extent of such implementation. It is obvious also that many factors outside the area of stage checkout, such as total program schedules and costs, may well exercise a determinant effect.

Neglecting these imponderables, it is suggested that a reasonable approach by NASA might be to phase into an early section of the S-IVB

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*SIL has since been scheduled for deactivation after S-IVB-501.

program a number of feasibility studies designed to produce more detailed cost versus benefits data for at least the following:

(1) DEE On-line Tie-in--The relatively small hardware cost would appear to be justified if any substantial setup or test rerun time can indeed be saved.

(2) Expanded Limit Checking--Since this definitely would require additional computing capability, feasibility might be established by first programming the Ground Instrumentation Facility computer at Sacramento to accomplish as much of the task as is practicable. The results of this would, over several vehicle check-outs, determine the relative value of the 100 per cent limit-check approach.

(3) Trend Analysis--This would require a determination of the magnitude of additional memory required, based upon number of critical components, quantity of data for each component, type of analysis for each test, and time within which answers are desired. This type of analysis probably should begin with a few critical components and expand gradually if the results attained justify the cost.

(4) Multiprogramming--A comparatively small study should determine the order of magnitude of setup and test time that could conceivably be reduced, and the test quality improvements versus the program effort required.

Further areas of expansion previously mentioned, such as increased usage if DDAS, more thorough fault isolation programs, combining of tests or conversion of more manual tests to automatic form are not stressed separately since it is considered that these will be evaluated in the normal course of utilization of the ACS.

If the result of feasibility studies permit implementation, (1), (2), and (4) would result in a more comprehensive and efficient application of conventional checkout techniques. Item (3), however, would represent a definite extension of scope in which the automatic system would process and utilize both immediate and historical data in a "continuum of testing."

Appendixes

S-IVB STAGE CHECKOUT SYSTEM DETAILS

A. FUNCTIONAL BLOCK DIAGRAM OF THE ON-LINE SYSTEM[3,5]

A functional block diagram of the major on-line components of the ACS is given in Fig. B-2. In addition to the on-line equipment, a CDC-924A computer and peripheral input-output equipment are used in support to assist in preparing and verifying checkout programs.

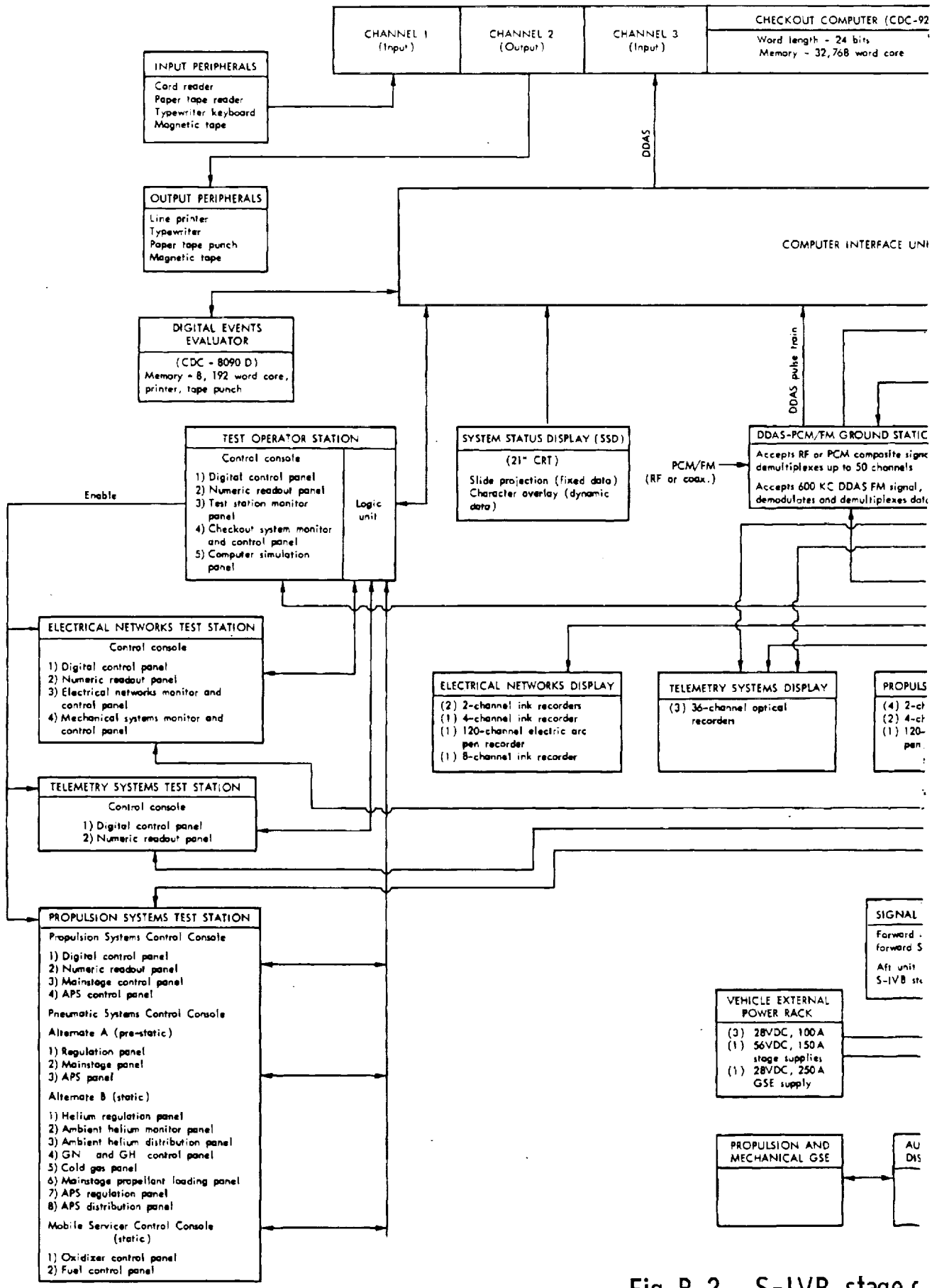
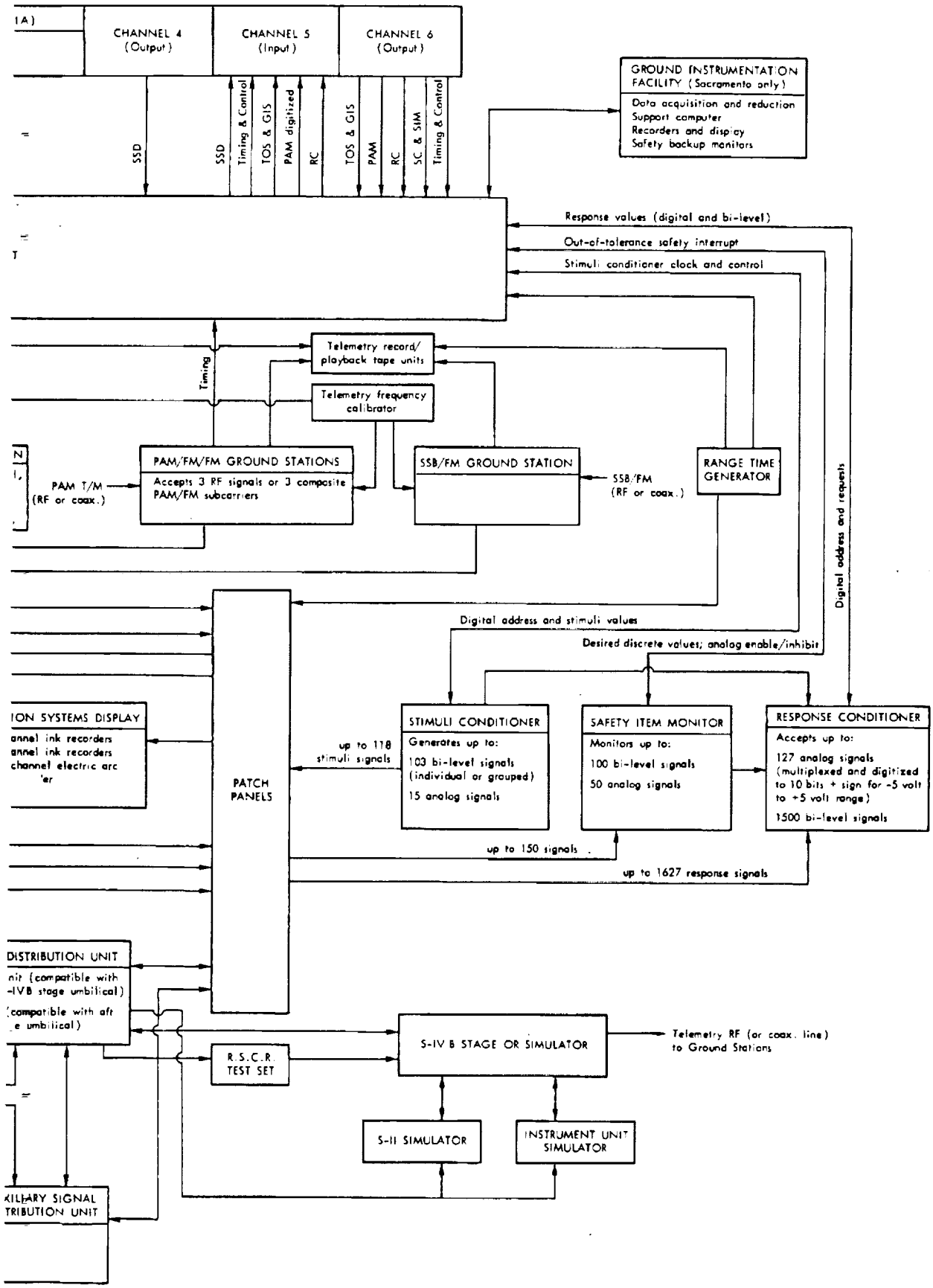


Fig. B-2—S-IVB stage c



heckout system

B. DESCRIPTION--MAJOR ON-LINE EQUIPMENT AND FUNCTIONS

Douglas Aircraft

MAJOR ON-LINE EQUIPMENT COMPONENTS AND FUNCTIONS[3,6]

1. Checkout Computer - Control Data Corp. 924A

   Input - Card Reader, Typewriter Keyboard, Console

   Output - Line Printer, Typewriter, Console

   Memory - 32,768 word core
   4 Magnetic tape units

   Word Length - 24 bits

   Function - Controls execution of test programs

   Records test results

   Monitors test stations for instructions

   Updates all displays

2. Computer Interface Unit (CIU)

   Function - Interfaces checkout computer with rest of ACS

   - Receives, decodes and stores digital data from or to the computer for appropriate addressing and cycling
   - Provides necessary level or signal conversion
   - Controls timing of communications

3. Test Operator Station

   Function - Permits Test Operator to monitor and control all tests

   Consists of: (a) Logic Unit

   (b) T.O. Control Console

   (c) Systems Test Stations: Electrical Network
   Telemetry Systems
   Propulsion Systems

(a) Logic Unit

Function - Accepts serial digital outputs from CIU and converts to light indications or numerical readouts

- Converts console switch operations into digital information and transmits to CIU for action

(b) T.O. Control Console

Consists of: (1) Digital Control Panel
(2) Numeric Readout Panel
(3) Test Station Monitor Panel
(4) Checkout System Monitor and Control Panel
(5) Computer Simulation Panel

(1) Digital Control Panel

Function - Provides T.O. with switches and indicators necessary to control computer

- Includes keyboard input which permits "Hold", "Stop," "Emergency Stop," "Resume" and "Clear" instructions

- Includes indicators for "Test in Progress," "Next Test," and "Keyboard" (operator-inserted) numbers, plus computer start indications

(2) Numeric Readout Panel

Function - Provides T.O. with capability to request and display any two numeric values available to the computer

(3) Test Station Monitor Panel

Function - Permits T.O. to enable and monitor Systems Test Stations (see below)

(4) Checkout System Monitor and Control Panel

Function - Permits T.O. to perform manual operations within ACS itself

- Provides indication of abnormal ACS conditions

(5) Computer Simulation Panel

Function - Provides T.O. with capability of inserting one computer word (24 bits) in parallel with CIU to simulate a computer output

- Provides indicators to monitor one word simulating a computer input

(c) Systems Test Stations

Function - Provide detailed monitoring data for major systems (Electrical Networks, Telemetry and Propulsion) at which those test personnel particularly responsible for each system can assist the T.O.

- Provide manual control capability in event of an ACS failure

- Permit (when enabled by T.O.) alternative test control by Systems personnel in addition to T.O. control

(1) Electrical Networks Test Station

Consists of:
(1.a) Digital Control Panel
(1.b) Numeric Readout Panel
(1.c) Electrical Networks Monitor and Control Panel
(1.d) Mechanical Systems Monitor and Control Panel

(1.a) Digital Control Panel - same as above

(1.b) Numeric Readout Panel - same as above

(1.c) Electrical Networks Monitor and Control Panel -

Function: Provides control and state indications of electrical power systems and networks

(1.d) Mechanical Systems Monitor and Control Panel

Function: Provides control and state indications of mechanical (hydraulic) stage systems

(2) Telemetry Systems Test Station

Consists of (2.a) Digital Control Panel
(2.b) Numeric Readout Panel

(2.a) Digital Control Panel - same as above

(2.b) Numeric Readout Panel - same as above

(3) Propulsion Systems Test Station

Consists of (3.a) Propulsion Systems Control Console
(3.b) Pneumatic Systems Control Console (two configurations)
(3.c) Mobile Services Control Console (static firing only)

(3.a) Propulsion Systems Control Console

Consists of (3.a.1) Digital Control Panel
(3.a.2) Numeric Readout Panel
(3.a.3) Mainstage Control Panel
(3.a.4) APS Control Panel

(3.a.1) Digital Control Panel - same as above

(3.a.2) Numeric Readout Panel - same as above

(3.a.3) Mainstage Control Panel

Function: Provides controls and indicators for safing and shutdown of stage propulsion system.

(3.a.4) APS Control Panel - Provides controls and indicators for safing and shutdown of APS system

(3.b) Pneumatic Systems Control Console

Configuration for dry checkout area
Consists of: (3.b.1) Regulation Panel
(3.b.2) Mainstage Panel
(3.b.3) APS Panel

Configuration for static firing area

Consists of: (3.b.1) Helium Regulation Panel
(3.b.2) Ambient Helium Monitor Panel
(3.b.3) Ambient Helium Distribution Panel
(3.b.4) GN_2 and GHe_2 Control Panel
(3.b.5) Cold Gas Panel
(3.b.6) Main Stage Propellant Loading Panel
(3.b.7) APS Regulation Panel
(3.b.8) APS Distribution Panel

Function: In general, the above provide manual control of the stage and mechanical GSE during checkout and static firing. Although the automatic system controls the mechanical GSE, 100% manual control capability is included as a safety back-up.

(3.c) Mobile Service Control Console (Static firing only)

Consists of: (3.c.1) Oxidizer Control Panel
(3.c.2) Fuel Control Panel

Function: Provide manual control capability for mobile services and propellant diverters used to load stage hypergolic propellant. As above, 100% manual control backup is included.

4. Signal Conditioners

Function - Provide signal conversion of all computer controlled or monitored functions that interface with the stage or mechanical GSE

Consists of: (a) Stimuli Conditioner
(b) Response Conditioner

(a) Stimuli Conditioner

Function - Accepts serial digital commands (address and desired stimulus value) from CIU and converts to bi-level (on-off) or analog signals routed to stage or mechanical GSE

- Bi-level Type I--63 0-VDC and 48 -28-VDC relay driver outputs
- Bi-level Type II--7 sets of 14 -28-VDC outputs
- Analog--0 to $\pm$ 5-VDC, 0 to +40-VDC, two sine wave or two variable step functions

(b) Response Conditioner

Function: Accepts serial digital commands (address of desired measurement point), accesses that point, converts the signal measurement to digital form, and relays the value back to the CIU

Capacity to measure and convert up to

127 analog signals (converted to 10 bits + sign for +5 to -5 VDC) (voltage dividers to handle 0 to 40 and 0 to 80 V signals)

1500 bi-level signals (200 not D.C. isolated between the input and response conditioner)

5. Safety Item Monitor

Function: Continuously monitors up to 100 bi-level and 50 analog functions simultaneously in accordance with computer-requested values. Generates an interrupt for undesired bi-level state or out-of-limit analog signal.

6. Signal Distribution Units

Function: Provide distribution routes to S-IVB stage and mechanical GSE

Consists of: (a) Signal Distribution Unit (to stage)
(b) Auxiliary Distribution Unit (to mechanical GSE)

7. Displays

Function: Provide visual indication to test personnel of status of test, and values of selected parameters.

Consists of: (a) Systems Status Display
(b) Propulsion Systems Display
(c) Electrical Networks Display
(d) Telemetry Systems Display

(a) Systems Status Display

Function: Serves as basic systems display unit of ACS

Displays on 21-inch CRT a functional representation of components of system under test (prepared on slides as "fixed" data) with overlay of dynamic values of test parameters

Capacity: up to 96 slides
up to 64 four-digit dynamic values per slide

(b) Propulsion Systems Display

Consists of: (1) Four 2-channel ink recorders
(2) Two 4-channel ink recorders
(3) One 120-channel electric arc pen recorder

Patched to propulsion system test points as desired.

(c) Electrical Networks Display

Consists of: (1) Two 2-channel ink recorders
(2) One 4-channel ink recorders
(3) One 8-channel ink recorders
(4) One 120-channel electric arc pen-rework

Patched to electrical networks test points as desired

(e) Telemetry Systems Display

Consists of three 36-channel optical recorders patched to T/M systems test points as desired

8. Telemetry Ground Stations

Function: Accepts telemetry data, either RF (through transmitter-receiver or via coaxial cable) or composite pre-modulated, demultiplexes, records and retransmits, if desired, selected data channels to CIU or display

Consists of (a) DDAS Ground Station
(b) PAM/FM/FM Ground Station
(c) SSB/FM Ground Station

(a) DDAS (Digital Data Acquisition System) and PCM/FM Ground Station

Function: Accepts either PCM/FM RF data link or DDAS signal FM pulse train, processes, and retransmits data to CIU

Demultiplexes up to 50 selected channels to analog or bi-level form for display and recording

Provides capability to adjust and calibrate input channel transducers and signal conditioners

(b) PAM/FM/FM (Pulse Amplitude Modulated/FM/FM) Ground Station

Function: Accepts up to 3 PAM/FM/FM signals (from the 3 stage T/M systems) either in RF form or as composite sub-carriers

Demodulates each PAM/FM/FM to a PAM pulse train for recording and display or for demultiplexing selected channels

Provides capability for digitizing selected channels for transmission to CIU

Provides capability to adjust and calibrate input channel transducers and signal conditioners

(c) SSB/FM (Single Sideband/FM) Ground Station

Function: Accepts SSB/FM signal, in RF or composite pre-modulated form, for demodulating and/or demultiplexing data for recording and display

Provides facility to calibrate input transducer and signal conditioners

(Note: Since SSB/FM data are primarily vibration and acoustic signals, considered of transient R&D value, this Ground Station is completely manual, with no ACS link.)

9. Discrete Events Evaluator (DEE)

Function: Monitors all discrete (bi-level or "on-off") signals continuously, providing both on line test printout and permanent event records with reference timing.

(This unit will consist of a Control Data Corp. 8090-D computer with 8,192 word core memory and peripheral input-output equipment. The DEE is presently not part of the S-IVB ACS).

10. Adjacent Stage Simulators

Simlators for the S-II stage and the Instrument Unit (IU) stage are included to provide simulation of any signals or loads normally a part of the Saturn I-B or V vehicle. Both simulators are controlled by the ACS.

11. Ground Instrumentation Facility (Sacramento only)

Provides additional data acquisition and monitoring capability to ACS. Accepts hardline signals, converts to digital format, processes selected data channels and transmits requested signals to ACS. Provides manual display and safety controls.

C. BASIC SOFTWARE

OVERALL FLOW CHART

The overall flow chart for the ACS on-line basic software is illustrated in Fig. B-3.

GENERAL DESCRIPTION

The on-line basic software (operating system) for the Douglas ACS provides (1) the necessary general-purpose operating programs for operator control, display, control of computer peripherals, such as tape readers and printers, and sequencing of test operations, (2) the subroutines that execute STOL[7] or ATOLL test-language statements from the specific test programs, and (3) the "STOL Simulator" or "ATOLL Simulator" program, which permits a reasonable degree of software-simulated system response for checkout of STOL or ATOLL programs. These programs are called collectively the "executive program," in Douglas nomenclature, and occupy approximately 10,000 words of working memory. (Of the remaining 22,000 words, about half are devoted to test-point calibration data and miscellaneous functions, and half to specific test programs.)

In this discussion, little distinction will be made between the treatment of STOL programs and ATOLL programs. STOL, the Douglas-originated language, will be used in its present form by Douglas through the checkout of S-IVB-202. ATOLL test programs will be used on S-IVB-203 and later vehicles.*

Douglas is writing a STOL/ATOLL translator, which will permit programs written in STOL to have true ATOLL documentation, and to appear to the operator as though they are running in ATOLL.** They are also writing a new off-line compiler that allows the engineer to write new test programs in Douglas ATOLL. The Douglas ATOLL test programs will be compiled by the new compiler into binary calling

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*The ATOLL conversion for S-IVB-203 and later vehicles has since been cancelled.

**Douglas reports considerable difficulty with this approach, and estimates of the conversion costs are approaching perhaps the magnitude of the original programming effort.

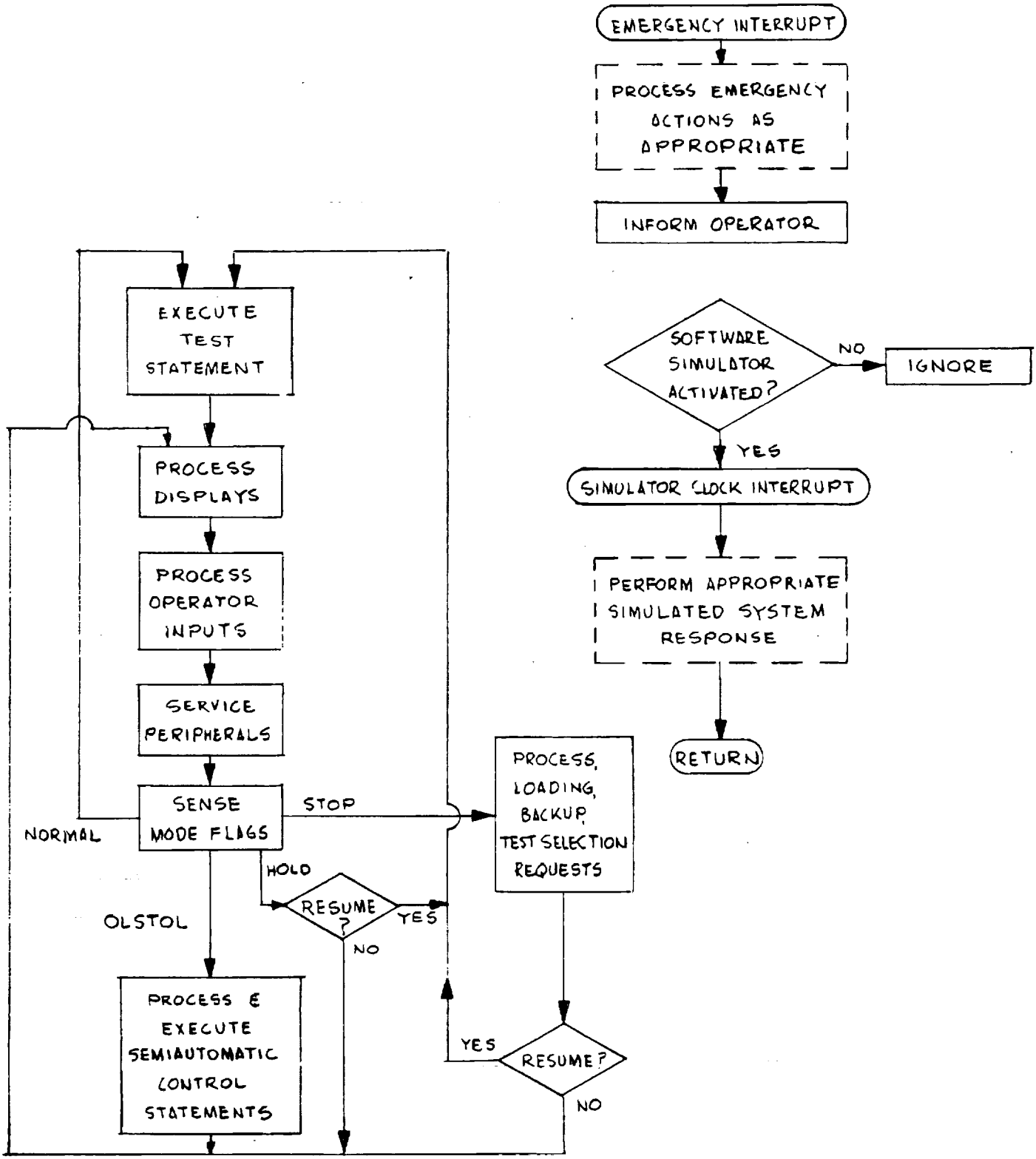

Fig. B-3—Overall flow chart, S-IVB

sequences* much like those used for STOL subroutines. The subroutines themselves, which execute the operation, will often be only small modifications of the corresponding STOL subroutines. Thus it is possible to program in ATOLL, yet salvage much of the thinking and programming that went into the on-line STOL "executive" and its subroutines. (As one result of this, Douglas ATOLL will use off-line compilation of calling sequences, instead of interpreting on-line.)

Douglas ATOLL will retain the software-simulation features (STOL Simulator) of STOL (changing the operators to fit ATOLL specs), to provide as much off-line debugging as possible before trying a test program on hardware. It will also retain the on-line semiautomatic control and program modification features of STOL (OLSTOL--On-Line STOL), again with changes to make operators fit ATOLL specs, since the Douglas ACS relies heavily on this form of manual intervention.

THE HOUSEKEEPING LOOP (FIG. B-4)

The central kernel of the on-line basic software is the "housekeeping loop." This provides for (1) continuous updating of displays on a 2-second cycle, (2) communication with computer peripheral equipment such as the printer, magnetic tape, etc., and (3) sensing of operator control and data entries.

The housekeeping loop occupies about 3.5 milliseconds. In order to avoid incompatibilities with peripheral-equipment data rates, it must be cycled at least every 50 or so milliseconds. A 25-millisecond interval would be necessary to maintain the 2-second update interval on all displays if the CRT display used its full capacity of 64 analog variables, and if all 10 numeric displays were active, but this combination is unlikely.

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*This implies a "hybrid" compiler/interpreter implementation of ATOLL. The off-line compiler translates ATOLL statements into a short, efficient program segment called a "calling sequence." On-line, the calling sequence activates immediately the necessary program subroutines. With a "pure" interpreter, the on-line program must perform this translation task before activating the subroutines, and hence on-line operations are considerably slower.

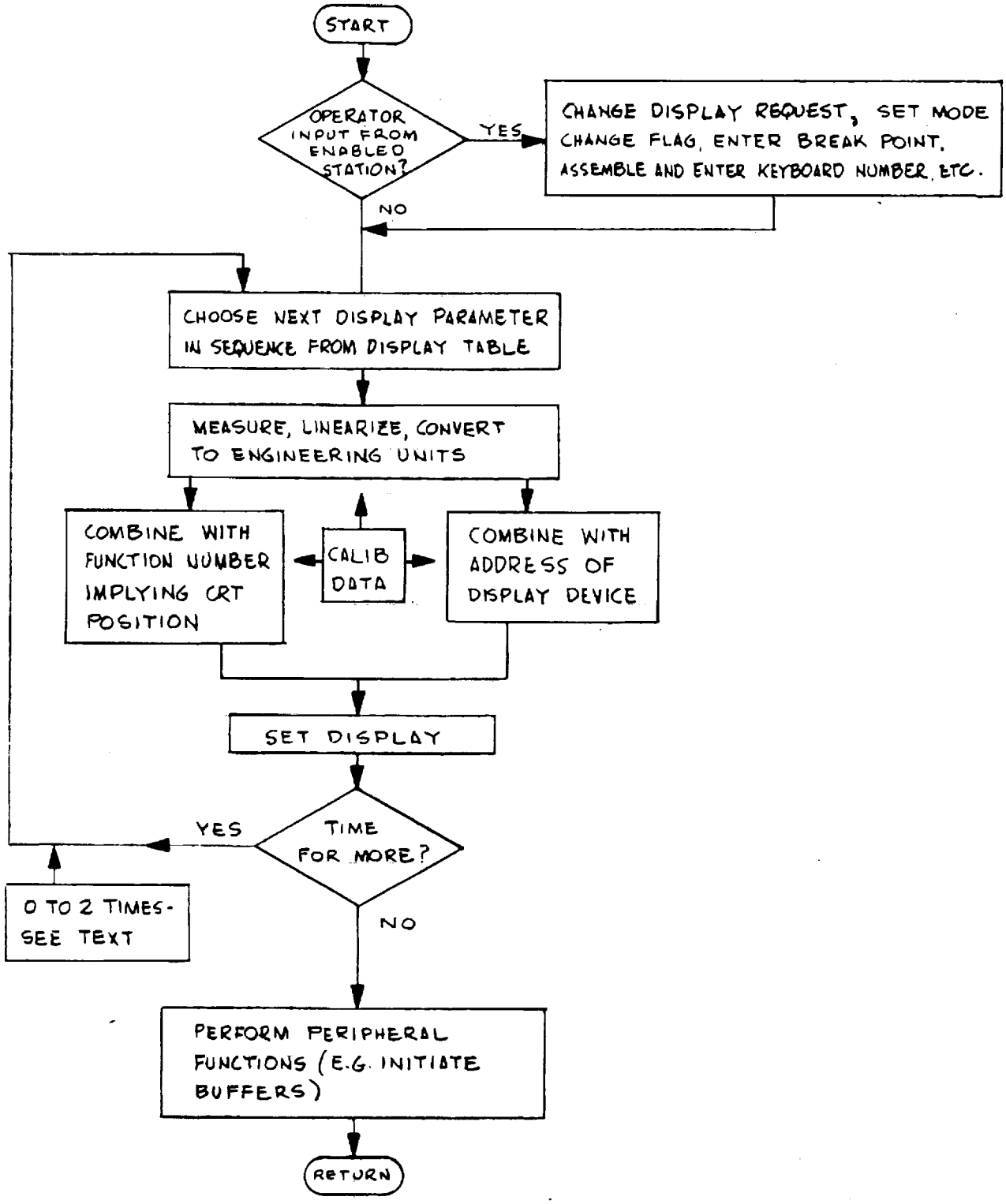

Fig. B-4 — Housekeeping loop, S-IV B

Normally, the routine cycles periodically during quiescent intervals, plus once after execution of each STOL or ATOLL statement. Long-duration statements (e.g., switch-selector settings including relay-contact feedback checks) permit housekeeping during the statement. Housekeeping can be locked out by "do not intervene" statements, or during execution of emergency actions.

The display operations of the housekeeping loop apply to both the CRT display and the numeric displays. The loop keeps a table in memory of which measurements are active (determined by the numeric-display request switches and by the CRT slide in use), and cycles through the table sequentially, updating each item in turn. The updating process consists of (1) making the measurement (analog or bi-level), (2) linearizing it and applying calibration factors as required, (3) converting it to engineering units, and (4) transferring the resulting number, accompanied by the appropriate display address, to the display. In one 3.5 millisecond cycle, the program can update one maximum-nonlinearity (fifth-degree) analog quantity, or three bi-level quantities, which is fast enough to meet the display updating speed requirements.

The operator-entry operations involve reading the operator push-buttons, switches, and keyboard, and setting flags,* assembling keyboard messages, or branching as a result. For example, a number from a numeric-display selector switch will be processed and transferred to the appropriate cell in the display table. For the Hold mode, a signal from the Hold button will set the "hold" flag, and the program will sense the flag and branch to the "hold" condition at the next permissible hold point. For another mode, called Breakpoint mode, the program will compare the current test number with a preselected breakpoint step number, and branch to "hold" when the two are equal.

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*A "flag" is an indication stored by the program at one time, to tell itself to do something at a later time. For example, if the operator momentarily presses the Stop button, the program senses this, and sets a flag that will tell the program to stop at the next permissible stop point. The operator therefore need not hold down the button until the stop point.

The peripheral operations are conventional, such as refilling or restarting Input/Output Data Channel buffers, which permit transferring blocks of data.

MAIN SEQUENCE AND TEST STATEMENTS (FIG. B-5)

During normal automatic operation, the test proceeds from one test statement to the next, with the housekeeping loop between statements. If a hold or stop is commanded, automatically or manually, the test program completes the last test statement before the appropriate point, then branches to the quiescent condition. A delay is inserted between statements; this (1) permits the housekeeping loop to act with a moderate timing margin and (2) permits normal system delays of 7 to 25 milliseconds to be accounted for in most cases without special "wait" statements. (The delay may be either 6 or 20 milliseconds, as set by a program flag. This does not include the execution time of the test statement itself.)

Test statements are processed in a hybrid compiler/interpreter mode.* The programmer's input language is processed by an off-line compiler into a compact calling sequence, which operates on-line to call a subroutine that actually performs the desired action. In this way, the relatively large amounts of time and memory space required for complete on-line interpretation are not required. Nevertheless, on-line changes and semiautomatic control can still be made in practically as convenient a language as the basic input, by means of the OLSTOL program, which is called when necessary.

Execution times for typical test statements are one to three milliseconds. A discrete output takes about one millisecond, including "echo checks" of the total discrete-output scan pattern, in which all relay-driver outputs are checked before the relays change state. An analog measurement and test for tolerance takes one to three milliseconds, depending on the degree of the linearization polynomial. Some statements take longer. For example, the switch-selector output may take 100 milliseconds, since it includes waiting to check the

*See footnote, p. B-38.

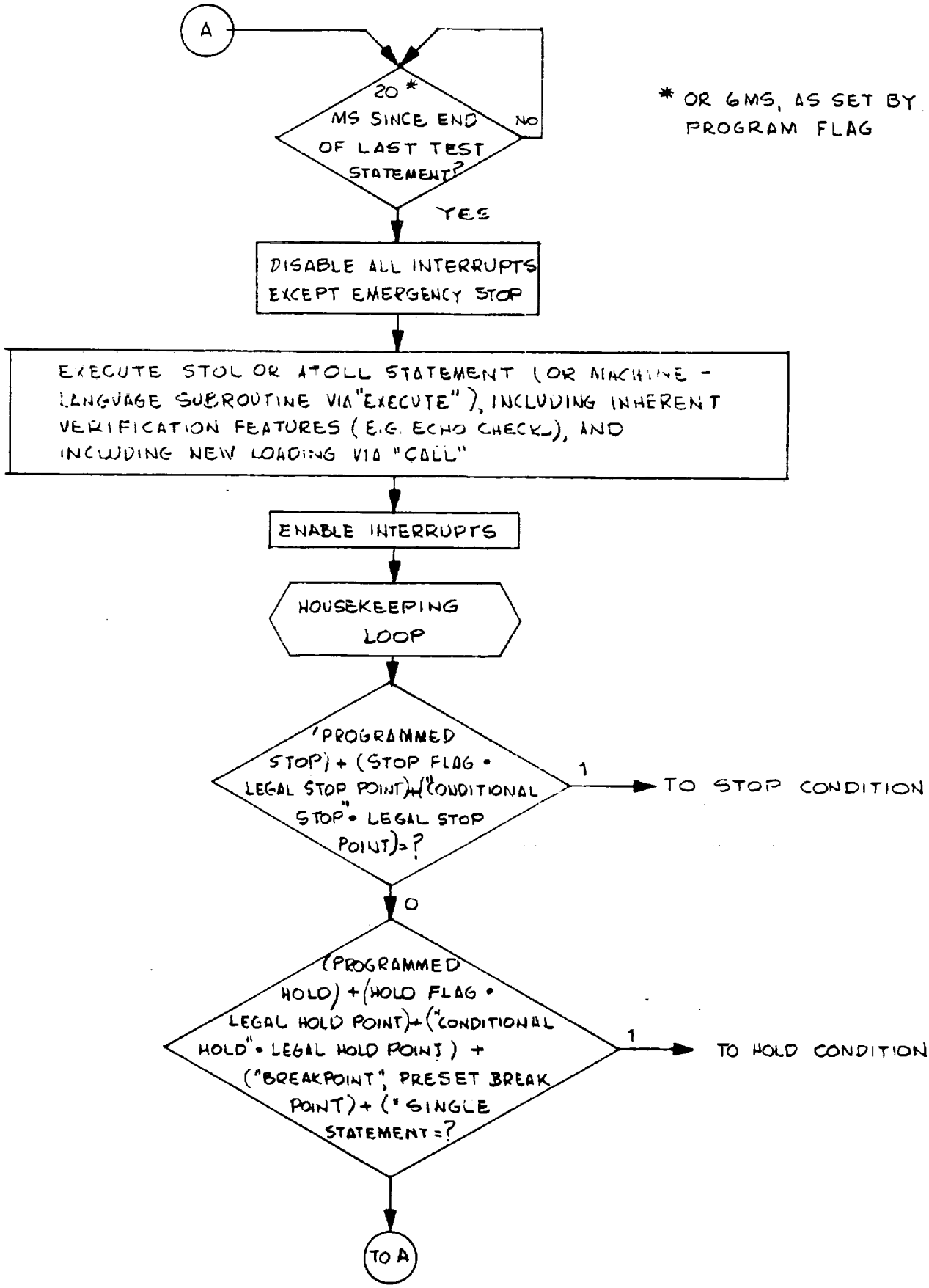


Fig. B-5 — Main sequence, S-IV B

responses from the electromechanical devices in the vehicle. The wait times are used for housekeeping. Statements that can result in no-gos (e.g., measurement out of tolerance, incorrect "echo check" on discrete output, etc.) receive special treatment in case of a no-go indication. In this case, the executive automatically performs a GSE self-test of the input channel that provided the information on which the no-go decision was based. For example, it feeds known voltages into the chosen analog input, or known discrete conditions into the echo-check response input, or known RACS conditions into the chosen DDAS channel. This process may require hundreds of milliseconds, depending on the speed of the self-check equipment. Only if the self-check is passed does the program go on to indicate a vehicle fault, and enter whatever fault isolation or display may have been programmed.

QUIESCENT AND SEMIAUTOMATIC OPERATIONS (FIG. B-6)

A "hold" condition is defined as a temporary cessation of testing, of limited duration, after which the same sequence is restarted. A "stop" condition is defined as a condition in which all systems are safe for an extended cessation of testing, and it may be followed by choice of a new starting point. Either may be entered from the automatic program or as a result of operator command.

Operator commands for loading new programs from tape are entered only from the "stop" condition. Automatic programmed calls for new programs from tape are performed during what amounts to a "hold" condition. (Douglas is at present working on an "overlay" routine, which will permit reading one program in from tape while another is operating.) If the operator calls for a rerun of portions of a program (from the "stop" condition), the program will automatically execute "backup" routines to return the system to a proper condition for the new starting point. The backup routines are programmed in the test language, as parts of the test program, and are posted* for

*A "posted" routine is one in working memory, ready to take care of some contingency during each stage of the program execution. It will vary its potential action automatically as the program progresses through successive stages.

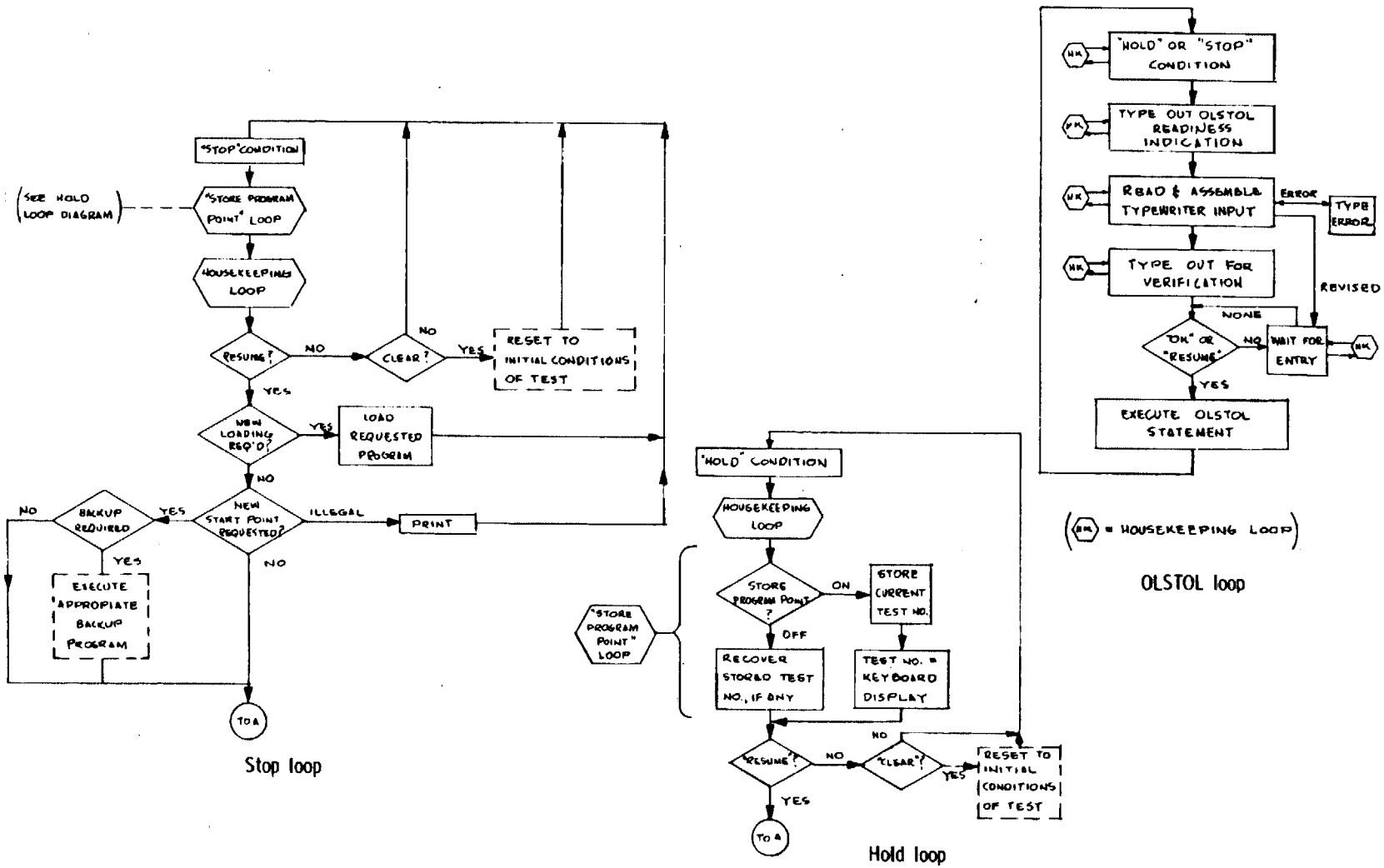


Fig. B-6—Quiescent and semiautomatic routines, S-IVB

each stage of the program. In the "stop" condition, the operator may restart at any legal start point, as chosen by the programmer.

For on-line program modification or for semiautomatic control, the operator may call OLSTOL (On-line STOL) or its on-line ATOLL equivalent. OLSTOL is operated from the typewriter keyboard. It has two functions:

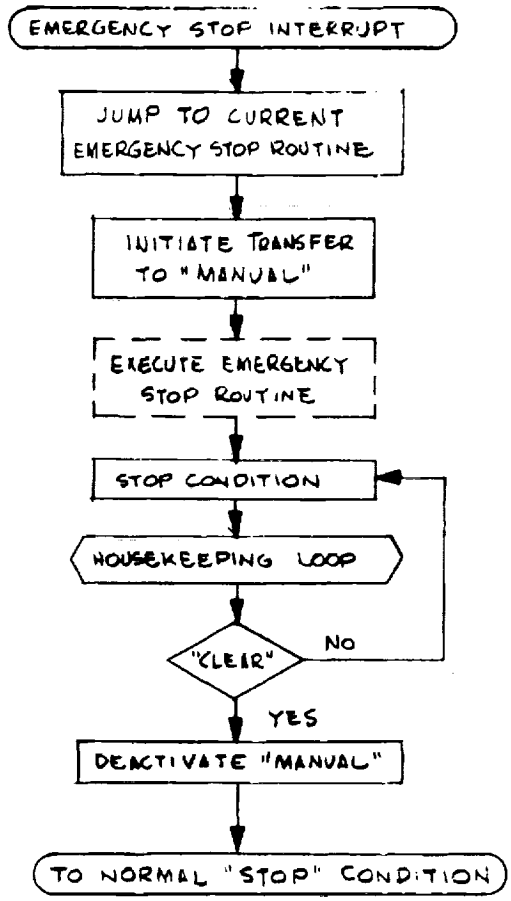
First, it permits the operator to enter and execute individual statements chosen from a subset of the test language. This provides computer-aided manual control, more or less equivalent to that with individually labeled pushbuttons and switches in the KSC dual 110A system. (Douglas also has a "manual" mode, using controls and readouts that bypass the computer completely, but this is planned to be restricted largely to safety functions.) The full error-checking and self-test functions of the test statements are retained in execution of statements from OLSTOL. However, inputs and outputs must be referred to by function number (or octal code), rather than by English name.

Second, it permits on-line modification of the automatic program. For example, if certain statements must be deleted from the program because certain pieces of equipment are missing, the operator uses OLSTOL to enter "Delete Statements XYZ, UVW," etc. He may similarly enter new test statements, change parameters, etc., and then may switch to the normal automatic mode and execute the modified program. He may start the program at any point, even one which the original programmer had not considered a legal start point, by an OLSTOL "go to" statement.

EMERGENCY ACTIONS (FIG. B-7)

In addition to automatic programmed responses to untoward conditions, and in addition to the manual mode, the basic software also provides for two types of emergency actions: Safety Item Interrupts and Emergency Stops.

The Safety Item Interrupt routine is initiated automatically by an interrupt from the hardware Safety Item Monitor. When such an interrupt occurs, the program first checks the inputs to discover the



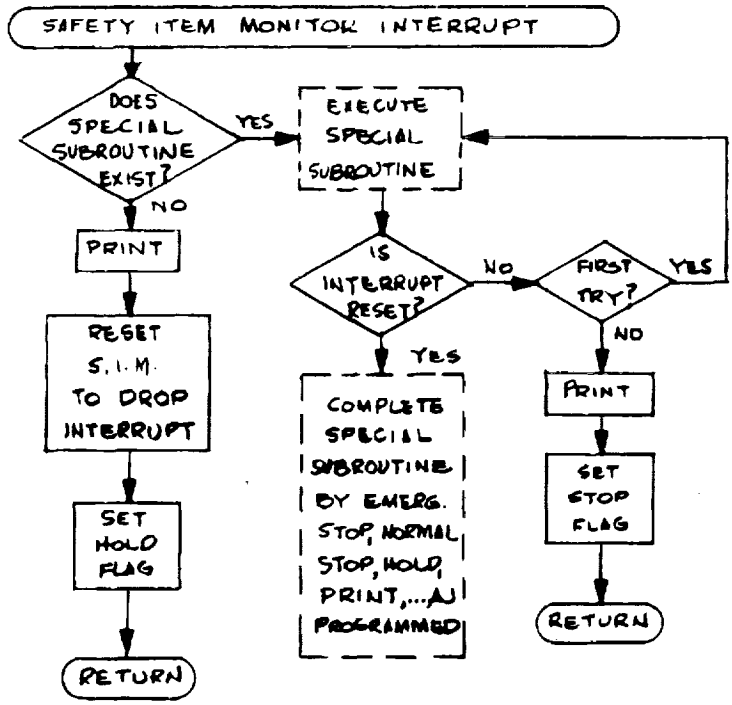


Fig. B-7 — Emergency routines, S-IV B

particular safety item at fault. It then investigates whether the programmer has preselected a subroutine to react to this item at this stage of the program. If he has, the subroutine (normally written in the test language) is executed. Part of the subroutine must inhibit the safety item from causing further interruptions (e.g., by driving the quantity back into tolerance, by inhibiting the analog comparator, or by reversing the stage of the discrete comparator). After the subroutine has been executed, the program checks to see that the interrupt has indeed been eliminated. If it has not, the program tries once more, then prints out the problem and enters "stop."

If the programmer has not indicated a desire for special treatment of this particular safety item at this particular stage of the program, the program merely prints the condition and resets the interrupt. The "hold" flag may be set to hold at the next permissible point under program control. The next hold point may be some time later, but the printout and display warns the operator to take any necessary quicker action manually.

The Emergency Stop button causes a combination of program and hardware actions. At each stage of the test program, the program has posted in memory a routine that performs any necessary program actions for Emergency Stop. At the same time, the system is returned to Manual, permitting hardwire safing actions to be taken as appropriate.

For both Safety Item Monitor and Emergency Stop, the basic philosophy is that the computer does only what is useful to aid the operator, while the operator is the real source of emergency reaction decisions and commands.

MODES AND CONDITIONS

The above programs, in conjunction with operator controls, establish a number of operating modes and conditions. Three modes are essentially hardware controlled: Emergency Stop, Manual, and Computer Word Simulator. In the last of these, commands are sent over the system digital-interface busses from 24 binary switches simulating a computer word output, and busses may be monitored by 24 lights.

The other modes result from the hardware. These are:

Normal Automatic .

Breakpoint, in which the operator can preselect any legal hold point. The program will then run automatically until this point, then hold. This permits, for example, running most of a program automatically, with on-line semiautomatic actions at one trouble point.

Conditional Hold, in which the program holds at every legal hold point.

Conditional Stop, in which the program stops at every legal stop point.

Single Statement, in which the program holds after every test statement, independent of whether the point is a legal hold point.

Software Simulation, in which all automatic modes are available, supplemented by the STOL or ATOLL Simulator program to provide simulated responses to programmed commands.

Store Program Point, in which a manually selected automatic program is run, while some other program is temporarily interrupted.

OLSTOL .

Annex B

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6. Douglas Aircraft Company, Schematic Drawings, various dates.

7. Douglas Aircraft Company, Missile and Space Systems Division, Phase I Design Review Summary, Automatic Checkout and Loading Electromechanical Ground Support Equipment, Saturn V and Saturn IB Programs, Report SM-43648, June 1963.

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Annex C

INSTRUMENT UNIT STAGE CHECKOUT

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CHECKOUT CONCEPT AND OBJECTIVES

BACKGROUND DATA

Marshall Space Flight Center, as the design and manufacturing agency for the Saturn launch vehicle Instrument Units, was also directly responsible for checkout of the IU stages for the Saturn I series, and the IU stages for Saturn IB through vehicle 204. For the remainder of the Saturn IB program (vehicles 205-212), and for all of the Saturn V IUs (vehicles 501-515), the International Business Machines Corporation Space Guidance Center facility at Huntsville has prime checkout responsibility, working under MSFC technical cognizance.

Checkout system hardware was designed at MSFC, with the Quality & Reliability Assurance Laboratory utilizing the RCA-110 computer as the control element for the later Instrument Units (IU-5 through IU-10), together with ESE from the original Packard Bell installation, and substituting the RCA-110A and new peripheral and GSE equipment for use on the Saturn IB.

Computer programming is the responsibility of the Computer Programming Section, Vehicle Systems Checkout Division, Q&RA Laboratory, through Saturn IB 204 (utilizing IBM personnel under MSFC direction). After that point, IBM will assume primary software responsibility.

STAGE DESCRIPTION[1]

The Instrument Unit is a nonpropulsive stage approximately 3 ft high located between the upper propulsive stage and the payload of the Saturn vehicles.

For Saturn I, the IU function is to provide guidance and control during all phases of flight, command and sequence the launch vehicle functions, and insert the payload, IU, and S-IV stage into earth orbit.

For Saturn IB/V, additional functions include insuring injection of the S-IVB, IU and Spacecraft into a lunar transfer trajectory, stabilizing the S-IVB, IU, and LEM during turn-around of the Command and Service Modules, and executing maneuvers to remove the S-IVB and IU from the Spacecraft orbit.

The Saturn IB/V IU consists of six basic systems:

1. Structural System--This provides mounting space for navigation and control hardware and interfaces structural loads between the S-IVB and Spacecraft.

2. Environmental Control System--This provides pressure-regulated, conditioned nitrogen for lubrication of the ST-124 inertial platform gas bearings of the guidance and control system, and also circulates and dissipates thermal energy generated by temperature-critical components using water methanol as the cooling agent.

3. Guidance and Control System--This continuously monitors and computes flight parameters for a predetermined mission, and transmits control signals to the appropriate stage attitude control devices. It also provides signals to activate the various flight sequence functions.

4. Measuring and Telemetry System--This includes sensors and transducers monitoring various physical and functional parameters within the IU, signal conditioning, and multiplexing equipment to convert the signals into a form compatible with RF transmission, and telemetry equipment for modulating and transmitting the data in PCM/FM, PAM/FM/FM, and SSB/FM format.

5. Radio Frequency System--This includes the RF portions of the telemetry equipment, plus vehicle tracking and command communications. The command receiver of the IU RF system receives updated guidance data from ground computers during all phases of flight, and relays this information to the IU guidance and control equipment for comparison and improvement of accuracy.

6. Electrical System--This provides the source power and distribution subsystem to operate the IU electronic and electrical equipment.

DESCRIPTION OF TESTS[2,3]

A checkout sequence for the Saturn IB Instrument Unit (201-204 series) is detailed briefly below as typically representative of computer control. Minor details may vary with modifications in launch vehicle configuration.

Test	Description
GSE Verification	
G-1	Computer Self-tests--diagnostic routines to determine the operational readiness of the RCA-110A checkout computer and peripheral equipment
G-2	Network Checkout Equipment--self-test programs to determine the operational readiness of the network checkout equipment, including discrete and analog input/output units
G-3	Navigation (G&C) Test Station--self-test programs to determine the operational readiness of the Navigation Test Station
G-4	Instrumentation and Telemetry Test Station--self-test routines to verify the functional readiness of the I&T Test Station
G-5	Digital Data Acquisition System Ground Station--self-test routines to verify the functional readiness of the DDAS Ground Station
G-6	Telemetry Ground Stations--to verify the operational readiness of the PAM/FM/FM, PCM/FM, and SSB/FM telemetry ground stations
G-7	Mechanical GSE--to verify the operational readiness of the mechanical/pneumatic GSE
Stage Verification	
Pre-test	Stage Receiving Inspection--a visual inspection to verify IU component status, cable connections, cover installation, cleanliness levels, etc.
Pre-test	Installation and GSE/MSE Connection--includes IU installation, electrical and mechanical interface verification, and connection to GSE and MSE
1	Pressurization Tests--to check for leaks in pneumatic connections and components

Test	Description
2 (Also GSE verif.)	Discrete Output Test--checks checkout computer's ability to energize each discrete output line individually on command
3 (Also GSE verif.)	Discrete Input Test--checks computer's ability to monitor each discrete input line
4 (Also GSE verif.)	Station Verification Test--to verify the electrical configuration of the ESE
5	Network Test, Part I--to verify control and proper distribution of electrical power, power transfer capability and operation of IU cooling systems
6	Guidance Computer Test--checks guidance computer's ability to furnish the required flight sequence timing pulses
7	Network Test, Part II--a functional and timing test of specific flight events before and after simulated liftoff
8	Emergency Detection System Test--tests detection capability and proper operation of Emergency Detection System
9	RF System Test--tests RF characteristics of IU telemetering systems
10	RF Compatibility Test--determines interference characteristics of RF telemetry signals
11	DDAS Versus Calibrator--tests all DDAS channels with calibrated signals provided to the channel inputs
12	RACS Verification--checks all RACS access points and high-low calibration levels to determine RACS accuracy for use in checkout

Test	Description
13	DDAS Versus Predicted--tests all DDAS channels with stage transducers activated. DDAS outputs are compared against values predicted from transducer calibration curve data.
14	DDAS Versus PCM--compares DDAS output data against equivalent channels derived from the PCM/FM telemetry signals through the RF link
15	DDAS Versus Telemetry Digitizing System--compares DDAS output data against equivalent channels derived from the PAM/FM/FM telemetry and digitized by the Telemeter Digitizing System
16	Telemeter Functional--tests signals from various points in the onboard telemetry systems and ground stations to determine end-to-end functional integrity of telemetering equipment
17	Navigation and Control Systems Functional Verification--checks stabilizer system functional parameters to determine functional operating capability
18	Servo Damping and Telemetry Verification--checks servo damping on the stabilizer gyro, accelerometer, and redundant gimbal servo loops, and identifies and checks polarity of the respective servo loop telemeter channels
19	Communication Line Test--to verify the interface between the flight computer and the RCA-110A ground checkout computer at the stage end, and between the Guidance Computer Panel and RCA-110A at the test control room end
20	Status Indicator Code Verification--sequentially calls up all AGCS ground and flight routines and verifies the issuance of each status indicator code
21	Switch Selector Functional Test--to verify the operational performance of the IU switch selector and associated electrical support equipment

Test	Description
22	Telemetry Measurement Calibration--ground computer sequentially commands the Guidance Computer to function in applicable modes of operation. Respective Guidance Subsystem telemetry measurements are identified and checked for polarity, magnitude, or scale factor via Ground Computer scan
23	Telemeter Output Register Test--provides a dynamic check of the data adapter telemeter output register through transmission of a changing bit pattern from Guidance Computer memory to the register
24	Discrete Telemeter Test--to verify the Guidance Computer/Data Adapter discrete output issuance function via the telemetry output circuit
25	Command System Orbital Load Test--To verify the AGCS orbital checkout function, ground tests are conducted to validate proper operation of the Data Adapter GSE/command switching and loading circuitry. In addition, the Guidance Computer load and "verify program sequencing" are monitored during this process
26	Data Output Collector Test--collects telemetered pseudo-flight prelaunch routine data. Since it involves the use of a general purpose routine, it may be used in the verification of other telemetered data.
27	Simulated Acceleration Processing Test--to validate the acceleration incremental input accumulation and processing function of the Guidance Computer and Data Adapter
28	A_1 Gain Test--to verify the correct A_1 gain of the control subsystem (from rate gyro input through Control Computer to actuator deflection)

Test	Description
29	G_2 Gain Test--to verify the correct G_2 gain of the control subsystem (from control accelerometer input through Control Computer to actuator deflection)
30	Emergency Detection System Rate Gyro Test--to verify the correct operation of the triple redundant EDS Rate Gyro Package and the EDS Rate Gyro Signal Processor
31	Control Computer Redundancy Test--to verify the correct operation of all primary and redundant signal paths through the Control Computer
32	Control Computer Delta-I Test--to verify the correct polarity and magnitude of the Control Computer Delta-I telemetry output
33	Attitude Calibration Test--to verify the following Navigation System functional parameters: (1) Scale factor, linearity, and polarity of the attitude command signal outputs to the Control Computer (2) Guidance computer attitude program commands (3) Stabilized platform multispeed resolver outputs
34	Stabilizer Accelerometer Analysis and Telemetry Verification--The Guidance Computer accumulates time and stabilized platform accelerometer pulses and outputs the total accumulations periodically. This test reads these outputs to compute the accelerometer time constants. In addition, the accelerometer telemetry measurements are identified and polarity is checked
35	Control Subsystem Null Test--to verify the Control Subsystem nulls with all navigation and control subsystems interconnected

Test	Description
36	A_o Gain Test--to verify the correct A_o gain of the control subsystem (from attitude command or error angle input, through the Guidance System, through the Control Computer, to the actuator deflection). Gain is checked for pitch, yaw, and roll
37	Data Analysis--Various special data analysis routines are programmed to provide the data needed for reports
38	Quick Look--data retrieval and evaluation routines programmed to permit test analysis
39	Special Programs--special programs needed for test station operation and routines needed to verify, control, and operate the auxiliary test equipment used in conjunction with the test stations
40	Electromagnetic Capability Test--tests of all instrumentation to determine whether EMC standards are met
41	Simulated Plug Drop--checks system compatibility, flight event timing and EDS circuits during a simulation of umbilical disconnection
42	Simulated Flight Test--for correct and sustained operation of all flight systems after power transfer has occurred and during the post-umbilical-ejection phase

CHECKOUT SYSTEM APPLICATION

The application of digital computer control to checkout of the IU was phased into existing manual and special-purpose semiautomatic test equipment and procedures at MSFC over the course of a number of Saturn I vehicles.

An R&D checkout and simulation facility, the Saturn Systems Development Breadboard Facility, was established under the cognizance of the Astrionics Laboratory to develop the operating hardware and

techniques and to verify computer programs under controlled conditions approximating those at the launch site.[4]

The Saturn I Breadboard became operational in March 1963, in a configuration similar to IU-5. It contained an IU complete with flight type hardware plus a simulated S-I stage, and associated GSE.

For the IU of the SA-5 vehicle, the breadboard was used to debug guidance computer programs and test the ST-124 stabilized inertial platform. For IU-6 through IU-10, the breadboard was updated to match each new vehicle configuration and additional computer-controlled tests added on a phased basis.

In step with the breadboard verification procedures, IU stage checkout, under Q&RA Laboratory cognizance, also increased the degree of automated checkout with each successive vehicle. By SA-10, the computer-controlled test schedule included the following:

Component Tests	Systems Tests
Flight Computer	Network System
Guidance Signal Processor	All Systems Plug Drop
Sequence Event Monitoring	Simulated Flight
Azimuth Laying	Stabilized Platform
Controlled Sequence	
Control Computer	
Control Sensors	

For the Saturn IB program, IU stage checkout utilizes the Saturn I experience. An upgraded computer, the RCA-110A, was substituted for the RCA-110, together with modified peripheral equipment, the DEE, and a new display subsystem.

IU checkout for 201 represents a continuing increase in the use of automation. Some gradual additional increase is planned beyond 201, but no major increase since the checkout is heavily automated.

In terms both of quantitative degree of automation and the complexity of computer-controlled tests, IU checkout represents by far the most advanced system of stage checkout. This is to be expected since the IU equipment is basically electrical-electronic, utilizing complex logic circuitry, which in turn demands complex automation in testing. Even before the introduction of the RCA-110/110A computers, for example, the test equipment used to check out a guidance computer was the equivalent itself of a special purpose digital computer.

Because of this, IU checkout may be considered as close to a practicable upper limit in the application of computer-controlled checkout to the Saturn/Apollo program, at least in percentage of test steps automated.

DEVELOPMENT OF TEST REQUIREMENTS AND PROCEDURES

Test requirements for IU components and subsystems originate with the cognizant design engineering groups for the flight hardware, primarily within the Astrionics Laboratory, and are developed from support documentation such as operating specifications and system schematic diagrams.

From the test requirements, and additional data such as cabling and interconnection diagrams and lists, the test engineers and programmers generate detailed test flow charts, procedures, and coded programs.

For those tests programmed in ATOLL, the test engineer prepares a test procedure on the ATOLL form. From this, the form data are keypunched to produce a set of cards, which together with the ATOLL translator (on magnetic tape) are entered into the program support computer. Under the control of the ATOLL translator, the computer translates the data on the cards into a compressed form and stores this compressed data on magnetic tape for later on-line use. In addition the computer prints out an identical copy of the data on the ATOLL form, for the convenience of the test engineer.

The test routine is then available for entry into the checkout computer, along with executive routine and operating system programs.

For those tests requiring complex, high-efficiency programming, coding is performed directly in machine language, working from flow chart diagrams prepared from the test requirements. The machine language is SLAP 2, the basic programming language of the RCA-110A (the ATOLL translator is itself written in SLAP 2).

Of a total of about 116 checkout computer programs scheduled for IU-201, about 14 are written in ATOLL (although this corresponds to approximately 90-99 per cent of the total instruction word count).

In addition to ATOLL programs, data tables for the machine language Instrumentation and Telemetry tests are written on special forms by the test engineers and translated by the support computer into final form. There is some emphasis on the separate data table format, to permit convenient revisions in case of changes in parameters and tolerance limits.

PRESENT AUTOMATION LEVEL

Computer control or "automation" of the checkout process for the IU has progressed farther than for any other Saturn stage or the combined vehicle prelaunch testing. This is true because first, the majority of IU components are primarily electronic or electrical in nature, and perform functions requiring precise timing and rapid response. This leads naturally to automatic testing involving electronic generation of simulated problems or operating conditions and monitoring resulting component or system performance, or to specialized critical dynamic tests and logic sequences. Complex units such as the guidance computer are in themselves digital computers for which checkout equipment of high performance capability is effective.

Second, since the IU design and manufacturing was an MSFC responsibility, a greater opportunity was present to phase automatic checkout equipment, also developed for MSFC, into an existing manual checkout capability. Thus, computer-controlled testing of Saturn vehicles started with the Packard Bell PB-250 system in 1961-62. Instrument Unit checkout of the later Saturn I vehicles, using the RCA-110 computer, was performed by many of the same people, using some of the same techniques and some of the Packard Bell ESE. For Saturn IB/V, the RCA-110A is used, with new ESE. Thus the increase of automation for IU checkout built

upon earlier experience and proceeded comparatively smoothly, in coincidence with development and verification of the checkout hardware and software.

Quantitative Estimate of Degree of Automation

The test sequence and weighting factors permit an approximate estimate of the degree of automation. Omitting GSE self-checking routines and pre-test or post-test procedures, we estimate the percentage of automation to be 85 per cent. This estimate includes a weighting for the increase in the number of test steps due to automation. It is assumed that when a test is automated, three to four automated test steps result on the average from one manual test step. This is due to a number of factors; measurements are more often performed several times and averaged, test sequences are more often repeated, or more combinations are checked automatically than would be checked manually.

Level of Automation

Figure C-1 depicts a measure of the type of computer decisions programmed, or "level of automation" for the Instrument Unit.

The computer communicates, processes, and sequences simple tests. It also conducts sequencing within a single "test program," although it does not sequence several programs in a "precedence list." An Emergency Interrupt entrance to the fixed shutdown routine from either the GSE or the operator (although the GSE interrupt is not yet used) is available and provides a reasonably good emergency capability, although there is no posting of emergency routines.

There is no posting of backup or restart routines, or definition of legal start points, but backup and/or recycle capability is provided within most of the programs. (The importance of emergency routines and backup routines in IU testing is less than in other areas.)

Little preprogrammed contingency reactions or adaptive testing is provided, although the semiautomatic modes provide some degree of automatic checking and other assistance to the essentially manual handling of contingencies.

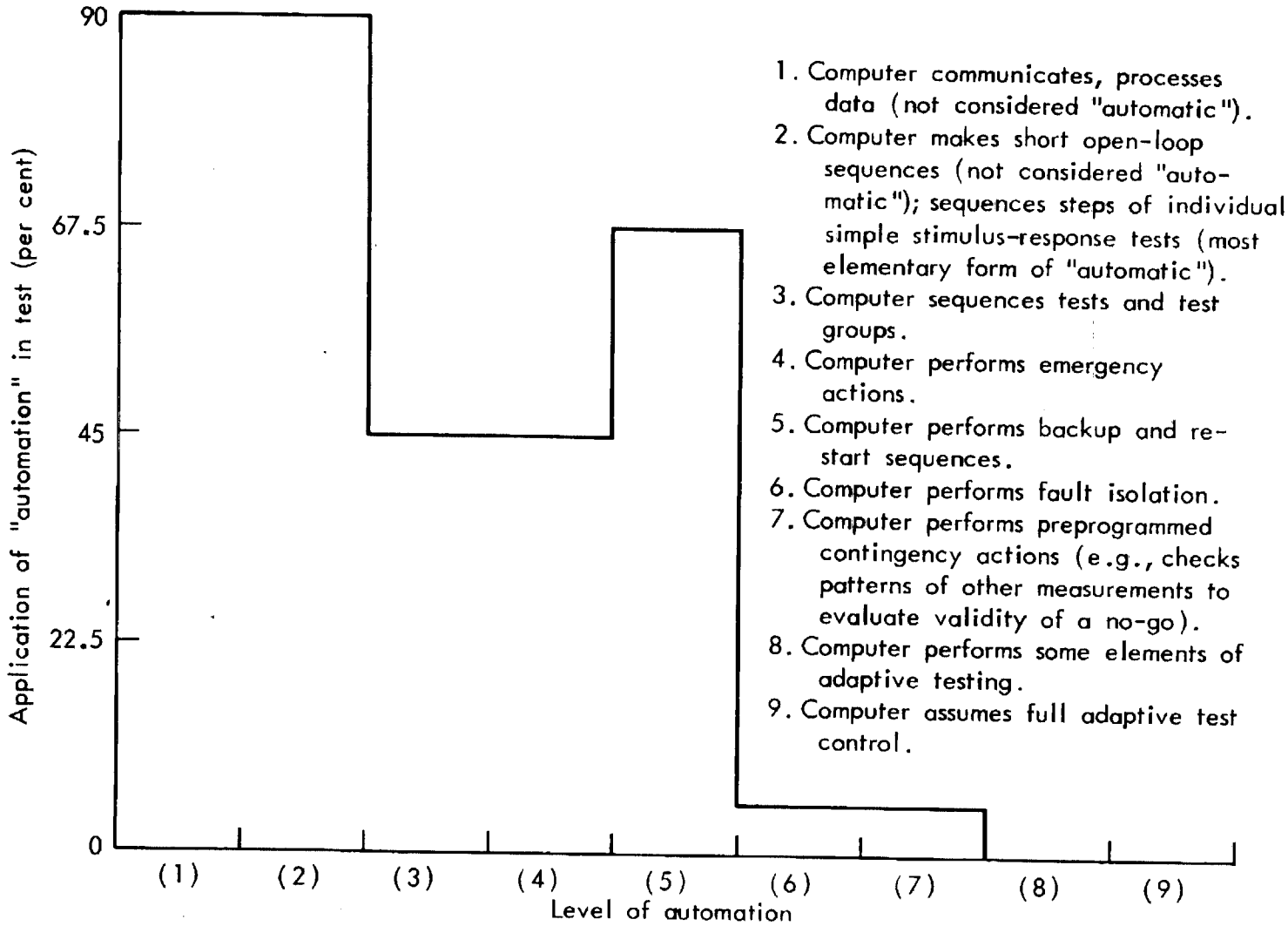


Fig. C-1—Automation level, IU

REVIEW OF PRESENT STATUS

Essentially all tests compatible with computer control are automated. Present limitations on automation efficiency (neglecting the small number of mechanical tests and procedures presently not amenable to automatic testing) are due to constraints imposed by checkout system hardware and software.

In the hardware area, the operating speed of the RCA-110A, although adequate to the checkout task, does impose some limitations both in the rate at which test sequences can be completed, and to a greater extent, upon the programming techniques required to implement the desired tests. The need for utmost programming efficiency so as not to compound the operating speed difficulties is one major reason why only 14 of 116 test programs are coded in ATOLL, with the more efficient machine language used for the remainder. This limited use of ATOLL in turn removes the test engineer to a greater extent from the final program.

A second hardware limitation is in the display area. Again, the Saturn IB consoles are adequate but permit very little man-machine flexibility. On the other hand, more extensive use of display data would overload the RCA-110A, both in terms of memory and operating speed. This restraint will be overcome for the Saturn V, in which a separate display computer, the DDP-224, will both relieve the RCA-110A workload burden and permit more flexible and greater display capability.

In the software area, apart from the limited use of the ATOLL problem-oriented language, comparatively little fault isolation or contingency programming is presently in use. Each is expected to increase gradually over the life of the Saturn IB/V project after the first vehicles are checked out with the initial set of programs, and system and component responses have become more familiar.

Thus the present status may be summed up by stating that, assuming there is no major change in automation system hardware, some increase in test automation may be possible due to more elaborate programming, but basically the present level of automation is near the practicable maximum.

FUTURE AUTOMATION

Without major revisions in checkout hardware, it appears that any increase in the degree or level of automation will be limited to the following areas:

Addition of more contingency, diagnostic, and fault isolation routines to the program library, after a sufficient body of test data has been compiled in practical checkout experience. This should begin to appear by vehicles 205 and 501, since both in the first case, transfer of software responsibility to IBM and in the second case, the differences required by the Saturn V launch vehicles may prod the introduction of such new routines. This will not significantly affect the percentage of automation, but will advance the level of computer judgment decisions.

The introduction of the expanded Saturn V display system will permit a significant step-function increase in the use of display data, both preprogrammed and that requested by the console operator on an unprogrammed basis. With the DDP-224 assuming the major display workload, this may also reduce the burden on the RCA-110A and consequently permit some gain in test efficiency.

From a longer range viewpoint, and requiring additional hardware and software funding, it may also be desirable to provide a real-time link between the Digital Events Evaluator and the RCA-110A checkout computer to permit the RCA-110A to process event transitions as part of a dynamic control loop rather than utilizing the events trail primarily as a historical record.*

With the DDP-224 on line, extensive limit checking of the analog signals in the DDAS for post-test evaluation may be possible, depending on the capacity and computing speed available for this task.

ESTIMATE OF FUTURE STATUS

Assuming that both of the previous possibilities are implemented, a practical ceiling will have been reached in the application of computer control to IU checkout. Beyond that point, the nature of the

---

*This would probably require changes in both the RCA-110A and the DEE.

testing requirements, plus perhaps the limitations of GSE, probably will provide diminishing returns for further major attempts to increase the degree of automation for the present sequence of tests.

It may well be, however, that the test sequence itself is subject to modification. With sufficient historical test data and using the automated equipment, which offers good repeatability of results, it is likely that the techniques of trend analysis and failure prediction will become more precise. This in turn will permit component test data, from receiving inspection through bench checking to installation, to be used in stage checkout to the extent that overall confidence test procedures may be simplified drastically.

An on-line tie-in of the DEE would also assist in the direction, permitting real-time monitoring of dynamics and rapid sequences, which again could provide the basis for trend data and marginality or failure prediction.

At this point, a significant step forward will have been achieved in the <u>use</u> (as opposed to the design) of automatic equipment in the checkout process.

Appendixes

INSTRUMENT UNIT STAGE CHECKOUT SYSTEM DETAILS

A. FUNCTIONAL BLOCK DIAGRAM FOR THE ON-LINE SYSTEM

Figure C-2 provides a functional block diagram of the major on-line components of the Instrument Unit Stage checkout system.

In addition to the on-line equipment, a GE-235 at Q&RA Lab and an RCA-110A (shared with the on-line system) are used for off-line support, program preparation, and verification for the Saturn IB vehicles 201-204. For 205 and later vehicles, and for all of Saturn V vehicles, an IBM 360-40 at the IBM, Huntsville, factory will also be available for support.

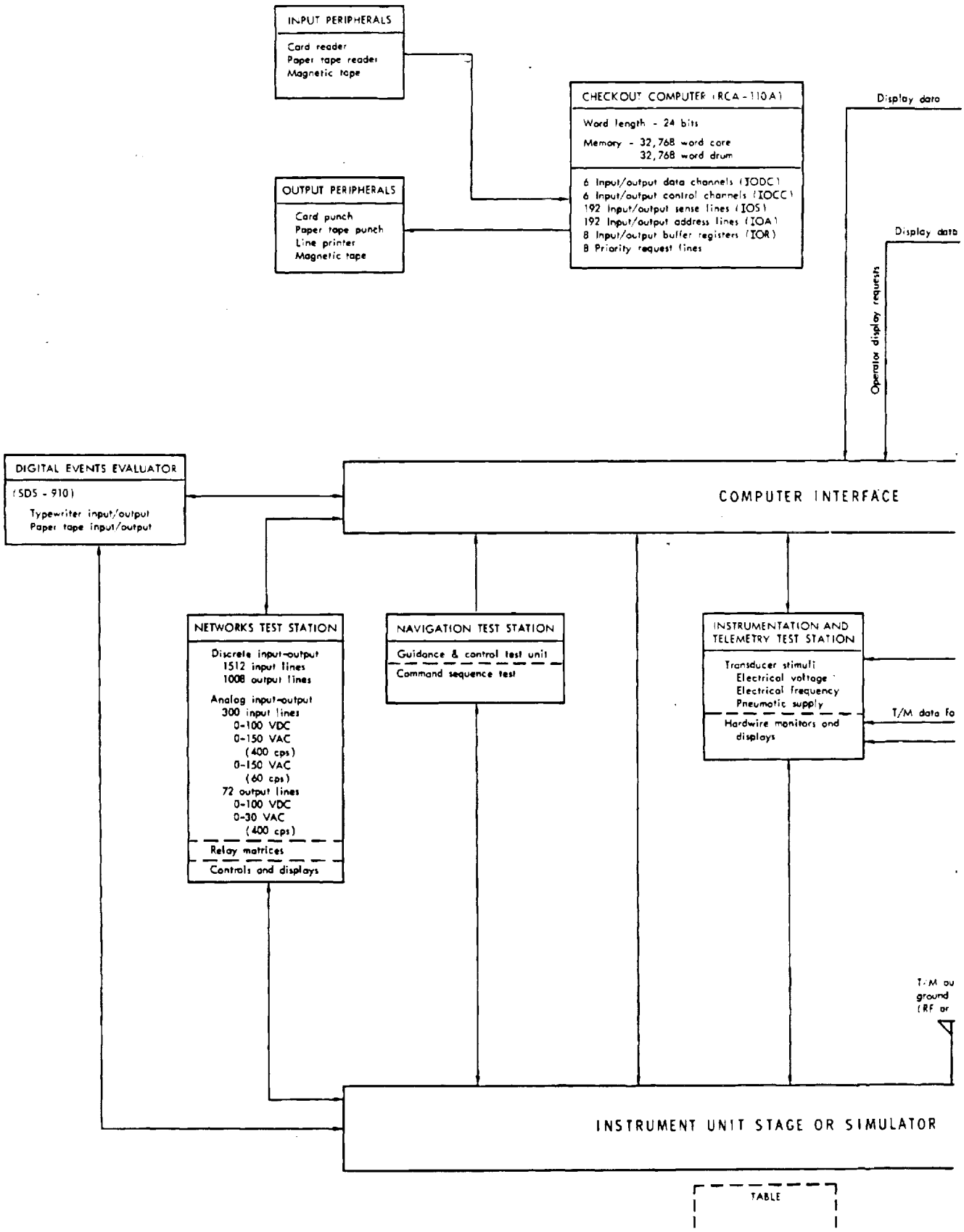
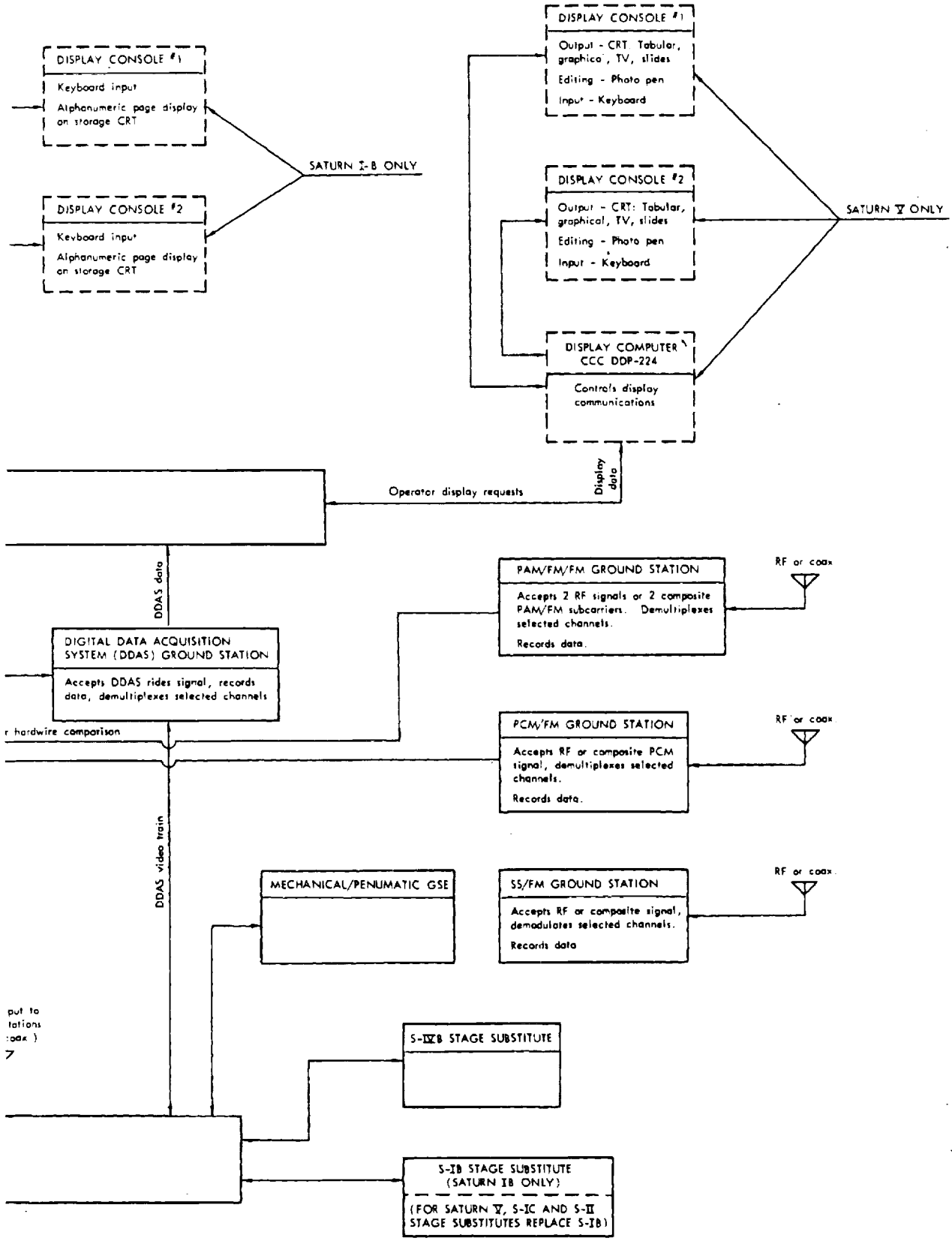

INPUT PERIPHERALS
Card reader
Paper tape reader
Magnetic tape
OUTPUT PERIPHERALS
Card punch
Paper tape punch
Line printer
Magnetic tape
CHECKOUT COMPUTER (RCA-110A)
Word length - 24 bits
Memory - 32,768 word core
32,768 word drum
6 Input/output data channels (IODC)
6 Input/output control channels (IOCC)
192 Input/output sense lines (IOS)
192 Input/output address lines (IOA)
8 Input/output buffer registers (IOR)
8 Priority request lines
Display data
Display data
Operator display requests
DIGITAL EVENTS EVALUATOR
(SDS - 910)
Typewriter input/output
Paper tape input/output
COMPUTER INTERFACE
NETWORKS TEST STATION
Discrete input-output
1512 input lines
1008 output lines
Analog input-output
300 input lines
0-100 VDC
0-150 VAC
(400 cps)
0-150 VAC
(60 cps)
72 output lines
0-100 VDC
0-30 VAC
(400 cps)
Relay matrices
Controls and displays
NAVIGATION TEST STATION
Guidance & control test unit
Command sequence test
INSTRUMENTATION AND TELEMETRY TEST STATION
Transducer stimuli
Electrical voltage
Electrical frequency
Pneumatic supply
Hardwire monitors and displays
T/M data fo
T/M ou
ground
(RF or
INSTRUMENT UNIT STAGE OR SIMULATOR
TABLE

Fig. C-2—IU sta



ge checkout system

B. DESCRIPTION--MAJOR COMPONENTS AND FUNCTIONS

MSFC/IBM IU CHECKOUT SYSTEM MAJOR ON-LINE EQUIPMENT, COMPONENTS AND FUNCTIONS

1. Checkout Computer--RCA-110A

Input - card reader, paper tape reader, display console, I/O channels

Output - line printer, card punch, paper tape punch, display console, I/O channels

Memory - 32,768 word core
32,768 word drum

Word Length - 24 bits

Input/Output Capabilities -

(a) Seven I/O Data Channels (IODC)

IODC No. 1 - paper tape reader/punch, magnetic tape units 1 and 2 and drum

IODC No. 2 - card reader, card punch, line printer, magnetic tape units 3, 4, and 5

IODC No. 3 - DDAS

IODC No. 4 & 7 - not used for IU

IODC No. 5 - discrete input/output to and from IU

IODC No. 6 - display consoles

(b) Analog Input/output system - 300 input and 72 output signals

(c) 192 I/O Sense Lines

(d) 192 I/O Address Lines

(e) Eight I/O Buffer Registers

(f) Eight Priority Request Lines

Function - Control executions of test programs
- Record test results
- Monitor test stations for instructions
- Update and display

Preceding page blank

2. Display Consoles

Function - Display test data and provide capability to request special data display and to make entries into computer

For the Saturn IB, two identical parallel CRT display consoles are provided, one at the computer room and the second for test conductor use in the control room. Each console has an entry keyboard to enable entry into the computer. For the Saturn V, two CRT display consoles are also used, but these interface through an additional display computer, a CCC DDP-224. Expanded and more varied display capability is provided, including editing features, graphical modes and faster updating.

3. Network Checkout Equipment

Function - Provide control and monitoring capability of stage electrical power and network equipment

- Provide discrete signal output stimuli and accept discrete signal input responses
- Provide analog signal output stimuli and accept analog signal input response

4. Navigation Test Station

Function - Provide capability to check out IU guidance and control equipment

- Provide simulated interstage signals
- Provide capability to monitor and verify IU sequence commands

Includes --

(a) Guidance and Control Test Unit

(b) S-IB, S-IVB Stage Signal Simulator

5. Digital Data Acquisition System (DDAS) Ground Station

Function - Accept DDAS signal (600 KC carrier FM by serial data pulse train) on coaxial cable from IU, and record data

- Demodulate, demultiplex, resynchronize selected data words for transmission to computer
- Provide capability to adjust and calibrate instrumentation channel transducers and signal conditioners

6. Instrumentation and Telemetry Test Station

Function - Furnish stimuli to IU sensors and transducers, under computer control

- Monitor instrumentation hardwire output signals for comparison against telemetered values

7. Telemetry Ground Stations

Function - Accept telemetry data, either RF (through transmitter receiver or via coaxial cable) or composite premodulated, demultiplex, record and retransmit if desired, selected digitized data channels to DDAS Ground Station

(a) PCM/FM (Pulse Code Modulated FM) Ground Station

Function - Accept PCM/FM RF data, process, record and retransmit selected channels to DDAS station

- Demultiplex selected channels to analog form for display and recording

- Provide capability to adjust and calibrate transducers and signal conditioner

(b) PAM/FM/FM (Pulse Amplitude Modulated/FM/FM) Ground Station

Function - Accept PAM/FM/FM signals either in RF form or as composite subcarriers

- Demodulate data to a PAM pulse train for recording, display or demultiplexing and digitizing selected channels

- Provide capability to adjust and calibrate transducers and signal conditioners

(c) SSB/FM (Single Side-band/FM/Ground Station)

Function - Accept SSB/FM signals in RF or composite premodulated form from high frequency (to 3KC) vibration and acoustic channels

- Demodulate and demultiplex data for recording and display

- Provide capability to adjust and calibrate transducers and signal conditioners

8. Digital Events Evaluator (DEE)

(Consists of a SDS-910 computer with output typewriter and paper tape punch)

Function - Monitor and record discrete events (bi-level or "on-off" signals) together with reference time data so that a permanent record of time-critical test events is maintained

C. BASIC SOFTWARE (FIGS. C-3 THROUGH C-5)

GENERAL[2,3,5]

The on-line basic software (operating system) for the Instrument Unit factory and quality checkout provides: (1) the necessary general purpose programs for operator control, semiautomatic display, control of peripherals, sequencing of steps within a test program, and (2) the subroutines that execute ATOLL statements.

Provision is made for both ATOLL and machine-language test programs. The machine-language programs are further controlled by a semi-specalized program called the "Guidance and Control Driver." The operating system occupies about 14,000 words of working memory, plus about 1,000 words for the G&C Driver.

The operating system is at present completely coded, and about 40 per cent checked out. The computer is to be hooked up to ESE in May 1965, and full operation of the operating system is expected in June, in preparation for first GETS tests by early July.

Machine-language programs form an important part of IU testing, because of the necessity for rapid and complex looping and handling of bit patterns for checkout of the guidance computer and to some extent the remainder of the guidance system. A few per cent of the test programs (expressed in number of words) will be in machine language. The ATOLL programs will be used largely for the extensive network functions in the IU. The ATOLL subset being implemented is similar to that implemented for the KSC breadboard two-computer system, and is far from a complete version of ATOLL Revision B.

TEST PROGRAM FLOW

The main flow of automatic programs is shown in the upper portion of Fig. C-3. Basically, a test program--whether ATOLL or machine-language--runs according to its own internal sequencing once initiated, without operating system control. During automatic program operation, the controls and displays are essentially "dead," except for control or display operations that have been specially programmed as parts of

the test program. No "housekeeping" is performed between ATOLL statements.

The operator may regain control of the system by requesting semiautomatic operation. This causes an interrupt to the program. Certain phases are regarded as non-interruptible; in these phases, the interrupt merely sets a flag, which is sensed by the test program at the end of the non-interruptible phase, at which point the semiautomatic request is honored. At present, the non-interruptible phases are regarded as very short subroutines or pieces of subroutines. For example, in ATOLL programs, the non-interruptible portions are only the data-taking regions of the subroutines. In machine-language programs, the only "standard" non-interruptible portions are ATOLL subroutines used by the machine-language programs. There is no procedure for writing "do not interrupt" or "safe stopping place" in ATOLL programs, since MSFC feels this is not usually critical for networks.

The DDAS is not buffered. A statement requesting a DDAS input causes that input to be picked up "on the fly" from the bit stream. (Actually, two successive words are picked up, to form a 20-bit sample.)

The operator or program may request a scan of the discrete inputs. During the scan, the discrete-input IODC inputs the complete set of discretes, and updates the discrete profile in memory. The program may thus refer to the up-to-date discrete profile as a simple memory reference.

SEMIAUTOMATIC OPERATIONS

The IU system has a "manual" control capability just like that of the KSC/breadboard system. Manual control switches can cause interrupts, which in turn may cause (1) a discrete output, or (2) a switch-selector output (or other pattern of discretes), or (3) calling and execution of a special program. (This special program will interrupt the one running at the time the switch is thrown, so use of capability (3) may have some limitations.)

Once the station is in semiautomatic mode, the operator may call a new program from tape, resume execution of the program (if any) that was interrupted, skip the next substep, recycle the program to the most recent step initiation (substep number ending in 00), or recycle the most recent substep. No "posting" of backup or restart routines is provided.

The operator also has what amounts to a partial-program and breakpoint option, in that he may request a specific starting and stopping point in the program to be executed. (Because of the extensive data packing performed off-line on ATOLL statements, it is not feasible to jump directly to a "start" point. Instead, the program runs from its start and searches for the starting point, without executing any commands. For example, a SCAN operation is coded by eight bits in the packed data.)

No provision is made for automatic sequencing of several test programs. The "precedence list" concept is not implemented. Programs are called from tape, and execution initiated individually by the operator.

No provision is made for continuous monitoring and display, or for continuous repetitive limit checking, except as programmed in a test program. The operator may request single display of single input quantity. He may also request a read-and-store operation to put a quantity in a table, or may request display of the contents of any ATOLL storage table.

The operator may command any single discrete or analog output, or any change in the discrete-input reference profile, semiautomatically.

EMERGENCY ACTIONS

An emergency power-down sequence is stored in core. It may be entered from an ESE interrupt (although none is yet used), from an operator interrupt, or from a test program. No provision is made for "posting" changes in this routine as a function of program progress. However, different power-down routines could be loaded as part of the process of loading different test programs that are called by the operator.

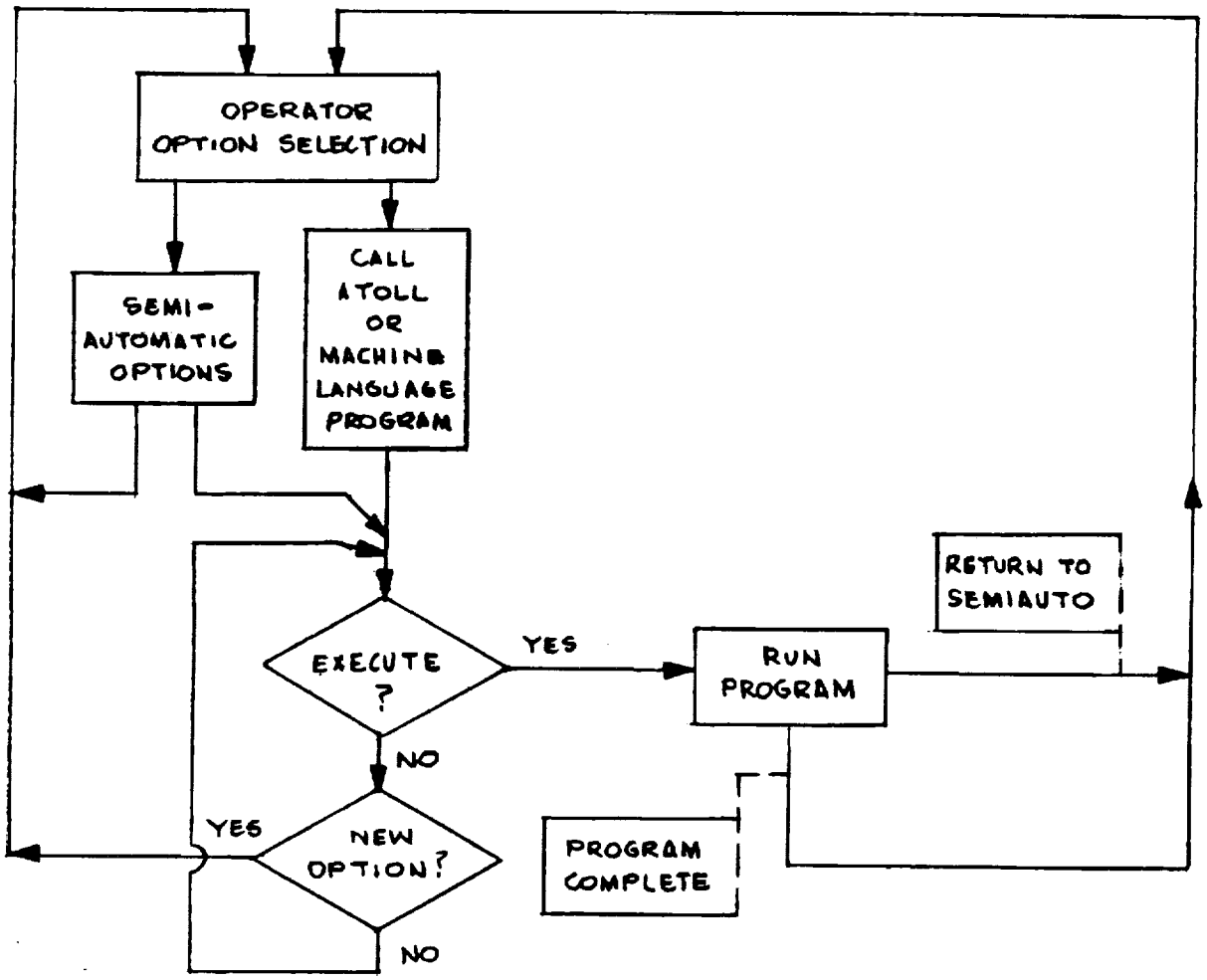


Fig. C-3—Overall flow, IU

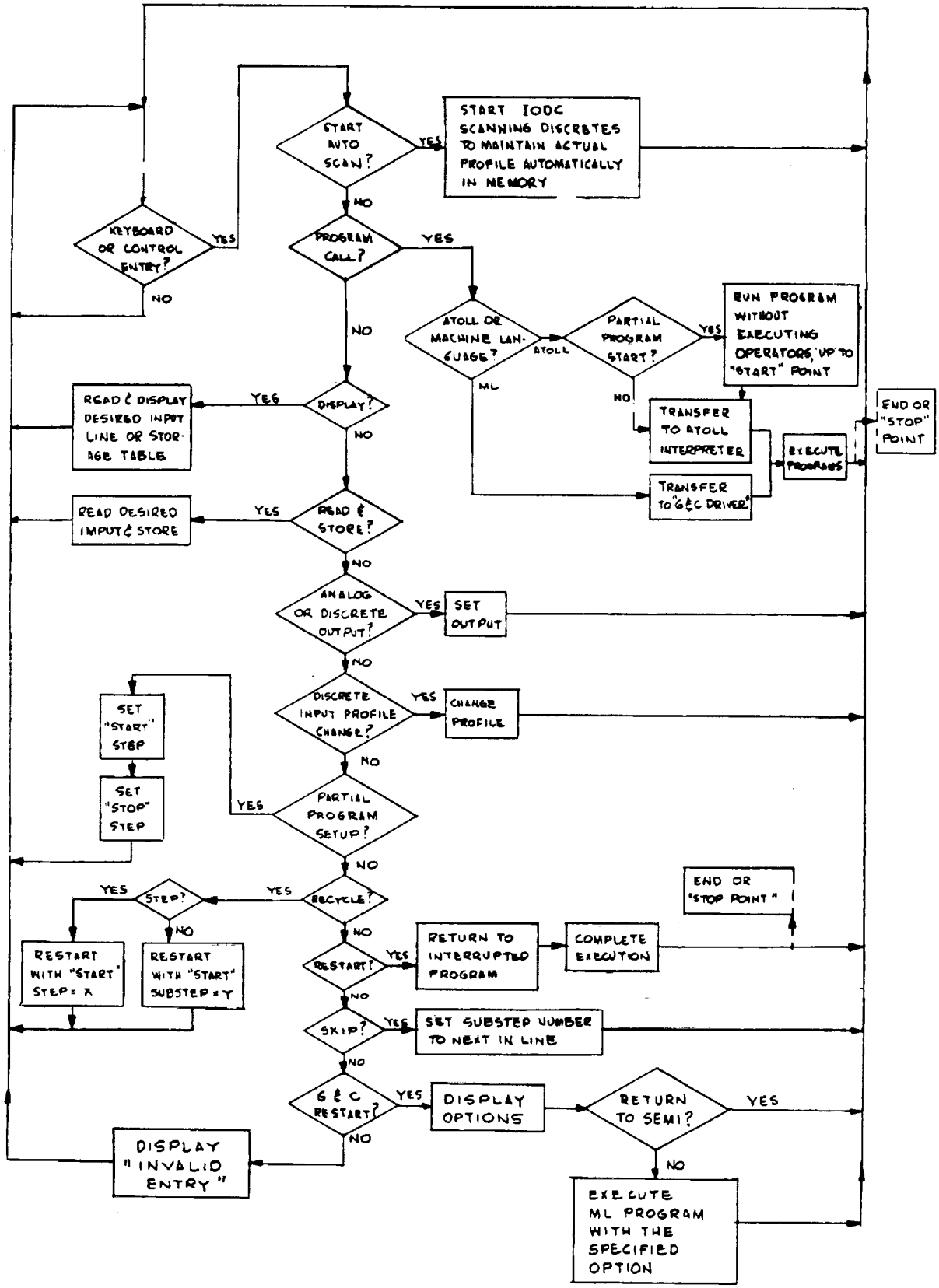


Fig. C-4—Main operating system control, IU

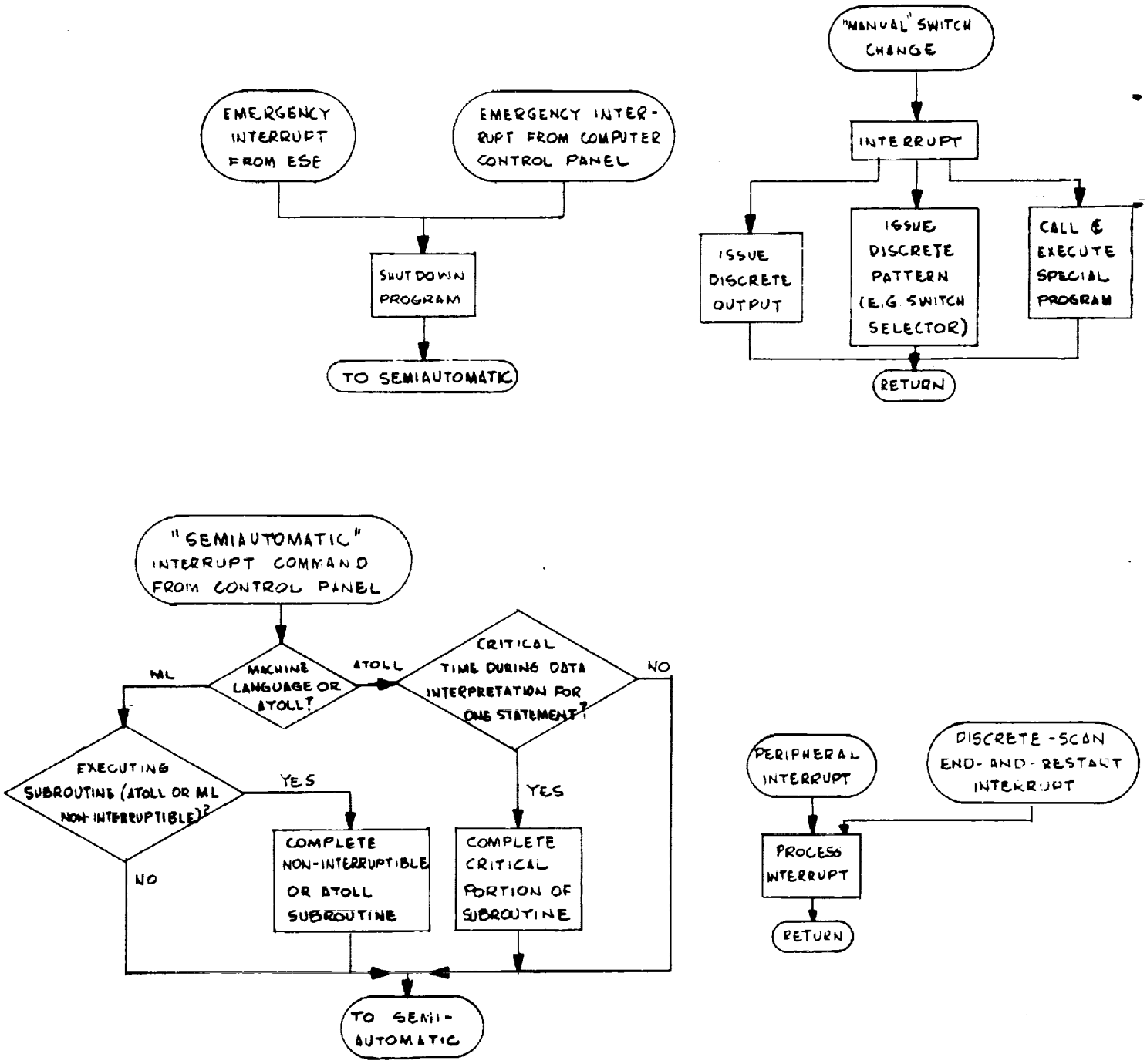


Fig. C-5—Interupts, IU

Annex C

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Annex D

APOLLO SPACECRAFT CHECKOUT

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COMMAND MODULE AND SERVICE MODULE CHECKOUT*

BACKGROUND DATA

Design and construction of the Command Module (CM), Service Module (SM), and Launch Escape System (LES) are the responsibility of the Space and Information Systems Division of North American Aviation, Inc. The M.I.T. Instrumentation Laboratory is associate contractor for the Guidance and Navigation System.

Engineering functions for both vehicle and GSE design are at Downey, Calif. Engineering functions for Guidance and Navigation design are at Cambridge, Mass. Factory checkout is performed by the North American manufacturing organization at the bench-check level, but checkout of the installed system and subsystems is the responsibility of the Apollo Test and Operations Department at Downey. No captive firing is performed until the system reaches Cape Kennedy (KSC). Checkout of the installed Guidance and Navigation equipment is also a North American responsibility, using test requirements supplied by M.I.T.

Computer programming for the checkout system is the responsibility of the Apollo Support Department of General Electric, operating nominally at Houston (but at present mostly at KSC), with some on-site programmers at Downey.

The North American "house spacecraft," Boiler Plate (BP) 14, was first connected to the checkout system in November 1964, and has been in use since then for development of spacecraft equipment, GSE, and computer programs. A second "house spacecraft," Boiler Plate 6, was planned but has been cancelled. The first flight spacecraft, Spacecraft 009, is to be launched on Saturn IB 201. At this writing, Spacecraft 009 was in subsystem and system checkout in the factory, and its successor, Spacecraft 011, was following it at a scheduled interval of 1-1/2 months. Guidance and Navigation equipment is first to be installed on Spacecraft 011, and checkout of Guidance and Navigation basic software for the ground computers was scheduled to begin late in June 1965 on BP 14.

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*Since the S/C (CM, SM, LEM) at factory and KSC all use the ACE system, the description of the ACE system and its automation growth projections are grouped in one presentation at the end of this annex.

System checkout is performed by a combination of manual equipment and a computer-based semiautomatic ACE (Acceptance Checkout Equipment) station. Three ACE stations are now in operation at Downey.

SYSTEM DESCRIPTION[1]

The NAA S/C system consists of: the Command Module, the Service Module, and the Launch Escape System. The LES is a solid-fuel rocket system used for spacecraft removal in early aborts. The SM contains the propulsion equipment required to return from lunar orbit. The CM contains the astronauts, their life-support equipment, and a small propulsion capability for maneuvering. In more detail, these systems include the following:

1. Launch Escape System

- Launch Escape Motor
- Pitch Control Motor
- Jettison Motor
- Separation System
- Canard
- Ballast
- Nose Cone with Q-Ball
- Launch Escape Tower
- LES Wiring Harness

2. Service Module

- Service Propulsion System
- Reaction Control System
- Environmental Control System
- Electrical Power System, including fuel cells
- CM-SM Separation System
- SM Jettison System
- Antennas

3. Command Module

- Control Programmer (unmanned missions only)
- Backup Attitude Reference System
- Power System Programmer (unmanned missions only)
- Heat Shield
- Stabilization and Control System
- Reaction Control System
- Mission Sequencer
- Displays and Controls
- Emergency Detection System
- Recovery System

Earth Landing System

Boost Protective Cover

Entry Monitoring System

Electrical Power System, including batteries

Communication System, voice, data, and TV

Environmental Control System, including Waste Management and Water Supply Subsystems

Instrumentation System

Guidance and Navigation System

DESCRIPTION OF TESTS[1,2]

The following description of tests is derived from the Operational Test Plan for S/C 009. Since the version available did not contain a complete listing of all Operational Checkout Procedures (OCPs) the listing contained herein was prepared by analysis of the verbal description of the test sequence, as contained in the Operational Test Plan. Therefore, the method of subdividing the test sequence does not necessarily coincide with that used by North American in assigning OCP numbers. Also, since Spacecraft 009 does not contain a Guidance and Navigation System, and does contain a Control Programmer, the test sequence does not coincide in some details with one that would be used for a manned spacecraft. Nevertheless, the listing is close enough to probable later S/C test sequences that it can be used as a guide for analysis.

1. Individual GSE and ACE Tests. Individual items of North American GSE are checked as necessary to ensure acceptable status, and the ACE status is verified by General Electric. North American GSE subsystems are then connected together to ensure compatibility and gross operability, prior to connecting them to ACE.

2. ACE and ACE/GSE Integrated Tests. North American ACE equipment and GSE are sequentially integrated with the ACE Ground Station, with testing at each step. When the system is complete, an overall integrated test is performed to verify overall ACE/GSE compatibility, and a Station Readiness Test is performed using program tapes for S/C 009, to ensure that the ACE (including GSE) is compatible with the software.

Pre-test. Installation of modules and hookup of GSE. The CM, SM, and LES are installed in the work stand, and system installation and updating are completed. ACE carry-on equipment and external servicing equipment are connected. The modules are connected together and interconnections are checked against a configuration checklist.

3. RF Cold Tests. Voltage standing wave ratio (VSWR) and attenuation characteristics are verified on the HF, VHF, UHF, C-band, command destruction, and scimitar antennas, and on all transmission lines and RF components.

4. Power Distribution Test. The DC power distribution system is checked under control both of ACE and the spacecraft internal control, including checks of bus distribution, undervoltage, external/battery power transfer, non-essential bus distribution, and CM interior lighting. Similar checks are then performed on the AC system, including also checks on the inverter controls.

5. Power System Programmer Test. The Power System Programmer, a part of the Control Programmer, is checked in conjunction with the power system for proper operation, and for proper reaction to all the possible major failure modes of the spacecraft electrical power system. Failures of the power system are simulated for this test.

6. Environmental Control System Test. ECS power and control circuits are tested prior to energizing other system components. Next, a dry checkout is performed on the water-glycol loop, the water management system, the individual sensing devices, and the spacecraft ECS displays and controls. The system is then filled, and the subsystems checked wet. Following this, the complete ECS is checked with a "suit loop stimulus generator," which simulates metabolic heat loads and exercises the cabin temperature control subsystem.

7. Communication System Test. The communication equipment in the Communication and Instrumentation System is tested. The Audio Control Center is checked for proper switching, transmission, and reception. The radio subsystems are checked for receiver sensitivity, transmitter power output, modulation mode compatibility, and correctly

decoded PCM signals, as applicable. These include the HF Transceiver, the VHF Communication Equipment, the Up Command System, the Command Destruct System, the UHF Receivers and Decoders in the Control Programmer, and the C-band Transponder. The Premodulation Processor, Diplexer, and Multiplexer are checked for function.

8. Instrumentation System Test. The instrumentation equipment in the Communication and Instrumentation System is tested. The PAM/FM/FM system is checked by exciting transducers and signal conditioners and observing results on the real-time readout. The frequency stability of all timing signals for on-board and ACE systems is checked through the Central Timing Equipment. The airborne PCM is checked, including checks of compatibility with the Reaction Control System and Spacecraft Propulsion System Engine, by real-time readout of decommutated data. Mechanical and electrical tests are performed by the on-board tape recorder for functional verification.

9. Reaction Control System Test. The SM RCS and CM RCS are checked in sequence. RCS propellant gauging is verified by the nucleonic sensors, the computer, and the display panels. All firing circuits and engine inlet valves on the SM RCS are verified. On the CM RCS, display panel response to firing circuit activation is verified, as is the sequencing operation of the fuel dump control box.

10. Service Propulsion System Test. ACE is used to verify all valves required for the SPS, and all engine functions are monitored locally and through the CM display panel.

11. Stabilization and Control System Test. The SCS is checked in all control modes at the interface with the SPS and RCS. Jet select logic, rate gyro torquing signals, and attitude gyro torquing signals are checked. SPS engine feedback loops are used to check rate and attitude gyro circuits during simulated SPS firing. Attitude and rate stabilization and translational control are checked in response to commands from the Control Programmer. Cross coupling of roll and yaw rate gyros is checked. The backup attitude reference system is checked concurrently with the attitude gyro checks.

12. Vehicle Separation and Sequencing Checks. Functional operation and timing of the SM Sequencer, the CM to SM Separation Circuits, the LES Sequencer, the LES Canards, the Earth Landing System, Recovery System, and Flotation Subsystem are checked via ACE. Pyrotechnic simulator units are used to sense proper operation of all pyrotechnic circuits.

13. Flight Programmer Test. The Flight Programmer consists of the Radio Command Equipment, the Backup Attitude Reference System, the Power Programmer, and the Control Programmer. The first three of these items have already been checked. Within the Control Programmer, the Radio Command Control Subsystem is checked for proper outputs for all 40 ground commands; and the Automatic Command Control Subsystem is checked for proper functioning of all timers and relays involved in normal or abort mission profiles. Next, the Flight Programmer is connected to the other equipment in the S/C and compatibility is verified both in the manual mode using Ground Control and in the automatic mode.

Pre-test. Vibration thrusters are installed around the CM and SM.

14. Qualification Verification Vibration Test. The S/C is subject to random vibrations from the vibration thrusters, and the indications of the ACE displays and telemetry ground station are monitored for deviation of any parameter.

Post-test, data review. Test data to date is reviewed by North American and NASA personnel. If test completion is satisfactory, permission is given to remove the S/C from the test stand.

Pre-test, and further installation. Carry-on equipment and all GSE are disconnected. The CM, SM, and LES are electrically disconnected and physically separated. The S/C is moved from the test stand to a low bay area. The SPS Heat Shield is installed on the SM, the SM is cleaned, the crew compartment and heat shield are installed on the CM, and mock-up or non-flight-rated components and parachutes are installed for the Earth Landing System (for Design Engineering Inspection and weight and balance functions). The CM is then cleaned.

Pre-test, Development Engineering Inspection and modification. After an S/C Development Engineering Inspection, modifications resulting from it, and any other mandatory changes, are made. The SM instrumentation telemetry kit is installed. A paper configuration is performed.

Pre-test, weight and balance preparation. The forward heat shield and boost protective cover are installed on the CM, and a simulated SPS engine nozzle on the SM.

15. Weight and Balance Test. The weight and center of gravity in both horizontal and vertical positions are determined for both the CM and the SM.

Post-test and pre-test. The boost protective cover, the forward heat shield, the dummy Earth Landing System, parachutes, and simulated nozzle are removed. The SM is placed on the Integrated Test Stand and aligned, and the SM servicing equipment is installed.

16. Instrumentation Telemetry Kit Test. This is checked out as a subsystem.

Pre-test. The CM is placed on the SM, aligned, and electrically and mechanically mated to it. The CM is also electrically, but not mechanically mated to the Launch Escape Tower. The S/C is then ready for Integrated Systems Test. The GSE including carry-on equipment is also moved to the Integrated Systems Test Station and installed.

17. Individual GSE and ACE Tests. Same as Test 1.

18. ACE and ACE/GSE Integrated Tests. Same as Test 2.

Pre-test. The GSE is connected to the spacecraft.

19. Integrated System Test, Part 1.

20. Integrated Systems Test, Part 2. All abort mission profiles and the normal mission profile will be demonstrated to NASA with ACE and GSE control for prelaunch phases, and ACE and GSE monitoring for post-launch phases.

Post-test. Test data are reviewed by NASA for official acceptance. The modules are separated and shipped to KSC.

DEVELOPMENT OF TEST REQUIREMENTS AND PROCEDURES[3,4,5]

Responsibility for the application of the ACE system is divided between Engineering and Apollo Test and Operations (AT&O). Engineering

sets test requirements and writes a process specification that theoretically defines the requirements, without reference to particular test equipment or procedures. (Actually the requirements are often written around specific equipment, and may amount practically to procedures.) AT&O, working with the process specification and the engineer, prepares an Operational Checkout Procedure, which is a detailed test procedure. The OCP is reviewed by NASA.

If the procedure requires only already available ACE subroutines, Engineering is responsible for preparing data tables of tolerances, addresses, etc., that apply these programs to a specific test. If new subprograms (e.g., new types of measurement processing) are required, either AT&O or Engineering may originate the requirement, but Engineering is the interface with General Electric programming.

North American Systems Engineering is preparing diagrams following the flow from GSE through the vehicle back to GSE, complete with plug and pin numbers. This effort is still at a relatively early stage. Verification of subprograms (basic software) is performed on the house spacecraft, BP 14. BP 14 is constructed using engineering wiring harnesses, and includes developmental, non-current versions of many subsystems.

It has not been possible to keep the installed equipment current with latest subsystem design changes. Therefore, although BP 14 contains equivalents of most or all of the subsystems in the first flyable unit (009), the systems are neither functionally nor physically identical, and it is not possible to perform final verification of specific 009 programs on BP 14. Insofar as specific 009 programs receive any final verification other than use in checking out the S/C, such verification will be performed with the ACE connected to 009 itself.

For the manual modes of ACE operation, some forms of program discrepancies will not seriously affect checkout as they would in fully automated systems. For example, it was NAA's experience that when erroneous tolerances were written into the programs on downlink quantities, the display blinked, as it is designed to. However, the

operator readily evaluated it, and subsequently ignored the blinking. Other forms of program and equipment discrepancies (some originating in human error, some in testing philosophy) have been circumvented in use by changes in procedures that take advantage of non-ACE alternatives, such as local monitoring and switching at the GSE and in the spacecraft cockpit (beyond that required with ACE-controlled procedures).

PRESENT AUTOMATION LEVEL

North American Aviation has received the first ACE-S/C ground station equipment, and it is operational; no major problems exist with its performance.*

Application of ACE-S/C was planned to begin on BP 14, with program verification and personnel training to be accomplished on 014 in preparation for checkout of 009, the first flight CSM, scheduled to be launched by Saturn IB 201, in early 1966.

Personnel training and development of user confidence in ACE-S/C have proceeded to the point where ACE-S/C is used (where applicable) for engineering and R&D testing, in addition to the subsystem buildup and acceptance testing for which it is required.

Program verification, however, has not been possible on 014 since its other uses as a hardware tool preclude prompt updating of its configuration to match 009.** ACE-S/C test programs will, therefore, have inadequate verification prior to use on flight hardware. This is undesirable because gross errors will be corrected, but problems of marginality or inadequate testing may be undetected.

In the area of test requirements and procedures and documentation of data such as test points, overall signal flow paths, and equipment interfaces, the Apollo program at NAA needs a broad, uniformly applied, and timely system definition and integration effort. The accelerated

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*All three ACE stations programmed for NAA have since become operational.

**The requirement for verification was waived for 009. Verification was not possible for 011, and plans call for discontinuation of BP 14 use for ACE program verification after December 29, 1965.

rate of the Apollo program reinforces this problem, with resultant interface mismatches and documentation difficulties.

With NAA being farthest along in the operational use of ACE-S/C, some of the problems posed above have already transcended the theoretical. In particular, these are noted:

(1) The succession of modifications and changes in 009 test requirements have already resulted in a high peak workload for GE programmers and have affected the turn-around time. To avoid delaying developmental testing, NAA is receiving special test tapes onto which they can incorporate their desired changes, and use these until formally approved programs are received. This results in a proliferation of unofficial versions of automatic test programs.

(2) The inability to maintain BP 14 to spacecraft 009 configuration has delayed computer program verification until actual checkout of 009. To further complicate this problem, it is presently understood that 009 may be shipped to KSC not completely assembled, with final assembly performed at KSC prior to prelaunch checkout.* In this situation, it will be extremely difficult to determine the adequacy of test programs, beyond the gross error category, particularly since the NAA and KSC GSE are not identical.

(3) Problems (1) and (2) have been further magnified by the difficulty of assembling the data required to freeze upon test requirements and procedures. Although the data are available, the early system analyses have required collection from multiple sources and consequent translation to a useful format.

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*The schedule of activities was changed to permit shipment of an essentially complete, tested S/C 009.

LUNAR EXCURSION MODULE CHECKOUT

BACKGROUND DATA

Design and construction of the LEM are the responsibility of the Grumman Aircraft Engineering Corporation. The M.I.T. Instrumentation Laboratory is associate contractor for the Guidance and Navigation System.

Engineering functions for both vehicle and GSE design are at Bethpage, N.Y. Engineering functions for Guidance and Navigation design are at Cambridge, Mass. Checkout of the assembled system, including acceptance test at the factory, is performed by the System Test group of the System Engineering organization, a part of the Engineering organization of the LEM project. The LEM Test and Support organization is responsible for shipment to Florida, Grumman activities in Florida, and activities at other field stations.

Computer programming for the checkout system is the responsibility of the Apollo Support Department of General Electric, operating nominally at Houston (but at present mostly at KSC), with some on-site programmers planned to be at Bethpage.

The Grumman "house spacecraft," LTA-1, is in the early stages of construction. Testing of the first flyable spacecraft, LEM-1, lags LTA-1 testing by four to six months. Two ACE stations are planned for Bethpage.* Grumman and GE are now beginning checkout of the ground station only, without the interfacing equipment used with the S/C. This is to be connected to LTA-1 in January 1966.

Checkout of the system is performed by a combination of manual equipment, ACE, and ACE-controlled GSE.

SYSTEM DESCRIPTION(6)

The S/C system produced by Grumman consists of one major element: the LEM. It includes separable descent propulsion for lunar landing, ascent propulsion for return to the in-orbit Command and Service Modules,

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*Both stations have since become operational.

controls and sensors for guidance, stabilization, and lift support, and communications and instrumentation. In more detail, these systems include:

- Propulsion
  - Ascent Equipment
    - Engine and Engine On-off Controls
    - Propellant Tanks and Plumbing
    - Pressurization Bottles, Controls, and Plumbing
  - Descent Engine Equipment
    - Engine, Engine Throttling Controls, Engine On-off Controls, and Engine Gimbaling
    - Propellant Tanks and Plumbing
    - Pressurization Bottles, Controls, and Plumbing
  - Electro-Explosive Devices
    - Landing Gear Deployment
    - Fuel and Oxidizer Crossfeed and Pressurization Commands
    - Ascent Staging
    - Descent Staging
    - Antenna Deployment
    - EED Batteries
- Electric Power
  - Power Generation Section
    - Power Source
    - Descent Stage Oxygen, Hydrogen Tanks, and Plumbing
    - Ascent Stage Oxygen, Hydrogen Tanks, and Plumbing
  - Power Distribution Section
    - DC Power Distribution
    - Inverter and AC Power Distribution
- Reaction Control
  - Redundant Thrusters, Manifolds, and On-off Controls
  - Propellant Tanks and Plumbing
  - Pressurization Bottles and Plumbing
- Environmental Control
  - Heat Exchangers, Water Management Devices, Gaseous Oxygen Tank, Coolant, and Pumps
  - Breathing Oxygen Control and Circulation
  - Portable Life Support Systems
  - Water Tanks
  - Water Evaporators
- Crew Equipment
  - Internal and External Lighting
  - Crew-related Structure
  - Waste Management
  - Food and First-aid Stores
  - Scientific Instrumentation
  - Spacesuits

Communications

- Antennas
  - Dual VHF In-flight
  - Dual VHF Lunar Star
  - Dual S-band Omnidirectional
  - S-band Erectable
  - S-band Steerable
  - Spacesuit
  - VHF AM Transmitter-receiver (LEM-CSM)
  - S-band Receiver, FM Transmitter, Phase Modulation Transmitter, and Power Amplifier (LEM-Earth)
  - Audio Centers
  - Premodulation Processor
  - TV Camera
  - Dual Spacesuit Transmitter-receivers

Instrumentation

- Sensors
- Caution and Warning Electronics
- On-board Checkout Electronics
- Signal Conditioners
- PCM and Timing Electronics
- Data and Voice Storage Equipment

Guidance and Navigation

- Inertial and Computer Equipment
  - Inertial Measurement Unit and Power Servos
  - Alignment Telescope
  - Coupling Electronics
  - LEM Guidance Computer
  - Landing Radar
- Rendezvous Radar
- Transponder

Stabilization and Control

- Abort Guidance Section
  - Attitude Reference
  - Abort Programmer
- Control Electronics Section
  - Rate Gyros
  - Attitude/Translation Control
  - Dual Attitude and Thrust Command Assemblies
  - Descent Engine Control

Controls and Displays

TEST DESCRIPTION

Because of the relatively early state of LEM development and restricted access to LEM documentation, detailed data from which a LEM test description could be derived were not received in time for inclusion in this report.

DEVELOPMENT OF TEST REQUIREMENTS AND PROCEDURES

Initial test requirements for the individual vehicle subsystems are defined by the subsystem area within LEM Engineering, the people involved with the flight subsystems design. Test functions are then defined in a preliminary, general way by the "Level 1" system diagram, an overall functional diagram that is the responsibility of System Engineering (a part of LEM Engineering). Definition of the test functions within the Level 1 diagram is performed either by the System Test group within System Engineering, or by the Test and Support area (an organization separate from LEM Engineering, which is responsible for post-acceptance installation, testing, and support activities). System Test is largely responsible for acceptance test planning. Equipment requirements to satisfy Level 1 test functional definitions are developed by the GSE System Group within GSE Engineering (another part of LEM Engineering).

After completion of the Level 1 functional diagrams, Level 2 diagrams are prepared. These are detailed functional block diagrams, showing all data and power flow, and following signals through units. Level 2 diagrams are control documents, and are the responsibility of System Engineering, or more specifically of the Systems Analysis and Integration Group, and are also signed off by Subsystems. However, due to the initial concentration of this group on vehicle systems, a large part of the Level 2 GSE diagram work has been performed by the GSE System Group.

Level 2A diagrams are also prepared by System Engineering and signed off by Subsystems. These are detailed block diagrams that combine complete functional signal information, wiring and plumbing terminal and routing information, and electrical and mechanical design

information in a readable format. Level 2A diagrams are well along for the vehicle, but are just beginning for the GSE.

Level 3 diagrams are detailed schematics of the subsystems called out by the Level 2 system diagrams. They are prepared by Subsystems and signed off by System Engineering.

Acceptance testing and subsequent field-site testing are controlled by the GORP (Ground Operational Requirements Plan). The GORP covers a sequence beginning just before system acceptance test at the factory and ending at launch. It is the responsibility of the test and support organization. However, planning and performance of acceptance tests are the responsibility of System Test, so they have a strong input to the GORP in this area.

Detailed test procedures are derived from the GORP, the system diagrams, and other system information. They are expressed in the ACE programs and in the Operational Checkout Procedures (OCPs). OCPs for acceptance test are prepared by System Test. OCPs for site testing are prepared by Test and Support. Both organizations will initiate ACE program requirements, but the basic ACE program organization (interface with GE) is within Test and Support.

PRESENT AUTOMATION LEVEL

The first ACE-S/C has been installed at Grumman and is now undergoing self-check and acceptance testing.

Grumman, because of its later delivery schedule, is to some extent benefiting from prior NAA experience. Its system definition and engineering group, after an initial delay, has established interface control. As an example, Grumman's Level 1 (LEM subsystem general diagram), Level 2 (general signal flow), Level 2A (detailed signal paths with components, connector points, etc.) and Level 3 (detailed LEM subsystem schematics) are all control drawings, with Levels 1 through 2A prepared by the system analysis groups and agreed to, in writing, by the cognizant LEM and GSE engineers. Changes are controlled in the same manner.

It is Grumman's present intent to keep its house LEM updated with flight versions to provide a program verification vehicle and also to maintain identity between factory and KSC GSE. Control is being

exercised by system analysis groups so that data flow and interface definition appear to be established reasonably well.

There is also expressed the determination to maintain identity between factory and KSC GSE, and to utilize the house LEM for program verification. These ambitions could fall short of fulfillment if unanticipated LEM design difficulties and modifications, plus schedule pressures, result in a large test program perturbation with very little available time to cope with it satisfactorily.

SPACECRAFT PRELAUNCH CHECKOUT

BACKGROUND DATA

Checkout activities for the spacecraft at Kennedy Space Center are the responsibility of Spacecraft Operations of the Launch Operations Directorate. The KSC field personnel of the various industrial contractors (NAA, Grumman, GE) work under the direction of this organization. All post-acceptance testing of the spacecraft modules is performed at KSC.

Initial testing concepts included the idea that KSC testing would be part of a unified factory-through-launch test sequence, with little duplication of tests between the factory and KSC except for overall system tests. This concept is not yet fully implemented, in part because of the differences in GSE resulting from facility differences, so that some additional KSC tests are essentially the same as factory tests. In addition to the tests similar to factory tests, KSC-peculiar tests include system cryogenic and hypergolic tests, static firing of the SM (no static firing of the LEM is planned), tests of the various interfaces between modules and between the S/C and other equipment, and prelaunch and countdown tests on the pad.

In addition to the non-ACE GSE and servicing equipment, five ACE stations will be present at KSC to support prelaunch tests, hypergolic tests, assembly tests, static firing, etc.* Of the five stations, one is now undergoing initial installation checks and the remainder are in earlier stages of manufacture or installation.

Checkout of the S/C is performed by a combination of manual equipment, ACE, and ACE-controlled GSE. Control of static firing will be through ACE.** Safing operations in the event of loss of prelaunch ACE control will be manual, by means of local controls. Most servicing will be under ACE control.

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*Two ACE stations have since become operational; all stations are scheduled to be operational by November, 1966.

**The static firing was actually controlled through ACE on 009.

The first flyable S/C to pass through KSC will be S/C 009. This is scheduled to be launched on Saturn IB 201, the first flyable Saturn IB, early in 1966.

SYSTEM DESCRIPTION

The Apollo S/C consists of the LEM, SM, CM, and LES. The LEM is described on pp. D-12-D-14, and the SM/CM/LES combination on pp. D-3, D-4.

In addition to the internal subsystems of the modules, there exist inter-module interfaces and interfaces with non-S/C equipment:

1. LES/CM/SM interfaces (factory checkout at NAA, verified at KSC)
2. SM/LEM interface (checked at KSC)
3. S/C and LV interface [mechanical, guidance, emergency detection system (checked at KSC)]
4. S/C and GSE and facilities interface (interface to carry on equipment checked at factory and verified at KSC; remainder checked at KSC)
4. S/C and Range interface (RF links checked largely at KSC with pre-checks at factory)

DESCRIPTION OF TESTS (7)

The following list of tests, with brief descriptions, is taken from the KSC plan for S/C 009, which is only a partial system. In particular, portions of the CM and SM are lacking (notably the guidance and navigation system), and no LEM is present. It was considered preferable to describe 009 tests, which are in a relatively detailed state of schedule planning, rather than describe tests of a more complete system that might be in a less advanced state of planning.

Test	Description
1	Receiving Inspection of LES--gross physical inspection
Pre-test	GSE Setup for LES
2	Motor Inspection
Pre-test	LES Buildup--build up aft and forward sections and mate

3	LES Bonding and Harness Checks
4	LES Weight and Balance Checks
5	CM Receiving Inspection--gross physical inspection
Pre-test	CM Environmental Control System Servicing
6	CM Electrical Power System and Instrumentation Checkout
7	CM Reaction Control System Checks
8	CM Servicing and Calibration
9	CM Cold Flow Checks
Pre-test	Move CM to RF Test Facility
10	CM RF Checks
Pre-test	Move CM to Weight and Balance Facility
11	CM Alignment, Weight, and Balance Checks (with LES)
Pre-test	Move CM to Cleaning Position and Clean CM
Pre-test	Move CM to Mating Stand
12	SM Reaction Control Quad I Receiving Inspection
13	SM Reaction Control Quad I Functional Check
14	SM Reaction Control Quad I Servicing and Calibration
15	SM Reaction Control Quad I Cold Flow Tests
16-27	(Same as 12-15 for Quads II through IV)
Pre-test	Move Quads to CM
28	SM Receiving Inspection
Pre-test	Connect GSE for SM Power, Propulsion, and Static Firing Checks
29	SM Electrical Power System and Instrumentation Checks
30	Service Propulsion System Functional Checks
31	Service Propulsion System Leak Checks

32	SM Servicing and Calibration
33	SM Static Firing
Post-test	SM Flush and Purge
34	Post-firing SM Leak Checks
Pre-test	Move SM to Cleaning Position and Clean SM
35	Receiving Inspection of Spacecraft Launch Adapter
Pre-test	Install Boost Dynamic Instrumentation on Launch Adapter
Pre-test	Install Ordnance on Launch Adapter
36	Fit Check, Launch Adapter vs. LV IU
37	Fit Check, Launch Adapter vs. SM
Pre-test	Move SM to Mating Stand and Install Reaction Control System Quads
Pre-test	Mate SM and CM and Move to High Bay
Pre-test	Install Nozzle Inertia Simulator, Move CM/SM to Launch Adapter Integration Stand, Connect GSE
38	Check CM/SM Interface
39	Frequency Response Check
Pre-test	Disconnect GSE, Remove Nozzle Simulator, Move to Altitude Chamber, Connect GSE
40	Cabin Leak Check
41	Environmental Control System Run with Flight Hatch
Pre-test	Disconnect GSE, Move to Polarity Checker, Connect GSE
42	Polarity Test--check attitude reference outputs for polarity while S/C is moved mechanically
43	Integrated Systems Test of CM/SM Combination
Pre-test	Disconnect GSE, Move to High Bay, Install Service Propulsion System Nozzle Extension
Pre-test	Move to Launch Adapter Integration Stand, Mate Launch Adapter to SM, Install Forward Deck Ordnance, Parachutes, FHS, Prepare for Move to Pad

Pre-test	Move to Pad, Mate Mechanically to LV, Set Up Complex
44	Integrated Test with LV Simulator
Pre-test	Connect Cables for Interface Test
45	Interface Test with LV
Pre-test	Connect Cables for Sequence Malfunction Test
46	Sequence Malfunction Test
Pre-test	Connect Cables for Plugs-in Integrated Test of Total SV
47	SV Plugs-in Integrated Test
Pre-test	Mate LES and TV
48	LES and TV Alignment Check
Pre-test	Connect Cables for RFI Tests
49	RFI Tests
Pre-test	Connect Cables for SV Plugs-out Integrated Test
50	SV Plugs-out Integrated Test
Pre-test	Ordnance Installation
51	RP-1 Tanking and S/C Pressurization Check
Pre-test	Connect Cables for Simulated Launch
52	Simulated Launch
Pre-test	Connect Cables for Simulated Flight
53	Simulated Flight
54	S/C Servicing
55	CM and SM RCS Tanking
56	Service Propulsion System Tanking
57	Countdown

DEVELOPMENT OF TEST REQUIREMENTS AND PROCEDURES

Test requirements and procedures for the S/C at KSC are the responsibility of the Spacecraft Operations portion of the Launch Operations Directorate. Spacecraft Operations personnel monitor and direct contractor personnel in the development and execution of tests.

Test requirements for KSC tests are the responsibility of the Apollo Test Manager and of the Electrical Systems and Mechanical Systems areas, all within Spacecraft Operations. The requirements are reflected as general test plans in the GORPs of the contractors, and as detailed OCPs and ACE programs for use at KSC. Specific tests and requirements have two main sources: tests performed at the factory (or adaptations of them to suit KSC GSE and facilities), by the contractors under MSC direction; and KSC-peculiar tests defined at KSC. Tests performed at KSC are split approximately half and half between these categories.

OCPs and ACE program requirements are prepared mostly by contractor personnel working at KSC under direction of the Mechanical Systems and Electrical Systems Divisions. The Checkout Equipment Division acts more or less as a service organization to supply the checkout equipment and programs to satisfy the requirements of the other two divisions, and to provide technical support on checkout problems. The specific ACE programs are prepared by GE at KSC (now nominally being transferred to Houston, but the transfer is only beginning, and a moderate level of on-site programming is expected to remain at KSC).

OCPs and test programs are checked out locally by software simulation, open-loop test equipment, and some limited hardware simulation, then on the flyable S/C.

Tests are performed by test teams made up of NASA personnel from Mechanical Systems and Electrical Systems, and contractor personnel.

PRESENT AUTOMATION LEVEL

ACE-S/C stations are in the process of installation at the Operation and Checkout Building, MILA, KSC.

Initial test concepts regarded prelaunch testing at KSC as part of a unified factory-through-launch sequence. This will be only partially implemented, since there are some GSE differences (mostly external to ACE-S/C) between the KSC complex and the factories, and therefore some duplication of testing is expected initially.

Prelaunch checkout of the spacecraft is performed by a combination of ACE-S/C, GSE controlled by ACE-S/C, and manually operated equipment. Control of hazardous tests such as static firing of the SM propulsion system will be through ACE, with some downlink monitoring by ACE-S/C.

Many mechanical tests that involve mechanical support equipment will not be performed through ACE-S/C. This is because the adapter interface equipment to permit ACE-S/C compatibility imposes too great a cost, time or equipment size burden (particularly since most of this equipment would be located on the LUT).

For the ACE-S/C controlled tests, KSC is also faced with the difficulty of program debugging and verification without, at present, a "house" spacecraft or hardware simulator. Some software simulation and verification is being performed but this is not completely adequate, especially where timing is critical.

Almost all KSC ACE-S/C programs presently under preparation utilize the manual mode in which one operator command is followed by a spacecraft response, with the result evaluated manually before proceeding. More complex sequences or closed-loop operations are visualized either after contractor request or more detailed KSC checkout experience.

For prelaunch operations at KSC, the ratio of ACE-S/C controlled tests to the total number of tests is lower than for factory tests. This is due to such new operations as propulsion system and ordnance tests, mechanical servicing and inspection, mating integrity tests, etc., and also to the physical limitations on adapter equipment at the mobile launcher or LUT.

Problem areas are most likely in interfacing ACE-S/C with ACE-S/C-controlled GSE and site facilities. Because of the generation of test program requests at KSC, and the availability of GE programming personnel locally, the longer communication path faced by NAA and Grumman is in most cases simplified, at least informally, to the point where liaison is not a major source of difficulty.*

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*The programming staffs at Grumman and NAA have since been expanded. This liaison has been augmented by extended visits of the Houston group.

Possibly a more serious area of concern is the maintenance of the test continuum concept in which tests at the factory site are intended to be the initial steps of a non-duplicative, comprehensive sequence culminating at KSC. This may be difficult to achieve because of (1) late modifications to spacecraft or test requirements resulting in incomplete factory checkout, and (2) marginal confidence in test results due to lack of program verification or non-identity in GSE.

If carried to an extreme, these could result in precisely the difficulty in correlating factory and KSC testing that ACE-S/C was designed to eliminate, and therefore in many factory tests being repeated, in one form or another, at KSC to guarantee prelaunch confidence.*

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*This may not be true if the block change concept is in fact enforced after S/C 012.

REVIEW AND PROJECTED AUTOMATION

CHECKOUT SYSTEM APPLICATION

The operating concept for the spacecraft checkout system is based on the ACE-S/C system, with its servicing and GSE appendages. Additional manual testing functions are performed in areas such as leak checking, radio-frequency testing, weight and balance testing, static firing control, local (near-spacecraft) safing controls, and test functions involving the telemetry (FM/FM) ground station. No non-ACE remote hardwire controls are planned. (This subsection will deal principally with the ACE-related functions.)

The ACE-S/C system and its appendages include the following equipment and functions:

(1) In the computer room and ACE control room:

- (a) The operator controls and their associated uplink computer
- (b) The downlink programmable PCM decommutator and its associated direct displays (strip charts, meters, and event lights)
- (c) The downlink computer and its associated computer-processed displays (alphanumeric engineering information on CRTs)

(2) Between the above and the spacecraft area:

- (a) A single uplink digital communication system driven by the uplink computer
- (b) A single downlink digital communication system that is time-shared among three sources of data in and near the S/C and that drives the downlink decommutator

(3) In the spacecraft area:

- (a) Specialized GSE, including carry-on equipment, that is controlled by the uplink and that provides information to the downlink

All communication between the ACE control room and the S/C passes over the single duplex serial digital communication link. Downlink discrete changes, downlink no-gos, and uplink commands are recorded on magnetic tape for later off-line analysis.

Initially ACE was to be used in a manual mode, with computers for communication and display processing. In this concept there is a one-to-one correspondence between operator controls and S/C (or GSE) hardware, just as if the operator control were connected as a manual hardwire device. Quantities to be monitored are displayed (1) directly on the decommutator output strip charts, meters, and event lights, or (2) on the CRTs, after being linearized and converted to engineering units by the downlink computer. Automatic or semiautomatic operations are limited to the tolerance checks performed automatically on measured values by the downlink computer.

Some extensions of this manual concept are available and in use at present. In the downlink, a number of different forms of data processing (before display) are available, such as averaging data, taking differences of two measurements, and the like. In the uplink, short-time, open-loop sequences of discrete outputs (e.g., relay sequences) may be programmed, and certain open-loop low-frequency wave forms may be generated by computer programs that exercise digital-to-analog converters in the GSE. In both, certain special open-loop programs are available, particularly in connection with the Guidance and Navigation System. Finally, in at least one case, a closed-loop operation is performed (synchronization of the Central Timing Equipment with ground timing signals).

Further extensions of the concept, to additional open-loop (semiautomatic) operations and to appreciable closed-loop (automatic) operations, are contemplated. It is the intention of the Manned Spacecraft Center to allow the extensions to develop naturally, as the contractors discover demonstrable needs for such extensions, rather than to execute any presently available plan for automation.* Some studies in this area are beginning, within the General Electric programming staff and within North American and Grumman, but they are still in a very preliminary state and are not regarded as of the highest priority. In

*MSC has since begun a program to develop ACE automation with extensive automation targeted for S/C 017.

concept, the two-computer system is designed so that such extensions could be made purely by new programming. However, problems of computer loading, data sampling rate, man-machine interface, availability of verification equipment, programming administrative arrangements, and the number of non-ACE manual functions may make closed-loop automation difficult.

PROGRAMMING AND PROGRAM VERIFICATION

Program requirements are originated by the contractors or KSC, in the form of data tables for existing processing routines, or subprogram specifications for new processing requirements. General Electric then prepares programs and verifies them, with the cooperation of the requesters. Program changes are prepared by GE subject to NASA direction and approval. Small changes may be prepared on site by local GE programmers with NASA approval.

Nominally, verification of programs follows verification of GSE, and is performed in three phases:*

Phase I:	Verification with software simulation, including tapes that simulate downlink data streams
Phase II:	Verification with GSE connected, but without a spacecraft
Phase III:	Verification with a spacecraft connected

For factory testing it was NASA's intention that the house S/C would be the vehicle for Phase III verification. However, NAA has so far found it impossible to keep the house S/C configuration up to date with the deliverable S/C, and the house S/C has therefore been useful only for verification of the basic software (subprograms), not for final verification of the data tables and programs for a specific vehicle. Phase III verification will be performed on the flyable S/C. In view of the short scheduled delivery interval between S/Cs, the fact that only one full house S/C will exist per contractor, and the present status of NAA updating on the house S/C, it appears that

*This process has since been changed.

this situation will continue for some time. The situation at Grumman is less clear, since its schedule is roughly one year later than that of NAA, and it still hopes to follow the house S/C concept. However, the rapid delivery schedule and limitation to a single house S/C are bound to make this difficult for Grumman also.

For post-factory testing, KSC will rely heavily on Phase I and II verification of KSC-peculiar programs. (About half the programs used at KSC will be KSC-peculiar.) There is an intention at KSC to make more extensive use of software simulation than the Phase I verification plans for factory checkout. Some use will be made of partial hardware simulators, for Phase III verification. However, nothing comparable, say, to the MSFC Saturn "breadboard" is planned. Thus, for the most part, final Phase III verification of the KSC-peculiar programs will be performed on flyable spacecraft.

In the absence of a house S/C with up-to-date configuration, Phase III verification on the flyable S/C is unavoidable, both at the factories and at KSC. This provides some risk of damage to the spacecraft. It also introduces the risk that non-damaging program inadequacies (e.g., incomplete testing or improper tolerances) may not be detected, since schedules will not permit a thorough checkout of the programs themselves, before their use as tools for checkout of the spacecraft. (This objection is less serious for operations in the purely manual one-to-one mode of ACE control.)

PRESENT LEVEL OF AUTOMATION

Estimates of level of automation in S/C testing are very gross because of insufficient data and are based mainly on NAA's plans for testing S/C 009. Grumman plans for LEM are as yet not sufficiently definite to enter the analysis, although they seem qualitatively to resemble those of NAA and KSC. KSC plans for S/C 009 are available in the form of a test planning schedule, which permits a less precise analysis to supplement the NAA factory analysis.

The term "automation," as used in this report, applies to closed-loop automatic functions. Few of the tests are implemented in closed-loop automatic fashion, so it appears more meaningful to use a new term, "manual-automation." We define "manual-automation" as the use of a computer-

based checkout system in an open-loop manual mode. The computer functions are confined to (1) open-loop communication and communication of manual commands, and (2) open-loop conversion and display of telemetered data, including indication of out-of-limit conditions.

Using this definition of "manual-automation," we estimate that approximately 50 per cent of the NAA factory tests of the assembled S/C and approximately 40 per cent of the tests at KSC are "manual-automated."

At all three installations, the level of automation is as shown in Fig. D-1. That is, the ACE system is used largely in its open-loop modes, with a small amount of simple closed-loop operation.

REVIEW OF PRESENT STATUS

The ACE-S/C concept developed by MSC, with General Electric acting as support contractor, represents a major NASA effort at standardization of checkout hardware, software, and test philosophy. This was considered more practicable for the S/C than for the LV, since only two major contractors (NAA and Grumman) were involved, with somewhat more lead time originally available. Also the prelaunch operations were considered as a continuation of factory "readiness" tests rather than as a completely independent testing sequence.

ACE-S/C, at present, carries with it both the advantages and disadvantages of standardization. Among the advantages are:

(1) A capability to consider the factory tests and prelaunch tests as part of a testing continuum since data can be more easily correlated. Tests or portions of tests do not require repetition at KSC simply because of the difficulty of translation of results of tests performed with different checkout equipment or programs, as may occur for the launch vehicle. Also implied is better factory-launch site liaison.

(2) Centralization of checkout hardware design and software preparation permits standardization and theoretically permits a greater efficiency in these tasks, and possibly more concurrence in time with S/C design.

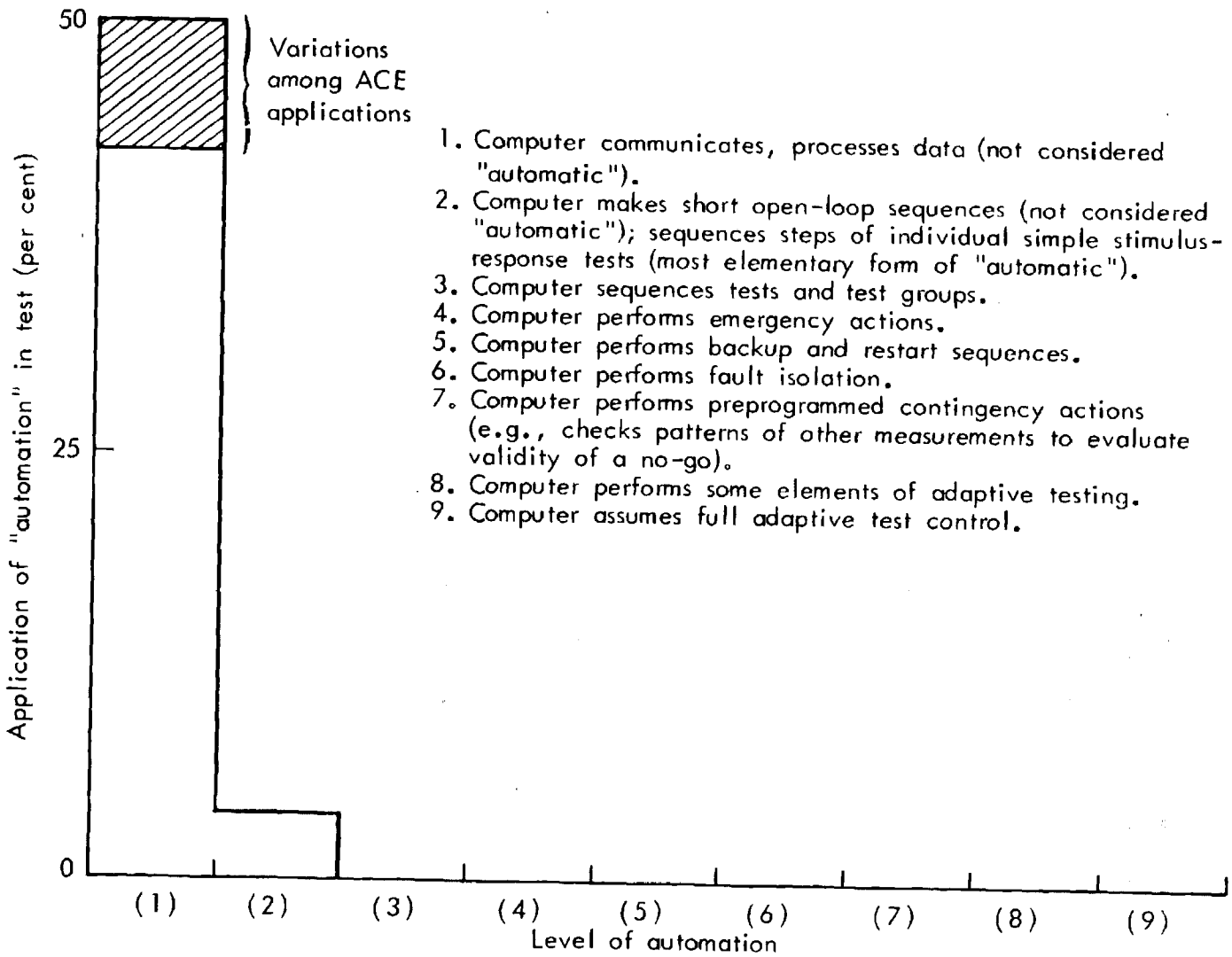

Fig. D-1—Automation level, S/C

(3) The carry-on concept of providing equipment for checkout only provides testing capability at minimum fly-away weight penalty.

(4) The PCM data stream technique used for both commands and responses is adaptable to a reasonably wide variation in test requirements.

(5) The system can be used in a manual mode initially, and test sequences automated progressively to a greater extent in the future.

Among the disadvantages are:

(1) Although the standardized design permits some flexibility, it cannot adapt to all peculiar test requirements so that a substantial amount of special purpose GSE is required at each ACE-S/C location. Furthermore, awareness of the need for this GSE tends to be delayed; in some cases it is evident only after indoctrination into ACE-S/C capability, which itself may lag because the ACE-S/C user is not the ACE-S/C designer.

(2) The centralization of program preparation is probably required to accomplish standardization. It does permit efficiency in the basic software package. However, it becomes a bottleneck in keeping up with last minute changes and modifications, which are a normal occurrence in closed-loop automatic tests.

(3) The data sampling and serial transmission technique of ACE-S/C is a limiting factor on checkout of high frequency or high speed signals. Thus, for example, radar, communications, telemetry, and RF tracking systems all require separate ground stations, while valve signatures cannot be timed, and G&C programs impose a strain on the data rate limit.

(4) Extension of the mode of operation from manual to semi-automatic to automatic may require more than simply program preparation. It appears that computer memory, workload and data transmission limitations may limit such desired features as closed-loop sequences, parameter limit checking and scaling, fault isolation, etc.* As one

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*This can be alleviated, with some disadvantages, by using magnetic tape for supplemental storage. This requires software changes and introduces problems in the time sharing, since some part of the desired program may have to be called up from tape.

example, even at this early stage it is believed that 100 per cent processing of all response data for S/C 011 may overload the ACE-S/C downlink computer.

At this point, since an operational history for ACE-S/C has not yet been established, it is difficult to assign relative weights to the various advantages and disadvantages. If test requirements do not vary appreciably from those presently planned and if S/C modifications eventually become minimized, the standardization advantages will have been justified.

The anticipated general problems regarding S/C checkout are concentrated less in the ACE-S/C ground stations themselves than in the areas of peripheral and support equipment, data flow and verification, and both intra-facility and inter-facility communications.

It has been noted that ACE-S/C can accomplish only a portion of the checkout task (because of checkout philosophy), with radar, communications, and certain mechanical subsystems being prime examples in which adaptation to ACE-S/C control proved either too costly or cumbersome. This has resulted, in general, in a larger effort in the design of special purpose, non-ACE-S/C support equipment than originally estimated. Increasing total checkout costs, time delays, and fragmentation of checkout responsibilities have been evident.

The centralization of computer programming responsibility within MSC/GE offers advantages of standardization and elimination of duplication, but poses a particularly severe limitation on flexibility, particularly the ability to make fast, last minute changes which, for one reason or another, must be considered the rule rather than the exception, especially if closed-loop automation is attempted. For these cases, which also are unfortunately prevalent when the pressure for completion of checkout and delivery are greatest, the 30-60 day "turn-around" time for generation of new computer programs can be a bottleneck. On-site programming efforts are reducing the problem; however, their effectiveness is limited by on-site manpower and by programming contractual relationships.

Within the ACE-S/C station itself, one human engineering problem already evidenced is the alphanumeric display. Operators required to

focus attention on pages of data displayed on a small CRT screen for considerable periods of time have exhibited both fatigue and boredom and, while this can be overcome in factory situations, it may pose more of a problem in the tenser atmosphere of prelaunch and countdown operations.

In addition, the intended simple transition from manual to automatic operation may require more equipment and organizational changes than were anticipated.

Experience to date with the use of ACE has been only at North American. Grumman and KSC are still installing and checking out their first stations, so evaluation of them must be based on their planning, plus any parallels that can be drawn between their situations and those of organizations with earlier schedules.

Development of user confidence in ACE has proven to be feasible. In the early stages of ACE usage at NAA on BP 14, the system was widely mistrusted (partly because of normal developmental "bugs") and often bypassed by manual operations. The early status of the programs contributed to the problem, since, for example, no-go tolerances were not all correct, and data displays would blink when it was obvious to the operator that nothing was wrong. Since there was no critical dependence on the ACE function (that is, the test procedures were designed for manual ACE operation, and could therefore be carried out by manual bypassing methods), there was no strong urgency to correct the situation. However, eventually the programs were corrected and the bugs (e.g. PCM synchronization problems) were removed. At the same time, the operators began to appreciate the usefulness of the system for their own purposes. Operator confidence has improved to the point that ACE is used (where applicable) for engineering tests, in addition to the buildup and acceptance testing for which it is required.

The present ACE application makes almost no use of its theoretical capability of closed-loop automatic control. Some use is made of semi-automatic functions such as timed relay sequences, but most control operations use one-for-one manual initiation of individual operations, via the uplink.

On the NAA house S/C the subsystems are present in some form, but the wiring, interfaces, and functional performances are different from those of the flyable spacecraft. Therefore, the house S/C is useful

only as a tool for engineering development and for checkout of basic software. The lack of configuration identity makes it impossible to use it to check out specific computer programs (or OCPs) for flyable spacecraft, as was NASA's original intention.

The problem seems due to: (1) the compressed schedule for S/C development (as compared with original plans), (2) administrative problems, (3) the rapid S/C delivery schedule combined with the fact that only one house S/C is authorized, and (4) the fact that the house S/C is envisioned as a multipurpose device with much of its time devoted to engineering development of the S/C design. As a result, specific programs and OCPs are checked out entirely on the flyable equipment.

This would not be a serious problem if sufficient time existed to perform the program and OCP checkout in series with the vehicle checkout. However, such is not the case, and as a result priority is assigned to vehicle checkout, rather than to checking the programs and OCPs. Vehicle checkout will automatically discover many of the program and OCP incompatibility problems, but is less likely to discover problems whose effect is merely to cause an inadequate test. Thus the absence of a flexible, rapid-response house S/C or simulator devoted principally to program and OCP checkout can ultimately reduce the confidence the user may have in the thoroughness of the checkout. Grumman has a strong system engineering organization that has been operating for about 18 months and that actively controls all interfaces and system functions. KSC has somewhat less of a problem, since much of the interface listing there is pre-defined by the manufacturer, and since the personnel and organizations are more strongly system oriented by virtue of their participation in overall S/C checkout.

There appear to be differences between Grumman and NAA in the control status of system documents. At Grumman, the functional and interface drawings produced by System Engineering are control documents. In theory, they are prepared from functional requirements before equipment design may begin. In practice, this is gradually being approached, but in many cases control begins simply when drawing is complete, which appears to be working out satisfactorily, although coordinating previous design efforts does occasion some delay. Vehicle system control drawings are well advanced; GSE system control drawings are less complete. At

NAA, the drawings produced by System Engineering are not control documents. Instead, the control documents are the released design drawings for the equipment units. System drawings follow the design drawings. System drawings for both GSE and vehicle are completed for S/C 009, although incompatibilities between them and the released equipment drawings are not yet fully eliminated.

Present ACE computer programs do not overload the computer speed capability. However, there is some probability that the programs for S/C 011 will cause an overload in the downlink processing programs. The basic reason for this is the ACE concept of 100 per cent processing of all downlink information, which is unlike LV checkout equipment. One hundred per cent processing is a useful function, particularly in the detection of unanticipated "glitches," but if the 011 downlink becomes overloaded, test designers will be faced with a difficult choice. Uplink speed may also be overloaded in the future, because of simultaneous analog function generation and timed discrete sequences, both of which imply a relatively large amount of high speed interrupt processing.

Present ACE programs have essentially used up the available computer memory. For example, at the time of writing, the downlink programs were organized to leave exactly three spare memory cells in the downlink private memory. The shared memory is mostly occupied by parameter tables.

Some comments have been received on the human-factors problem of the display CRTs. The relatively small CRTs (resulting in small character size) and the tabular page presentation of data combine to make it difficult to monitor data visually for long periods.

The ACE concept of performing all monitoring functions via a serial PCM stream appears to be working well in general, although there are certain areas where it is a significant limitation on test quality. In particular, valve signatures are impossible to check due to the limited data rate, and certain guidance and control functions strain the data rate to its limit.

In summary, ACE appears to have proven itself (with minor exceptions) as a tool for manual test control with some semiautomatic

functions, and for preprocessing and aiding manual test monitoring functions. The usual problems of computer memory size, system engineering, program verification, and procedure verification have appeared. In some respects, the essentially manual nature of present ACE usage has mitigated the effect of these problems, since it has often been possible to bypass ACE and perform the same basic test function that ACE would have performed. The concept of 100 per cent limit checking is a useful one, but this and other factors are causing speed loading problems in the computer system.

FUTURE AUTOMATION

In general, the impetus for increases in ACE-S/C automation level is expected to come from the using contractors. No planning or system engineering group is charged with a definite responsibility for planning extension of ACE automation.* (Some studies in this direction have begun within GE, GAEC, and NAA on a low-priority basis.) So far, most contractor requests have been for additional semiautomatic functions rather than closed-loop automatic functions. A rapid increase in requests for closed-loop functions is expected once test personnel are well acquainted with computer capabilities. Nevertheless, the absence of a definite automation planning group will affect the speed and smoothness of the introduction of automation.

Additional increases in automation percentage, insofar as the "manual-automation" use of ACE is considered to be automation, would be available if certain GSE items were made ACE-compatible. For reasons of cost, it has been decided so far that these functions should be separate and manual. However, the cost difference may not be as large as at first anticipated, at least for equipment to be used at the launch pad, since almost-automatic signal conditioning and conversion equipment may be required to transmit test data to manual equipment at the base of the launch tower.

Certain S/C functions will be difficult to automate in the near future, either because of limited space for GSE near the S/C on the tower, or because the equipment being tested is not sufficiently

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*This has since been changed; extensive automation is planned by S/C 017.

analyzed. An example of the former is certain flow testing on the launch towers. One contractor estimated that automating a manual "suitcase" full of valves and gauges would require a unit so large that it could not be placed on the tower work area. An example of the latter was suggested at KSC to be in the fuel cell area, where "uncrinkling" of the membranes must be performed at low differential pressures and flow rates, which are difficult to predict. In some cases, relatively small additional effort in analysis, plus a more widespread appreciation by mechanical engineers of the state of the art in automation, could remove the obstacles.

The basic ACE system itself is theoretically capable of extension to further closed-loop automation without hardware changes, by adding closed-loop computer programs. To a certain extent, the capability is usable, and indeed has been used in at least one case. However, a number of practical limitations exist that may make it difficult to take full advantage of this capability. These include the following:

1. Memory Capacity. As mentioned earlier, the downlink private memory is used up, and the shared memory is crowded. The uplink private memory has some spare capacity, but not enough for extensive automation. This problem can be solved at relatively small cost, by adding memory banks.

2. Computer Speed. As already mentioned, the speed of the downlink computer is in danger of being overloaded by the basic 100 per cent limit-checking monitor function. It is not desirable to eliminate this function, so almost all closed-loop programs will probably have to operate in the uplink computer. However, if the closed-loop programs must operate simultaneously with uplink generation of analog functions and timed sequences, the speed margin on the uplink computer may also be small. Part of this problem could be solved by removing the program from responsibility for generation of such things as sine waves, which can be generated by relatively inexpensive signal-generation modules, preset and initiated by the program. The remainder of the problem could probably be solved by administrative or programmed limitations on what uplink functions can be commanded at each stage of

checkout, so that two or more speed-consuming functions are not required at once.

3. Program Verification. Compared to checkout of open-loop programs, checkout of closed-loop programs requires considerably more work on real hardware or accurate simulators. It is necessary to have an up-to-date simulator, or else check out the programs on flyable equipment--with significant schedule time allocated specifically to test-program checkout. The problem could be largely solved by (1) assigning the present house S/C or a new additional house S/C to test program checkout as its sole task, and (2) making administrative arrangements such that it can be kept current with the released flyable designs, perhaps by using preliminary engineering information, with six months lead time before flyable equipment acceptance. The high delivery rate may possibly require two simulators for this purpose.

4. On-line Program Changes. Since it is often difficult to ignore faulty areas of a closed-loop test program (unlike open-loop manual and semiautomatic programs), it is necessary to be able to fix or "patch" a program on-line during program checkout. It has been suggested that the C-START and suitable software could be used for this, but such a use would be cumbersome and require considerable error-prone manual encoding. The LV systems solve this problem with an alphanumeric keyboard and software that permits making changes in test-oriented language. To translate this scheme to ACE would require new software, memory increases, and possibly prohibiting most test functions during the program change operations (to prevent overloading the computer speed), plus some expedient such as placing the computer typewriter on a rolling table with a long cable. A partial and less useful solution would be to use the C-START as suggested, aided by computer room operations, with the full attention of the programmers.

5. Test-oriented Language. The usefulness of a test-oriented language for closed-loop test programs is unquestioned, in cases where the programs are simple enough to be expressed in an easily learned

language. (Most ACE operations would be of this character if automated.) It permits test engineers to understand and control the operations of the closed-loop computer program, thus permitting extensive on-line changes, speeding checkout, reducing error rate, and facilitating engineering and quality review. Unfortunately, the computer speed and memory required for the operation of interpretive test-oriented languages will not permit one to be used with ACE, at least with the present uplink and downlink requirements. A compiler language would not be so subject to the speed and memory limitations, but suffers the disadvantage of requiring off-line operations to make changes. The problem could be solved by removing some of the high speed requirements from the uplink computer, as suggested in the previous paragraph, and by increasing the memory size.

6. PCM Data Rate. The basic PCM data rate is such that most points must be sampled 50 times per second or less often. This limitation arises from the number of points to be sampled, the data link speed, and the computer speed. A very small number of points may be sampled more often, by supercommutation and special programs (or by direct strip-chart outputs from the PCM decommutator, bypassing the computer). Tests requiring rapid response measurements are fairly common in closed-loop automatic testing, and such tests would be severely limited by this data rate. The problem could be solved by permitting the uplink computer also to access the data source, in random-address fashion, while the downlink continues monitoring. (Downlink monitoring might be inhibited during the single word time of uplink access.)

7. Programming Organization. The present programming organization is well suited for the development of standardized basic software for a geographically dispersed system. Thus it has been suitable for the early development of executive programs and standard sub-programs for manual and semiautomatic application of ACE. To some extent, the same approach is applicable to the certain parts of programming for closed-loop automation, such as simple, non-time-critical functions that can use standard uplink/downlink communication subprograms. However, in general,

closed-loop automation requires intimate contact between the test engineers and the programmers, because of the greater complexity and precision required in defining closed-loop operations. (The ideal limit of this tendency is for the test engineer to do his own programming, perhaps in a test-oriented language.) This contact is of the same nature as that required for development of present ACE programs for a specific vehicle (as opposed to basic software), but is more extensive and less susceptible to standardized communication procedures. Therefore, as closed-loop automation becomes more important, the importance of on-site programming will increase, as will the desirability of having the programmers work as if they were S/C contractor employees. The latter point refers to the fact that contractual sell-off relationships interposed between test engineers and programmer will make cumbersome the necessary give-and-take of instant changes required during--and after--development of a closed-loop program.

Unlike all other Apollo/Saturn functions (except the purely "manual-automated" portions of LV and IU checkout), the ACE system is designed around an independent time-sharing concept, in which each console acts as though it has a test system all to itself. This is a valuable characteristic, especially for prelaunch checkout, and should not be sacrificed in the attempts to achieve automation, in spite of the severe problems of computer speed that may result. Preferably, the time-sharing orientation of ACE should be continued into the closed-loop automation. At least, the restrictions on "simultaneity" should be limited to the closed-loop programs, with time-sharing retained for semiautomatic and manual functions, even during operation of a closed-loop program.

ESTIMATE OF FUTURE STATUS

It is the opinion of some people in the project that a fair degree of automation will be present in the ACE areas of testing at not too late a date in the program, perhaps by the end of Block I for the CSM and by the middle of Block II for the LEM. However, our opinion is that this is contingent on removal of most of the difficulties

mentioned earlier. The typical reaction of users to ACE is just now in the process of swinging from dislike, founded on conservatism and lack of familiarity with computer-based equipment, to a realization of the usefulness of the computer-based approach. There is some danger that success of ACE in the manual and semiautomatic modes may make people over-optimistic about how easy it will be to attain success in the closed-loop automatic mode. The problem will be made more difficult by a very justifiable and reasonable desire to retain all of the features of the manual/semiautomatic system, adding the automatic operations on top of these. One must apply the old adage that "the computer can do anything, but it cannot do everything"--that is, the desire of enthusiastic users to have the computer do everything at once can drive the cost and development time of the hardware and software out of reach.

Thus the increase in level of automation will depend on the money and manpower available to make the suggested changes (or others, such as adding a third processor) in the hardware and software. If we assume that (1) the total memory size is increased by, say, 16,000 words, (2) most time-consuming, high speed interrupt functions such as analog waveform generation are removed from the uplink, (3) the uplink is given access to test data addressing and readout, and (4) some solution is provided for the program checkout problem, then it is probable that the average level of automation could increase from its present 1.1 to about 3.0 or 3.5 by late in the program.

The increase in percentage of automation will also depend on cost decisions. Much of the GSE that is at present independent could be remoted for ACE control, making the corresponding tests into ACE tests. For example, the radar test equipment could include signal conditioning and conversion equipment to transform pulse rates, microwave signal levels, etc., into DC voltages or discretes for ACE measurement. Similarly, the manual valve controls could be motorized under ACE control. At present there seem to be no plans to carry out these particular modifications. However, some small increase in percentage of automation is to be expected as the users learn more about the system's capabilities, perhaps as much as five per cent.

Appendixes

GENERAL ACE-SPACECRAFT SYSTEM

A. ACE-S/C SYSTEM DESCRIPTION

BACKGROUND DATA[8]

For checkout of the Apollo spacecraft, the Manned Spacecraft Center has developed a standardized group of equipment, termed Acceptance Checkout Equipment, Spacecraft (ACE-S/C), designed for use at both major contractor facilities (North American Aviation and Grumman) and at the Kennedy Space Center launch site.

To minimize fly-away weight, a portion of the ACE-S/C system that provides stimuli to the spacecraft and accepts response signals has been constructed in "carry-on" form, that is, equipment carried into the spacecraft and connected for prelaunch checkout, but removed prior to launch.

A complete ACE-S/C system therefore includes a ground station, carry-on equipment, and facilities to properly interconnect all components.

General Electric's Apollo Support Department, under MSC guidance, constructed the ACE-S/C ground stations and provides ACE installation and maintenance personnel at all facilities. Carry-on equipment is furnished by NAA to all facilities.

With MSC concurrence, GE is also responsible for the programming software associated with the ACE-S/C computers, providing both a basic library applicable to all users and also specific test programs peculiar to each facility.

ACE-S/C installations are employed at:

1. North American Aviation, Downey, Calif.--subsystem and integrated system testing of the Command Module and Service Module during the final stages of assembly and checkout
2. Grumman Aircraft Engineering Corporation, Bethpage, N.Y.--subsystem and integrated system testing of the Lunar Excursion Module during the final stages of assembly and checkout

3. Kennedy Space Center, Merritt Island Launch Area (MILA), Fla.--subsystem and integrated system testing and prelaunch checkout of individual modules and the mated spacecraft

4. Manned Spacecraft Center, Houston, Tex.--spacecraft testing under simulated space and lunar environments.

At the time of writing, ACE-S/C stations are operational at NAA and MSC, and in the process of installation at GAEC and KSC.

The ACE-S/C is an integrated checkout and display system providing centralized, programmed control of spacecraft checkout operations. It permits manual, semiautomatic, and automatic operational modes. Both independent subsystem testing and integrated system testing are accommodated.

Specifically, ACE-S/C performs the following functions:

Provides the control, display, data processing, and recording required to control S/C stimuli equipment (uplink).

Receives, processes, displays, and records S/C parameter data derived from S/C ground and flight telemetry systems (downlink).

Provides self-check and calibration capability for itself and related equipment.

ACE-S/C may be divided into two functional systems: the uplink system and the downlink system. The uplink system is the equipment that forms the communication path for all test commands and sequences transmitted to the spacecraft. It also carries verifications of receipt of valid commands from the S/C back to the Ground Station. The downlink system is the equipment that forms the communication path for S/C responses and test data to the Ground Station recorders and displays.

UPLINK SYSTEM

Control of the test sequence can be manual or automatic, depending upon the computer programming. In every case, tests are initiated at various system control consoles by setting switches on units called Selections To Activate Random Testing (START) modules. This arrangment

provides commands in digital form to the uplink system computer. The types of commands vary from individual event functions (specific relay action) to the callup of prestored computer subroutines, which control sequences of events and/or various analog operations at the spacecraft.

The ACE testing of each functional S/C system is controlled from an associated group of system control consoles. Each system control console group operates simultaneously with and independently of the other system console groups, and has a variety of test command capabilities for the automatic checkout of a particular S/C system. In order that the computer may systematically process each of the many parallel inputs, a unit called CUE (Communication Unit Executor), operating essentially as a commutator, interrogates each START module on all of the system consoles in sequence. The interrogations occur at a high rate, and to the console operators there is no perceptible delay in their individual test procedures. When an interrogation determines that a command input exists at a particular START module, the sampling process ceases momentarily while the CUE transfers the digital command to the uplink computer.

The computer interprets and acts upon the command under program control, and if some action is required in the S/C, the computer formulates a digital command message for transmission to the spacecraft. The digital message is converted to a serial bit stream by a Data Transmission and Verification Converter (DTVC) and transmitted to the spacecraft vicinity over hardline link.

Verification of command messages is accomplished by redundant transmission between the DTVC and a receiver/decoder at the S/C location, and a bit-by-bit comparison of the redundant words. In addition, checks are made of each message to determine whether it has a legal address. Verification reply messages are transmitted redundantly from the S/C locations to the DTVC where verification of redundancy is made. The fact that a message was delivered to the computer and the fact that verification of proper transmission tc the S/C locations was obtained are indicated to the control console operator by appropriate lights on the START modules.

At the S/C location, the message is received and decoded, and the proper stimulus is generated and applied to the spacecraft.

DOWNLINK SYSTEM

Spacecraft performance and status are monitored by sensors coupled to the flight telemetry system, carry-on checkout equipment, and S/C service equipment. Most of the measurements are commutated, converted to digital form, interleaved, and transmitted in a serial pulse-code-modulated (PCM) format over a hardline link to the data acquisition equipment in the Ground Station. A small portion of the data is frequency modulated (FM) and is transmitted over a separate hardline link. (Some data points do not transmit to the ACE-S/C system.)

In the Ground Station the data is received by data acquisition equipment. The FM data is recorded directly on wideband magnetic tape and by visual recorders and, normally, no further distribution is made. For the PCM data (which is also recorded on wideband magnetic tape), the Digital Acquisition and Decommutation System synchronizes the incoming serial bit stream, decommutates, addresses each event and analog data word, and prepares these words for multiple parallel transmission. The PCM data follow three paths after leaving the decommutator.

Selected portions of the decommutated PCM data are accepted by a second computer (downlink computer) for processing. This processing includes comparison of analog functions with predetermined limits and the conversion of these functions into engineering units. A binary word representing the value of the function in engineering units is transferred into the core memory of a Symbol Generator and Storage (SGS) unit. From this memory data are transferred on demand to any of the alphanumeric Cathode Ray Tube (CRT) displays on the system control consoles. The data are displayed on the CRT as a decimal number in engineering units in a "page" format. When a parameter has been determined to be out of limits, that specific portion of the CRT display can be caused to blink at a slow rate.

A second data path transfers the digital data to an Event Storage and Distribution Unit (ESDU). By recognizing addresses this unit accepts only event words and stores them in registers. Each bit of an event word represents the status of a discrete event. The outputs of the storage registers turn on lights to actuate event recorders to indicate when the event occurs. The event lights and recorders are on the system control consoles.

The third path transfers the binary data to the system control consoles. Each system console accepts appropriately addressed data and stores the data words in registers. Since only analog data words are accepted by the system consoles, the outputs of the registers are transformed by digital-to-analog converters, and the analog signals are displayed on meters and analog recorders on the console.

PHYSICAL CONFIGURATION

Physically, the ACE-S/C Ground Station contains three separate equipment areas: the Control Room, the Computer Room, and the Terminal Facility Room. This provides for logical equipment grouping and separation of personnel concerned with different aspects of system operation.

The Control Room contains the primary controls and displays of the ACE-S/C Ground Station. These are arranged in a series of consoles grouped according to functional S/C systems, thus providing a central location for stimulating and monitoring the performance of each functional system.

The START modules are the test command controls. The displays include the alphanumeric CRT displays, analog recorders, event recorders, meters, event lights, real time, countdown time, and system status displays where required. In addition the consoles contain voice communication equipment.

Wall clocks displaying real time and countdown time and, in some cases, ceiling-mounted closed-circuit television monitors are also provided in the Control Room.

The Computer Room contains the computer complex, a portion of the command system, the data acquisition and decommutation equipment, a portion of the alphanumeric CRT display system, and Ground Station checkout equipment.

The computer complex includes a computer complex console, two computer modules (computers), a memory module (shared by the two computers), and associated peripheral equipment.

The Terminal Facility Room provides a flexible interface between remote S/C test areas and the ACE-S/C Ground Station. It also provides certain support and interfacing functions within the Ground Station.

The Terminal Facility Room contains the Terminal Patch Facility, the Timing Group, a portion of the command system, and portions of the alphanumeric CRT display system.

The Timing Group comprises a Time Code Generator, which drives the various real time displays in the Ground Station, and a Countdown Generator which drives the various countdown displays.

OPERATING PERSONNEL

During a normal, full-scale test period, a single typical Ground Station is manned by approximately 50 people.

A terminal equipment engineer and a specialist monitor and control the equipment in the Terminal Facility Room.

Approximately eleven men are stationed in the Computer Room. These include the ACE system engineer, who mans the computer complex console and supervises the functional operation of the Ground Station, two programmer/analysts who man the uplink and downlink computer consoles, a computer engineer, a decommutation engineer, two specialists, and four technicians.

Approximately 37 men are stationed in the Control Room. The system test conductor and the test project engineer are seated at the elevated Test Conductor Console where they can observe all Control Room operations. The test engineers concerned with the various functional S/C systems are stationed at their respective console groupings. In general, the senior test engineers are seated at the low consoles in

the center and the test engineers whom they direct stand at high consoles in an outside row.

The approximate breakdown by functional grouping is as follows:

Console Group	Men
Test Conductor Console	2
Instrumentation	2
Communications	2
Environmental Control	5
Fuel Cell and Cryogenics	4
Power and Sequential	7
Guidance and Navigation	4
Stabilization and Control	3
Propulsion and Reaction Control	6
Total test personnel	35

In addition to the test personnel, a display and control engineer and a specialist are stationed in the Control Room to monitor all displays and the performance of all system consoles.

CHECKOUT CAPABILITY

Since the ACE-S/C design was standardized and development initiated concurrently with S/C design, firm, detailed test requirements were not available at an early date, and in many cases are not yet frozen. The intent, therefore, was to make ACE-S/C a flexible modular, general purpose system easily adaptable to almost all requirements.

This has been achieved to a great extent. Individual R-START modules for each test sequence and individual pluggable stimulus generators, for example, result in a large quantity of essentially duplicative equipment but do provide a wide capability and are easily replaced or modified to meet changes in requirement.

With this capability, ACE-S/C can perform the majority of subsystem and integrated system tests, either completely within ACE-S/C, or by controlling external GSE and service equipment through ACE-S/C. There are limitations, however, to ACE-S/C capability, which include a substantial minority of checkout tests. These are briefly outlined as follows:

1. High Speed Measurements--Each individual PCM train, before interleaving, transmits data at 51,200 bits

per second. (The interleaved train is at 204.8 K bits/sec.) For 8-bit analog signals, this equals 6,400 samples per second. Assuming a range of 50 to 100 channels being monitored, this provides 64-128 samples/channel/sec, which can reproduce data in the 10-30 cps range with reasonable accuracy.

Thus, for analog data, a practicable upper limit of perhaps 50 cps (or conversely, a time event occuring in 20 milliseconds) can be monitored by ACE-S/C, without cumbersome supercommutation schemes. For this reason, some higher frequency data at present is transmitted in FM form and recorded directly, without computer control.

Not many measurements fall into this high speed category, but more advanced timing tests in the future may aggravate this shortcoming.

2. RF Measurements--Separate telemetry radar and communication ground stations are provided at each facility, apart from ACE-S/C, since it has proved more practicable to utilize this manual special purpose equipment than to attempt to adapt these measurements to ACE-S/C control. RF compatibility and interference tests are also non-ACE-S/C.

3. Non-electrical Tests--Although some mechanical GSE is ACE-S/C-controlled and monitored, the majority of non-electrical service and test equipment is manual, with possibly some ACE-S/C downlink monitoring. This includes pressurization and leak tests, cryogenic, hypergolic, and ordnance tests.

B. FUNCTIONAL BLOCK DIAGRAM[8,9]

A generalized ACE/SC functional block diagram is given in Fig. D-2. Minor differences exist among the various locations. Details of major components are described in the following section.

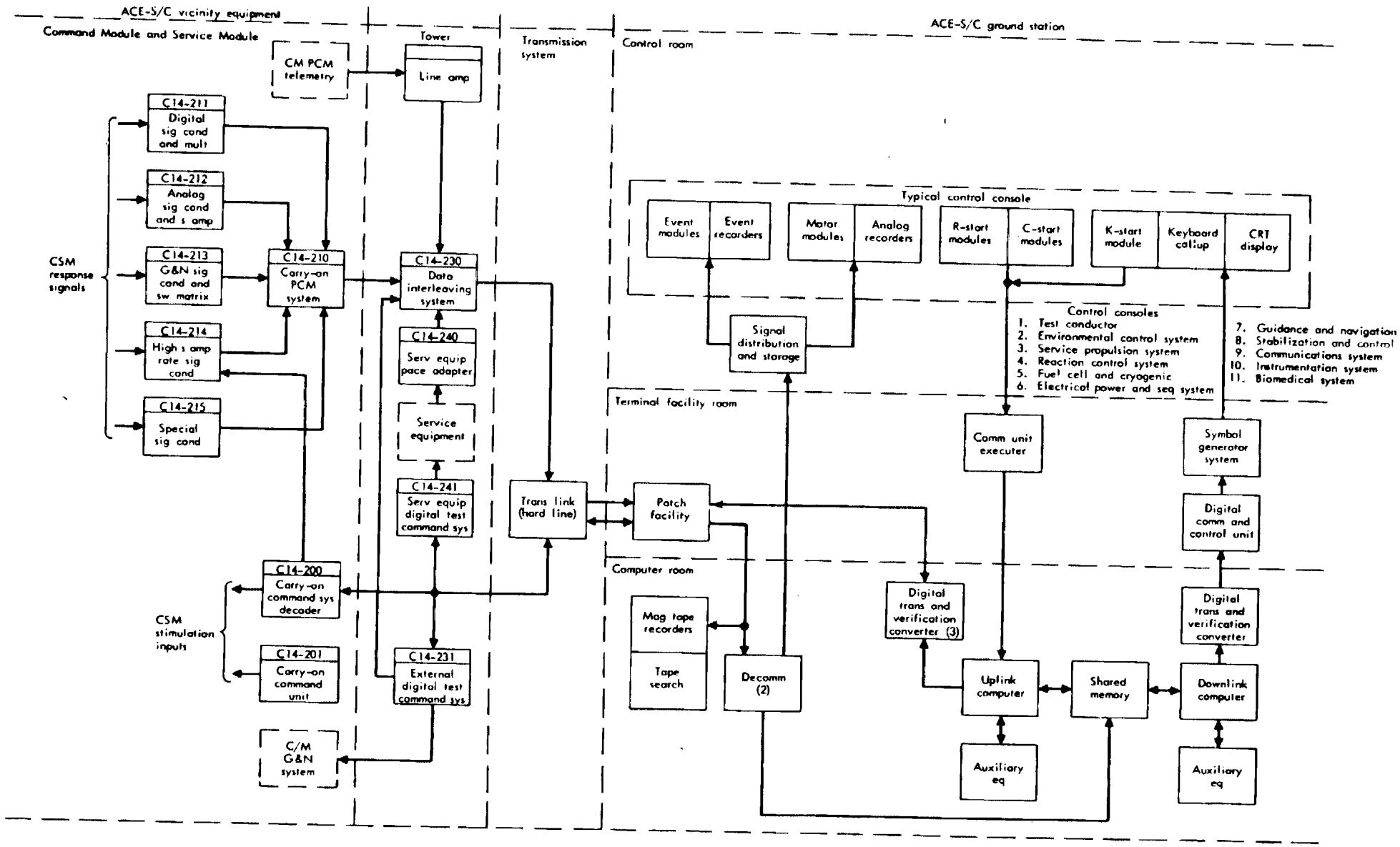

Fig. D-2—ACE - S/C system

C. DESCRIPTION--MAJOR COMPONENTS AND FUNCTIONS, ACE-S/C[9,10]

1. Ground Station

Function - Accepts incoming serial PCM data from the spacecraft, decommutates, records, and displays information

- Scales and converts data to engineering units
- Compares selected data against allowable limits
- Converts operator test requests into computer language for subsequent transmission of stimuli or commands to the spacecraft.

Consists of - Control Room Equipment

- Computer Room Equipment
- Terminal Facility Room Equipment

(a) Control Room Equipment--Includes the Test Conductor Console and the following subsystems consoles:

(1) Environmental Control System

(2) Service Propulsion System

(3) Reaction Control System

(4) Fuel Cell and Cryogenic System

(5) Electrical Power and Sequential System

(6) Guidance and Navigation System

(7) Stabilization and Control System

(8) Communications System

(9) Instrumentation System

(10) Biomedical System (optional).

Console Functions--(apply to all consoles except as noted)

Permits test engineers to transmit commands or stimuli to the S/C via R-START, C-START or K-START modules. R-START modules initiate the entry of up to 4 bits of binary information via relay closure to control discrete events

C-START modules initiate entry of decimal information (10 digits and sign) as computer instructions. K-START modules are used only for checkout of the S/C guidance computer, entering test commands via a keyboard or a punched paper tape reader

Record and/or display:

analog signals converted from decommutated digital form

discrete events signals

alphanumeric data

Signal Distribution and Storage

Function- Stores data from decommutator and distributes to appropriate console

Includes- Decommutator Distribution Unit (amplifies and fans out decommutator digital work to Event Storage and Distribution Unit)

- Event Storage Distribution Unit (decodes event words and distributes discrete event signals, with timing information, to consoles)

(b) Computer Room Equipment--Includes the following:

(1) Control Computers (uplink and downlink)

(2) Shared Memory

(3) Computer Auxiliary Equipment

(4) Decommutators

(5) Data Transmission and Verification Converters

(6) Magnetic Tape Recorders and Tape Search/Control

(1) Control Computers--Control Data Corp. 160G

Memory -8,192-word core per 160G computer

Word Length -14 bits (13 data, 1 parity)

Input/Output -one buffered channel

-one non-buffered channel

Function -Uplink computer accepts test operator commands from START modules and converts into commands or stimuli transmitted to S/C and GSE.

-Downlink computer accepts response data from S/C and GSE, converts into engineering units, checks against limits, and distributes to control consoles

(2) Shared Memory--Control Data Corp. 169G-3

Memory - 24,576-word core

Function - Permits each computer to utilize portions of shared memory as required for data storage, addressing or computation

(3) Computer Auxiliary Equipment--Includes the following:

(a) Typewriter (1 per computer)

(b) Card Reader (1 per computer)

(c) Magnetic Tape Transports (2 per computer) and Controller

(d) Line Printer (Downlink only)

(e) Card Punch and Controller (1 per system)

(f) X-Y Plotter (2 per system)

(4) Decommutators (two)

Function - Accepts serial PCM bit stream (204.8 K bits/sec) from S/C and GSE, converts to eight-bit parallel words, assigns addresses, and supplies data words to signal distribution units for transmission to display and recording consoles and computers

(5) Data Transmission and Verification Converters (four)

Function - Three units convert parallel digital test command words from the Command Computer to serial format and transmit them to the S/C test area. They then receive a verification reply and transfer this to the computer. The fourth DTVC forms part of a chain that transmits display words from the display computer to Symbol Generator and Storage Unit

(6) Magnetic Tape Recorder and Tape Search/Control

Function -This records and plays back the raw PCM bit stream, and also any FM, voice or miscellaneous signals transmitted in addition to PCM

(c) Terminal Facility Room Equipment--Includes the following:

(1) Digital Communication Control Unit

(2) Symbol Generator and Storage Unit (SGS)

(3) Communication Unit Executor (CUE)

(4) Patch Facility

(5) FM Equipment

(1) Digital Communication Control Unit

Function - Converts serial display data words from the display DTVC to parallel formats and performs a verification check on these words. Also provides the control signals necessary to enter the data words into the SGS

(2) Symbol Generator and Storage Unit

Function - Receives the digital display data words from the Digital Communication Control Unit, and converts these words to analog voltages to create an alphanumeric display on console CRT display units

(3) Communication Unit Executor

Function - Controls the two-way communication path between the test operators and the command computer

- Scans all START modules sequentially and stops at START having entered data. Transmits this data and its address to the computer

(4) Patch Facility

Function - Provides patching facility between units, and between ground stations, for various test configurations

(5) FM Equipment

Function - Accepts data in FM form from S/C for those channels whose bandwidth content is too high for ACE PCM format

Includes - FM Discriminators

- Analog Recorders

- FM Calibrator

2. Carry-on and Facility Equipment

(a) Uplink Digital Test Command System (DTCS)

Function - Converts computer commands and addressing data into corresponding stimuli to the appropriate S/C subsystem or GSE

Includes - Receiver Decoders

- Base Plates

- Pluggable Stimulus Modules

(1) Receiver Decoder

Function - Receives computer command data, compares and checks for correct codes

- Routes commands to the appropriate base plate and stimulus modules

(2) Base Plate

Function - Contains up to 4 stimulus modules, which are pluggable and can be changed at any time

- Provides power to modules

(3) Pluggable Stimulus Modules

Function - Provide stimulus to S/C and/or GSE. Three module types are available. Relay for discretes, Silicon Controlled Rectifier for high speed switching and high currents, and Digital-to-analog (D/A) for analog signals

(b) Downlink Digital Test Monitoring System

Function - Accepts response signals from S/C and GSE, converts to interleaved serial PCM form and transmits data to decommutator

Includes - Signal Conditioners

- PCM Systems

- PCM Interleaves

(1) Signal Conditioners

Function - Carry-on modules that convert S/C transducer signals into a normalized 0-5 volt DC range for digitizing into PCM form

(2) PCM Systems

Function - Includes multiplexing and digitizing equipment to produce 3 separate PCM data streams, (1) carry-on equipment data, (2) flight data, (3) service equipment data. Each PCM stream is at the rate of 51.2 kilobits per second

(3) PCM Interleaver

Function - Interleaves the 3 PCM 51.2 kilobit streams, plus 1 spare, into a single 204.8 kilobit PCM stream for transmission to the downlink decommutator

D. BASIC SOFTWARE

GENERAL[11,12]

The on-line basic software for ACE-S/C* provides (1) the necessary general purpose operating programs for sensing inputs from the operator controls, controlling displays and peripherals, and time-sharing these actions among the operator control positions, and (2) the subroutines that perform specific actions such as encoding commands or scaling data for display.

The basic programs and subroutines are written by General Electric at KSC (now being transferred to Houston), on the basis of detailed specifications prepared by the using facility. Preliminary checkout of the basic programs is performed at the programming facility, aided by software simulation of S/C responses. Final checkout and verification is performed at the operational ACE station.

Specialized program function requirements are treated administratively as additions to the basic software. For example, the special programs for checking certain Guidance and Navigation functions are specified to GE in the same way as the general purpose routines such as measurement conversion, and their programming and checkout follow the same procedures.

Specific test programs for a particular S/C consist only of data tables, to be interpreted by the basic software. These are assembled automatically (by GE, Houston) from tabular coded and decimal data supplied by the user. Last minute changes are assembled on-site by resident GE personnel.

The uplink computer and the downlink computer are regarded as two essentially independent subsystems. Minimal provision for intercommunication is provided via the shared memory and special subroutines.

UPLINK COMPUTER BASIC SOFTWARE (FIG. D-3)

After initialization, the Communications Unit Executor (CUE) hardware begins scanning the START inputs. Meanwhile, the uplink computer enters its low-priority executive routine, which so far

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*A new software concept has since been initiated. This would use a magnetic tape storage for segments of the programs through the use of a real time monitor for access to both uplink and downlink programs.

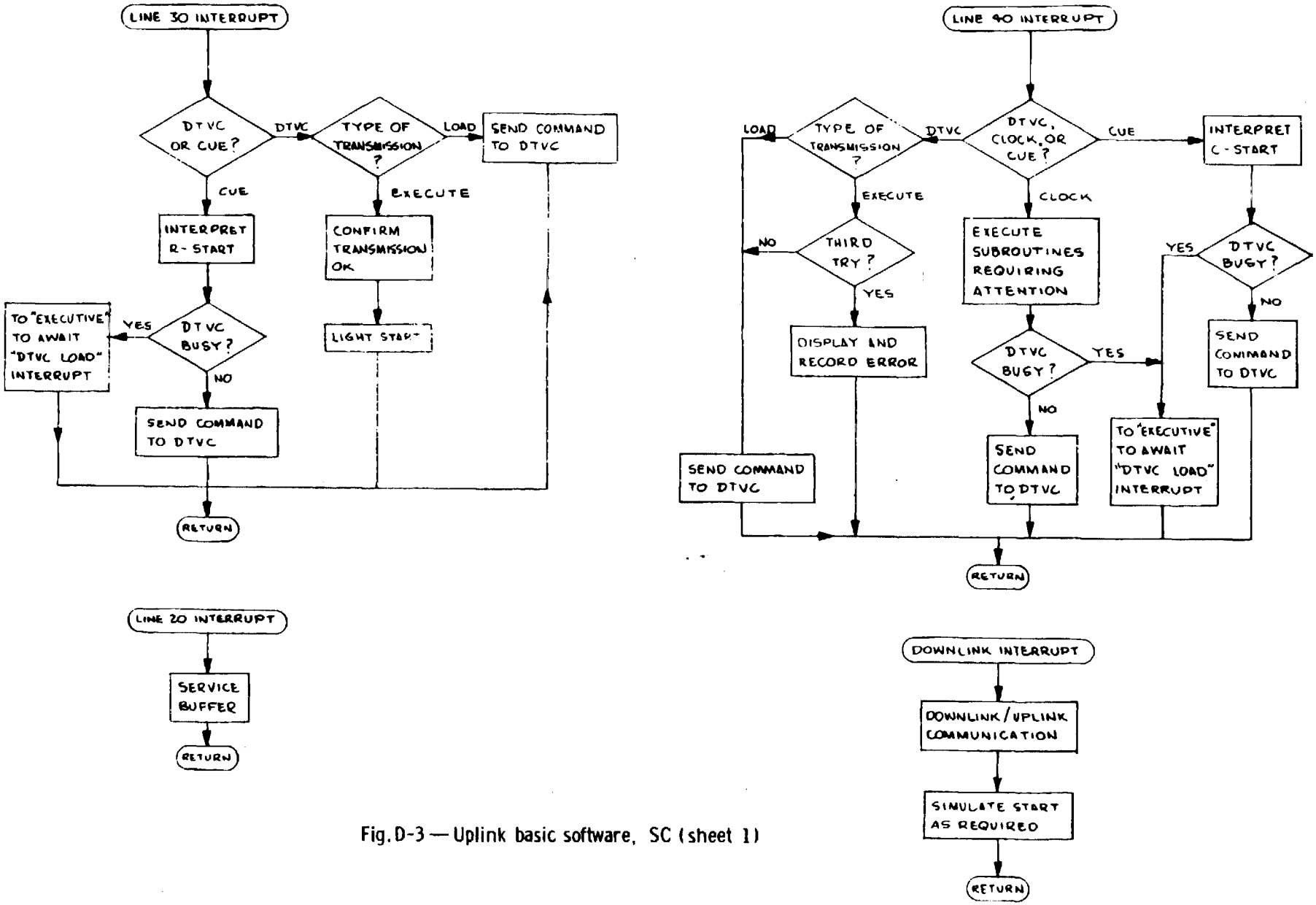


Fig. D-3 — Uplink basic software, SC (sheet 1)

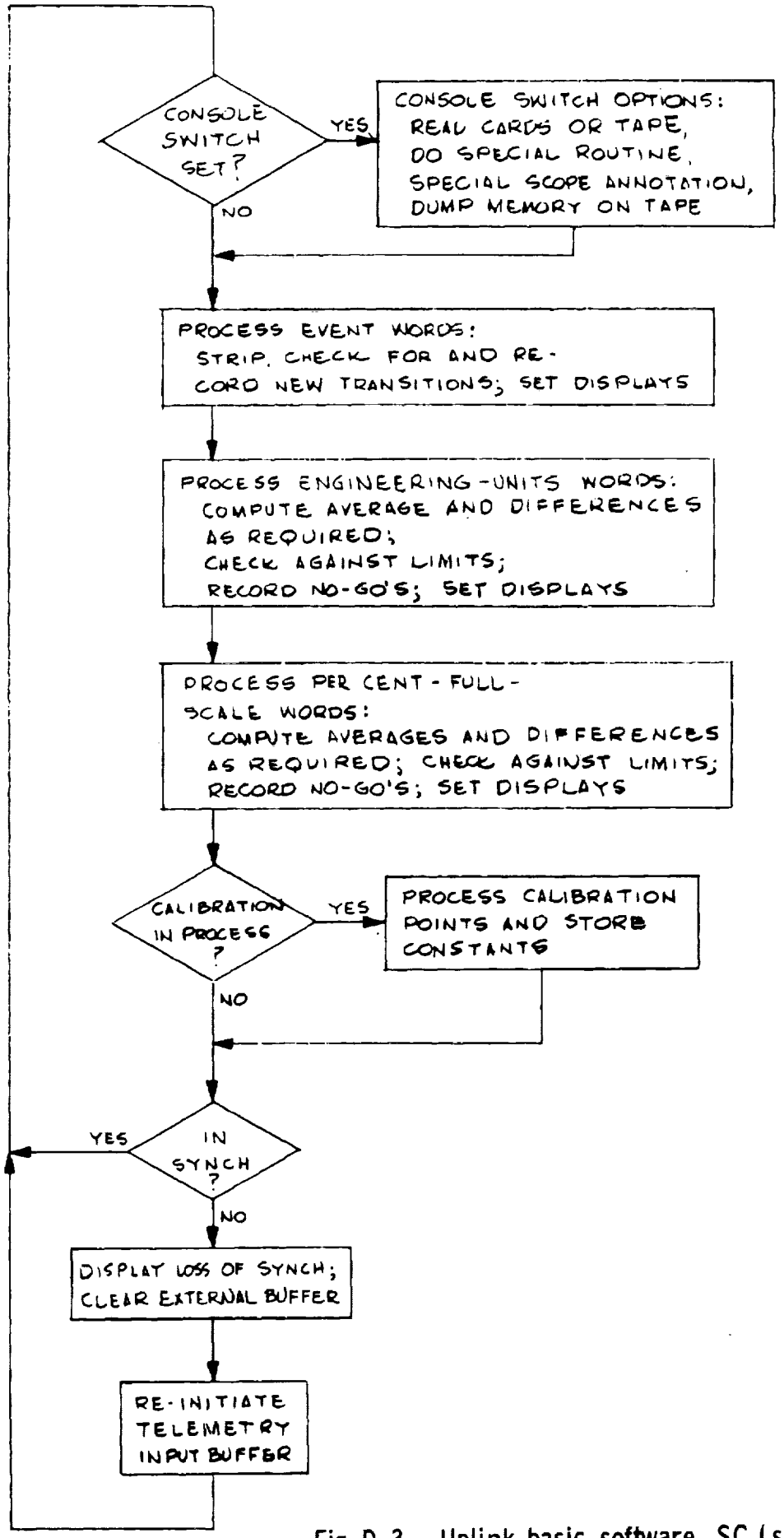


Fig. D-3 —Uplink basic software, SC (sheet 2)

is concerned only with (1) low-priority computer-to-computer information transfer, if any, and (2) running a basic self-test loop. (Other functions for the low-priority executive routine are so far undefined.)

When a START Execute button is pressed, the CUE interrupts the low-priority executive routine. The computer decodes the START input and enters the necessary subroutines for execution of the input and transmission of resulting commands to the remote equipment. The decoding process is aided by the extensive data tables (command addresses, subroutine parameters and entrances, etc., for each START) in the shared memory. The Executive subroutine can be broken by a Line 30 Interrupt. This Interrupt may come from either the Digital Transmission and Verification Converter (DTVC) or an R-START module. The DTVC Interrupts are to verify a correct transmission (but not correct execution of the command), and, at this time, the console Execute lighting is handled with the CUE scan being reselected. The R-START Interrupt will allow a command word to be input, evaluated, and output to the DTVC.

The Executive subroutine may also be broken by a Line 40 Interrupt, which can come from any of three sources: the real time clock, the DTVC, or the C-START module. If the clock generated the Interrupt, the appropriate subroutine is called upon to furnish the required analog function output, after necessary clock servicing has been completed. If the Interrupt came from the DTVC, it could mean that a transmission error occurred. If the transmitted word was a Load Buffer Memory, error condition was expected, and an exit is made to the Execute Buffer Memory output subroutine. If it was an error, another attempt to transmit is made--up to a limit of three tries. If unsuccessful in three transmission attempts, the error routine is called on. The C-START Interrupt will allow four command words to be input, evaluated, and output to the DTVC. In the case of a special function, the needed input parameters are placed in the variables location of the subject subroutine. As commands are transmitted, they are recorded on magnetic tape along with the time of transmission and an error notation, if applicable. One exception to this is in the case of continuous analog functions (sine wave, etc.) where only the command initiating the function is recorded, not each individual point. A Line 20 Interrupt is used to reservice

the output buffer. Check points for errors (including DTVC Interrupt failure) are throughout the program, using hardware checks as well as programmed techniques.

If the command involves timed rather than immediate functions, such as a relay sequence or analog waveform, the corresponding subroutine remains active during later Timer Interrupts, for the purpose of updating the output commands. A periodic Timer Interrupt services analog waveform outputs 250 times per second. A presettable Timer Interrupt services timed sequences such as relay sequences. Both Interrupts are associated with a significant amount of programming for their interpretation.

The basic R-START program function is the transmission of one 4-bit message, representing the status of one 4-switch R-START module, to the communication link, This involves decoding of the R-START address, encoding the relay subgroup address from a data table, transmitting the resulting address and 4-bit data word to the communication link, and reacting to the DTVC verification feedback. (The feedback check is of the communication link only, not the relay drivers.) A subroutine is also provided to permit a single R-START to initiate a short open-loop sequence of relay commands. A special subroutine is also provided, which permits more than one R-START to drive a particular relay command (in a few cases), although the special data-encoding requirement implied by this causes memory-space limitations on the technique.

The most basic C-START function is the setting of a steady voltage output from a digital-to-analog converter in the GSE. To perform this, the program decodes the C-START address and data, encodes an address and the command voltage into a digital-to-analog command for the communication link, and reacts to the DTVC verification feedback. The C-START may also be used to set timers, to provide manual input data to other subroutines (an elementary form of on-line program control), and to initiate timed analog waveforms generated by the computer program. Available programs will generate steps, ramps, low-frequency sine waves, rectangular waves, and a "degaussing" waveform consisting of an AC waveform of slowly varying amplitude--all by computer-directed variation of DC digital-to-analog converters in the GSE.

K-START uplink programs are, so far, less well defined. They will be concerned largely with control and loading of the guidance computer memory.

The basic uplink software also includes provision for communication with the downlink computer (at present used only for setting the Central Timing Equipment), and provision to record all commands on magnetic tape for off-line analysis.

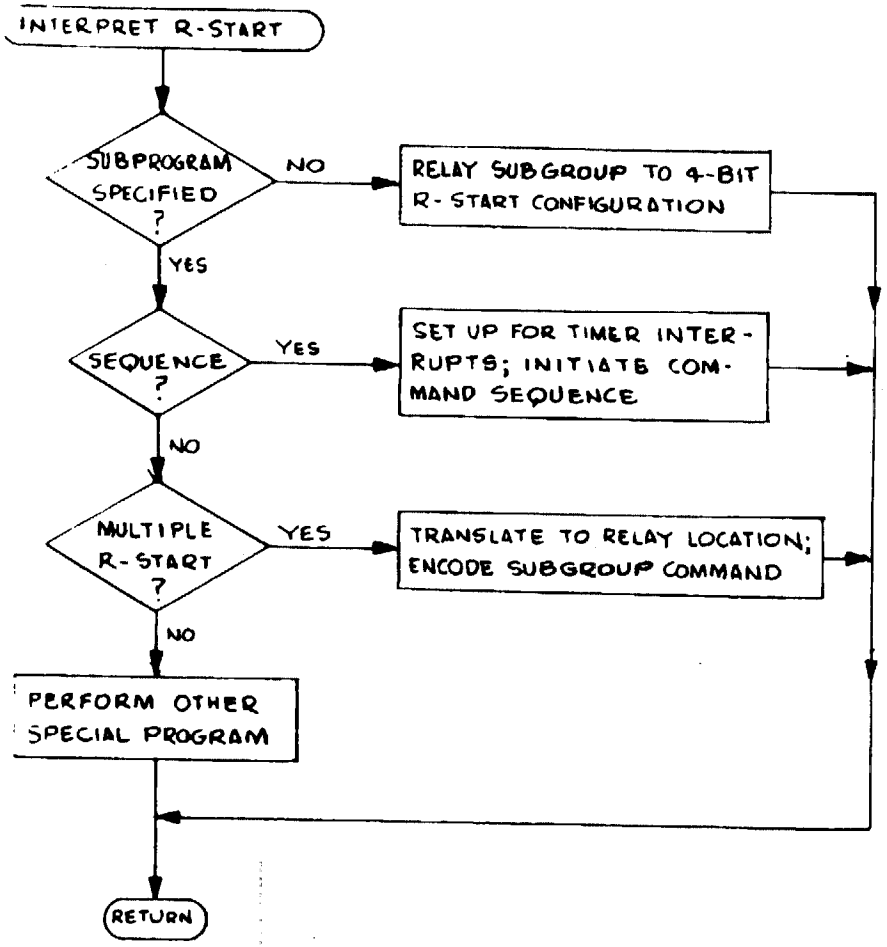
The uplink computer is time-shared among the operator consoles by virtue of the scanning function of the CUE. Reaction speeds of the subprograms are rapid enough that actions will normally be within human reaction times. Long term functions, such as generation of analog waveforms, are time-shared by timer interrupts.

Task loading of the uplink computer has so far not been a problem, but generation of multiple simultaneous analog waveforms, relay sequences, etc., may change this.

DOWNLINK COMPUTER BASIC SOFTWARE (FIG. D-4)

The downlink programs process information deposited in memory by the DDAS. At a rate preset for each piece of data (maximum 50 times per second), the downlink extracts the relevant data from the frame, processes it (e.g., by averaging) if necessary, linearizes it and converts it to engineering units, and checks it against limits, once per second. The result is displayed, blinking if tolerance is exceeded. For each stage of the test procedure, the relevant data and its tolerance limits may be separately preprogrammed. For event data, the program strips relevant bits from the eight-bit telemetry words.

General purpose processing functions available include checking every sample, checking samples less frequently (once per N samples, where N is preprogrammed), checking the average of a given number of samples, checking for a given change of value, and checking for a given difference between two measurements. In addition, more specialized functions are programmed for tests of the Central Timing Equipment and the Guidance and Navigation equipment, including a routine that processes one special high-rate (200 samples per second) input.



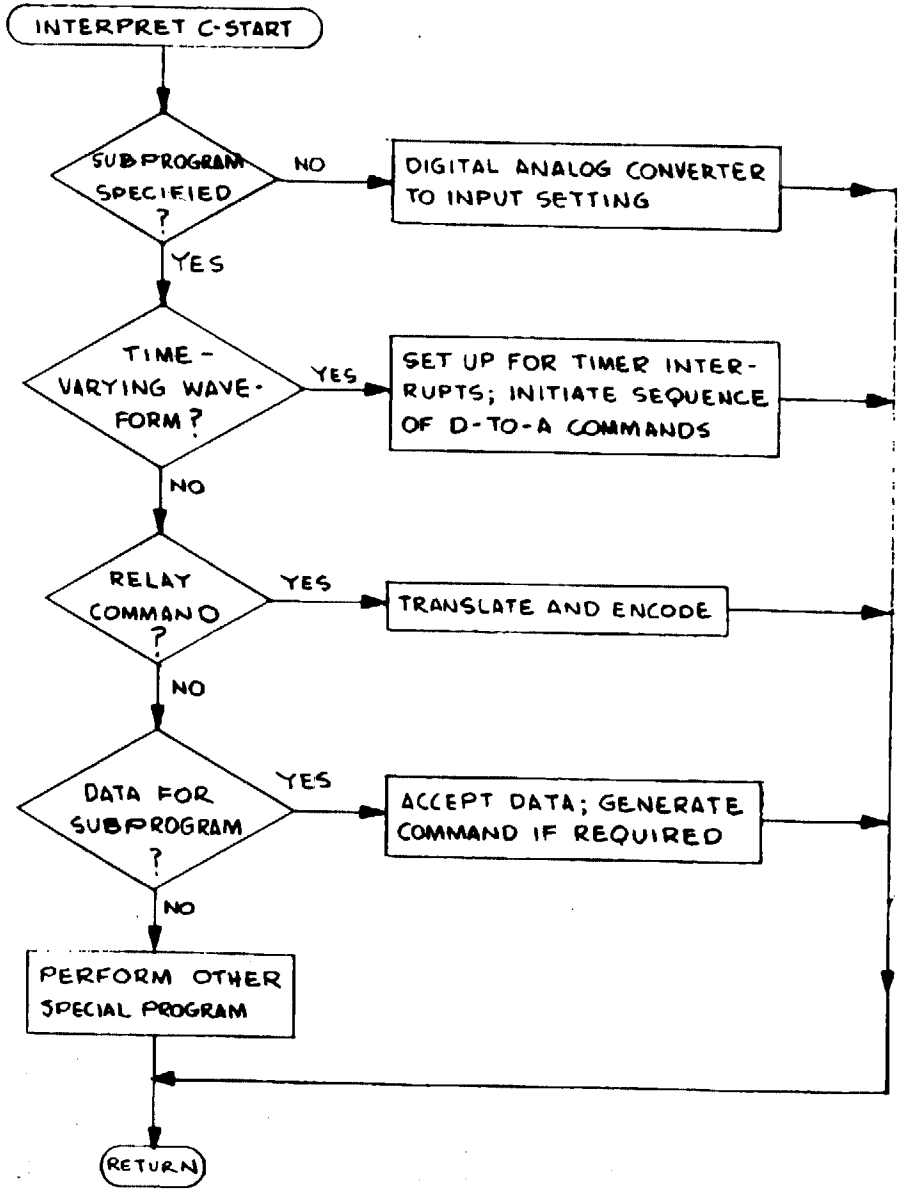


Fig. D-4 — Downlink basic software, SC (sheet 1)

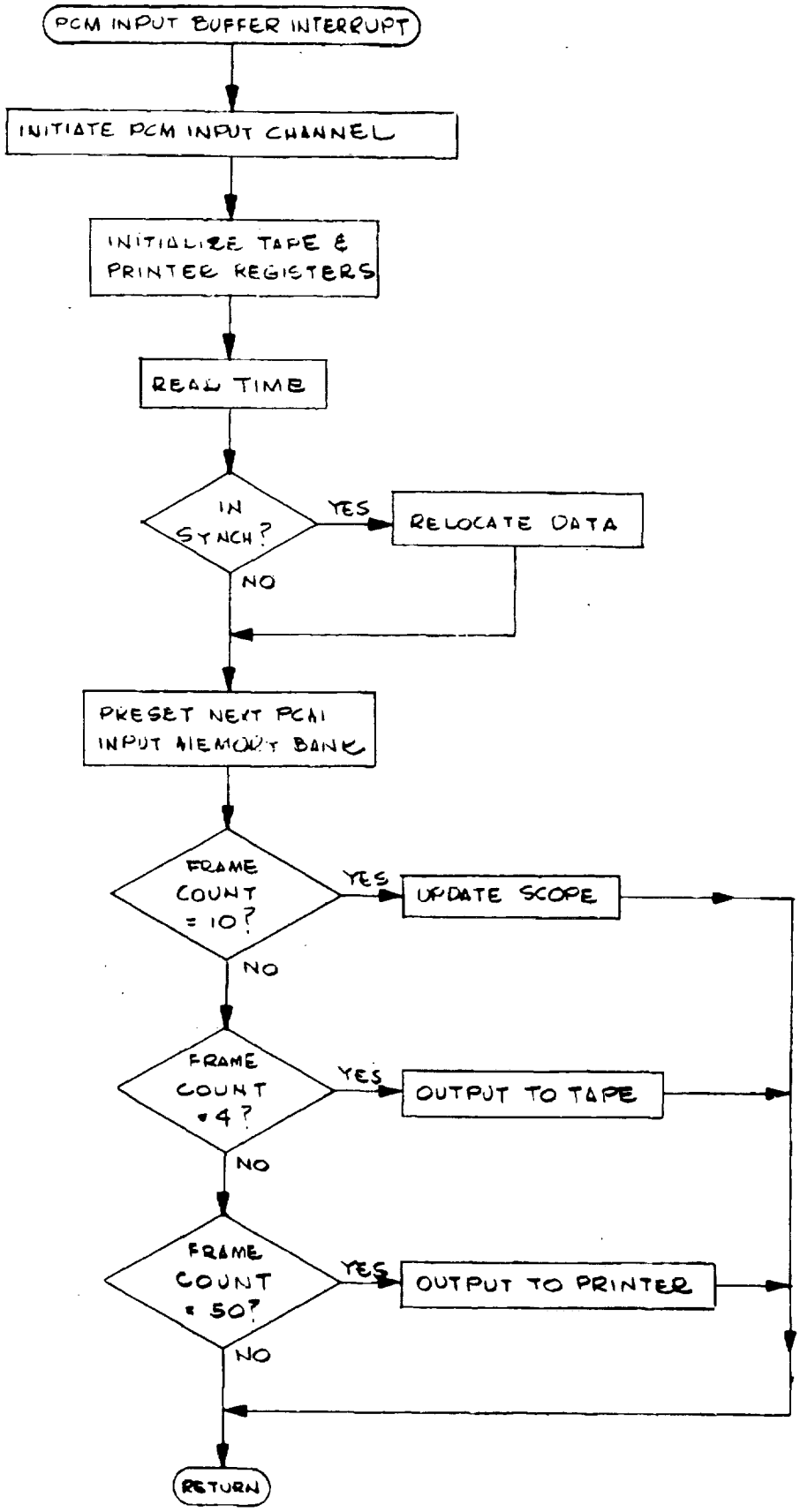


Fig. D-4— Downlink basic software, SC (sheet 2)

The basic downlink software also includes provision for communication with the uplink computer (at present used only for tests of the Central Timing Equipment) and provision to record no-gos and events on magnetic tape for off-line analysis.

Loading of the downlink computer may be estimated from the following:

(a) Initial analysis indicated that 500 analog and 300 event inputs would cause 70 per cent loading.

(b) On BP 14, 200 analog and no event inputs caused 35 per cent loading

(c) Some responsible personnel expect that the computer will be overloaded, causing some cutback from full desired capability, by S/C 011.

Downlink control functions are basically accomplished by the use of various subroutines, which are referenced as needed.

Sequence of processing is controlled by the Downlink Executive Routine, which performs the following after initialization:

a. Subroutine linkage consists of fixed sets of instructions that control entries to and returns from particular subroutines (events, engineering units, etc.). These linkage routines supply the subroutines with the first parameter address for the data word being processed before transferring control. After return, linkage routines determine if more data words are to be processed and repeat the procedure if necessary.

b. Summary filing outputs accumulated data from a common output area in memory, as specified prior to test.

c. Supervisory control provides access to the Program Executive Routine by the use of console jump switches.

Major subroutines are discussed below.

Parameters Subroutine. Each subroutine has an associated set of parameters that control the processing done by the Downlink Executive Routine. The amount of processing done is a function of the number of parameters required for that category (specific type of data). Each subroutine also has a control register that locates the first parameter of its category. A set of parameters is related to each scope annotation.

Parameters, control registers, and scope annotations are assembled prior to test as a separate file on magnetic tape that also contains the Downlink Control Program. Several S/C tests or phases may be assembled and stored as consecutive test records on this test file tape. Thus, changeover for a new test requires only that scope annotation and parameters be read into memory from the magnetic tape.

After data for a new S/C test is read into shared memory, the new scope annotation is buffered out to the scope for display. The Downlink Executive Routine then performs a calibrate-and-checkout test, which yields a scaling reference for the off-line plotter and allows verification of processed data.

Any parameter may be changed by change cards, which are processed by the Program Executive Subroutine.

Program Executive Subroutine. This routine functions as a control program and provides the means for rapid changeover from one S/C test to another S/C test on the test file tape. All entries to this routine are made with cards that may call on any routine that is in memory or on the test file tape. Call cards and change cards are normally prepunched prior to a test series.

An alternative method of accessing some of the desired routines is provided by console jump switches.

Input-output Subroutine. The telemetry data input is initiated by an interrupt signal from decommutation interface equipment. It is then buffered through an external channel into two separate areas, alternatively, in optimum groups of subframes. A real time clock reading (range time) is stored to relate a time to each subframe. If the last area to receive data is in synchronism, data to be processed is transferred to a relocatable data table. Otherwise, data relocation is bypassed and loss of synchronism is indicated on the scopes. Output of processed data to scope, magnetic tape, and on-line printer is controlled by counting subframes. The output rates can also be controlled by card input through the Program Executive Subroutine.

Scope update normally occurs once every second. Data is stored for range time, processed data, and out-of-limits indications, if applicable. Out-of-limits conditions are indicated by blinking the applicable data displayed on the scope.

Selections for write or print will be provided for out-of-limits alarms, selective intervals, and event transitions. The printer is used on a time-available basis. All other filing is on magnetic tapes. These tapes may be used as input to off-line programs for generating test summary reports and off-line plots. The tape output format is standardized to permit direct input to the off-line printer.

Events Subroutine. Events are given by a single word (PAM data) or bit (PCM data) representing an on/off condition. Each event is processed to determine its present condition, then compared to the previous condition. If a transition occurs, the present on/off condition, time of transition, and a flag indicating transition is stored for magnetic tape and printer output. The on/off condition is also indicated on the scope. The format of event parameters is stored in the shared memory.

Engineering Units and Per Cent Subroutine. Data is processed in one of three ways:

a. The average of every Nth point
b. Use of every Nth point
c. Use of data point D_n if $|D_n - D_k| > N$ when $N > k$ with regard to sample time, and N is a pre-established positive difference.

Since there are several functions of each type to process, each function has a parameter set that provides the information necessary for selection of processing type, and to perform the processing.

With P representing "per cent," and E representing "engineering units," the input data may be expressed as X, an independent variable. If the data is P - P(X), the conversion is by table look-up. For engineering units conversion, the function $E_n(X)$, $n = 1, k$ for each of the k different functions is predetermined, and the curve is divided into equal increments so that any point may be found by linear interpolation between two known points. The results of processing through this subroutine are converted to BCD and stored for output use. The format of engineering units and per cent parameters is stored in the shared memory.

Return to Zero Calibration Subroutine. Return to Zero calibrations are performed on S/C sensor outputs that are modified and amplified before commutation, compensating for drift within the amplifiers. These calibrations may occur in any order and in any time sequence. When a calibration occurs, a time inhibit allows the amplifier to stabilize and permits the operator to evaluate data displayed on the scopes. A manual option also allows the operator to make a final decision as to whether the calibration should be performed by the computer.

When calibration results are received by the computer, this subroutine calculates zero shift and amplifier gain constants, which are used to modify all measurements subject to Return to Zero calibrations. The format of Return to Zero calibration parameters is stored in the shared memory.

Annex D

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Annex E

S-IC STAGE CHECKOUT

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CHECKOUT CONCEPT AND OBJECTIVES

BACKGROUND DATA

Design of the S-IC booster stage for the Saturn V launch vehicle was performed jointly by MSFC and The Boeing Company, Aerospace Division, Saturn Booster branch. One test stage and the first three flight stages are scheduled for checkout by Boeing personnel at MSFC, with the Quality and Reliability Assurance Laboratory responsible for pre-static and post-static checkout and the Test Laboratory responsible for static firing tests.

Boeing, using the NASA Michoud facility at New Orleans, La. is scheduled to manufacture a Facilities Checkout Vehicle, a Dynamic Test (S-IC-D) stage and all flight stages beginning with S-IC-3. Factory acceptance checkout will be performed at Michoud, and the stages after the initial vehicles noted above will be static fired at NASA's Mississippi Test Facility, and returned to Michoud for post-static checkout.

Boeing's Huntsville facility, with MSFC direction, is integrating the checkout system and preparing the test procedures and computer programs.

The Michoud plant is scheduled to have a four-cell checkout complex, with the first set of GSE operational by the end of 1965. A second set will also be manufactured, and the third cell will use the checkout system shipped from MSFC after S-IC-2 testing is completed. The fourth test cell is presently planned for backup only.

STAGE DESCRIPTION(1)

The S-IC is the first stage booster for the Saturn V launch vehicle. It is 138 ft long and 33 ft in diameter, with a main stage propellant capacity of 4,400,000 lb and a rated thrust of 7,500,000 lb.

Major S-IC systems (grouped for convenience in checkout) are as follows:

1. Structure System--This consists of nine subsystems, the Forward Skirt, 350,000 gallon Oxidizer Tank, Intertank, 220,000 gallon Fuel Tank, Base Heat Shield, Thrust Structure,

Fins and Engine Fairings, Wiring Tunnels, and Destruct Ordnance. Fins and Engine Fairings are not installed until the stage is in the Merritt Island Launch Area (MILA) Vertical Assembly Building (VAB).

2. Propulsion System--This includes the five F-1 engines and the necessary support equipment. The engines use liquid oxygen (LOX) as the oxidizer and RP-1 as the fuel. The fuel is also used as turbopump bearing coolant, hydraulic fluid for engine gimbaling, and as the working fluid for engine control subsystems. Propulsion subsystems are LOX, Fuel, Gaseous Nitrogen (GN_2) Control Pressure, GN_2 Purge Pressure, and F-1 Engines subsystems.

3. Electrical and Stage Sequencing System--This includes the Power Distribution Subsystem and the Stage Sequencing Subsystem. The Power Distribution Subsystem supplies 28-v DC to all stage loads (from GSE power sources during checkout and from flight batteries during prelaunch and flight). In addition, 5-v DC regulated power is supplied as reference voltage to the measurement system (from 28-v DC to 5-v DC on-board power converters). Prior to flight only, 208-v AC, 60-cycle power is distributed from GSE or facility supplies to the turbopump heaters. The Stage Sequencing Subsystem initiates various stage functions, in proper sequence after liftoff, upon receipt of digital coded signals from the flight computer in the Vehicle Instrument Unit.

4. Range Safety System--This system permits flight termination by ground command. Two identical, independent subsystems are used. Upon receipt of RF command signals, engine shutdown and propellant dispersion are effected by the activation of Exploding Bridge Wire (EBW) detonators, which set off shaped charges.

5. Instrumentation and Telemetry Systems--The Instrumentation System, via appropriate transducers, provides information on the functioning of stage systems and associated environmental conditions. During ground checkout, data values are transmitted via coaxial cable by the Digital Data Acquisition System (DDAS) link, and via either air link or coaxial cable by the PAM/FM/FM, PCM/FM, and SSB/FM Telemetry Subsystems. During flight, all information is transmitted by RF telemetry. The Flight Instrumentation System uses more than 900 transducers and associated signal conditioners. Additional transducers may be used for static firing or ground checkout and removed prior to launch. Almost all channels have Remote Automatic Calibration System (RACS) capability. An on-board tape recorder is provided to record data during the RF "blackout" period at separation. The data are later played into the Telemetry System on command.

6. Control and Guidance System--This consists of the Control Instrumentation and Thrust Vector Control Subsystems. Control Instrumentation provides angular velocity and acceleration (pitch and yaw) data to the Instrument Unit. The IU control computer analyzes this input and sends command position signals to the Thrust Vector Control Subsystem to position the nozzle of each engine. Each of the four outboard engines is gimbaled independently.

7. Stage Separation System--In flight, this system effects separation of the S-IC from the S-II stage upon receipt of commands from the Stage Sequencing Subsystem. Linear-shaped explosive charges, set off by EBW detonators, are used to split the stages at the separation line, while retrorockets in the S-IC, again fired by EBW units, provide the reverse thrust to slow the S-IC and permit unhampered separation and firing of the upper stages.

8. Visual Instrumentation System--For visual monitoring during static firing or flight, two television and four film cameras are provided. The TV system transmits during flight, while the cameras are ejected from the stage during flight for subsequent recovery.

9. Emergency Detection System--This consists of multiple sensors and voting circuitry to monitor critical functions such as rough combustion and loss of thrust.

DESCRIPTION OF TESTS[1]

The following tests are representative of a factory acceptance or post-manufacturing and static firing S-IC checkout sequence.*

Test	Description
GSE Verification	
G-1	Computer Self-tests--self-test and diagnostic routines supplied by the computer manufacturer for checkout of the RCA-110A computer and its peripheral equipment. Additional tests are:
G-1a	(1) Integrated complex

*Changes have since been made in this test sequence.

Test	Description
G-1b	(2) Ignition sequences
G-1c	(3) Launch Equipment Electrical Simulator
G-2	Control and Monitor Station--self-tests that perform checkout of the Control and Monitor Station equipment, including:
G-2a	(1) CRT display
G-2b	(2) Test step indicators
G-2c	(3) Count clock equipment
G-2d	(4) Local controls for test equipment and cell warning, Launch Sequencer, and emergency control
G-3	Electrical Test Station--a self-test program that checks out the Electrical Test Station, including tests of:
G-3a	(1) Range safety equipment
G-3b	(2) Power control and monitor equipment for the measurement system
G-3c	(3) Engine gimbaling
G-3d	(4) Upper stage electrical network simulation
G-3e	(5) Switch selector control
G-3f	(6) Separation system
G-4	Mechanical Test Station--a self-test procedure, largely manual, that checks out the Mechanical Test Station (pneumatics and hydraulics), including checks of:
G-4a	(1) Hydraulic Supply and Distribution System
G-4b	(2) Emergency venting controls
G-4c	(3) Pneumatic Power Supply and Distribution System
	These tests are performed in conjunction with an automatic program for monitoring signals from these GSE elements

Test	Description
G-5	Data System Test Station--self-test procedure, partly manual, that checks out the Data System Test Station:
G-5a	(1) Integrated Telemetry Ground Station
G-5b	(2) DDAS ground equipment
G-5c	(3) RACS
G-5d	(4) Instrumentation and calibration equipment
Stage Verification	
Pre-test	Stage Receiving Inspection--a visual inspection to verify component status, cable connections, cover installation, cleanliness levels, etc.
Pre-test	Installation in Test Cell and GSE/MSE Connection--includes S-IC mounting and installation, electrical and mechanical interface verification, continuity tests, and connection to GSE and MSE
Pre-test	Environmental Control System Test--checks temperature, pressure and flow rate of conditioned air supplied by the Ground Cooling Unit to the S-IC forward compartment
1	Electrical Systems Startup--a sequence to verify GSE and stage power supplies and interconnections. The sequence: (a) verifies readiness of GSE to provide stage power (b) verifies inactive status of stage systems prior to power application (c) applies GSE power to stage (d) checks power distribution and transfer Individual items tested include: (1) Stage DC power supplies (2) GSE DC power supplies (3) OAT (Overall Test) batteries

Test	Description
	(4) Power distributors (5) Electrical startup (6) Internal power transfer (7) External power transfer
2	GN_2 Control System Confidence Leak and Functional Tests--to verify ability of the GN_2 Control System to accept maximum pressure levels, and to check for leakage at all components, fittings, and lines
3	Power System Test--a check of bus voltages performed after Tests 1 and 2. Programs are provided for: (1) Internal Power System (2) External Power System Both programs provide monitoring of 28-v DC and 5-v DC buses for in-tolerance values
4	DDAS and PCM/FM System--an end-to-end functional and linearity check of the stage and GSE DDAS and PCM/FM Systems, including automatic calibration signals. The DDAS signal from the coaxial cable is compared against demodulated PCM/FM data
5	PAM/FM/FM System--an end-to-end performance and accuracy test of the stage telemetry and PAM/FM/FM Ground Station, including RF characteristics, subcarrier oscillator and discriminator linearity, multiplexers and demultiplexers, tape recorder and calibration
6	SSB/FM System--an end-to-end performance and accuracy test of the stage telemetry and SSB/FM Ground Station, including RF characteristics, calibration linearity, frequency response, modulator and demodulator, multiplexer and demultiplexer

Test	Description
7	Stage Sequencing System--a check of the Sequencing System, made by transmitting a programmed series of digital coded signals from the checkout computer to the stage switch selector, and verifying the operation of the appropriate function relays in the sequence and in the control distributor
8	Signal Conditioner Verification (RACS)--to verify the calibration and proper operation of the flight measurement system signal conditioners. Calibration signals are switched to each signal conditioner in sequence, and the channel output is compared with stored data. Out-of-tolerance values require manual recalibration or replacement
9	Flight Measurement Profile Test--to detect changes in transducer output for no input. All channels are scanned, and those varying by more than 2 or 5 per cent from the predicted output for atmospheric pressure, normal temperature, and unstimulated inputs are recorded and adjusted
10	Channel Identification Test--an end-to-end test of all instrumentation channels to verify that each transducer's output occurs on the assigned telemetry channel, that it does not occur on any other channel, and that all transducers are functioning
11	Pressure Test Prerequisites--functional tests of Pressure System components that require removal of component test plugs for connection of test lines. System leak tests later verify proper reinstallation of plugs. Tests include: (1) Functional test of prevalve flowmeters (2) Functional test of LOX flow control valve (3) Functional test of mechanical opening of LOX tank vent and relief valves

Test	Description
12	Pressure Confidence Test--a preliminary check of stage pressurability to ensure personnel safety during subsequent leak testing. Pressures are gradually raised to high levels, with personnel restricted to Control Room monitoring of gross leaks via speaker microphone boxes. Areas tested include: (1) Calibration lines (high pressure) (2) GN_2 Ground Control and Stage Purge System (3) Fuel Pressurization System, fuel tank and lines (4) LOX Pressurization System, LOX tank and lines
13	Pressure Switches Calibration Verification and Line Leak Test--pressurizes, in incremental steps, stage pressure switches through their calibration lines to check actuation and deactuation. Simultaneously, components are manually tested for leaks
14	Stage Pressurized Leak Tests--to check for leakage at all critical components of pressurized systems. Bubble and halide leak detection methods are used, plus flowmeters for valve seat leakage. Leak tests include: (1) Purge System (2) LOX System (3) Fuel System
15	GN_2 Onboard Purge System Functional Tests--verification of the functional operation, including pressure monitoring and valve timing, of the major GN_2 Purge System components under computer control
16	LOX Subsystem Functional Test--verification of the functional operation, including pressure monitoring and valve timing, of LOX Subsystem components

Test	Description
17	Fuel Subsystem Functional Test--verification of the functional operation, including pressure monitoring and valve timing, of Fuel Subsystem components
18	Engine Subsystem Tests--include fluid control system fill, bleed, and leak checks, a functional test for thrust vector control, and for engine components, and Electrical System tests for the five engines (1) Fluid Control System fill and leak check (2) Engine gimbal (3) Fluid Control System fill and bleed (4) Thrust vector control accuracy and transient response (5) Engine start-stop sequence (6) Fluid Contamination Analysis (7) Engine Electrical Systems (8) Purge Tests (9) Functional test of components
19	Engine Cutoff Test--to verify that an engine cutoff signal will be generated by predetermined combinations of cutoff parameters plus an enabling signal from the stage sequencing system, and that a cutoff signal will not be generated without the enabling signal or by incorrect signals
20	Television System Test--a test of the TV Instrumentation System for functional operation and RF transmission characteristics
21	Range Safety System Test--to verify functional operation of the dual range safety systems. Closed-loop (coaxial cable) and open-loop (RF air link) commands are transmitted and the safe and arm, cutoff and propellant dispersion outputs monitored. Pulse sensors simulate the EBW detonator circuits

Test	Description
22	Stage Separation System Test--a functional test of the Separation System done by transmitting "arm" and "fire" commands through the Stage Sequencing System and monitoring the following DDAS outputs: (1) Separation firing units charging voltage (2) Separation firing relay operations (3) Separation pulse sensor output (4) Retrorocket firing units charging voltage (5) Retrorocket firing relay operation (6) Retrorocket pulse sensor output
23	Film Camera System Test--verification of the Film Camera System by loading cameras with film, installing camera capsules, and operating through a short cycle, with ejection and recovery arming circuits inhibited. Exposed film is developed and viewed for quality and time-event markings
24	RF Compatibility Test--to verify that no interaction exists among stage RF systems and other stage electrical/electronic equipment. Systems are activated individually and in combination while being monitored for interference effects
25	Simulated Static Firing Test--a final confirmation test of the operational readiness of all stage systems for captive firing. The test sequence is identical to static firing, without propellant loading and with the time scale from T-5 hours to T-90 seconds compressed. From T-90 seconds through the firing sequence, real time is used
26	Electromagnetic Interference Tests--a qualification acceptance test to the requirements of MIL-E-6051C, with the level of detail determined by QC representatives

Test	Description
Post-test	Disconnect GSE/MSE--progressive safing of all systems followed by disconnection of GSE/MSE lines, fittings, cables, couplings, etc., and installation of protective covers
Post-test	Weight and Center of Gravity--physical determination of stage weight and center of gravity, using a weighing stand instrumented with load cell transducers for weight and mathematical calculation of CG from weight data
Post-test	Stage Shipping Inspection--a visual inspection to ensure readiness for shipping
Post-test	Removal from Test Cells--removal of stage for shipment to static firing test site
	Installation of Stage--vertical mounting in Static Firing Test Stand and verification of engine-to-stage alignment
27	Repeat Tests 1 through 9, 11 through 23, and 25, with minor changes due to differences in facility and safety emphasis
28	Static Firing Countdown (T-1 day to T-90 seconds)
29	Static Firing Countdown (T-90 seconds to Engine Start)--under automatic control of Terminal Countdown Sequencer, but initially not with computer
30	Static Firing (Short Duration, 30 seconds)
31	Repeat Tests 27 through 29
32	Static Firing (Long Duration, 85 seconds)
Servicing	Propellant Draining and F-1 Engines Purging
Servicing	Post-static Firing Engine Servicing
33	Firing Evaluation Test--repeat Test 27
34	Post-static--repeat pre-tests, Tests 1 through 9, 11 through 23, add simulated plug drop to Test 24, and repeat Test 25

CHECKOUT SYSTEM APPLICATION

The checkout system being developed by MSFC/Boeing for the S-IC is intended to use computer-controlled testing fully for all electrical tests and on a limited basis initially for non-electrical tests. Full backup capability for conducting all tests manually is provided.

Propellant loading and static firing will be performed under manual control with the computer phased in gradually, first exercising only a monitoring function in parallel with manual hardwire instrumentation and later assuming, with increased confidence, a control role.

Whether automated checkout is introduced in step-function form at Michoud will depend upon the results of checkout of the first three flight vehicles at MSFC. (Apart from program verification during the initial MSFC tests, Boeing anticipates an extensive Ground Equipment Test Set (GETS), especially of the electrical networks, so that GETS can act as a simulator. GETS simulation for instrumentation and telemetry is less comprehensive but may be expanded in the future.)

The S-IC checkout system uses the RCA-110A computer as the control element, complemented by peripheral input-output and memory storage elements. Through interface equipment, the computer communicates with a Test Conductor's Control and Monitor Station and three test stations--Electrical Power-Electrical Test, Data System Test and Mechanical Test.

The Control and Monitor Station provides display and control functions for the Test Conductor who can enable any Test Station and monitor test progress and status. The Electrical Power Station controls, distributes, and monitors power equipment for checkout system, GSE, and stage. The Electrical Test Station checks out electrical networks, range safety, and ordnance systems. The Data System Test Station checks out vehicle transducers, signal conditioning, telemetry, and DDAS equipment. The Mechanical Test Station provides a capability for control and monitoring of pneumatic and hydraulic tests.

Three complete test complexes are planned for Michoud for a workload consisting of pre-static and post-static checkout of 13 S-IC vehicles (3 through 15), for a total of 26 test sequences. The first checkout system is scheduled to become operational in late 1965, with

S-IC-3 scheduled for completion of pre-static checkout by February 1966.* Thus, three months is the maximum time expected to be available for checkout.

During application of the checkout system, Boeing anticipates using automatic programs as soon as verification is complete, with manual backup available as necessary. For contingency procedures during an automatic test, programming permits backing down automatically to a start configuration and switchover to manual control. In addition, the ATOLL executive includes capability for on-line program changes and semiautomatic control. These are expected to be used primarily during tests immediately preceding final acceptance.

The extent of automatic fault isolation is uncertain at present since priority is being devoted to go/no-go confidence programming.

DEVELOPMENT OF TEST REQUIREMENTS AND PROCEDURES

Since the initial S-IC vehicles (one test stage and the first three flight stages) will be tested at MSFC facilities, the development of an overall end item test plan and the associated test requirements and procedures is a Boeing program. These requirements and procedures are submitted to MSFC for approval.

The Huntsville operations in the engineering department of Boeing's Launch System branch include a ground systems design project team that has responsibility for checkout and GSE system requirements, detailed test requirements, computer programming and applications, and GSE design.

General test requirements for the first flight stage are listed in Ref. 1. It describes the stage systems, the planned sequence of tests and a non-quantitative summary of the proposal and approach for each major test. The detailed checkout procedure displayed earlier is then derived.

NASA contractual provisions require dual procedures to be prepared for all automated tests, the automatic program and a manual backup procedure.

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*Schedule has since changed.

The primary automatic test procedures are prepared at Huntsville and the manual and manual backup test procedures are prepared at Michoud, partly to distribute workload and partly to provide the eventual checkout system operating groups at Michoud with detailed knowledge of the equipment and its application. Work at Huntsville and Michoud is correlated by sending key Michoud engineers to the Huntsville facility for intermittent terms of temporary duty. In addition, copies of detailed requirements (11 volumes at present) are furnished to Michoud.

Procedures drafted at Boeing are submitted (together with the automatic programs) for MSFC approval via the Boeing GSE system requirements group at Huntsville.

Boeing personnel anticipate little use of manual backup procedures after the first few stages, but they believe the insurance value justifies the effort, quoting the Bomarc project as an example. There, about 24 months were required to debug all programs for the card-programmed semiautomatic test equipment. For the S-IC, about four months of verification and debugging time is scheduled for the first stages. In addition, since no complete breadboard checkout system or stage simulator is available for verification, startup problems may well necessitate the use of the backup procedures.

Automatic programs are intended to include:

(1) A procedure, written in ATOLL, that can also be duplicated manually

(2) The semiautomatic control operations available through the basic software to the test conductor

(3) The critical monitor routines that are part of the executive program.

An attempt is being made to correlate the manual backup procedure with the automatic program on a one-for-one basis, even to the extent of such functions as echo checking if practicable. In a power-up sequence, for example, where many routine cross-checks are made by the computer, they will also be called out on the manual backup procedure, but in the future may possibly be deleted if this proves too time-consuming.

To date, programs have been elementary (essentially a sequence of discrete operations in a straight line) so that the one-for-one correspondence has generally been maintained. Future programs, such as those for propellant loading or static firing, will probably prove more difficult. Subroutines, for example, are awkward to translate into equivalent manual operations.

The computer program tapes prepared for automatic tests are considered as NASA acceptance specifications documents. With the tapes are associated configuration lists characterizing the vehicle.

Changes in automatic or manual procedures may be approved by NASA representatives on a red-line basis, to be formally approved later.

Overall schematic diagrams for each stage/GSE interface function are prepared by the GSE design group at Huntsville, and point-to-point wiring diagrams of individual signal paths and list assignments are responsibilities of the same group.

Stage schematics and wiring diagrams are responsibilities of the stage design groups, with the GSE engineers beginning from the umbilical interface.

PRESENT AUTOMATION LEVEL

At this writing, the computer controlled checkout systems for the S-IC stage of Michoud have not yet been assembled. Therefore the estimates of degree and level of automation "achieved" are based upon Boeing test plans and software.

When the tests listed earlier are used as a base and pre-test and post-test procedures and GSE self-test routines are omitted, we estimate the automation to be 60 to 70 per cent. This estimate includes a weighting for the increase in the number of test steps due to automation. It is assumed that when a test is automated, three to four automated test steps result on the average from one manual test step. This is due to a number of factors; measurements are more often performed several times and averaged, test sequences are more often repeated, or more combinations are checked automatically than would be checked manually.

Figure E-1 depicts the level of automation for the Boeing system. The computer communicates, sequences simple tests and test groups using ATOLL extensively in a well-thought-out hierarchy of test subdivisions.

The availability of an Emergency Shutdown interrupt routine, and the slightly cumbersome manual entry to the shutdown block, provide a reasonably good emergency capability, but both posting of emergency routines and an immediate manual entry to such routines are lacking.* Backup and restart at the block level are well handled by the block structures and programming rules, but no posted backup routines are used, and backup below the block level is not directly provided for.

A Fault Isolation option is provided when a no-go occurs, and programming is being provided for some implementation of it. No pre-programmed contingency reactions or adaptive testing are provided, although the semiautomatic modes include a degree of automatic checking and other assistance to the essentially manual handling of contingencies.

REVIEW OF PRESENT STATUS

Since at this writing no operational experience with the S-IC automatic checkout system exists, a review necessarily is based upon anticipated results.

The S-IC factory checkout system may be considered a "median" among the various stage systems, both in hardware and intended extent of automation.

The provision for 100 per cent manual backup in testing capability, including preparation of test procedures, indicates a conservative approach to automation that involves some duplicative effort but may well be justified to meet delivery schedules, particularly in the initial startup period when program and equipment debugging are major areas of uncertainty.

The decision that propellant loading and static firing will be performed manually for the foreseeable future is another indication

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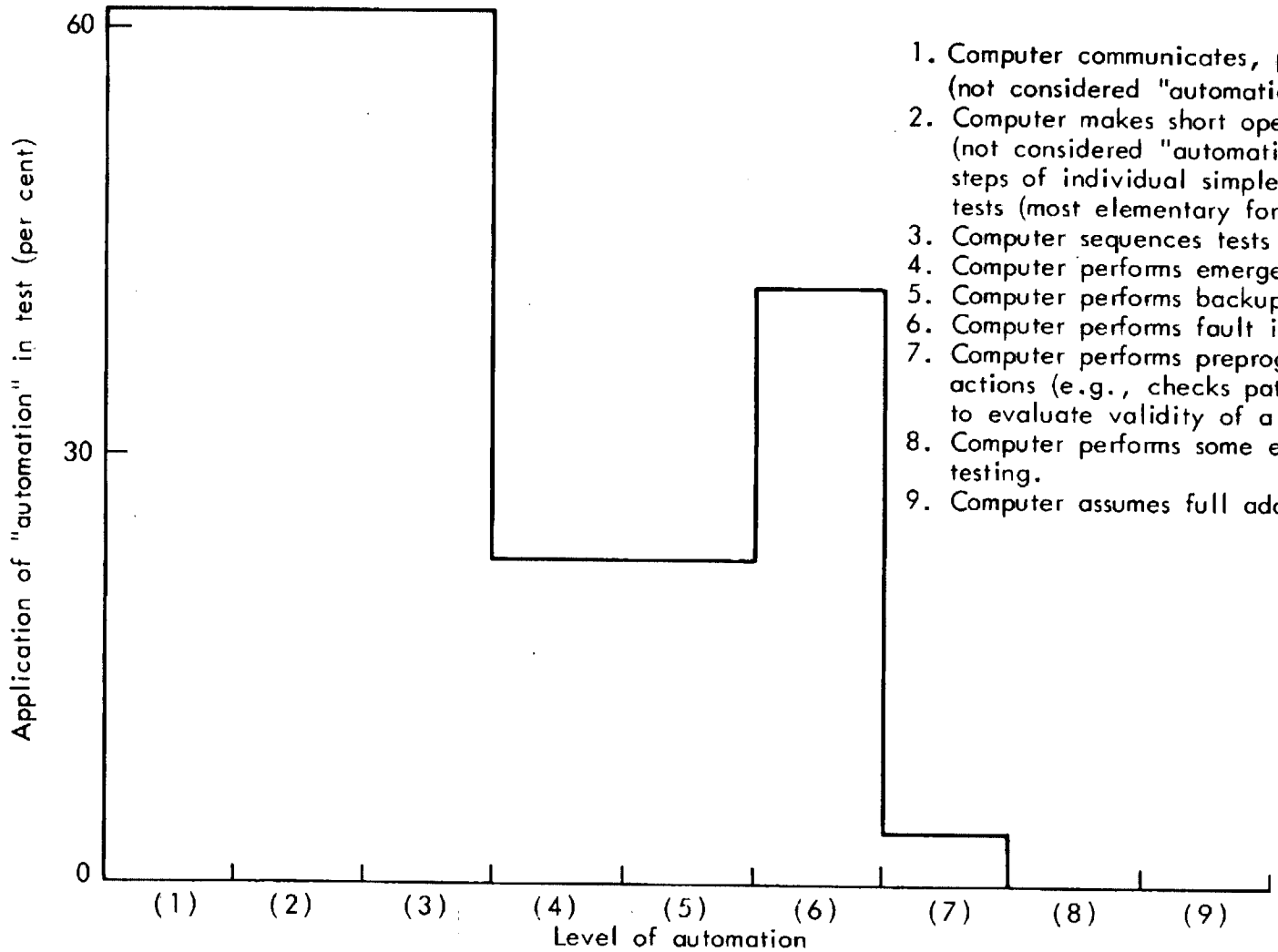
*Plans have since been made to implement this capability.



1. Computer communicates, processes data (not considered "automatic").
2. Computer makes short open-loop sequences (not considered "automatic"); sequences steps of individual simple stimulus-response tests (most elementary form of "automatic").
3. Computer sequences tests and test groups.
4. Computer performs emergency actions.
5. Computer performs backup and restart sequences.
6. Computer performs fault isolation.
7. Computer performs preprogrammed contingency actions (e.g., checks patterns of other measurements to evaluate validity of a no-go).
8. Computer performs some elements of adaptive testing.
9. Computer assumes full adaptive test control.

Fig. E-1—Automation level, S-IC

that achievement of a high confidence level and a history of experience with computer control are considered prerequisites before automating critical tests. This decision is also related to the fact that operations are just beginning at a completely new facility, MTF.

In factory checkout, however, the BEITP and the detailed test programs being prepared indicate the intent to introduce automation as a step function in "conventional" areas, those considered adaptable to automatic control. These include electrical power and networks, instrumentation and telemetry, hydraulic and pneumatic components. Major operations remaining manual are leak testing of pressurized systems and adjustment and calibration of I&T signal conditioning, plus tests of some specialized equipment such as SSB/FM, range safety, TV and camera, etc.

The automatic tests initially implemented will employ some elementary fault isolation routines, but the diagnostic function is considered low priority until some experience has been gained with straight-line checkout sequences. Standard redundancy techniques, such as scanning and checking all other lines when one line is activated, will be incorporated into initial programs. As in other systems, hazardous conditions will be monitored independently by hardwire instrumentation as well as by the computer.

The assembly and testing of the first S-IC stages at MSFC (and the consequent close MSFC/Boeing relationship) undoubtedly will provide the Michoud facility and personnel with sufficient operational checkout experience to simplify startup problems for the testing of the later stages. Even if the checkout equipment were identical, however, such factors as different physical layout and dimensions at the Michoud test cells will impose some perturbations in terms of noise, timing, etc., which in turn will require program reverification and modification.

The absence of a breadboard checkout and simulation facility to check and debug test programs in advance may prove to be a serious handicap. To some extent, this may be minimized by considering the GETS as a minimal simulator and keeping it updated to new stage configurations.

The expected benefits of automation include more comprehensive and repeatable testing, more convenient data analysis, and perhaps some reduction in test time toward the end of the program. In addition, the magnitude of some tests, such as calibration checking of approximately 1,000 instrumentation channels, is great and testing manually might simply make meeting test schedules impossible, regardless of the number of people used.

Conversely, the initial cost of automation, particularly as amortized by only fifteen S-IC stages, is expected to be higher than that for manual checkout. However, such items as improved quality of checkout, personnel training, and future ability to meet accelerated schedules may be considered as long range benefits.

Although the S-IC development is expected to parallel in general the pattern of the S-IB, with MSFC conducting the initial testing and initial debugging and verification, there are some important differences.

Boeing will no doubt benefit from the MSFC establishment of procedures and startup experience, which will simplify the factory acceptance testing at Michoud. However, with the S-IC, there is no long prior history of testing on a very similar vehicle, as in the case of the S-IB where in effect the S-I provided a proving ground for both design and checkout.

Without this prior background, the lack of a breadboard checkout and simulation facility (or an updated, flight-configured test stage) means that checkout procedures and programs are verified on the flight vehicles they must check out. This may cause schedule problems, especially with early stages. In addition, with many modifications to the successive stages, it could prove a burdensome problem throughout the program.

Limited computer speed may affect the amount of dynamic testing performed and the flexibility of non-preprogrammed display operations.

FUTURE AUTOMATION

Without a body of operating experience, it is even more speculative to estimate possible future increases in the application of automation

to S-IC checkout. Nevertheless certain trends appear logical for implementation, while others require extensive tradeoff evaluation.

Assuming that the presently planned automatic tests are successfully performed on the first scheduled stage, it is expected that during the program the following will occur:

(1) Increased preparation and inclusion of diagnostic, fault isolation, and contingency routines with automatic programs. These are within present hardware capability, requiring only test experience and software preparation.

(2) As in other stage checkout facilities, an increase in the use of DDAS is reasonable. This would include more data channels, possibly temporary storage and evaluation of dynamic data to a greater extent, and less reliance on hardwire umbilical connections.

(3) Extension of automatic control into the propellant loading and static firing area, after the computer equipment has been used in a monitoring mode for sufficient time to acquire familiarity with its characteristics and confidence in the programs and contingency routines.

When (3) is implemented, the quantitative increase in degree of automation is estimated at 5-10 per cent, but this is a lesser consideration than the critical nature of the tests.

From a long range viewpoint, favorable consideration may be given to a real-time link between the DEE and the RCA-110A, together with assignment of a limit checking and control function to the DEE. This may well relieve a heavy RCA-110A workload, and add a new capability at moderate cost.

It is also probable that the more convenient data format produced by the automatic system will stimulate a greater effort in trend analysis and failure prediction. Since this is an off-line function, and since it also cuts across organizational lines to the extent that it affects stage design, reliability and checkout, implementation may be relatively slow.

ESTIMATE OF FUTURE STATUS

The transient problems involved in the transfer of checkout responsibility from MSFC to Michoud after the first two flight vehicles

will somewhat inhibit the rate of increase of automation, even though the checkout equipment and programs are theoretically considered as interchangeable between facilities.

With achievement of the initially planned degree of automation estimated by the fifth or sixth flight vehicle, a substantial further increase seems unlikely for the limited number of additional vehicles anticipated. This reasoning is particularly related to the absence of a breadboard facility to develop and verify new tests and computer programs. The operational test cells at Michoud are planned so that configuration updating can be performed at one cell while testing progresses at the others, leaving virtually no "open time" for automation development.

A practical optimum, therefore, would include the present automated tests, plus the substantial task of automating propellant loading and static firing, plus a gradual increase in fault isolation programming. It is emphasized again that a major increase in number of vehicles contracted could well revise the "optimum" estimate.

To a lesser extent, future increases in automation are also limited by the RCA-110A, whose I/O, speed, and memory limitations imply programming difficulties for certain aspects of testing.

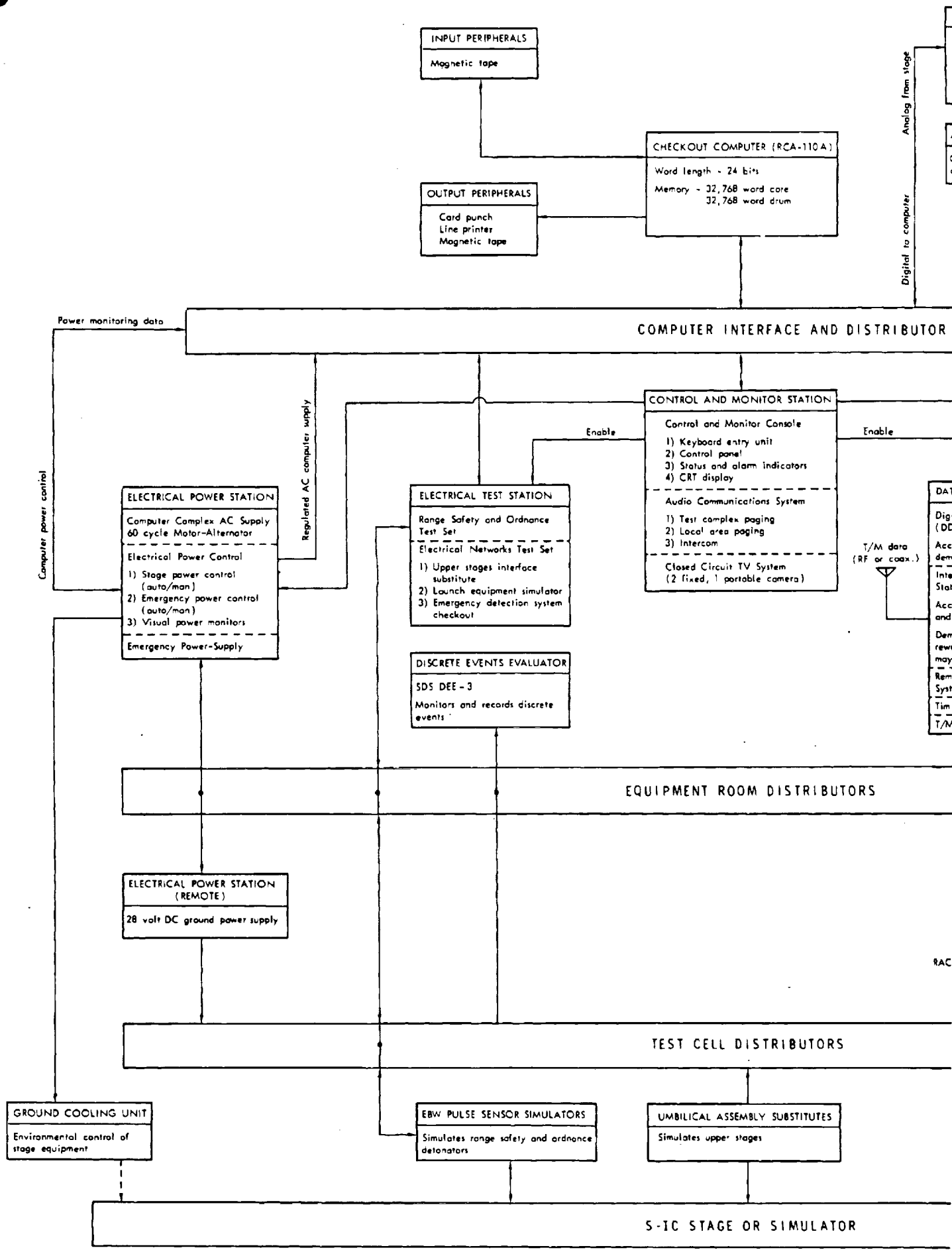
Appendixes

S-IC STAGE CHECKOUT SYSTEM DETAILS

A. FUNCTIONAL BLOCK DIAGRAM OF THE ON-LINE SYSTEM[1]

Figure E-2 presents a functional block diagram of the major on-line components of the S-IC stage checkout system.

In addition to the on-line equipment, a GE-225 computer at Michoud, an IBM-7094 at Slidell, and a GE-235 computer at MSFC (shared with IU Verification) and associated peripheral equipment are utilized as support computers in preparing and verifying check-out programs.



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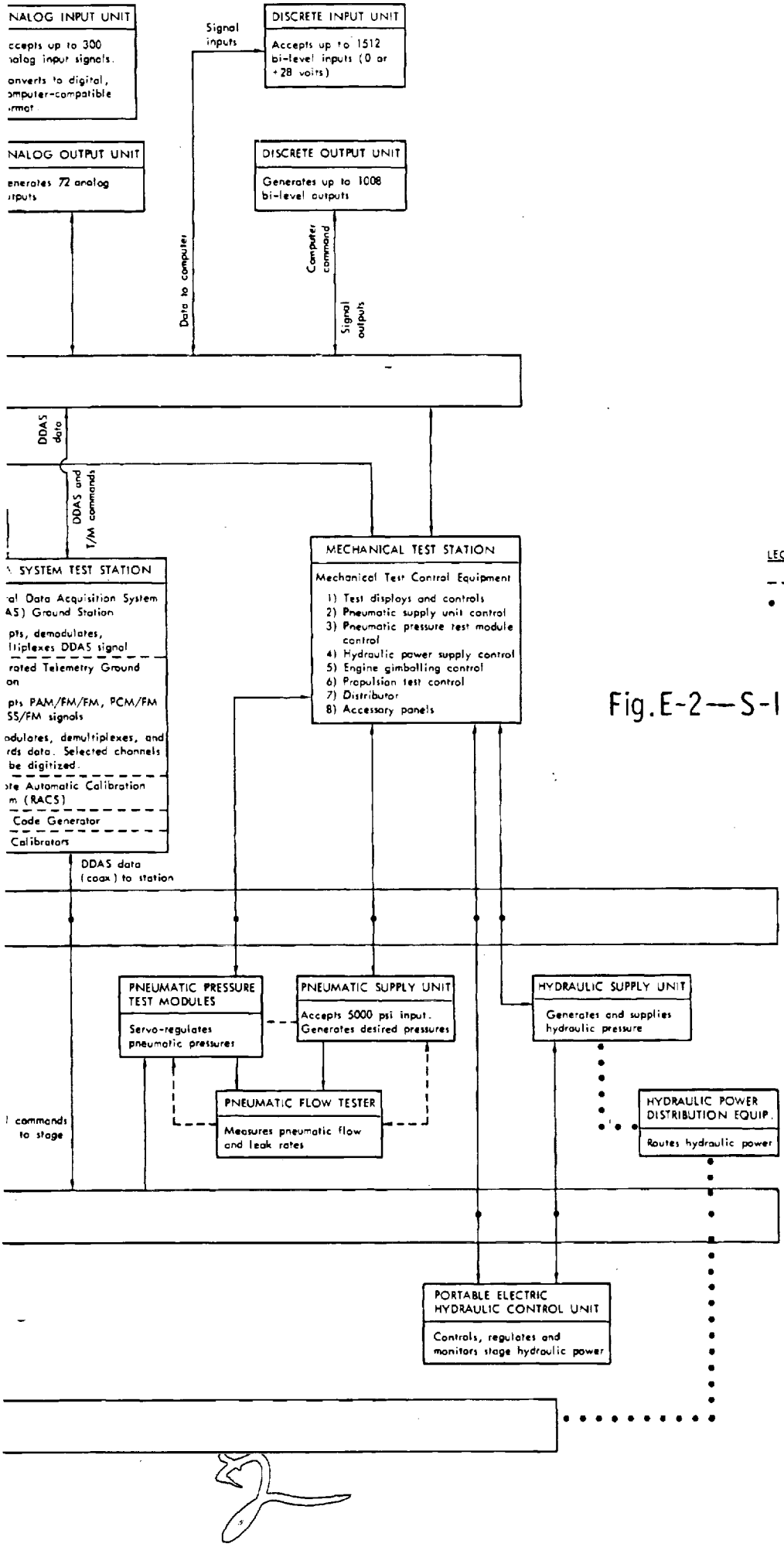

Fig. E-2—S-IC stage checkout system

B. DESCRIPTION--MAJOR COMPONENTS AND FUNCTIONS

(The Boeing Company)

MAJOR ON-LINE EQUIPMENT, COMPONENTS, AND FUNCTIONS[1]

1. Checkout Computer - RCA-110A

   Input - card reader, I/O channels

   Output - line printer, card punch, I/O channels

   Memory - 32,768 word core

   - 32,768 word drum

   Word Length - 24 bits

   Function - Controls execution of test programs

   - Records test results

   - Monitors test stations for instructions

   - Updates all displays

2. Analog Input Unit

   Function - Accepts up to 300 analog signals from stage or GSE, converts selected channels to digital form for computer evaluation

3. Analog Output Unit

   Function - Accepts computer commands, generates up to 72 analog voltages for transmission to stage or GSE as control signals or stimuli

4. Discrete Input Unit

   Function - Accepts up to 1,512 discrete (bi-level 0 or +28 volt) input signals from stage or GSE. Signal lines can be addressed in groups of 24. Selected channels are evaluated by computer under command

5. Discrete Output Unit

   Function - Under computer command, generates up to 1,008 bi-level signals used to drive relays that control or supply discrete stimuli to stage or GSE

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6. Control and Monitor Station

Function - Permits test conductor to monitor, communicate with, and control computer, test stations, and test status

Consists of - Control Monitor Console

- Audio Communication System
- Closed Circuit TV System

(a) Control Monitor Console

Function - Provides manual controls for test suspension, data retrieval, data input to computer, test progress control, treat Test Station enable, and control functions within console

- Permits computer entry, via keyboard, for test instructions, identification, and data
- Monitors critical and hazardous test parameters
- Provides CRT display for supplementary test data in trouble-shooting and maintenance

(b) Audio Communication System

Function - Provides general paging capability throughout the test complex area

- Provides localized paging capability between the test cells, control rooms, test support rooms, and technical offices
- Provides intercommunications among all test stations
- Provides a stage sound monitor system, used in conjunction with a speaker/microphone unit (a listening device during stage leak testing)

(c) Closed Circuit TV System

Function - Provides visual monitoring of stage and test cell activity. Three cameras and monitors are provided for each test cell, two fixed and one portable

7. Electrical Power Station

Function - Controls, distributes, and monitors ground power equipment for checkout system, GSE, and stage

Consists of - Electrical Power Control Equipment

- 400 cycle AC Ground Power Supply
- 60 cycle AC Ground Power Supply

- 28 volt DC Ground Power
- Emergency Power Supply
- Ground Cooling Equipment

(a) Electrical Power Control Equipment

Function - Controls application of AC and DC power to the stage and GSE

- Controls emergency power to the stage
- Monitors all critical voltages, currents, frequencies for both stage and GSE power
- Permits either automatic or manual control

(b) 60 Cycle AC Ground Power Supply

Function - Provides regulated 208-volt, 3-phase, 4-wire, 60-cycle power to the checkout computer and associated peripheral equipment

- Isolates computer power from facility power

(c) 28 Volt DC Ground Power Supply

Function - Provides 28-volt DC to stage buses and systems, under either computer or manual control

- Provides remote voltage sensing capability

(d) Emergency Power Supply

Function - Provides capability to maintain power, with negligible switchover transients, necessary for those stage systems in which power failure might cause a hazardous condition

- Permits switchover to be programmed automatically or made manually

(e) Ground Cooling Equipment

Function - Provides a source of cool conditioned air to temperature-sensitive stage equipment during checkout, under control of the Electrical Power Control Equipment

8. Electrical Test Station

Function - Provides capability, under either automatic or manual control, to check out:

Range Safety System

Ordnance Devices

EBW Pulse Sensors

Electrical Networks

- Provides capability to monitor and record, with time history and out-of-tolerance notation, all discrete or digital event signals

Consists of
- Range Safety and Ordnance Test Set
- EBW Pulse Sensor Equipment
- Electrical Network Test Set
- Digital Events Evaluator

(a) Range Safety and Ordnance Test Set

Function
- Provides capability to test, under either automatic or manual control, the stage range safety command systems and the retrorocket ordnance system, including:

  Command Receivers

  Secure Decoder

  EBW Destruct System Controller

  EBW Firing Units

  Safe and Arm Circuitry

- Provides secure RF link to conduct tests without danger of RF interference

Consists of
- FM Signal Generator
- Test Coder and Power Supply
- RF Distributor
- Displays
- Local/Automatic Control

(b) EBW Pulse Sensor Equipment

Function
- Simulates the EBW detonator circuitry by accepting a command pulse and responding with a signal indicating whether detonation command is received satisfactorily

(c) Electrical Network Test Set

Function
- Simulates interface conditions and signals between S-IC and associated Saturn V stages, to permit checkout under simulated launch environment

Consists of
- Upper Stages Electrical Interface Substitutes
- Launch Equipment Electrical Simulator
- Emergency Detection Checkout Equipment

(d) Digital Event Evaluator

Function - Senses all state changes of discrete events, records data with identification and time correlation

Consists of - Scientific Data Systems 910 Computer with specialized peripheral equipment

9. Mechanical Test Station

Function - Provides capability for computer or manual control of pneumatic and hydraulic tests including:

Application of heater power and thermostat cycling

Performance of all valve operation, timing, and sequencing

Activation of pressure switches

Logging all component cycles to provide running totals

Application of pneumatic and hydraulic pressures to the stage, in the sequences necessary for checkout

Consists of
- Mechanical Test Control Equipment
- Pneumatic Supply Unit
- Pneumatic Pressure Test Modules
- Pneumatic Flow Meters
- Hydraulic Power Supply Unit
- Portable Electrical Hydraulic Control Unit
- Hydraulic Power Distribution Equipment

(a) Mechanical Test Control Equipment

Function
- Provides control, both automatic and manual, of system under test, test stations, malfunction indication and displays major test parameters
- Monitors and controls emergency or hazardous conditions

Consists of - Controls and display for:

Pneumatic Supply Unit

Pneumatic Pressure Test Modules

Hydraulic Power Supply

Engine Gimbaling

Propulsion Test

(b) Pneumatic Supply Unit

Function - Accepts 5,000 psi facility supplies of gaseous helium, and either gaseous nitrogen or dry air, and reduces these facility supplies to a number of lower regulated pressure levels, either for direct application to the stage or further regulation by the pneumatic pressure test modules

(c) Pneumatic Pressure Test Modules

Function - Each module generates a precision regulated pressure upon electrical command through a servo-regulator

(d) Pneumatic Flow Meters

Function - Measures pneumatic leakage and flow rates during tests, and provides data to Mechanical Test Control Equipment

(e) Hydraulic Power Supply Unit

Function - Supplies hydraulic fluid to the stage for bleeding and filling operations, proof testing, engine start and engine gimbal tests

(f) Portable Electrical Hydraulic Control Unit

Function - Provides capability, in the immediate vicinity of the stage, for regulating fluid pressure and flow, shutting off the Hydraulic Power Supply Unit, and decreasing hydraulic pressure to zero at the umbilical connections

(g) Hydraulic Power Distribution Equipment

Function - Routes and distributes hydraulic power from the Hydraulic Power Supply Unit to the stage test cells

10. Data System Test Station

Function - Accepts telemetry data from stage in various forms, demodulates and records signals

- Converts selected data to computer and compatible form for evaluation
- Provides capability to check out all stage instrumentation channels and flight telemetry equipment
- Provides capability to furnish automatic calibration signals to instrumentation channels

Consists of
- DDAS Ground Station
- Integrated Telemetry Ground Station
- RACS

(a) DDAS Ground Station

Function
- Accepts DDAS signal (600 kc carrier, frequency modulated by data pulse train) on coaxial line from stage and records data
- Demodulates, demultiplexes, resynchronizes selected data words for transmission to computer
- Provides capability to adjust and calibrate input channel transducers and signal conditioners

(b) Integrated Telemetry Ground Station

Function
- Accepts RF or composite signals from 3 PAM/FM/FM, 2 SSB/FM and 1 PCM/FM stage telemetry systems, either via air link or on coaxial cable
- Demodulates and records data
- Converts selected data to computer-compatible form for evaluation
- Provides capability to measure RF parameters
- Provides timing signals for reference and synchronization
- Provides T/M calibration equipment
- Provides capability to adjust and calibrate input channel transducers and signal conditioners

(c) RACS

Function
- Provides calibration signals, under automatic or manual control, to all stage instrumentation channel signal conditioners
- Provides ability to select channels, either singly or in groups, for calibration
- Provides lamp display of channel status

C. BASIC SOFTWARE

GENERAL

The on-line operating system for the RCA-110A used by MSFC and Boeing for S-IC factory checkout provides: (1) the general purpose control for sequencing automatic functions, performing limited semi-automatic test functions, and requesting semiautomatic display functions, and (2) the necessary subroutines and table structures to provide a rather complete implementation of ATOLL (Revision B, modified). These programs are called collectively the ATOLL Operating System.[2,3,4]

The Boeing MSFC system is basically ATOLL oriented. It has the usual ATOLL capability to execute machine-language routines. About 70 per cent of the coding (expressed as number of machine words) will be in ATOLL. At present, the ATOLL translator and operating system are working, although not in final form, and Boeing states that coding of first version test programs is 80 per cent complete.

ATOLL statements are preprocessed off-line into (1) subroutine calling sequences including data contained in the ATOLL statement, and (2) references within the calling sequences to the appropriate analog interface data table. (The interface table is also available to machine-language programs, and may be displayed and modified on-line in the semiautomatic mode.) Preprocessing is at present performed on an IBM-7094, but a program for the GE-235 is in process.

No software simulation is yet included in the system, but Boeing states that some activity in this direction is in progress. However, extensive error checking, updating, and editing capabilities exist with the IBM-7094 and GE-235.

The basic operating system is shown in outline in Fig. E-3. This makes evident the sharp distinction between semiautomatic and automatic operation. For example, no provision is made for display monitoring of operator-selected points while an automatic program is running. This is regarded as unnecessary for factory checkout, although static firing may impose different conditions.

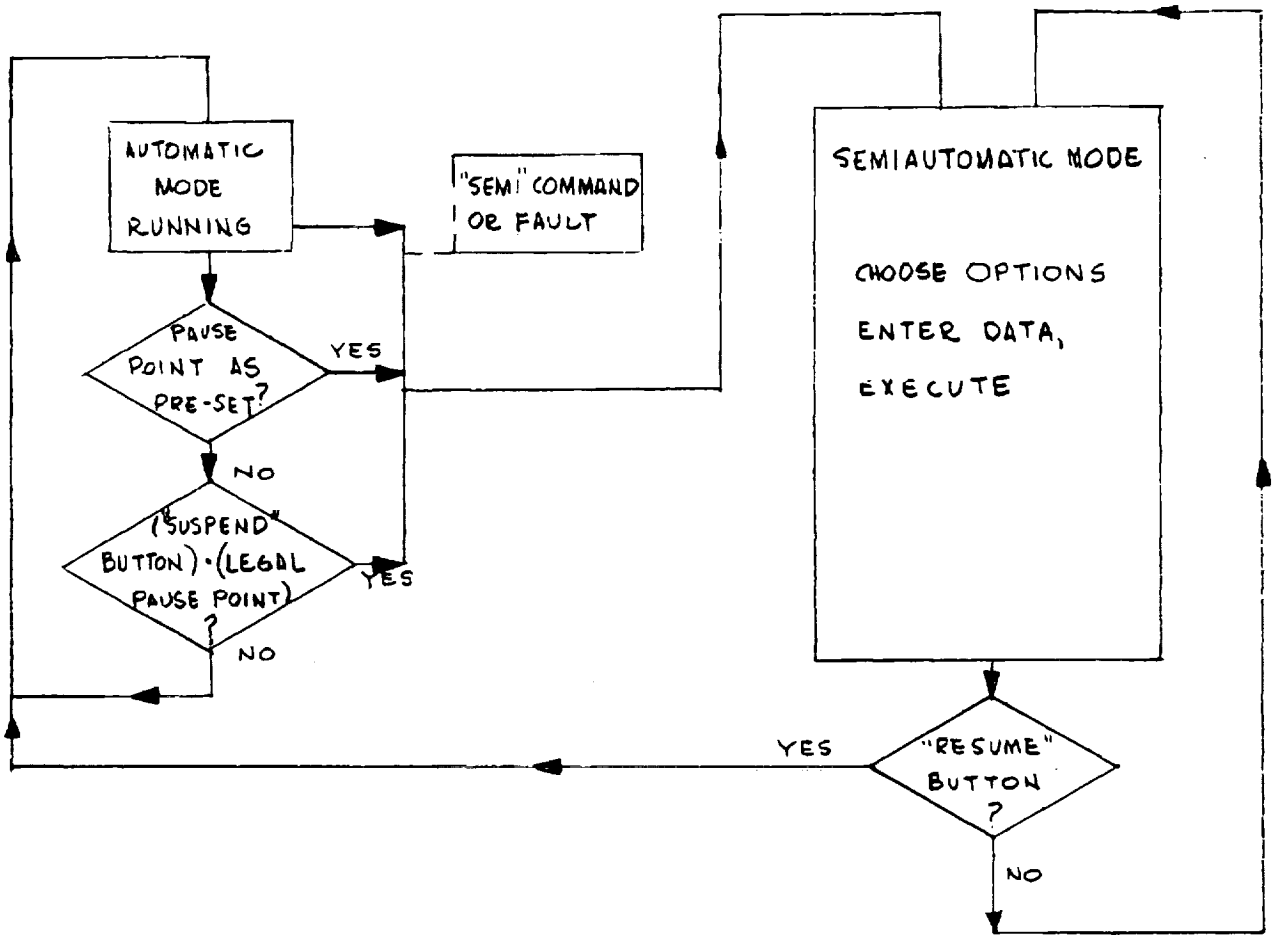

Fig.E-3—On-line basic software, S-IC

The ATOLL Operating System, including ATOLL subroutines, occupies about 12,000 words of memory. Most of the remainder is allowed for the calling sequences and data tables for specific programs. Data tables are variable in size depending on the program demands. An overlay (load-while-compute) function is not provided, since there is no provision for look-ahead in the CALL statement. (Factory checkout speed requirements make this unnecessary.) All subroutines are loaded with each main program before execution.

Operating speeds of the system have been chosen to be compatible with relay speeds. For example, execution of a typical ATOLL statement takes about 10-50 milliseconds, exclusive of GSE and system response delays. There is normally no appreciable delay or "housekeeping" between Substeps. At the beginning of a Test Step, about 100 milliseconds is used in "housekeeping." Timing is important only in the Overall Test, which is run with an external countdown clock.

TEST PROGRAM OPERATION AND AUTOMATIC-MODE HOUSEKEEPING

The Automatic mode program logic is shown in Fig. E-4. Of major importance is the hierarchy of program subdivisions:

1. Program Sequence: The entire array of test programs to be run at one sitting, as pre-chosen arbitrarily by the test supervisor when he enters his "precedence list."
2. Test Program: A major automatic program, perhaps testing a complete system within the vehicle. Always begins with a Beginning of Execution (BOEX) operator, which ensures that the equipment is configured properly to perform the test program. Always includes a Beginning of Shutdown (BSDN) operator. Always ends with an END operator.
3. Test Block: A subdivision of a test program, testing some aspect of the system's performance. Within one program, each test block starts from a configuration common to all blocks in that program, and returns to this configuration at the end of the block. Always begins with a Beginning of Test Block (BOTB) operator.
4. Test Step: A subdivision of a test block, which typically performs one associated set of stimulus, measurement evaluation, timing, and recording operations. The program may hold (suspend) at the end of a test step without danger.

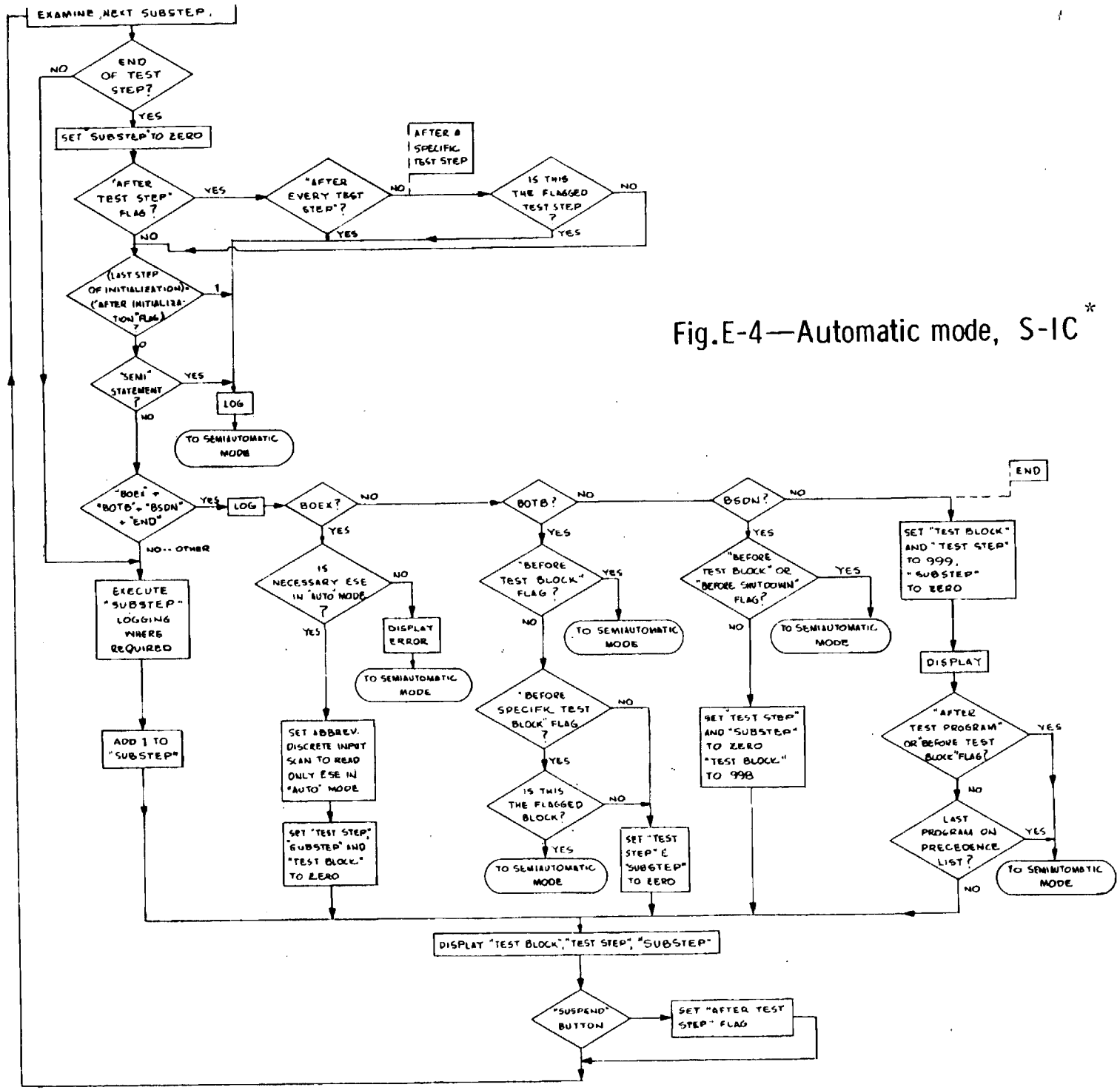

Fig. E-4—Automatic mode, S-IC*

*This is no longer an exact representation.

5. Test Substep: An elementary operation within a test step, for example, an ATOLL statement.

Testing ideally proceeds from the beginning of the first program in the precedence list through the end of the last program in the precedence list, without interruption except by semiautomatic statements when a routine manual function must be performed. For the more usual case, the operator may set the program to stop at any particular test step, before every test block, after initialization, before shutdown, before some specifically named test block, and after every test program. He may also press the Suspend button at any time, and the program will stop at the next safe point (end of the current test step).

SEMIAUTOMATIC MODE

Control is provided by the Option button, which allows programmed operator choices. While waiting for commands, the program merely cycles in a monitoring loop, waiting for and acting on commands. No "continuous" display function is provided, although there is a programmed "display routine" associated with all hold points.

The display system has separate logic and a 2,000-word memory, and has some controls of its own that are not shown in Fig. E-5 (e.g., Erase), even though they may have minor effects on the program.

The option system is entered by pressing the Option button. The display then indicates which options are available. The operator selects one by entering the indicated number on the keyboard. The display then gives him additional instructions for activating that option from the control buttons or display keyboard.

Two of the options can result in immediate action: the Command Mode option and the Display option. The Command Mode option permits execution of a limited subset of ATOLL directly from the keyboard, by typing in the command. The subset is limited to discrete inputs and outputs, scans, analog reads, analog outputs, and setting timers or flags. The Display option permits the operator to request a display of a data table in the program, display of historical data on some

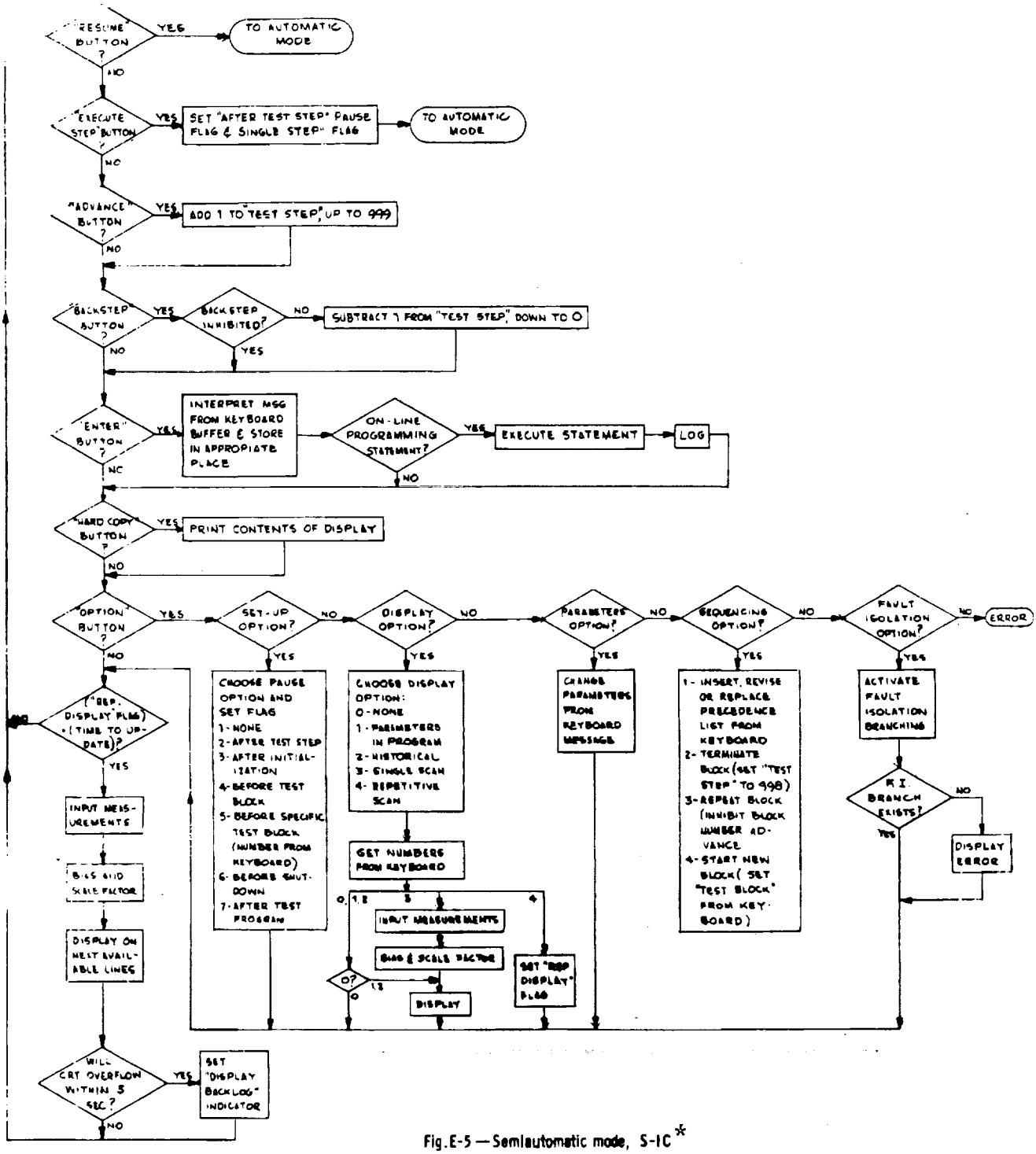

Fig. E-5 — Semiautomatic mode, S-1C*

*This has been changed since the survey was performed.

point for which historical data are kept by the program, or performance of the display routine, which has been preprogrammed for the point at which the program is holding.

Other options, in effect, modify future operation of the program. The Setup option sets up the conditions under which the program will pause, as mentioned earlier. The Delete and Restore options permit on-line deletion and restoration of steps and substeps. The Override and Clear option permits overriding discrete-input no-gos and changing the reference profile to the actual profile. The Fault Isolation option permits the program to resume at a fault isolation branch, after having stopped for a no-go. If no such branch has been programmed, the operator is so informed. The Critical Scan and Limited Scan options are standard ATOLL variations of the Scan operator. The Parameter Manipulation option permits the operator to change the data tables generated by the ATOLL program (tape), and ATOLL statement operands. The Sequencing option permits entering or changing a precedence list.

Other options permit repeating a step or substep, starting an arbitrarily selected block, starting the shutdown block, entering fully manual operation, or simply resuming automatic operation.

EMERGENCY AND INTERRUPT OPERATIONS

The Emergency automatic interrupt (from GSE) causes immediate transfer to an emergency shutdown routine that is part of each Test Program. Varying the routine as testing progresses (by means of a Post Emergency Shutdown operation) is being considered, but is not yet considered necessary for factory checkout.

Other uses of interrupts are for the normal peripheral functions. Because of the relatively relaxed environment of factory testing, extensive use of interrupts has in general been regarded as an unnecessary and possibly dangerous complication.

Manual shutdown is performed by entering semiautomatic mode via the Suspend button at the end of the current test step, and choosing the Shutdown option.

Echo-check (check of discrete-output profile after each such output command) is not provided for discrete outputs.

Operations involving the computer are expected not to involve the separate manual controls. Manual control may be initiated as a computer option. Semiautomatic operations will of course be mixed with automatic ones.

There is no provision for Post Backup routines within a test block. Backing up within a block is not an option, although steps and substeps may be repeated. The block structure makes block-to-block Post Backup unnecessary. There is nothing specifically called Hold or Stop, but the hierarchy of test subdivision makes this unnecessary and may be more flexible.

There is no provision for multiprogramming, which is regarded as unnecessary in this situation.

The operator is prohibited from skipping Shutdown section, except by selecting the fully Manual mode, which removes all program control.

Annex E

REFERENCES

1. The Boeing Company, Launch Systems Branch, Stage (S-IC-I)--End Item Test Plan, MSFC Drawing 66B10901, rev. November 10, 1964.

2. The Boeing Company, Saturn Booster Branch, Checkout Monitor Program, Document No. SK66B-7423-RP-0003 (Preliminary), May 5, 1964.

3. The Boeing Company, Launch Systems Branch, Boeing ATOLL Test System Functional Specifications, Document No. D5-11435, December 16, 1964.

4. Charts presented by The Boeing Company to the MSFC Automation Sub-board 4 on September 24, 1963 and February 13, 1964.

Annex F

S-II STAGE CHECKOUT

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CHECKOUT CONCEPT AND OBJECTIVES

BACKGROUND DATA

Design and checkout of the S-II stage are the responsibility of the Space and Information Systems Division, North American Aviation, under the technical cognizance of MSFC.

Engineering functions for both vehicle and GSE design are located at Downey, Calif. Factory acceptance testing is conducted by the Manufacturing Department at the Seal Beach (Calif.) facility, subject to MSFC Quality and Reliability Assurance (Q&RA) Laboratory approval. Static firing and post-static testing will be conducted at NASA's Mississippi Test Facility (MTF) as a responsibility of the Test and Operations Department, with captive firing procedures and post-static checkout approved by NASA MTF personnel.

The Test and Operations Department also conducts R&D testing at the Santa Susana Flight Laboratory (SSFL) in California and has responsibility for installation and operation of the Electro-mechanical Mockup (EMM) at Downey, which is the S-II breadboard checkout facility and stage simulator.

A battleship stage has been tested manually at SSFL, with emphasis primarily upon propulsion system components. Originally, SSFL was also scheduled to check out an all-systems vehicle under computer control. This plan has been altered and all computer checkout equipment removed from SSFL.

This S-II-T test stage will serve both as an all-systems vehicle and as a facilities-checkout vehicle. Partial acceptance testing, on a manual basis, will be performed at Seal Beach, with shipment to MTF scheduled for September 1965. Final assembly and manufacturing modifications will take place at MTF prior to pre-static checkout. Checkout and static firing of S-II-T at MTF are scheduled to begin in October or November 1965, on an automatic basis (except for static firing) if checkout hardware and programs are complete.

It is anticipated that the first computer-controlled checkout at Seal Beach will be performed on S-II-I, the first flight stage. Checkout for S-II-I is presently scheduled to commence in January 1966.

Two separate checkout stations are scheduled for Seal Beach and one for MTF, plus the EMM at Downey, apart from off-line support equipment.

STAGE DESCRIPTION[1,2]

The S-II stage, the second stage of the Saturn V launch vehicle, is approximately 81 ft long and 33 ft in diameter, with a main stage propellant capacity of 930,000 lb, and a rated thrust of 1,000,000 lb. Flight duration is 395 seconds, thus increasing the vehicular velocity from about 5600 mph to 16,500 mph and the altitude from about 40 miles to 113 miles.

Major S-II systems (grouped for convenience in checkout) are as follows:

1. Electrical Power System--This includes a 7-bus power distribution network, power transfer switching between ground power supplies and in-flight power, and batteries for providing flight power.

2. Switch Selector--This is a solid-state decoder that receives digital coded pulses from the LV IU and sends outputs to a relay controller that controls the various stage systems.

3. Flight Measurement System--This consists of all instrumentation to collect and transmit stage measurements, including transducers, signal conditioners, and telemetry equipment. System capacity is approximately 1,200 separate measurement signals. Telemetry systems include PCM/FM, SSB/FM and PAM/FM/FM.

4. Flight Control System--This consists of 4 hydraulic systems to provide power for gimbaling each of the 4 outboard engines. Each system has one pitch and one yaw electrically controlled, hydraulically operated servo actuator with electrical feedback, a main pump, and auxiliary motor pump and an accumulator reservoir manifold assembly.

5. Propellant Dispersion System--This system provides flight and range safety in the event of deviation from the assigned flight corridor, by initiating engine shutdown, spacecraft separation, and propellant tank detonation upon receipt of ground commands.

6. Separation System--An ordnance system consisting of linear-shaped charges initiated by EBW detonations,

designed to fire the S-II ullage rockets, complete second plane separation and S-II/S-IVB separation, and fire S-II/S-IVB retrorockets.

7. Propellant Management System--This provides control, monitoring, and checkout capability for propellant utilization, loading, quantity indication, and depletion engine cutoff.

8. Pressurization System--This system (a) supplies ullage pressure, using helium gas, for the propellant pump requirements, (b) provides venting, (c) furnishes pneumatic pressure to actuate the engine recirculation system valves, and (d) monitors for over-pressure conditions.

9. Engine Systems--Each of the 5 J-2 engines operates in association with the Propellant Feed System, which supplies propellant and the Recirculation System, which circulates the propellants through the main fuel pumps and back into the tanks. Engine servicing subsystems include the turbopump purge, hydrogen and oxygen pump seal drains, engine helium tank fill, hydrogen start tank fill, hydrogen start tank vent control and relief, thrust chamber purge and chill, and engine failure shutdown subsystem.

DESCRIPTION OF TESTS[1]

The following test sequence is representative of a factory acceptance and pre-static checkout sequence at Seal Beach, and static and post-static testing at MTF.

Test	Description
GSE Verification	
G-1	Computer Complex Verification--to verify proper operation of the checkout computer and peripheral equipment, including:
G-1a (NAA Test No. 07T000-101-00)	(a) Memory Test--checks the ability of the computer to store and recover information in each memory location

Test	Description
G-1b (NAA Test No. 07T00-102-000)	(b) Instruction Test--checks the ability of the computer to execute instructions and recover information from each word (24-bit) memory location
G-1c (NAA Test No. 07T000-103-00)	(c) Input-output Test--consists of peripheral equipment input-output selection instructions that verify operation of the following: Line Printer Card Reader Card Punch Controller Magnetic Tape Synchronizer and Tape Units Console Paper Tape Reader and Punch
G-1d (NAA Test No. 07T000-104-000)	(d) Echo Check--verifies the interface between the computer and each of the following: Test Conductor Console Electrical Test Station DDAS Test Station Telemetry Test Station
G-1e (NAA Test No. 07T000-105-000)	(e) Test Conductor Console Computer Control Test--checks the ability of the Test Conductor Console to control the computer
G-1f (NAA Test No. 07T000-106-000)	(f) Alphanumeric Display Acceptance Test--verifies the proper operation of the display unit located in the Test Conductor Console
G-2	Electrical Test Station Verification--programs to self-test the operational readiness of the Electrical Test Station, including: (approximately 12 routines)
G-3 (NAA Test No. 07T000-140-000)	DDAS (Digital Data Acquisition System) Test Station Self-test--a self-test of DDAS by execution of all station commands that can be automatically verified

Test	Description
G-4	Ground Equipment Test Set (GETS) Test--to verify the overall checkout system and GSE operation and GSE/stage compatibility. Provides functional responses to checkout system and simulates stage interface
Stage Verification	
Pre-test	Stage Receiving Inspection--visual inspection to verify component status, cable connections, cover installation, cleanliness levels, etc.
Pre-test	Installation in Test Cell and GSE/MSE Connection Test--includes S-II mounting and installation, electrical and mechanical interface verification, continuity tests and connection to GSE and MSE
1	Continuity Compatibility Test--resistance check of vehicle interface and umbilical connections, to assure absence of short circuits and stage readiness for power
2 (NAA Test No. 07T000-150-000)	Electrical Power System Test--to verify the integrity of the Power Distribution System and its control circuitry. Energizes and checks voltage levels and operating sequences of stage ground power buses and flight buses. Verifies timing and operation of power transfer switches
3 (NAA Test No. 07T000-159-000)	Switch Selector Test--to verify proper operation of the solid-state decoder that normally receives commands from the IU and in turn controls operation of S-II stage systems. Checks timing of decode and operate functions and verifies that Switch Selector is ready for use but does not check stage systems control channels

Test	Description
4 (NAA Test No. 07T000-151-000)	Measurement System Test--to verify the operation and calibration accuracy of instrumentation channels and telemetry equipment. These include:
4a	(a) DDAS vs. Hardwire--end-to-end verification of DDAS channels, including a RACS high-low-run check, and a comparison against hardwire inputs
4b	(b) DDAS vs. PCM/FM--to compare PCM/FM data through the RF loop (via coaxial cable) with equivalent DDAS channels
4c	(c) RF Systems--checkout of RF characteristics of telemetry equipment, including frequency, power, deviation, etc.
4d	(d) PAM/FM/FM--checkout of PAM/FM/FM systems through the RF loop (via coaxial cable) from the stage to the telemetry ground station, including a high-low-run RACS test.
4e	(e) Integrated Flight Measurement System--checkout of IFMS with comparison of coaxial cable and RF air link data, and recording of all in-flight calibration commands
5	Measurement System Test--manual and/or semiautomatic tests to verify operation and calibration accuracy of telemetry ground ground stations and stage transducers and signal conditioning equipment. These include:
5a	(a) Some system tests not implemented in 4c
5b	(b) SSB/FM--checkout of SSB/FM systems with calibration signals monitored by visual and tape recorders
6 (NAA Test No. 07T000-156-00)	Flight Control System Test--verifies the ability of the Flight Control System to precisely control the gimbaling of the four outboard rocket engines. Hydraulic pressure supplied by the auxiliary motor pump and accumulator reservoir is checked, pitch and yaw actuators are cycled, and operations of flight control functions of Switch Selector Channels are verified.

Test	Description
7 (NAA Test No. 07T000-157-000)	Propellant Dispersion System Test--to verify that commands are generated in proper sequence to allow engine shutdown, spacecraft separation, and propellant tank detonation. Checks ground radio command system, airborne receivers and controllers, and operation of pulse sensors that simulate dispersion detonators
8 (NAA Test No. 07T000-153-000)	Separation System Test--verifies commands to S-II ullage rockets, second plane separation, S-II/S-IVB separation, and retrorocket EBW detonators. Checks out individual Switch Selector and Controller channels and performs end-to-end verification to pulse sensors that simulate separation detonators
9 (NAA Test No. 07T000-155-000)	Propellant Management Test--to check out propellant utilization, loading quantity indication, and depletion engine cutoff subsystems. Electronic controllers are checked out by simulating open circuit, dry and wet sensor conditions. Engine cutoff subsystem is validated by sequentially operating the controllers to verify the depletion signal gates, and to check for proper timing
10 (NAA Test No. 07T000-154-000)	Pressurization System Test--to verify correct operation of pressurization system components. Includes functional checks of solenoid valves, vent valves, tank pressures, pressure regulators, and the actuation portion of the recirculation system
11	Leak Tests--a series of manual tests performed in conjunction with Pressurization System checkout programs. Includes visual and mechanical inspection of all critical components such as valves, regulators, fittings, etc., under pressurized conditions to determine if and where leaks exist
11a-d	Performed on 4 major subsystems

Test	Description
12 (NAA Test No. 07T000-152-000)	Engine Systems Test--to verify operation and timing sequences of engine systems, which include Prepellant Feed System, Recirculation System, and Engine Servicing System. Test includes time-critical sequences for each engine individually and then as a cluster. Propellant Feed and Recirculation Systems are checked for correct valve actuation and positioning, with critical valves checked for actuation time. Primary engine system commands received by the engines from the IU Switch Selector are verified
13 (NAA Test No. 07T000-158-000)	Integrated Systems Test--to verify the countdown operations and flight readiness of the complete S-II stage and its characteristics. Specific tests include:
13a	(a) Electrical Power System Check--verifies electrical power system readiness
13b	(b) Measurement System Check--verifies calibration and readiness of all instrumentation and telemetry channels
13c	(c) Networks Checkout--verifies all electrical and electro-mechanical systems (less those operated in the Simulated Flight Test below) for functional readiness
13d	(d) Simulated Countdown--tests preparatory operations and procedures for all countdown and prelaunch activities
13e	(e) Simulated Flight--tests all flight operations from liftoff through S-IVB separation, both with umbilicals connected and disconnected
13f	(f) Measurement System Check--repeats test to ensure accurate calibration of test data
14	RF Compatibility Test--to verify that no interaction exists among stage RF systems and other stage electrical/electronic equipment. Systems are activated individually and in combination while being monitored for interference effects

Test	Description
15	Range Safety System--to verify functional operation of the Range Safety System, conducted both on a closed-loop (coaxial cable) and open-loop (air link) basis
16	Electromagnetic Interference Tests--a qualification acceptance test to the requirements of MIL-E-6051C, with the level of detail determined by QC representatives
17	Data Evaluation--final evaluation of data before removal of stage
Post-test	Disconnect GSE/MSE--progressive safing of all systems followed by disconnection of GSE/MSE lines, fittings, cables, couplings, etc., and installation of protective covers
Post-test	Weight and Center of Gravity--physical determination of stage weight and center of gravity, using a weighing stand instrumented with load cell transducers for weight and mathematical calculation of CG from weight data
Post-test	Stage Shipping Inspection--a visual inspection to ensure readiness for shipping
Post-test	Removal from Test Cells-removal of stage for shipment to static firing test site
Pre-test	Mount stage in test stand, instrument, and align
18	Repeat Tests 2 through 15 (with slight variation in detail tests)
19	Checkout of manual controls and displays
20	Tanking and flushing, including chilldown, checkout of instrumentation, hydraulics, engine gimbaling, etc.
21	Static Firing (Short Duration)
22	Integrated Systems Test--with checkout of manual controls. Repeat Tests 21 and 22 for several short-duration firings
23	Static Firing (Full Duration)
24	Integrated Systems Test

Test	Description
Servicing	Clean and purge, remove special instrumentation
25 Post-static	Repeat Tests 2 through 15 (with slight variation in detail tests)
Servicing	Remove from test stand, prepare for shipment

CHECKOUT SYSTEM APPLICATION

The operating concept for the S-II stage checkout system assumes eventual computer control of all test sequences that are practicable for automation. In addition, full concurrent capability for performing any test manually is provided, both as a contractual requirement and as a backup system for contingency operation, troubleshooting, and repair.

Although 100 per cent manual capability is available in the equipment, at present the only formal manual test procedures being prepared are for the hybrid tests of propellant loading and static firing at MTF, and it is intended that automatic programs be applied in all other tests planned for automation. Some use of manual procedures in the "automatic" areas may be required for scheduling reasons. The existence of ATOLL programs can facilitate the generation of adequate manual procedures (particularly if the ATOLL Remarks column has been used effectively).

Manual control is achieved on what might be termed a "translation" basis. Front panel controls are designed to present to the test engineer a group of functions similar to those used with manual test systems, although they may not be arranged physically for optimal manual use. When a control is activated, however, its output is in a form compatible with the digital computer output it replaces, so that the communication equipment and remotely programmable GSE "see" the signal identically to an automatically controlled equivalent (except for the slower rate). This approach combines minimum retraining of test personnel with use of the same communication and control components for either automatic or manual testing.

Under automatic control, at present the computer is excluded from taking part in any emergency or safety reactions, which are activated through separate hardwire instrumentation. This concept may change with increased confidence in computer operation and also increased knowledge of what emergency situations may arise.

The checkout system uses the Control Data Corp. 924A computer as the prime control element, complemented by peripheral input-output and memory storage elements. Through appropriate interface equipment, the computer is linked to a Test Conductor and Display Console and five test stations (Electrical, DDAS, Telemetry, RF, and Pneumatic).

The Test Conductor and Display Console permits the test conductor to enable any test station and monitor test status and results, including hazardous condition control.

The Electrical Test Station generates the proper electrical stimuli for the stage and for control of other GSE such as power distribution equipment and a remote electrical station. It provides test control capability for RF, pneumatic, and hydraulic GSE. In addition, it receives response signals, which are monitored directly, under manual control, or transmitted to the computer under automatic control.

The DDAS Test Station receives pulse-code modulated telemetry data from the stage and converts this into suitable format for computer evaluation. It also provides a capability for calibrating instrumentation channels, including signal conditioning and telemetry components.

The Telemetry Test Station receives PAM/FM/FM, PCM/FM, and SSB/FM telemetry signals, either via air link or coaxial cable, from the stage and records all data with time reference. Selected channels may be converted to computer format and automatically evaluated.

Responsibility for design, manufacture, installation, verification, and operational use of the S-II checkout systems is divided among three departments, Engineering, Test and Operations, and Manufacturing.

The Engineering Department (as part of the vehicle and GSE design and system integration functions) includes both checkout hardware design and software or computer applications groups.

The Test and Operations Department uses the checkout systems at MTF and SSFL, and furnishes support at KSC. It also maintains operational cognizance over the EMM at Downey. In addition to its using function, T&O is responsible for physical installation, debugging, and acceptance testing of the checkout systems themselves. This is usually accomplished with each rack group or functional block of GSE being "bought off" on a modular basis, with final system testing performed with automatic Ground Equipment Test Set (GETS) programs.

The Manufacturing Department, apart from assembling the S-II stages, also constructs the in-house portions of the checkout hardware, working to drawings prepared by Engineering. Manufacturing quality control personnel are also users of the checkout system, with responsibility for performing factory acceptance and/or pre-static testing at Seal Beach, before shipment of the stage to MTF.*

DEVELOPMENT OF TEST REQUIREMENTS AND PROCEDURES(3)

Basic test requirements for S-II systems and subsystems originate with the stage design engineering groups in the form of a "process specification," which describes the purpose of the test, parameter to be measured, allowable tolerances, and any critical sequences.

The process specifications are routed to the Manufacturing and T&O Departments, and to the System Engineering and Computer Applications group within the Engineering Department. Then T&O prepares an end-item acceptance test plan, while a Computer Applications and T&O team translates the process specification into a Program Requirements Document (PRD), which is a preliminary non-contractual item defining the general outline of the automatic test program. After review of the PRD, a Program Description Document (PDD) is then prepared by the same team as a controlled, contractual document. The PDD includes the test description, a full set of detailed flow charts, and the ATOLL test statement printout.

The System Engineering group's function is to prepare overall schematic diagrams, defining interfaces and functional and physical interconnections. Ideally these should be available sufficiently prior to program coding to enable programming to proceed without delay because of inadequate interconnection data.

Within the Computer Applications group, a Requirements section (including engineers and T&O specialists) converts the process specification into the PRD. The test is divided into automatic and manual sequences if necessary, and coordinated with current stage configuration and interfaces. Generalized flow charts are also prepared. The PDD is then prepared from the revised PRD, implementing the test requirements in ATOLL or machine-language form. The final PDD for each test program includes program identification, purpose, scope, stage system description,

*Test operation has since been transferred to Test and Operations.

initial conditions, operating instructions, test sequence description, and ATOLL listing.

Computer operation and processing support are also provided to assist in program development, debugging and verification, to prepare and maintain documentation such as automated wire lists, and signal flow data, and to maintain updated system configuration information.

From the time an approved, fully released process specification is made available to Computer Applications to the completion of the automatic test program has, in the past, involved about six months, although preliminary comment from the programmers back to the stage design engineers may occur after the first month or so. To this interval must be added the preparation time of the process specification itself to arrive at the total time to achieve any automatic program.

During installation and acceptance testing of the checkout system GSE at Downey, Seal Beach, and MTF, T&O personnel use the PPDs, including the basic ATOLL listing, for reference. It is anticipated that heavy use of the ATOLL Text operator and the Remarks column will be of assistance.

PRESENT AUTOMATION LEVEL

Since, at this writing, no S-II checkout station is operational, any estimate of present automation level must be based upon NAA test plans and those software requirements that have been defined.

When the tests listed on pp. F-6 to F-11 are used and the pre-test and post-test procedures and GSE self-test routines are deleted, we estimate the automation to be 60 to 70 per cent. This estimate includes a weighting for the increase in the number of test steps due to automation. It is assumed that when a test is automated, three to four automated test steps result on the average from one manual test step. This is due to a number of factors; measurements are more often performed several times and averaged, test sequences are more often repeated, or more combinations are checked automatically than would be checked manually.

Figure F-1 also shows the level of automation for the S-II system. The computer communicates, processes data, compares limits, and sequences simple test and test groups.

The availability of an Emergency Interrupt entrance (so far not used), the slightly cumbersome entry to a posted Shutdown routine (via the semi-automatic option), and the immediate manual entry to the posted Shutdown routine after no-go provide a good emergency capability, although immediate manual entry at other times involves option selection.

No posting of backup routines, or rules for definition of backup points, are inherent in the software, but some backup provisions are provided by the six recycle-point options and by the ability of the programmer to designate legal entry points.

Fault isolation to the replaceable unit was an objective of some of the early test programming; it has been given lower priority for the time being, but NAA expects to return to it after main-line programs are working. No preprogrammed contingency reactions or adaptive testing are provided, although the semiautomatic modes provide some degree of automatic checking and other assistance to the essentially manual handling of contingencies.

REVIEW OF PRESENT STATUS

Since there has been to date no operational experience with the S-II stage checkout system, a review necessarily is based upon anticipated results, plus problem areas that have appeared so far.

In overall concept, the S-II system is similar to most other Saturn IB/V stage contractors' checkout systems. The central computer complex (CDC-924A) and peripheral equipment are similar to the Douglas S-IVB system, while the 100 per cent manual backup capability for checkout corresponds to Boeing's S-IC system. The decision not to automate propellant loading and static firing initially at MTF also parallels the S-IC case, and was largely at MSFC direction.

Presently, NAA is preparing only automatic test programs for tests intended to be under computer control, indicating that the manual backup test procedures are considered lower priority, and that if possible, automation will be introduced as a step function.

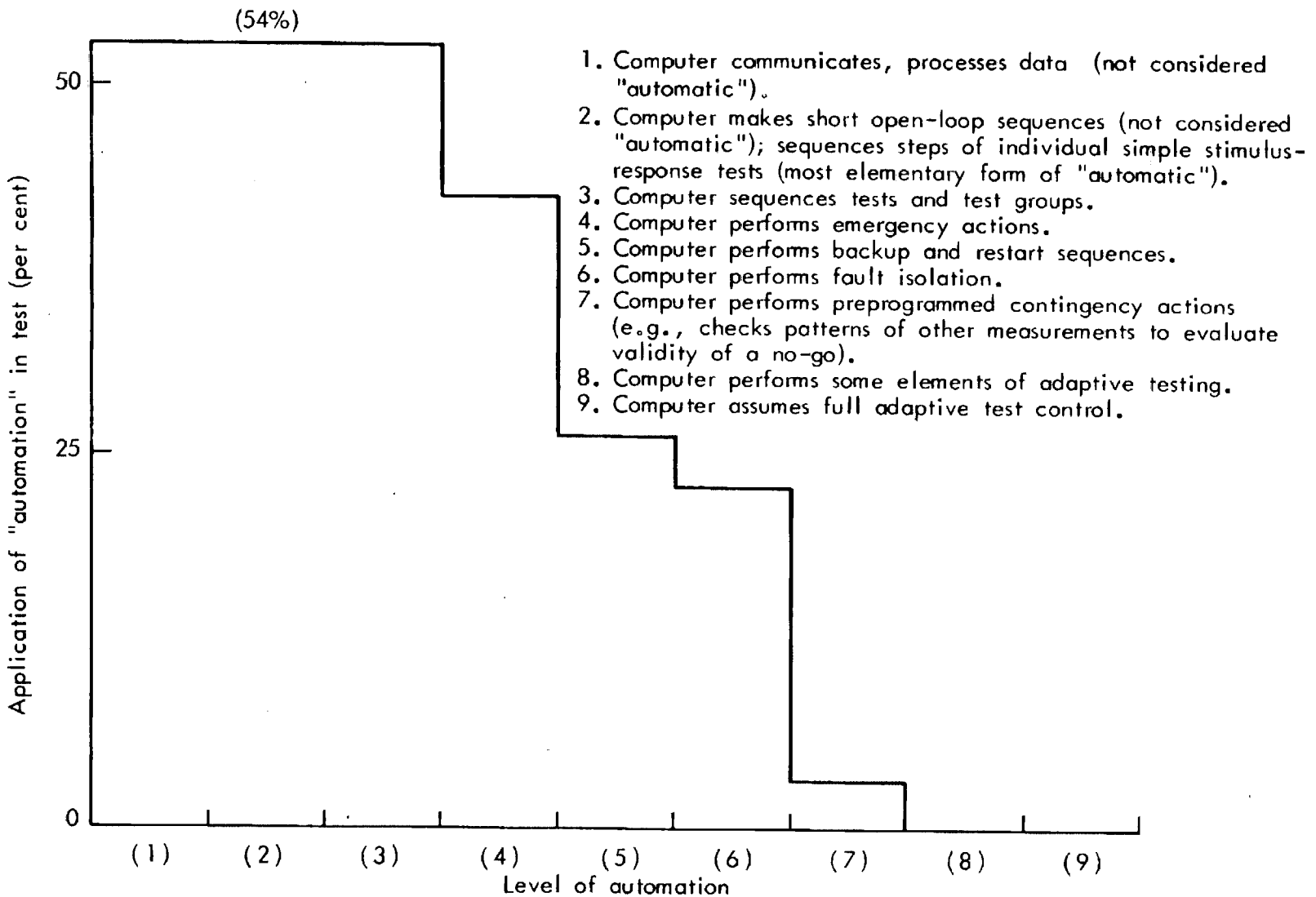


Fig.F-1—Automation level, S-II

In the hardware and software implementation of the checkout system design, problem areas have arisen that appear to present a substantial delaying factor in applying the planned level of automation, at least for the early S-II vehicles. These include:

(1) Completion and acceptance testing of the Electro Mechanical Mockup (EMM) has been delayed to the point where its utility as a program and hardware verification facility and stage simulator is questioned, since there may be insufficient time available on the EMM to achieve these goals and still meet present stage delivery schedules, particularly if the EMM is to be updated to match vehicle configuration.

(2) There are at this writing some equipment performance problems in the Electrical Test Station. These include both generalized problems, such as noise and transient pulses, and lack of specific capability for certain tests. As an example of the latter, measurements of valve timing characteristics cannot be performed simultaneously for the five J-2 engines due to limitations in scanning speed.

(3) The preparation of computer programs has also been delayed, to some extent by changing requirements, but possibly to a greater extent by the need for programming personnel to gather detailed interface information from multiple sources in a cumbersome data communications process.

These problems are typical of a complex program. However, the magnitude of the difficulties might have been anticipated somewhat by an earlier, in-depth, system requirement definition by a centralized group with authority for establishing and maintaining control of interfaces, both stage/GSE and GSE/GSE.

To some extent, the traditional organization of airframe divisions compound this problem. The EMM, for example, was designed by Engineering, built by Manufacturing, and installed, tested, and operated by Test and Operations. This is not unusual, and has certain advantages, but it magnifies the information flow and feedback difficulties met in initial debugging of the system (including its software). If the EMM

is considered primarily as a breadboard and verification tool, rather than a personnel trainer, the importance of flexibility and quick turn-around time to adapt to changes cannot be overemphasized.

No insoluble problems in eventually achieving the planned level of automation are visualized, but the practical results may be to delay the efficient application of the automated checkout system, with a correlated cost increase for the overall stage checkout function.

FUTURE AUTOMATION

Any estimate of possible future increase in level of automation for S-II stage checkout is speculative since no practical operating experience for the checkout system and software has yet been accumulated. Nevertheless, certain projections appear logical for implementation during the life of the Saturn V program in the natural course of using the equipment and becoming more familiar with its capabilities, coupled with passing the major initial startup perturbation.

Within the present contractual scope it is expected that the following will occur:

Increased preparation and inclusion of side-loop (rather than straight-line sequence) programming and achievement of diagnostic, fault isolation and contingency routines with automatic programs. These are within present hardware capability, requiring only test experience and software preparation.

Following the trend of other stage checkout facilities, an increase in the use of DDAS is reasonable. This would include more data channels, possibly temporary storage and evaluation of dynamic data to a greater extent, and less reliance on hardwire umbilical connections.

Extension of automatic control into the propellant loading and static firing area at MTF. This would come after the computer equipment has been used in a monitoring mode for sufficient time to acquire familiarity with its characteristics and confidence in the programs and contingency routines.

From a longer range viewpoint, and requiring NASA approval and funding, the following possibilities are under consideration at NAA:

A real time link between the DEE and the CDC-924A control computer. This would permit complete on-line evaluation of all hard-wire discrete data as part of a dynamic control-verification system, as well as expediting post-test evaluation of the recorded data.

More comprehensive computer control of non-electrical tests, possibly requiring separate pneumatic, hydraulic, and propulsion test stations. This would be an improvement over interfacing through the Electrical Test Station as at present.

Since all of the above represent major cost and schedule modifications, they are not visualized for near term achievement, and trade-off considerations would have to be evaluated for implementation even at a later date.

As a possible by-product of increased automation, it is also probable that the more convenient data format produced by the automatic system will stimulate a greater effort on trend analysis and failure prediction. Since this is an off-line function, and also cuts across organizational lines to the extent that if affects stage design, reliability and checkout, implementation may be relatively slow.

ESTIMATE OF FUTURE STATUS

It is obvious that an estimate of the future status of S-II checkout automation depends upon the rate of achieving the initially planned operating level, plus a determination of which expansion possibilities may be implemented. The latter particularly will be influenced also by broader considerations of program schedules and costs.

Over the period of development and checkout of the presently contracted 15 flight vehicles, it appears that checkout of several vehicles will be required to reach the primary goal of achieving the full intended use of the computer-controlled equipment. As the program progresses, expected and unexpected modifications in stage configuration will require a continuous level of effort to update test programs and GSE.

These efforts, taken in conjunction with the projected problems with the EMM as a verification facility, indicate that no major increase in checkout automation is likely for one to two years. This may be even more evident at MTF, in terms of eventually achieving automatic control of propellant loading and static firing, because the extensive new facilities and vastly different physical dimensions for equipment, cabling, etc., will impose a second set of step-function constraints beyond those at Downey and Seal Beach.

Appendixes

S-II STAGE CHECKOUT SYSTEM DETAILS

A. FUNCTIONAL BLOCK DIAGRAM OF THE ON-LINE SYSTEM[4,5]

Figure F-2 (p. 23) is a functional block diagram of the major on-line components of the S-II stage checkout system.

In addition to the on-line equipment, a CDC-924A computer and peripheral input-output equipment are used in support to assist in preparing and verifying checkout programs.

B. DESCRIPTION--MAJOR ON-LINE COMPONENTS AND FUNCTIONS [4,5]

1. Checkout Computer - CDC-924A (NAA C7-101, -103, -104, -105)

   Input - card reader, typewriter keyboard, console

   Output - line printer, typewriter, console, card punch

   Memory - 32,768 word core

   - 4 magnetic tape units

   Word Length - 24 bits

   Function - Controls execution of test programs

   - Records and evaluates test results

   - Monitors test stations

   - Updates display

2. Computer Interface Equipment

   Function - Interfaces computer with rest of checkout system

   - Receives, decodes, and stores digital data from or to the computer for appropriate addressing and cycling

   - Provides necessary level or signal conversion

   - Controls timing of communications

   Consists of - Computer Isolation and Drive Rack (C7-109)

   - Buffer Equipment Rack (C7-106)

   - Local Digital Drive Link Rack (C7-107)

   - Remote Digital Drive Link Rack (C7-108)

   (a) Computer Isolation and Drive Rack

   Function - Amplifies and shapes computer outputs so that transmission distances may exceed 50-foot maximum from computer

   - Isolates GSE signal-point ground from computer-signal ground through gating and isolating transformers

   - Provides capability to switch computer control between Computer Console and Test Conductor Console

   (b) Buffer Equipment Rack

   Function - Interfaces computer complex and Test Stations

   - Provides storage, timing, logic and signal conversion as required

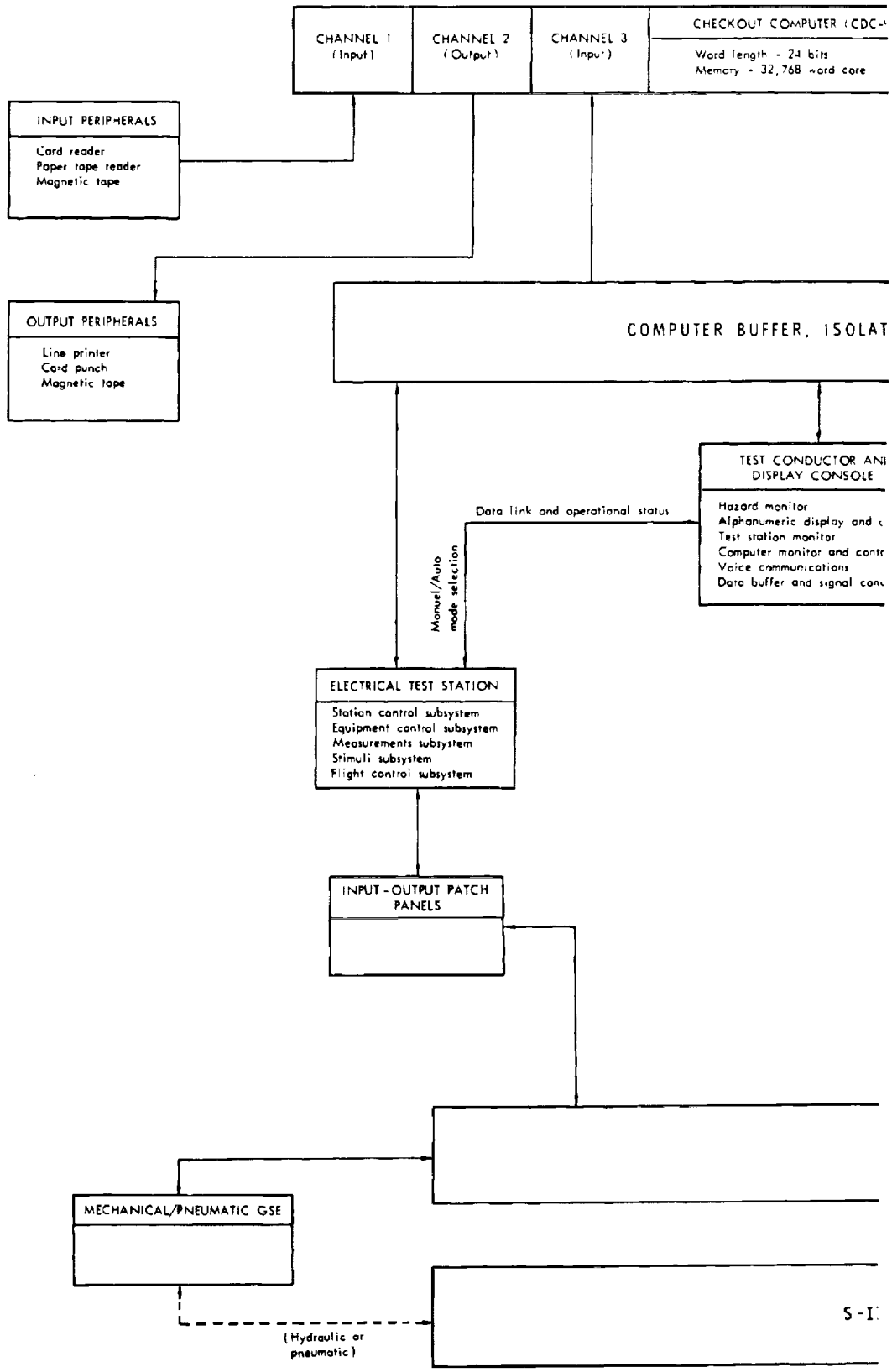
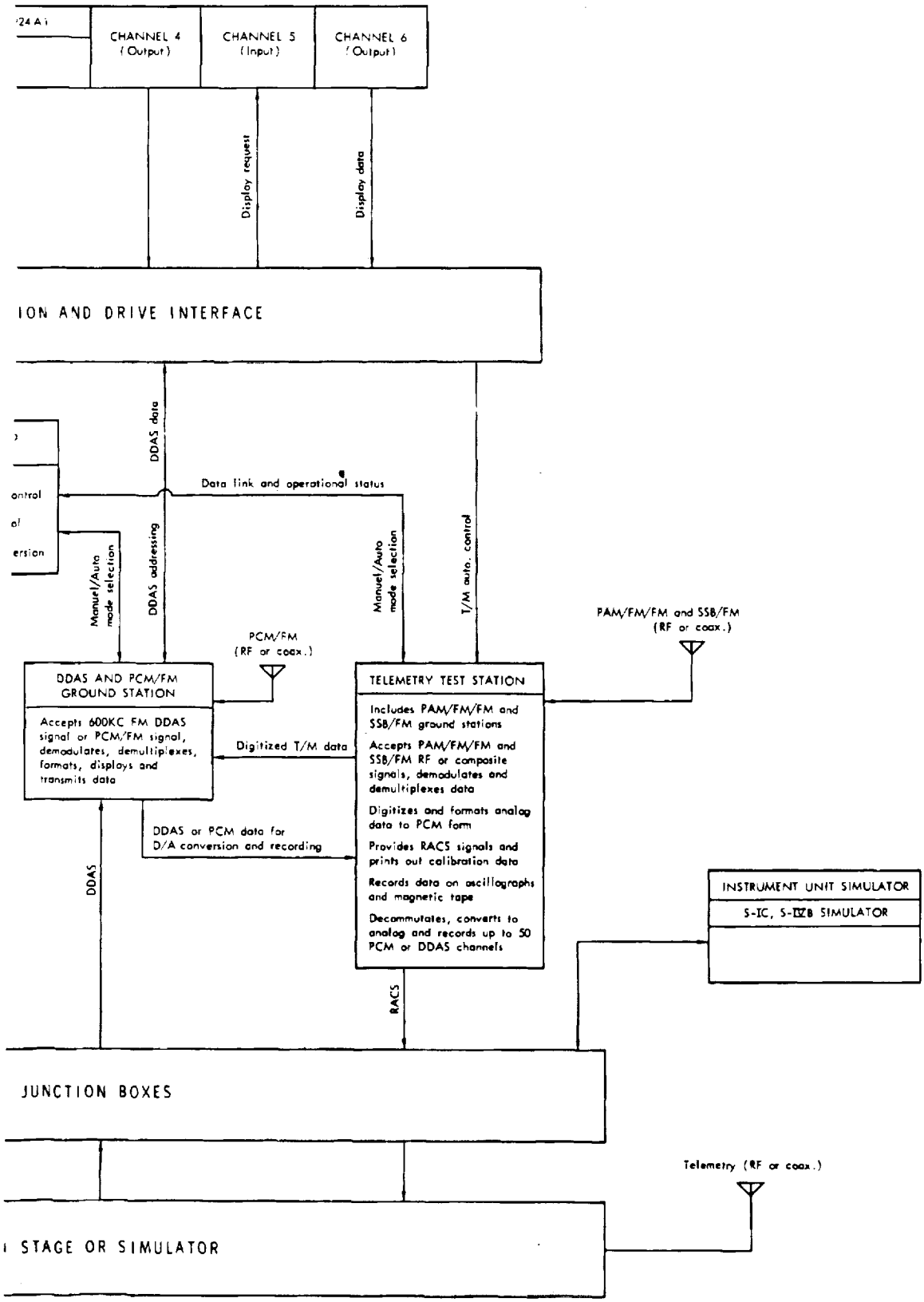


Fig. F-2—S11 sta



ge checkout system

(c) Local Digital Drive Link Rack

Function - Provides additional drive for digital signals from checkout complex to equipment located less than 300 feet from Buffer Equipment Rack

(d) Remote Digital Drive Link Rack

Function - Provides additional drive for signals from equipment located more than 300 feet from Buffer Equipment Rack (located in remote checkout station area)

3. Test Conductor Console (C7-102)

Function - Permits Test Conductor to monitor and control all tests, in either automatic or manual mode

Consists of - Hazard Monitor
- Alphanumeric Display and Control
- Test Station Monitor
- Computer Monitor and Control
- Power Control
- Output and Input Registers and Decoders
- Intercommunication set

(a) Hazard Monitor

Function - Informs the test conductor, via lamp display, of conditions that affect the safety of personnel, stage, or GSE
- Transmits a computer interrupt for cutoff signals

(b) Alphanumeric Display and Control

Function - Displays detailed information regarding test in progress
- Provides capability to call up and display any data in computer memory
- Provides outputs for hard copy
- Permits data word modification or editing by Test Conductor

Consists of - 19 inch CRT (1024 max. characters per page simultaneous display)
- 8,192-character (8-page) Core Memory
- Command/Control Keyboard (page selection, erasure, mode and format selection)
- Input Keyboard (data request entry)

Preceding page blank

- Hard-copy Printer
- Logic and Buffer circuitry

(c) Test Station Monitor

Function - Permits automatic or manual mode control and monitoring of Test Stations

- Monitors and displays operational status of buffer and data link interfaces
- Controls and monitors any of three stage phases, Function Checkout, Static Firing, or Leak Test

(d) Computer Monitor and Control

Function - Provides computer monitor and control capability to the Test Conductor during any automatic test

Monitor indications include:

Computer Stop

Computer Input/Output Stopped

Computer Error

Channel Active (channels 1-6)

Odd Storage Fault

Even Storage Fault

No Exit

Computer Power On

Sense

Master Caution

Computer Controls include:

Selective Jump

Selective Stop

Start

Test Conductor Console/Computer Console Select

(e) Power Control

Function - Provides console power controls and monitors indications

(f) Output and Input Registers and Decoders

Function - Allow Test Conductor to communicate with computer by providing formating logic and buffering circuitry

(g) Intercommunication Set

Function - Provides 20 channels of voice communication, controlled by Test Conductor, to communicate with personnel throughout the checkout complex

4. Digital Events Evaluator

Function - Monitors all discrete (bi-level or "on-off") signals continuously, providing both test program control and permanent event records with time correlation

Consists of - Control Data Corp. 8090-D Computer with 8,192 word core memory and peripheral input-output equipment

5. Digital Data Acquisition System (DDAS) Test Station (C7-400)

Function - Receives 600 kc FM DDAS signal via coaxial cable from stage, demodulates to serial pulse train, converts data to computer-compatible form for evaluation, records and displays data

- Receives PCM/RF telemetry signal via air link or coaxial cable, demodulates to serial pulse train, converts data to computer-compatible form for evaluation, records and displays data

- Permits automatic or manual calibration and test of all DDAS instrumentation channels

Consists of - Automatic Control and Display Rack (C7-401)

- Local Control and Display Rack (C7-402)

- PCM Rack (C7-403)

- Computer Adapter Rack (C7-406)

(a) Automatic Control and Display Rack

Function - Provides computer control capability to command and monitor DDAS operation

Consists of - Input/Output Buffers, Registers, Decoders

- Echo Check Logic

- Word Selector Logic

- Display Logic

- PCM Format Buffer (interfaces with PCM format rack in Telemetry Station)

(b) Local Control and Display Rack

Function - Provides capability to manually control DDAS station, duplicating all sequences possible in automatic mode

(c) PCM Rack

Function - Receives DDAS or PCM/FM signals, demodulates and formats data

- Provides "quick-look" capability for incoming data in digital (10-bit binary lamps) or analog (meter) form

(d) Computer Adapter Rack

Function - Converts data from binary to binary-coded-decimal (BCD)

- Provides storage for computer and displays requested data

6. Telemetry Checkout Station (C7-500)

Function - Receives PAM/FM/FM, PCM/FM and SSB/FM telemetry signals, via antenna or coaxial cable, demodulates, demultiplexes and routes data to recorders or displays

- Provides capability to convert selected data to computer-compatible form for evaluation

- Permits calibration and adjustment of all telemetry instrumentation channels

Consists of - Automatic Control and Display Rack (C7-510)

- PCM Format Rack (C7-511)

- Oscillograph Rack (C7-512)

- Decommutation Rack (C7-513)

- Discriminator Rack (C7-514)

- Receiver Rack (C7-515)

- Tape Recorder Rack (C7-516)

- SSB/FM Demultiplexer Rack (C7-518)

- PCM Rack (C7-519)

(a) Automatic Control and Display Rack

Function - Interfaces with checkout computer

- Provides automatic or local control modes

Consists of - Input Register

- Station Buffer

- Output Register

- Subaddress Decoder

- Data Selection Decoder

- Clock Driver

- Decoder Driver
- Control Instruction Decoder
- Manual Control Panel
- Telemeter System Display
- Automatic Display Panel
- Automatic Display Logic
- Measurement Calibration Control
- Printer

(b) PCM Format Rack

Function - Accepts analog outputs of telemetry FM discriminators, multiplexes and digitizes data in PCM format for transmission to DDAS station or computer

Consists of - Multiplexer
- Analog-to-digital Converter
- Program Control Logic
- Program Patch Panel
- Program Counters

(c) Oscillograph Rack

Function - records in visual analog form, demodulated and demultiplexed output signals from the PAM/FM/FM, SSB/FM, and PCM/FM telemetry systems

(d) Decommutation Rack

Function - Converts the commutated PAM train to decommutated analog DC signals, up to 30 channels at a time

(e) Discriminator Rack

Function - Separates composite FM signal into channels, and demodulates into analog form

Consists of - Discriminator System
- Universal Counter-timer and VAF Converter
- UCT Control Logic
- UCT Buffer
- Spectrum Analyzer
- Telemeter Calibrator
- Discriminator Patch Panel
- Reference Track Mixer-demodulator

(f) Receiver Rack

Function - Receives VHF telemetry signals by air link and coaxial cable, and demodulates into video form

(g) Tape Recorder Rack

Function - Records all telemetry data in video form on magnetic tape

- Reproduces data by playback of selected channels

(h) SSB/FM Demultiplexer Rack

Function - Receives the composite SSB signal from the receiver and separates the signal into 15 data channels

(i) PCM Rack

Function - Accepts PCM data from the PCM/RF receiver or the DDAS station

- Synchronizes and decommutates data

- Converts up to 50 selected channels to analog form for display

Consists of - Synchronizer

- Conductor

- Data Control

- Simulator

- Data Switch

- Quick Look

- Digital-to-analog Converter

- D/A Converter Calibrator and Power Supply

7. Electrical Test Station

Function - Provides capability, under computer or manual direction, to control and monitor the following stage systems and ESE/MSE:

Destruct

Separation

Electrical Power

Thermal Control

Propellant Feed

Fill and Utilization

Electrical Control Computer

- Transducer Calibration
- Engine Actuation
- Engine Systems
- Pneumatic Console
- Hydraulic Console

Consists of
- Station Control Subsystem
- Equipment Control Subsystem
- Measurement Subsystem
- Stimuli Subsystem
- Flight Control Subsystem

(a) Station Control Subsystem

Function
- Interfaces with computer buffer
- Provides internal timing and synchronization
- Interfaces with manual checkout controls

Consists of
- Master Clock
- Input/Output Registers
- Subaddress and Control Instruction Decoders

(b) Equipment Control Subsystem

Function
- Provides control and monitoring of Measurement, Stimuli, and Flight Control Subsystems under command of Station Control Subsystem

Consists of
- Command Distributor Decoder (to Stimuli CD relays)
- Flight Control Decoder (to FC relays)
- Servo Analyzer Decoder (to FC SA)
- Transducer Calibration Decoder (to Stimuli TC relays)
- Electrical Control Computer Decoder (to Stimuli ECC relays)
- Multiplexer Decoder (to FC Multiplexer)
- Test Point Selector Decoder (to Measurement TPS)
- DMM Decoder (from Measurement Digital Multimeter)
- UCT Decoder (from Measurement Universal Counter-timer)

- Limit Detector Self-test Decoder (to Measurement Limit Detectors)

(c) Measurement Subsystem

Function
- Measures discrete and/or analog signal responses for transmittal to computer

Consists of
- Solid State Scanner (1,536 channels)
- Digital Multimeter (0-1, 0-10, 0-100, 0-1000 volts DC and AC, and resistance)
- Universal Counter-timer (1 cps-10 mc frequency, period, time interval, ratio)
- Voltage Limit Detectors (0-5 volt adjustable comparators)
- Test Point Selector (Cross-bar matrix)

(d) Stimuli Subsystem

Function
- Provides capability to generate up to 1,000 discrete (0 or 28 volt bi-level) signals under computer command, either singly or in parallel 8-bit or 13-bit word form

Consists of
- Command Distributor Relays
- Transducer Calibration Relays
- Electrical Control Computer Relays

(e) Flight Control Subsystem

Function
- Provides electrical control of engine gimbaling hydraulic equipment
- Measures engine static and dynamic responses

Consists of
- Flight Control Relays
- Flight Control Amplifiers
- Servo Analyzers
- Multiplexer

C. BASIC SOFTWARE

GENERAL

The on-line basic software for the NAA S-II ACE provides: (1) the necessary general purpose programs for operator control, display, control of computer peripherals, and sequencing of automatic test operations, (2) the subroutines that execute ATOLL statements from specific test programs, and (3) a capability for a reasonably high degree of software simulation of test responses for checkout of programs. These programs are called the ATOLL Executive, and occupy approximately 10,000 words of memory plus approximately 8,000 words for tables of program and temporary storage data, 1,000 words for "input buffer" storage of specific test programs from tape, and 1,000 words for "output buffer" storage of event-trail data to be recorded on tape.

Information on S-II, the ATOLL Executive, is derived mainly from Refs. 6 and 7, and conversation with NAA personnel.

Off-line preprocessing (on a CDC-924A) consists mostly of editing and compaction of the input test statements. Interpretation is performed on-line on the compacted information. The interpretation consists largely of placing the data fields in a set of data tables, then jumping to an execution subroutine on the basis of the operator field.

North American ATOLL is quite extensive, and differs from other ATOLL versions in a number of respects, including: (1) Additional operators are defined to permit programmer-oriented operations such as indexing moving data, etc. (For example, looping is permitted, with different displays for each cycle.) (2) The meaning of the READ operator is restricted to reading information. Evaluation is performed by a separate EVAL operator, and return to semiautomatic by deliberate use of the SEMI operator. (3) Recording of the event trail is an executive function rather than requiring deliberate RECD statements. (4) Several other significant but less outstanding differences and extensions exist.

The execution subroutines are designed with separate numeric tables and processing areas, to permit maximum flexibility for changes in this operation.

The software-simulation checkout of ATOLL programs is performed on a separate installation, the Computer Program Development Facility (CPDF). The CPDF contains a CDC-924A, peripherals, and a test conductor console display/control unit, but no GSE. After checkout against software simulation on the CPDF, programs are planned to be taken to the EMM for checkout on hardware.

An overall diagram of the main flow is shown in Fig. F-3. It is expected to provide full facilities for operation of automatic programs and on-line semiautomatic ATOLL statements and changes. Non-ATOLL executive functions are at present limited to the event-trail recording; no monitor or display routines are included. The present version is now almost completely debugged except for certain deferred operations, as far as this is feasible on the CPDF. Debugging has begun on the EMM.

Improvements over the present version are expected to begin soon, and are desired for the S-II-I configuration of EMM. These will include display and monitor executive functions (as requirements are defined), a "validation" check on the discrete output profile after a DISO (similar to the Douglas "echo check"), coding improvements such as design of a new, faster loader, and complete implementation of all operators.

HOUSEKEEPING AND MONITOR FUNCTIONS

The basic programming viewpoint used for the NAA executive is that the monitor functions should be subordinate to test program operating functions. That is, monitoring functions are performed during delays incidentally required by the program or GSE, but no housekeeping is performed between test substeps or steps.

At present, Monitor (Fig. F-4) is confined to processing tape operations and running the time-increment clock. The tape operations are conventional, except no interrupts are used. The time-increment clock is a memory cell. Every 1, 10, or 100 milliseconds, as determined by a programmable switch, a time pulse interrupts the program and Monitor then decrements the delay counter and checks it for zero. At zero, the time interrupt is inhibited, and the program returns

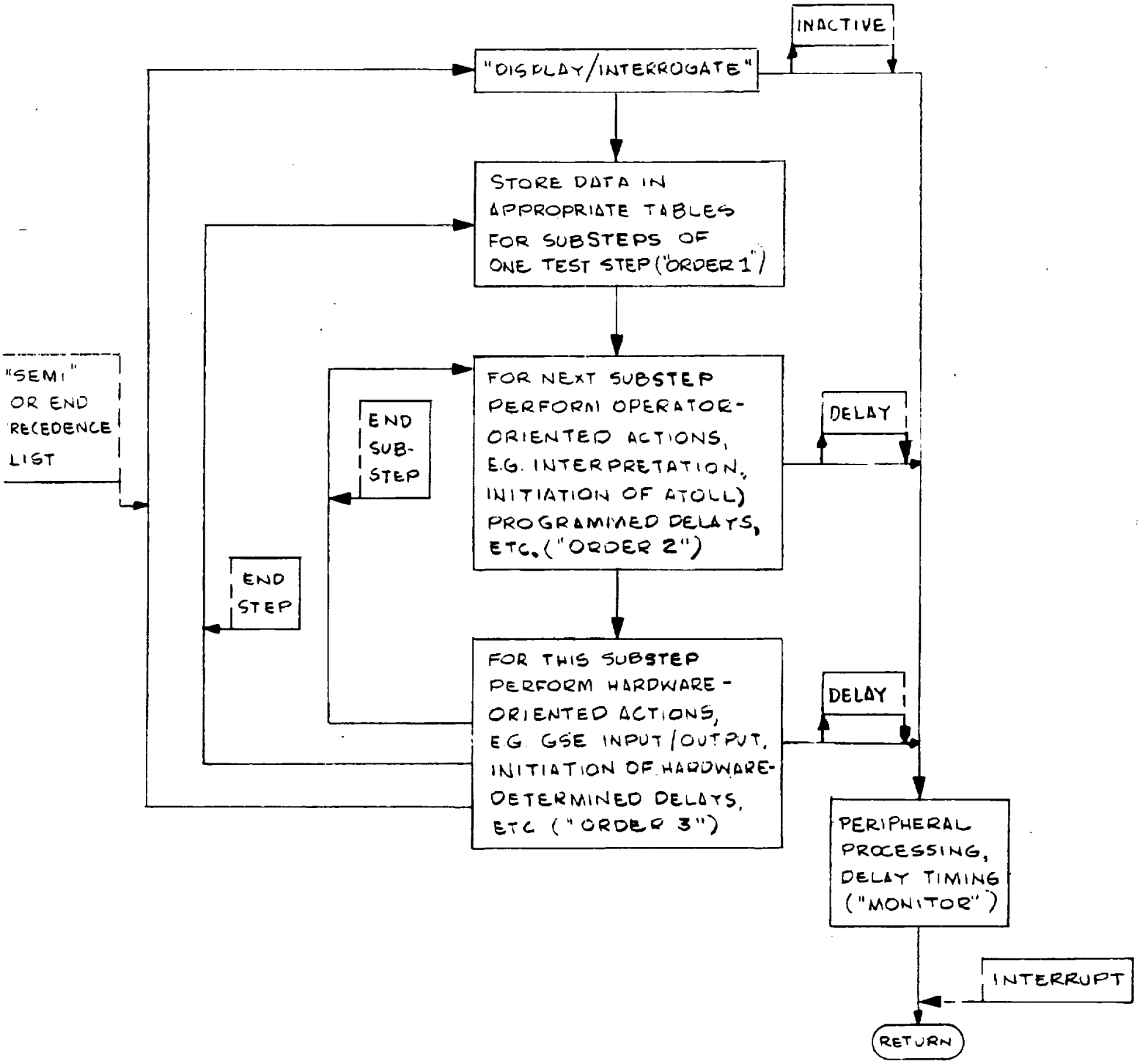


Fig. F-3—On-line basic software, S-II

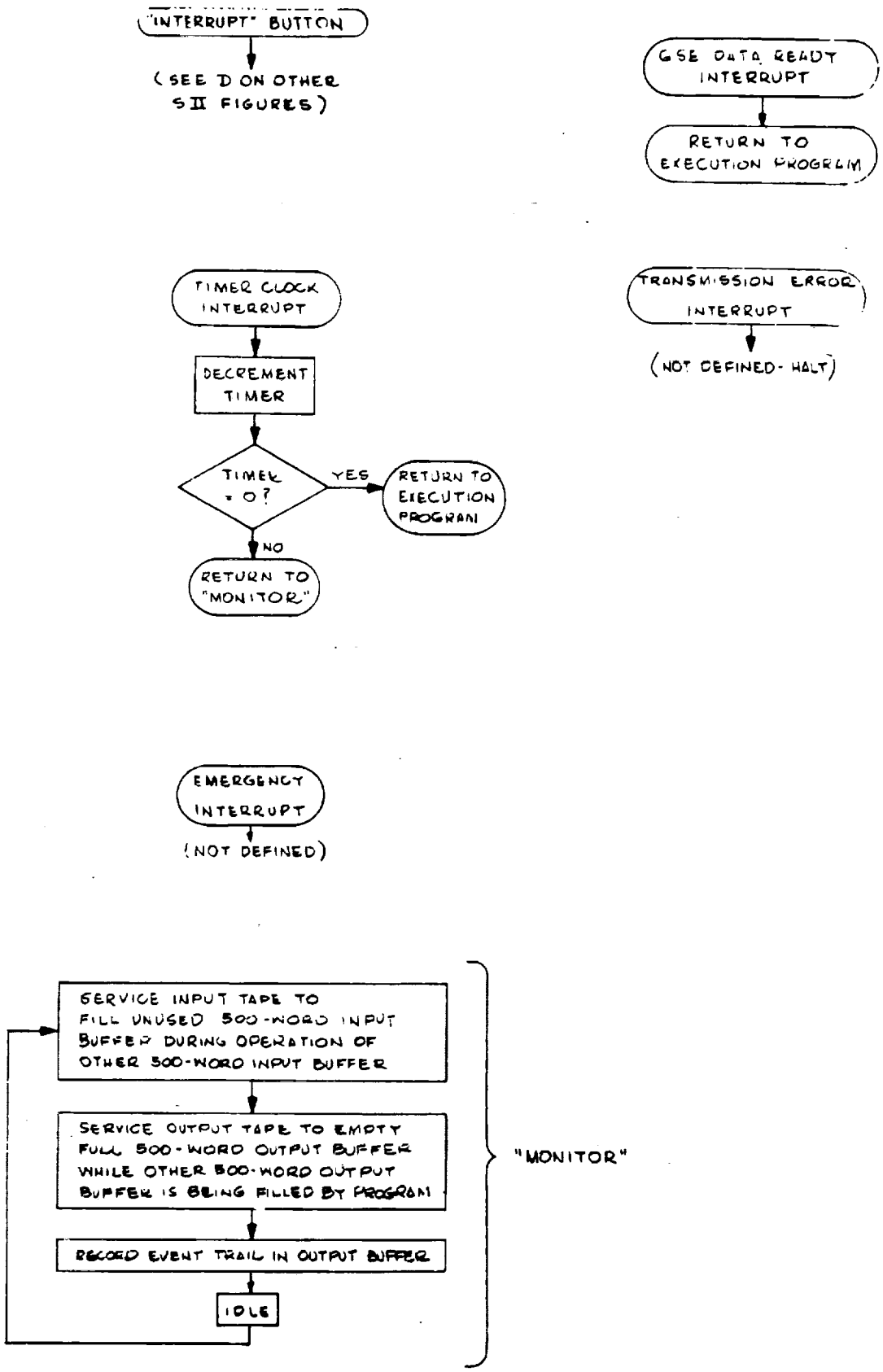


Fig. F-4—"Monitor" and interrupts, S-II

to the delayed operation. (Monitor may also be interrupted by the other interrupts, as will be discussed later.)

It is planned that future display monitoring, status monitoring, etc., will be extensions of Monitor. No such capabilities exist at present.

MAIN SEQUENCE

The main sequence for preprogrammed operation is shown in Fig. F-5. Tests are divided in hierarchical fashion. The largest division is a "procedure;" procedures may be run independently, and may be selected to any order for the precedence list. (It is up to the specific test programmer to ensure that this does not cause trouble; no rules have yet been published to ensure starting from and returning to a standard configuration.) Next is a step, composed of several ATOLL statements; holds may or may not be legal at the end of a step, at the programmer's option, but there does exist a control mode in which the program holds at the end of every step. The lowest division is a substep, or single ATOLL statement; there is no way to enable a hold at the end of a substep, unless it is also the end of a step or is a SEMI operator, and there is no substep by substep mode.

Main execution is divided into three orders. Order 1 is the initiation of a step, including unpacking all data for all substeps and storing them in tables for ready access by subroutines. This reduces the number of decisions to be made while running, and makes possible fast looping within a step (since the data for the entire step are in readily accessible form).

Order 2 includes all computer-oriented operations for the execution of a substep. It includes data processing operations, arithmetic, initiation of programmed delays, and most internal decisions.

Order 3 includes all GSE-oriented operations for the execution of a substep. It provides input-output address translation (from the interface table), input-output commands, input-output sequencing, and timing and delay functions required by the nature of the GSE. (In some cases the timing may actually be involved with the vehicle equipment.)

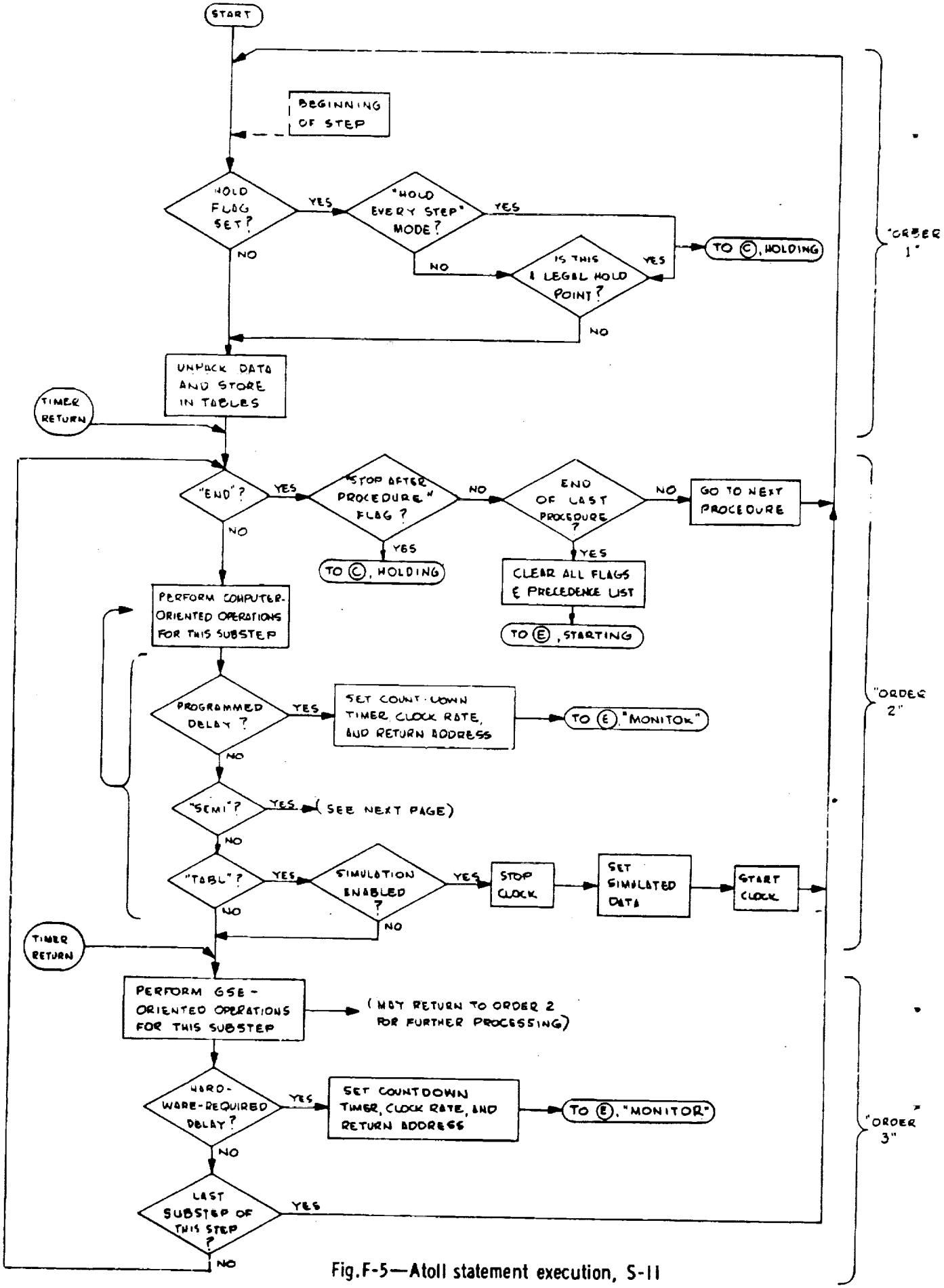


Fig. F-5—Atoll statement execution, S-II

Exclusive of delays, typical timing is estimated (not yet measured) as follows: Order 1--1 to 5 ms per step (several substeps); Order 2--1 or 2 ms per substep; Order 3--2 ms per substep.

The buffer structure allows a "read-while-operate" or "overlay" mode for test programs, which, if the loader is made reasonably fast, should permit straight-line programming of indefinite length. If much more use is made of posted routines, however, the buffer area may be inadequate.

DISPLAY/CONTROL, SEMIAUTOMATIC AND EMERGENCY ACTIONS

When the precedence list has been entered, the operator may select one of a number of Main Options, as shown in Figs. F-6 and F-7. The figures are largely self-explanatory, except for the distinction between Main Options and other options.

Main Options (Fig. F-6 and upper left corner of Fig. F-7) are listed on a single display, and are available whenever testing is started or held.

The options resulting from SEMI (Fig. F-7) are those that might be needed in case of no-go, or after preselected manual steps. The first SEMI option, to which the selection cursor is pre-positioned, is the posted shutdown routine. Thus in case of no-go, the operator can react quickly; a single depression of the Start button causes shutdown. Other options require manual cursor positioning. From SEMI, the programmer may permit up to three legal recycle steps and three legal recycle substeps, although no provision is made for posting a backup routine.

The Interrupt button provides a way to cause a Hold at the next legal hold point, or to erase the precedence list if already in Hold. From Hold (Fig. F-8), the operator may repeat the most recent step (if the programmer has flagged this as permissible), or may go to the Main Option list to provide arbitrary choice of the next entry point, without posted backup routine, and without inhibition except that the entry point must be a legal one.

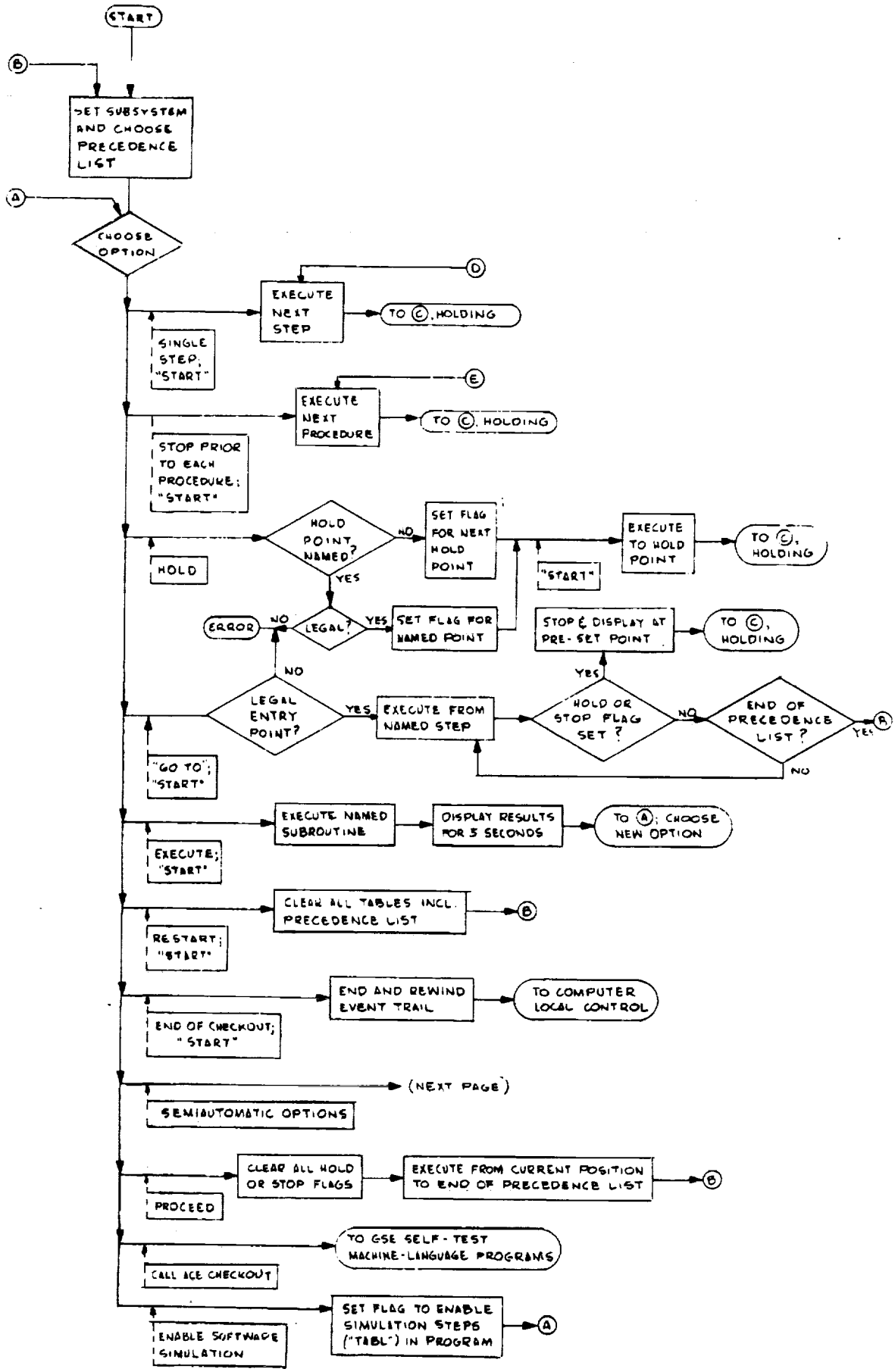


Fig. F-6—"Display/interrogate" and execution, main options, S-II

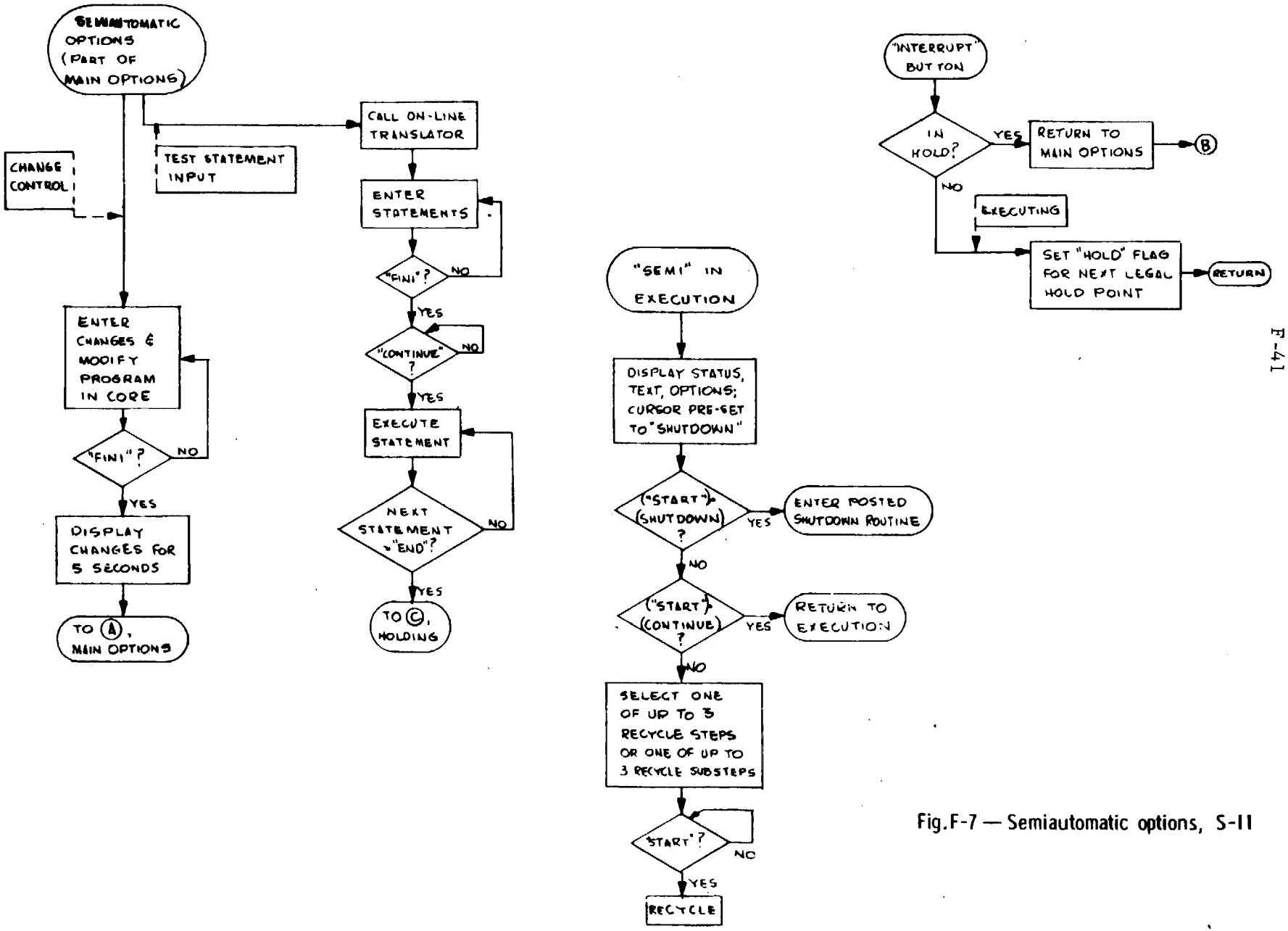


Fig. F-7 — Semiautomatic options, S-II

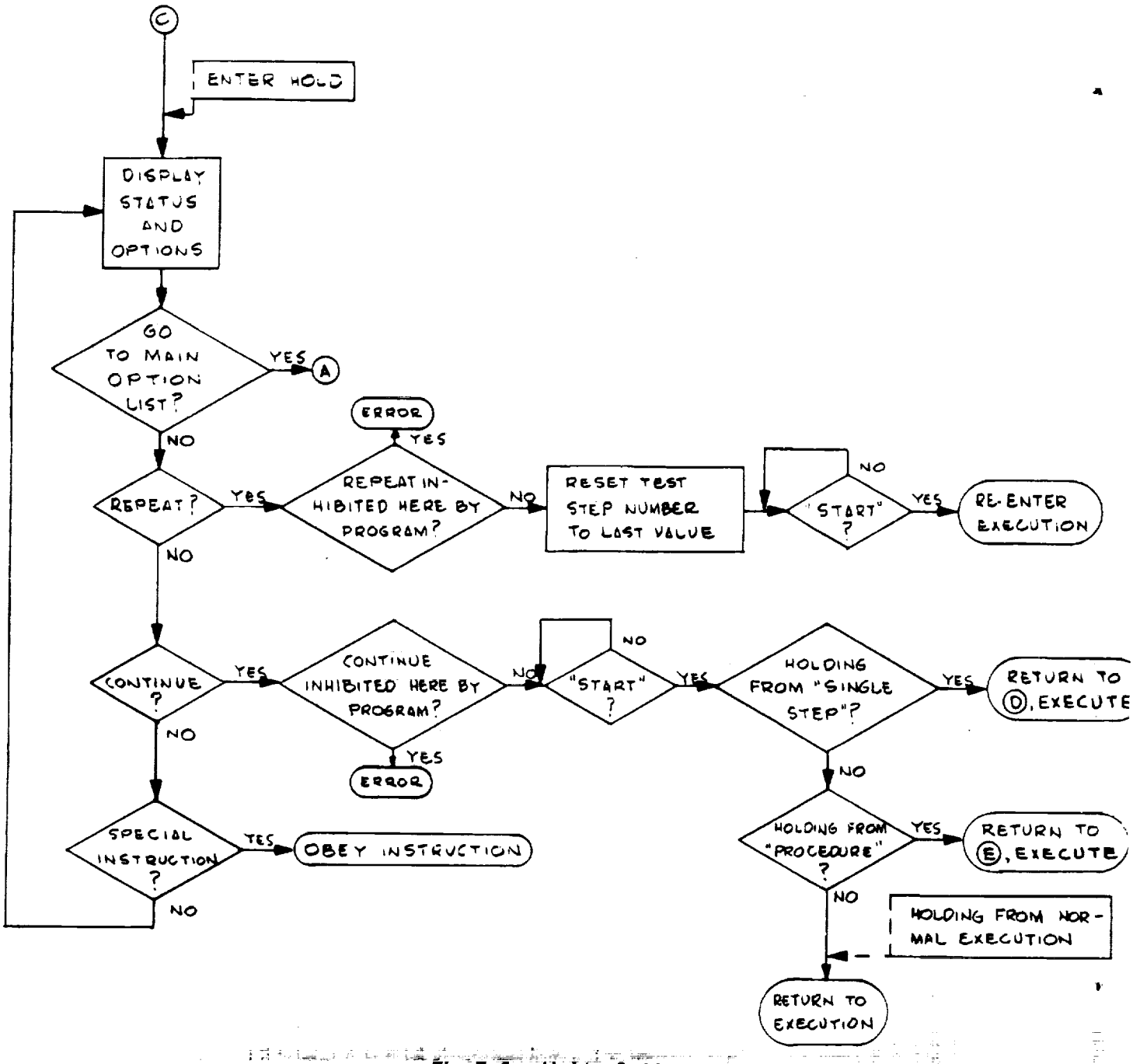


Fig. F-8—Hold, S-II

The program may be modified on-line with the Test Statement Input and Change Control options. The first of these permits the operator to create an ATOLL step and execute it from the console, and the second permits on-line insertion and deletion of steps or substeps for the preprogrammed automatic operation.

One option is Enable Simulation. This permits the program to act on the software simulation steps that have already been embedded in it. A software simulation step is a TABL operator, which inserts a simulated response value into the response area of the data tables, at a position determined by its arguments. (For example, TABL 1 DDD3 will cause the DDD3 response storage location to be set to 1.) Since the execution program consists of subroutines that read and enter the data tables, this simulates the actual response. The clock is stopped during TABL execution, although there is a minor timing error due to Order 1 processing of the TABL substep.

An emergency interrupt exists, but no provision has yet been made to use it. The only emergency reactions are

1. Operator initiation of a posted shutdown routine when SEMI gives him control (e.g., after a no-go detected by the program).
2. Use of the Interrupt button to cause a Hold at the next legal hold point. Faster reaction is not possible, short of a computer halt from the computer control panel.
3. Any emergency branching, which may be programmed as a part of a specialized test program.

No self-tests are programmed as integral parts of the basic software. The operator may, if he so desires, call the GSE self-test program (a machine-language program) from Main Options, if he does not trust a reading.

Annex F

REFERENCES

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2. Parker, W. F., "Saturn S-II Operations Development Progress," AIAA/NASA Flight Testing Conference, Paper No. 65-201, February 15-17, 1965.

3. North American Aviation, Space and Information Systems Division, S-II Systems Design Test and Checkout Requirements, SID-64-1963, February 22, 1965.

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5. Britt, R. E., and D. D. White, "Fault Isolation Techniques in the Saturn S-II Automatic Checkout Equipment," Proceedings of the Automatic Support Systems Symposium for Advanced Maintainability, Paper 9-B, June 7-9, 1965.

6. North American Aviation, Space and Information Systems Division, Display/Interrogate-display Description, ID:07T000-160-000, March 11, 1965.

7. North American Aviation, Space and Information Systems Division, ATOLL Operator Directory, rev. March 22, 1965.

Annex G

SATURN I/IB/V LAUNCH VEHICLES
VEHICLE PRELAUNCH CHECKOUT

Checkout Concept and Objectives G-2

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CHECKOUT CONCEPT AND OBJECTIVES

BACKGROUND DATA

The John F. Kennedy Space Center has the responsibility for prelaunch checkout, countdown, and launch of all Saturn/Apollo vehicles.

Saturn I Block I vehicles were launched from Launch Complex 34, which is now being updated to Saturn IB configuration in preparation for Vehicle 201, scheduled for an early 1966 launch. Saturn I Block II vehicles were launched from Complex 37, which will also be configured for Saturn IB after the launch of SA-10, the last Saturn I vehicle.

For the Saturn V series, whose first flight vehicle (501) is scheduled for launch in early 1967, Launch Complex 39 at the Merritt Island Launch Area (MILA) is presently under construction.

Saturn I

For the Saturn I vehicles (S-I booster, S-IV second stage, IU, plus payload or spacecraft), the Blockhouse for Complex 34 (or 37) served as a Launch Control Center (LCC) located about 1500 feet from the fixed launching pad.

A complete manual checkout and launch system is controlled from the Blockhouse. Remote fueling facilities are provided on the pad and controlled from Blockhouse fueling panels. Stimulation measurement circuitry is located on the pad for calibration purposes.

One RCA-110 computer complex is located in the Blockhouse, in parallel to the manual circuitry, so that either automatic or manual control is available.

Saturn IB[1]

For this configuration, both complexes, 34 and 37, have dual-computer installations. One RCA-110A is in the Blockhouse LCC and the other is in a pad base area that contains an equipment complex called

the Automated Ground Control System (AGCS). Each computer has associated peripheral and input-output equipment.

The computers are interconnected by a two-way digital communication link, the main medium for data transmission whether tests are computer or manually controlled. To this extent, computer and data link operation are vital to checkout, even for a fully manual sequence of tests.

An expanded group of ESE/MSE is provided in both the LCC and the AGCS to match Saturn IB vehicle requirements and to provide appropriate computer interfaces.

Like Saturn I, the vehicle is again assembled at the pad with the S-IB booster, S-IVB second stage, IU and S/C tested individually to some extent and then mated together.

Saturn V[1,2]

An entirely new vehicle assembly, checkout, and launch concept will be used for the Saturn V vehicles. The individual stages (S-IC booster, S-II second stage, S-IVB third stage, IU, and S/C) are received, tested, and assembled into a mated vehicle within the Vehicle Assembly Building (VAB), which is 524 ft high, 513 ft deep, and 700 ft wide, located some miles from the launch pad.

Within the VAB the vehicle, including the S/C, is mounted on a Launch Umbilical Tower (LUT), which contains its own equipment room area. At the completion of assembly and checkout a crawler-transporter moves the entire LUT assembly, containing the vehicle, to the pad where the LUT is positioned and the crawler-transporter withdrawn.

While the vehicle is on the pad a mobile service structure is moved into position and major ordnance items installed. High pressure leak tests, fueling, and final vehicle checkout are performed, with pad equipment providing power, air conditioning, and other facilities.

All vehicle operations prior to launch are controlled from the Saturn V LCC adjacent to the VAB.

The checkout system resembles the Saturn IB checkout system somewhat, with one RCA-110A computer in the LCC and a second in the LUT, connected through a data link. However, the GSE is considerably expanded to meet Saturn V vehicle requirements, and a new, more flexible computer display system is provided.

VEHICLE DESCRIPTION

Figure G-1 illustrates the dimensions and major capabilities of the Saturn IB and V launch vehicles. Details of each stage are found in the corresponding stage description sections.

Saturn I payloads consisted either of simulated or partially complete Apollo S/C or non-Apollo units such as the Pegasus micrometeorite detection satellite. Vehicle 201 of Saturn IB will contain the first flight Apollo S/C, 009, with its independent Service Module (SM) and Command Module (CM) propulsion systems.

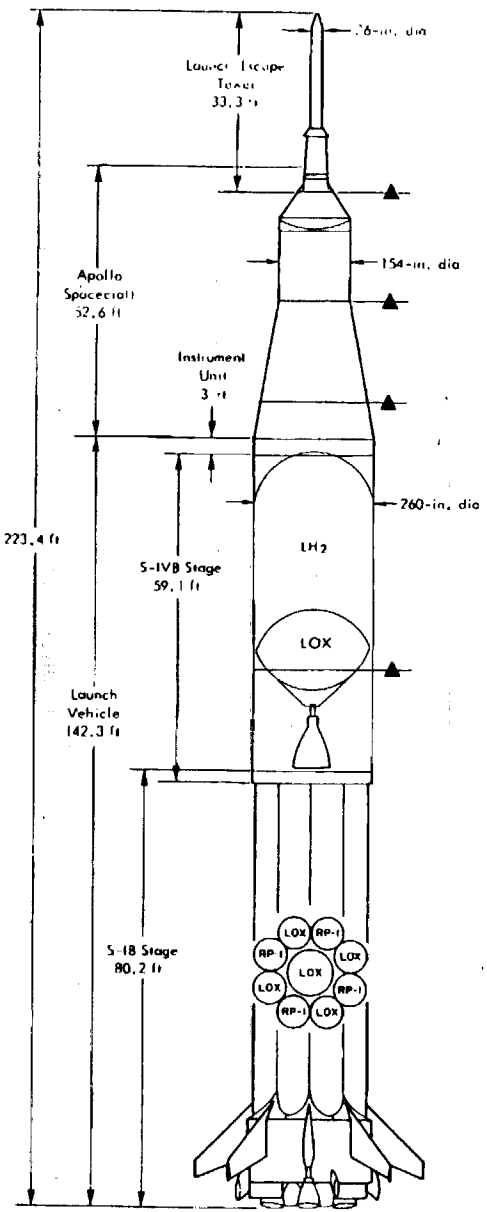
DESCRIPTION OF TESTS[1,2]

The Saturn IB Launch Vehicle 201 will be the first of the 200 series vehicles to be launched using the Saturn Launch Computer Complex (SLCC) for integrated checkout and control of major vehicle subsystems. The SLCC is composed of two general purpose computers--one RCA-110A at the Blockhouse (BHC) and one at the Launch Control Center (LCC)--which are interconnected through a two-way digital communication link and operationally controlled by an executive control program referred to as the SLCC Operating System program.

The system accepts control data from display console keyboards and ESE 2- and 3-position switches as well as standard card and tape equipment inputs. These are used, under program control, to generate discrete signals to the system and the launch vehicle. The SLCC receives discrete status inputs from the vehicle and portions of the ESE as well as analog data via the Digital Data Acquisition System (DDAS).

Software being provided for the 201 vehicle SLCC will enable the majority of ESE vehicle control discrete signals and a representative group of vehicle semiautomatic checkout, test, and monitor functions to be channeled through the SLCC. As a result, the ground computer complex will perform as a major communication and control channel to the vehicle during the prelaunch checkout and launch countdown periods for this series of vehicles.

A representative test sequence for the 201-204 series (Saturn IB) of vehicles is listed on the following pages. Although subject to modification, it will serve to illustrate the degree of automation.



SATURN IB

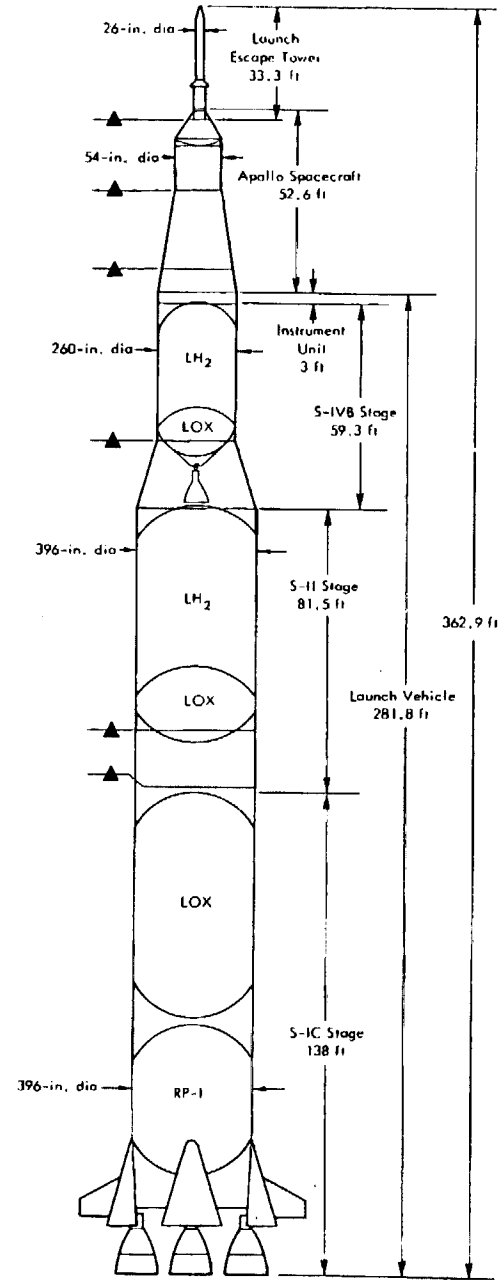
SATURN IB

S-IB	
• Dry Weight	87,800 lb
• Main Propulsion Engine	Rocketdyne H-1 (8)
Total Nominal Thrust	1,600,000 lb (sea level)
Propellants	LOX and RP-1
S-IVB	
• Dry Weight	23,800 lb
• Main Propulsion Engine	Rocketdyne J-2 (1)
Total Nominal Thrust	205,000 lb (vacuum)
Propellants	LOX and LH_2
INSTRUMENT UNIT	
• Dry Weight	4,150 lb

SATURN V

S-IC	
• Dry Weight	300,000 lb
• Main Propulsion Engines	Rocketdyne F-1 (5)
Total Nominal Thrust	7,610,000 lb
Propellants	LOX and RP-1
S-II	
• Dry Weight	81,900 lb
• Mainstage Propellant Capacity	970,000 lb
• Main Propulsion Engines	Rocketdyne J-2 (5)
Total Nominal Thrust	1,025,000 lb
Propellants	LOX and LH_2
S-IVB	
• Dry Weight	27,400 lb
• Mainstage Propellant Capacity	230,000 lb
• Main Propulsion Engine	Rocketdyne J-2 (1)
Total Nominal Thrust	205,000 lb
Propellants	LOX and LH_2
INSTRUMENT UNIT	
• Dry Weight	4,150 lb

▲ Flight Separation Points



SATURN V

Fig. G-1—Apollo vehicles

Test	Description
GSE Verification	
G-1	Computer Self-tests--self-test and diagnositc routines provided by the computer manufacturer to check out the two RAC-110A computers, the computer/ESE interface equipment, the displays and controls, and the data link. It is performed prior to attaching ESE, and as a basic check during later operations
G-2	ESE/GSE Separate Tests--a series of tests of the ESE and GSE that will be connected to the computer system, performed at the rack or station level before integrating the complete system
G-3	GETS Tests--a series of tests performed with the GETS connected to the ESE in place of the stage. It is performed manually, with the aid of a special monitoring program that displays and prints all discrete input and output activity. Its function is to check out the correct relationship between the "manual" blockhouse switches and indicators and their corresponding events at the vehicle/GSE interface. In the process of doing this, it also checks most of the interface devices used by the automatic programs. (One automatic program, the GETS Discrete Activity Monitor, is provided for use during GETS validation tests, and a Wet test program is provided to monitor fuel loading discretes.)
Stage Verification	
Pre-test	Stage Receiving--a pre-test operation in which the stages are received individually at KSC and transported to the launch tower

Pre-test	Receiving Inspection--a visual check for component status, damage in shipment, cable connections, etc.
Pre-test	Vehicle Erection--a pre-test operation in which the stages are stacked at the launch tower
Pre-test	ESE/GSE Connections--a pre-test operation in which electrical and mechanical connections are made to the individual stages, and stage substitutes connected to the interstage connectors
1	Vehicle Alignment Check--a mechanical test to check the alignment of the vehicle in its prelaunch position
2	Pre-power Checks--a group of tests of continuity, wiring, impedances, etc., to ensure that it is safe and proper to apply electrical power
3	Power-on Tests--sequences and checks electrical power-on to all stages, and checks for proper loading of power buses and proper functioning of power switching equipment in the stage
4	Cooling System Check--a short test to ensure proper operation of the cooling system for the electrical equipment used on all subsequent electrical tests
5	Measurement Calibration--checks and adjusts the measurement system up to the telemeter inputs. It includes adjustment of signal conditioners, RACS checks, and checks of transducer outputs at ambient inputs. Specific programs include: DDAS/RACS Pre-processor Program DDAS/RACS Tolerance Update Program DDAS/RACS Calibration Program
6	RF System Components Check--checks the RF transmitters and receivers associated with the command, tracking, and range safety functions
7	Telemetry System Check--an end-to-end test of the telemetry system, including excitation from every channel through RACS, and ambient conditions

Pre-test	Interstage Electrical Mating--a pre-test operation in which the stage substitutes are removed, and the stages are connected together in flight configuration
8	Hydraulic Systems Tests--tests of hydraulic pumps, valves, and actuators. They also include engine gimbal exercising and leak testing of the hydraulic system
9	Pressurization Tests--tests of valve operation, pressurization functioning, and pressure leaks in the pneumatic, propulsion, and engine subsystems
10	Navigation System Tests--tests of the guidance and control system, including:

(a) Launch Vehicle Digital Computer (LVDC) Tests (to check out the guidance computer and its interface unit)--including:

Data Load and Verify Test Program
Sector Sum Check Test Program
LVDC Switch Selector Test Program
Pseudo Flight Test Program
Simulated Flight/Preflight Monitor (Plugs In) Program
Simulated Flight Post-processor Program
LVDC/DDAS Test Program
Accelerometer Pulse Count Test Program
Gimbal Angle Read Test Program
LVDC/LVDA Ladder Output Test Program
Power and/or Redundancy Test Program
LVDC/LVDA Discrete Output Test Program
LVDA/LVDC Discrete Input Test Program
LVDA/LVDC Self Test Program

(b) Stabilized Platform (ST-124) Tests--to check and perform platform turn-on and turn-off, nulling automatically, and monitor accelerometer outputs for display, including:

Azimuth Laying Program
Accelerometer Monitor Program
ST-124M Automatic Null Check Program
ST-124M Turn-on Program
ST-124M Turn-off Program

(c) Flight Control Tests--to check the flight control system from the LVDC and gyros to the engine gimbaling, involving gyro torquing and rate gain measurements. (S-IB tests are automatic; S-IVB tests are not.) These include:

S-IB Overall Steering Test
S-IB A_o Gain Test

11 EBW Checks--a group of tests of the EBW equipment used for stage separation, propellant dispersion, ullage rocket ignition, etc. Pulse sensors are used in place of live ordnance to measure the output signals

12 Switch Selector Tests--to validate the operational status of each stage switch selector from the SLCC without use of the LVDC:

SLCC Switch Selector Interface Test Program
SLCC Switch Selector Channel Test Program

13 Power Transfer Tests--check the proper functioning of the internal/external power transfer circuits, including such features as battery voltage decay and switch timing

14 Malfunction Sequence Tests--check the equipment that detects malfunctions for the Emergency Detection System (EDS) and for the final phase of the countdown sequence

15 S-IVB Monitor Test--a variable scan rate monitor program for major areas of the S-IVB system

16 EDS Tests--check the redundant logic and displays of the EDS, including the abort message interface for the spacecraft (without the spacecraft in place):

Engine Out Abort Test Program
Rate Excessive Test Program
Space Vehicle Abort Test Program
Command Module Indicator Verification Test Program

17 Launch Vehicle Systems Test 1--the first test in which launch vehicle systems are run together in a preliminary system function. It checks compatibility of the stages, and performs portions of the countdown

18	Launch Vehicle Systems Test 2--carries the systems and compatibility testing to the point where the swing arms are retracted
19	Propellant Umbilical Leakage Tests--propellant umbilicals are connected, and leak tests are performed on the connections and associated equipment
Pre-test	Spacecraft Mating--the spacecraft is hoisted into place and mechanically mated with the launch vehicle. Electrical connections are not yet made
Pre-test	Escape Tower Installation--the escape tower is hoisted into place and installed on the spacecraft
20	S/C-complex Compatibility Tests--a group of tests in which the electrical interface between the spacecraft and its ESE (including ACE) is verified for compatibility
21	Launch Vehicle Systems Test 3--a more extensive simulated countdown test of the vehicle in which testing is carried beyond the point at which the electrical umbilicals are ejected
22	Space Vehicle Alignment Check--checks the capability of the S/C guidance system to perform alignment properly
Pre-test	S/C/LV Electrical Mate--S/C and LV are electrically connected together in flight configuration
23	EDS Tests with S/C--a check of the EDS, but with the S/C attached to the interface; the spacecraft indications are also checked
24	Space Vehicle Systems Test 1--a check of the total vehicle as a system, running a preliminary simulated countdown
25	Space Vehicle Systems Test 2--a more complete system test of the total vehicle, carrying the simulated countdown past ejection of the electrical umbilicals
Pre-test	Move Vehicle to Pad

Pre-test	Ordnance Installation--the ordnance items (igniters, propellant dispersion charges, etc.) are installed
26	RF Compatibility Test--a check of all transmitters, other interference generators, receivers, and other interference-susceptible devices for proper operation in the environment of each other and the KSC ground facilities
27	Simulated Full Pressure Tests--a check of vehicle and GSE pressurization systems without applying actual pressures, preparatory to the Full Pressure Test
28	Full Pressure Test--a full-scale final check of all pressurization systems in the S/C and launch vehicle
29	Propellant Tanking Test--a group of tests in which propellant is loaded and unloaded, to check all propellant handling GSE and internal equipment. It is aided by the automatic propellant calculation program
30	Simulated Flight Test--a test in which the internal systems go through a dry run of countdown, liftoff, and flight
Pre-test	Ordnance Connections--ordnance items are connected to the system, and safe/arm devices are installed
Pre-test	Equipment Removal--work platforms, miscellaneous GSE, and carry-on equipment are removed, leaving the tower and S/C physically ready to be loaded and launched by remote control
31	Hypergolic Loading--hypergolic propellants are loaded for the S-IVB and S/C attitude control rockets and for the LEM and SM engines
32	RP-1 Loading--the S-IB fuel is loaded. An automatic program provides calculations of present and predicted fuel density to aid the manual operation
Pre-test	Pre-countdown and Arming Tower Removal--the facilities are prepared for countdown and the arming tower is removed from the S/C (the launch tower remains connected)

33 Terminal Countdown--the final prelaunch sequence. It includes final checks and alignment, cryogenic loading, facilities and range checks, and the launch sequence. It is manual except for the following items:

- Platform checks and azimuth laying as abo
- LVDC checks as above
- RACS checks of DDAS measurement lines
- EDS tests as above
- Cryogenic tanking calculations (separatel automated, not in the digital computer system)
- Switch selector checks as above
- Flight control checks as above
- Launch sequencing (separately automated, not a part of the digital computer syste

CHECKOUT SYSTEM APPLICATION

The requirements for prelaunch checkout and launch operations a sufficiently different from those of factory stage checkout to warra a brief discussion.

Since prelaunch checkout is basically related to the total mated vehicle, and factory checkout to a single stage, the testing emphasis is dissimilar. Factory checkout is in general more detailed and exhaustive; prelaunch is concerned primarily with interfaces and syst integration.

Facility constraints are more rigid for prelaunch. This is true not only because of the addition of volatile and dangerous propellant cryogenic fluids, and high pressure gases, but also because in the electrical area there are extraneous electromagnetic radiation, noise and pickup from cabling, etc.

Factory checkout will in most cases correct obvious malfunctions and eliminate problem areas. Problems remaining at the time the stages reach the prelaunch area are likely to be more subtle, involvi intermittent failures or equipment interaction. This requires more flexibility in prelaunch checkout techniques.

Prelaunch and countdown operations are much more time-constrained, by launch windows, range operations, emergency

procedures, etc. Schedule pressures (consistent with launch safety and mission effectiveness) are the dominant factors in determining which checkout techniques may be applicable.

The result of these differences is that for a prelaunch checkout, the intent is to perform integrated end-to-end tests where possible, avoiding subsystems tests. No-go conditions for one system should not be permitted to hold up checkout for other systems, so that simultaneous parallel setup or testing of different systems is normal.

In addition, the high level of competence of prelaunch personnel and the heavy experience gained with manual checkout equipment and techniques represent a twofold delaying factor in the application of automation. First, the tight schedule pressures tend to force test engineers to proceed with checkout in the manner with which they are most familiar and requires the least learning time, i.e., manual control. Second, the competence level and history of success imposes a natural reluctance to depend upon new techniques.

With this in mind, the specific application of computer control to Saturn prelaunch checkout may be examined. For Saturn I, an RCA-110 computer and related equipment was basically connected in parallel with a completely separate manual checkout system, so that for each test the choice between manual or automatic control was available. A failure of any portion of the computer system would not prevent proceeding with prelaunch checkout and countdown.

For the later Saturn I vehicles (SA-5 through SA-10), computer control of selected tests was phased progressively into the existing manual checkout procedures. In the main, the tests included only those that were difficult or time-consuming to conduct manually, such as guidance and control system testing, and scanning and monitoring the multiple instrumentation channel outputs via the DDAS data stream. Some overall systems tests were programmed, but essentially on a redundant basis.

For Saturn I, therefore, the extent of automated checkout was essentially limited to especially compatible tests, and to familiarizing test personnel with some of the capabilities and operational procedures associated with the computer hardware and software.

For the Saturn IB series, there are important differences both in the operating concepts and the application of automatic equipment to prelaunch checkout. Although the overall percentage of tests actually under computer control may not increase drastically, at least in the early vehicles, the physical equipment is such that the computers are linked to almost all tests. The digital data link between the RCA-110A computers in the blockhouse and AGCS serves as the major communication medium between the vehicle and the test personnel, whether or not the test is controlled manually. There are many hardline connections also, but primarily for safety monitoring.

Since there are no longer completely separable manual and automatic signal paths, computer operation is necessary to completion of a full checkout and, conversely, a computer or data link failure will halt a checkout.

This distinction is both functional and psychological. From a psychological viewpoint, the computers are no longer an optional alternative choice but a basic element of the checkout system, which to a great extent cannot be bypassed. Functionally, the checkout system can be operated initially under almost fully manual control, with the computers and data link regarded as a somewhat more complex switch and stimulus-response communicator. As user confidence is increased and program software can be prepared, the degree of automation can rise substantially with minimal hardware modification.

The Saturn V checkout concept is similar to that of the Saturn IB, but the increase in GSE for the larger vehicle, plus the new technique of assembly in the VAB, will no doubt introduce major perturbations. The prior experience accumulated from the Saturn IB will no doubt serve to clarify Saturn V requirements.

In addition, the new and expanded display system for the Saturn V will provide additional man-machine interface capability. This in turn should lead not only to increased use of automation, but possibly more judicious distribution of judgment decisions between test personnel and the computer equipment.

The large quantity of GSE required at the prelaunch area for Saturn IB/V checkout plus the increased involvement of computers make

GSE self-test procedures critical to maintaining launch schedules. At present, automatic self-test programs for GSE are in preparation, with most diagnostic routines planned as off-line functions.

DEVELOPMENT OF TEST REQUIREMENTS AND PROCEDURES

The Astrionics Laboratory at MSFC is responsible for the development of hardware and software to be used for prelaunch and launch operations involving total vehicles at the launch site. The ESE for the Saturn vehicles at KSC, while in many cases possessing the same capability, is physically different from ESE used in factory checkout. This is due to various reasons:

(1) Two different organizations have technical responsibility, Q&RA for the factory and Astrionics Laboratory for the launch site

(2) Different physical environments, including cable run distances, site facilities, grounding technique, etc.

(3) Division, at the launch area, of equipment into "launch-critical" and "non-launch-critical" groups

(4) Detailed design data for factory ESE are not available, in general, at the time launch-site ESE design must commence

This difference in checkout ESE interacts to a major extent with the generation and implementation of test requirements and procedures, so that it is normal for the same portion of a stage to be tested with different procedures at the factory and at the launch site.

As an aid to both hardware and software development and verification, the Astrionics Laboratory established the Saturn Systems Development Breadboard Facility at MSFC. The Breadboard Facility is intended to include computer and ESE complexes identical to those at the KSC launch sites, plus vehicle simulators. The simulators, to the extent practicable, consist of flight hardware with electrical interface simulation where flight hardware cannot be used.

The Breadboard Facility became operational in March 1963, in a configuration similar to Saturn I Vehicle SA-5. It has been periodically updated to match successive vehicle modifications, and is presently being configured for Vehicle 201 of the Saturn IB series.

A separate Saturn V Breadboard Facility is under construction at MSFC, with a scheduled operational date of late 1965. Because of overlapping vehicle flight schedules, the IB and V facilities will be in use simultaneously.

These facilities provide the Astrionics Laboratory with the R&D and verification capability necessary to proceed from the original definition of test requirements through supervision and coordination of the final test procedures, whether manual or automatic.

Although test requirements and software are, as stated, a responsibility of the Astrionics Laboratory, KSC personnel, as users, exercise strong influence upon software and in many cases perform the major document preparation, including test procedures and flow diagrams. In particular, those procedures involving launch site facilities are almost exclusively prepared at KSC.

In addition, IBM's Space Guidance Center at Huntsville is contracted to serve as Astrionics' support contractor to prepare the computer programs for those tests to be conducted automatically, plus the executive and operating system routines. IBM personnel therefore act to some extent as a "series link" between Astrionics system and ESE engineers and KSC test engineers.

Attempts to trace the generation and flow of test documentation must therefore be fragmented into several categories.

Computer-controlled Tests

Decisions as to which tests are to be under computer control are arrived at through joint agreement between the Astrionics Laboratory and KSC.

IBM, working under Astrionics direction, has prepared operating system specifications and programs for the executive and housekeeping routines of the RCA-110A computer. A specification for the test programs for Vehicle 201 has also been prepared for all automatic tests, and program coding is now in process.

To prepare the test programs, IBM has in many cases acted as a system integration (rather than strictly a programming) group, since

basic documentation was often inadequate or being modified. Documentation included:

Stage system schematic and wiring diagrams and test requirements, originating from the stage contractors and transmitted through Astrionics

Checkout computer and ESE schematic and wiring diagrams and test requirements, originating from RCA for the 110A computer, from ESE manufacturers of those items procured as off-the-shelf, and from Astrionics for ESE developed in-house

Facilities and desired test procedure requirements from KSC

With this information, IBM prepared preliminary specifications which, after review and concurrence by both Astrionics and KSC, form the final specifications from which programs are prepared.

After coding and program preparation, the test tapes are run at the Breadboard Facility for verification, and modified as necessary. From the contractual viewpoint, final acceptance of test programs takes place after successful Breadboard verification.

Manually Controlled Tests

For Saturn I, since the computer complex was in parallel with an independent manual checkout system, manual and automatic test procedures were prepared separately with only the cross-checking necessary to assure achieving the desired test requirements.

For Saturn IB/V, however, even manual operations such as operating a console switch to activate a discrete signal rely on the computer-to-computer data link for signal communications, and therefore involve computer programming to the extent needed to interleave and properly channel the flow of information.

The same type of basic documentation discussed above is used for manual tests, but in this case KSC system engineers define the test requirements. From these, they prepare an engineering-language test flow diagram that serves as a communication document to computer programmers who, at KSC, also have an engineering background.

The programmer then attempts to program the test, conferring as required with the systems and test engineers, since considerable information, such as tolerances or timing, is not always available in written form.

The resulting test is a hybrid; so far as the test engineer is concerned he is operating a switch to produce a desired effect in a manner identical to that for a manual system, but the implementation of his action requires computer programming.

Facility Tests

Numerous tests and related procedures involving the launch site facilities, such as RP-1, LH_2, LOX and water storage and control are controlled by separate devices (Loading Computers) and are connected on a hardline basis, bypassing the computer link.

In these cases, the original test requirements are generated at KSC by the cognizant system engineer and converted to written test procedures similar to traditional prelaunch step-by-step manual procedures.

Summing up, for Saturn IB/V, even though the vast majority of tests are basically manual in nature, the computer hardware and software are involved to a major extent. This reflects itself in the format requirements for test procedures, so that almost all KSC test engineers of necessity will have a substantial contact with the capabilities and constraints of the automatic portions of the checkout system.

PRESENT AUTOMATION LEVEL

Because of the wide variety of operations conducted during prelaunch and launch, it is difficult even to categorize these operations into test or non-test (which includes handling, setup, etc.) groups. Such areas as range tracking, interface with site facilities, and others are examples.

For this reason, any quantitative estimate of the degree of automation achieved in checkout must be based on arbitrary assumptions and represents only an approximation. Nevertheless, the estimate so obtained may serve a useful informational purpose and assist in future planning.

When the test sequence on pp. G-6 to G-12 is used as a base (representative of Saturn IB, Vehicle 201), and GSE self-verification tests and those operations classed as pre-tests or post-tests are omitted,

we estimate the automation to be 10 to 20 per cent at this time. This estimate includes a weighting for the increase in the number of test steps due to automation. It is assumed that when a test is automated, three to four automated test steps result on the average from one manual test step. This is due to a number of factors; measurements are more often performed several times and averaged, test sequences are more often repeated, or more combinations are checked automatically than would be checked manually.

The type of computer decisions and judgments made, defined as "level of automation," for the automatic operations at KSC, is shown in Fig. G-2. The computer communicates, processes data, sequences simple tests, and sequences test groups.

The availability of an Activity Indicator interrupt (not yet used), a fixed no-go exit from the General Monitor routine, and a somewhat cumbersome manual entrance to the Test End portion of each program, provide reasonably good emergency reactions.

No posting of emergency routines is provided, although the Test End routine varies with the program, providing a partial equivalent; no immediate direct manual entrance to Test End is provided. No back-up or recycle means are provided in the basic software, although the capability of varying the precedence list provides a portion of this in effect.

No general approach to fault isolation is formulated, although some fault isolation information is implied by the failure indications. No preprogrammed contingency reactions or adaptive testing are provided, although the individually labelled switches and lights, the semiautomatic modes, and the associated small sequencing, interpretation, and checking programs provide good assistance to the manual handling of contingencies.

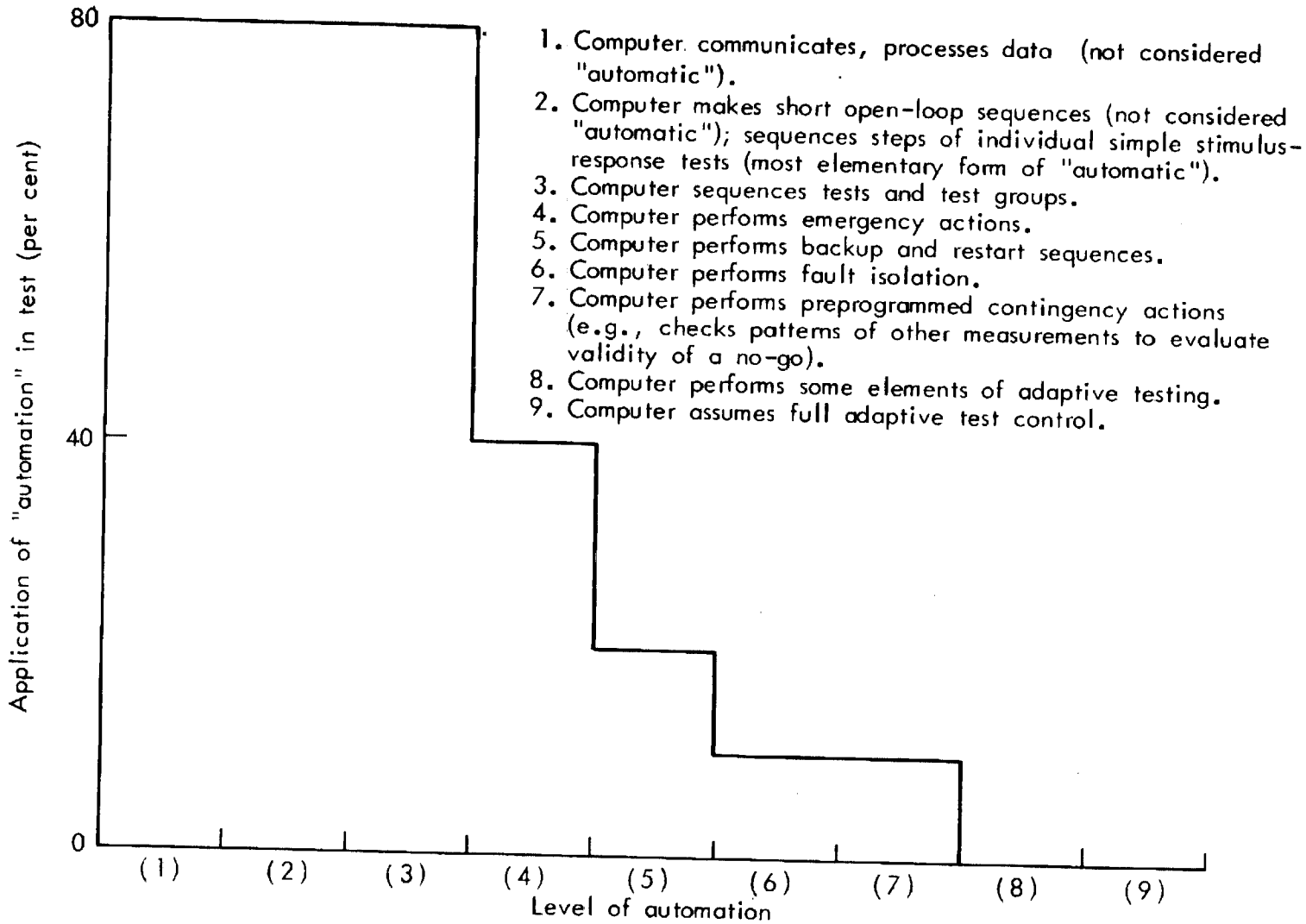


Fig. G-2—Automation level, LV

REVIEW OF PRESENT STATUS

As previously noted, the site-peculiar and mission-peculiar requirements of prelaunch and countdown operations at KSC are such major determinants that the effects of introducing computer control into checkout cannot simply be extrapolated from the experience gained at stage or static firing checkout facilities.

Prior to the first Saturn IB flight vehicle, SA-201, automation of Saturn IB checkout was essentially a parallel option, available as desired. Although a number of automatic tests, primarily G&C and integrated systems, were included in the SA-5 through SA-10 Saturn I vehicles, the computer complex was considered as a necessary adjunct only for a few complex tests that were obviously impracticable to perform adequately on a manual basis.

With the new Saturn IB dual computer and data link configuration, no major increase in the percentage of computer-controlled tests will be evident immediately, but the operational changes, both real and psychological, will be substantial.

The computer and peripheral equipment, even for manually controlled tests, are now a series element in the checkout chain. Approximately 80 per cent of the test steps performed use the computer data link for communications so that some programming and data translation are necessarily involved, and this implies also a requirement for more familiarity by test engineers with the computer complex.

One pertinent example of the effect of this new configuration is the assumption of either manual or automatic control during the course of testing. At present, plans are to have three switch control positions, "Off," "On," and "Automatic." Since it is expected as a matter of course that during many automatic test sequences the test engineer may wish to assume instant manual control, a basic question involves just what should happen when a switch is thrown from the Automatic to the On (manual) position.

The computer program may at that time be performing a sequential operation that must be completed or it may be calling for test stimuli that may involve some hazard if not controlled precisely. To meet these possibilities, present programming is such that switching from Automatic to On does not immediately abort the program but permits it to continue until it reaches a point where it tries to set or reset a discrete signal now controlled by a manual switch setting. The automatic program will then continue if the manual discrete setting is the same as the programmed value, but stop if there is a conflict and permit full manual control from that point on. The time interval between switch activation and transfer of control is anticipated to range from 10-50 milliseconds, which would be imperceptible to the test engineer.

It is obvious that this arrangement requires the checkout engineer to have as much familiarity as possible with what the automatic programs actually are doing in any particular sequence, so that a manual override is not requested at an impracticable time. Conversely, computer programmers must include a continuous search of "critical" switch configurations at points where manual-automatic conflict might be undesirable.

When the switch is transferred back from the On to the Automatic position, the inhibit on that particular discrete is removed and the computer program can proceed. Again, however care must be exercised that conditions are valid for resumption.

In effect, therefore, the manual-automatic capability is now more a "partnership" arrangement than two options. This should eventually provide a higher level of capability and efficiency, but will require an initial familiarization and debugging interval during which problems may appear magnified.

In this initial period, good man-machine communications are of major importance in establishing confidence in the automatic equipment. The man-machine communications are basically the controls for input into the system and the displays and indicators for output data from the system. In particular, the main dynamic display for any automatic checkout system is of prime importance so long as humans are in the checkout loop.

For Saturn IB, six Display Consoles are located in the LCC, with the ability to request "pages" of data from the computer. (Although graphical capability is provided, no programming is in preparation to implement this.) Data pages have been programmed, in terms of format and content, to reflect the test requirements and related desires of the cognizant subsystem test engineer, and generally are composed of discrete values and selected DDAS channel values.

Although this type of display is conventional and adequate to the basic checkout task, it offers little flexibility and marginal control capability and to some extent limits the efficient application of the computer capability. (However, as noted below, the converse is also true since a major increase in display requirements would probably overload the RCA-110As, both in memory capacity and operating speed capability.)

A time history on analog quantities, for example, is desired, and at present must be supplied via supplementary strip-chart records in real time even though they are recorded on magnetic tape for later analysis at both the LCC and the Centralized Instrumentation Facility.

As examples of the potential utility of the display system, even on Saturn I the CRT display was used as a control device in azimuth laying. Programs were called in through the display keyboard, with the computer controlling platform driving, and dynamic results displayed on the CRT.

More of this dynamic test capability is invaluable in adapting to unexpected conditions or fault isolation and troubleshooting, but a greater degree of flexibility is necessary in the display. As presently planned, the Saturn V display will provide this flexibility to a considerable extent. Such fixtures as selective editing and erasing, rapid display updating, light-pen introduction of data, graphical and slide capability, plus the availability of a separate display computer, will permit use of the checkout system to a much greater degree for non-programmed situations.

This capability may be inhibited (initially at least) by classing the display system as "non-launch-critical." Although this serves the desirable purpose of limiting launch-critical equipment to an absolute minimum, there is a related limitation on utility since the programming effort may be adjusted accordingly.

This may become more evident with increased use of computer control in prelaunch tests. At present, the operating speed capability of the RCA-110A computers is not imposing a severe restriction on test efficiency, but this can only worsen as expanded requests for data, display, test status, fault isolation, etc., are generated. Even now, for example, there are discrete events such as valve closures in which a time resolution of 5 milliseconds is desired. Since a discrete signal scan loop for the RCA-110A runs about 30-40 milliseconds, it is necessary to record these events on the DEE for off-line evaluation, or prepare highly specialized programs with limited overall application. Although this serves the purpose, it is less desirable than an on-line, closed-loop evaluation and does not reflect a large improvement in efficiency over a manual technique.

A second example of hardware limitation is in the time required to perform computations, to scale, and to linearize data into engineering units (while also performing other functions). In fuel-loading correction calculations, a 5-second updating cycle was requested but a 15-second cycle was provided.

It is generally true that automatic equipment can never fulfill completely the burgeoning demands placed upon it, but it appears that the margin between computer capability and anticipated requirements, particularly for the Saturn V vehicle, may be extremely narrow.

In terms of planned incorporation of automation for the Saturn IB Vehicle 201 prelaunch checkout, the major use is in equipment monitored by the Electrical Engineering, Guidance and Control Systems Division. This includes electrical networks, flight computers and controls, and guidance elements such as stabilized platforms. This is to be expected, both because the equipment to be tested is electronic in nature and because the cognizant engineering personnel are more familiar with computer operations and capabilities.

Automation in the instrumentation and telemetry area is limited to DDAS and RACS tests. Since the Central Instrumentation Facility (CIF) at KSC already is available, including a data acquisition system and data reduction and support computers, the decision has been made that I&T checkout and monitoring, except for DDAS, would

be a CIF responsibility, to be performed on an open-loop basis via RF link.

In effect, therefore, CIF acts as a service facility to the Blockhouse test engineers in I&T measurement and checkout. For checkout, it is expected that the Blockhouse will control all test setups and insertion of stimuli, with the responses monitored by the CIF. Results will be transmitted by telephone informally, and confirmed later with hard-copy data.

Programming for the CIF data reduction computers is not presently related in language or format to the checkout computers.

The CIF will no doubt reduce the RCA-110A computer workload, but at the cost of some fragmentation of the checkout planning, programming, and operational tasks, with consequent poorer liaison.

There is practically no use of automation at present in the mechanical and propulsion systems of the launch vehicle. Engine gimbaling and response tests are considered electrical tests and are scheduled for future automation. There is also an automatic program in 201 to calculate fuel density to obtain correction factors for manual control of propellant loading. For Saturn V, 501, this is to be expanded to include automatic control of the RP-1 fuel loading system.

In the mechanical area, lack of "design for automation" in the flight hardware restricts the potential for computer control. For example, simulation of ignition and pressure buildup are impracticable, and EBW simulators are not part of the final vehicle.

In all areas, since basic test programs have first priority, comparatively little diagnostic or fault isolation programming has been considered to date.

The use of ATOLL in prelaunch checkout is limited primarily to on-line program modifications, as an aid to test engineers, and restricted from basic programming because of computer speed limitations and the complexity of the initially selected checkout tasks to be automated. Machine language programs, being more difficult for test engineers to understand, increase the importance of program debugging and verification. This in turn enhances the role of the Breadboard Facility, which is the

KSC program verification and simulation facility. Coordination between KSC and Breadboard Facility personnel appears excellent.

An additional benefit of the Breadboard Facility (if implemented early) is that it provides some advance indication of the operating reliability of the major checkout components, including the computers, peripheral equipment, and ESE. This enables KSC to bolster the potentially less reliable items and is particularly important since the flight hardware itself is of highest reliability; many malfunction indications during checkout are due to GSE discrepancies.

Summing up the present status of automation in LV prelaunch checkout at KSC, the following points may be stated:

1. Although the percentage of tests under computer control is still low, a continuing contact with the automatic equipment is forced as a result of the Saturn IB/V system configuration. This will present familiarization problems initially.

2. No direct compatibility usually exists between stage checkout and prelaunch checkout equipment or procedures. Some information feedback takes place informally.

3. No single system planning, engineering, and integration group exists at KSC assigned the future planning of KSC checkout operations. The MSFC groups such as the Astrionics Laboratory have portions of this responsibility, but the designer-user relationship is variable and fluid.

4. Hardware and software appear to be capable of handling the short term checkout tasks, but not with any major expansion in the degree or level of automation.

5. Personnel training and development of confidence in the automatic equipment will for some considerable time to come exercise a major constraint upon increase in automation.

FUTURE AUTOMATION

As an aid in estimating the increase in checkout automation over the span of the Saturn program, it is useful to compare the plans for checkout of Saturn IB, Vehicle SA-201 and Saturn V, Vehicle SA-501.

Since SA-201 is scheduled for an early 1966 launch and SA-501 for early 1967, there is approximately a one year interval between the two.

The computer-controlled test programs for SA-201 are listed on pp. G-6 to G-12. For SA-501, the same programs are scheduled, plus the following additions:

1. Automatic control of RP-1 fuel loading system (in addition to the fuel density calculations)
2. Checkout of the stabilized platform (in addition to azimuth alignment)
3. Checkout of the flight control system (in addition to steering and gain tests)

These tests, when implemented, represent an increase in percentage of automation of 5-10 per cent over the SA-201 checkout. In level of automation (types of computer decisions and judgments), there would be no appreciable advance.

It must be remembered, however, that the use of computer control for SA-501 is limited because of the major effort necessary to design, construct, and verify the new Complex 39 facilities. This naturally dictates a minimum, rather than an ambitious, automation program until familiarity and confidence with the equipment operations are established.

During the step-function effort of achieving operational status at Complex 39, it is anticipated that there will be a moderate and gradual increase in tests under computer control for the checkout of Saturn IB (SA-200 series) vehicles at Complexes 34 and 37. Some of this may be transferable to Saturn V, depending upon the timing and required modifications.

The short term increase in automation for Saturn IB (expected to occur as a continuation of the present level of effort) would include:

1. Addition of computer programs to achieve almost full automatic checkout of all guidance and control components and electrical networks. The test sequences probably will be fragmented to permit parallel setup and testing of different subsystems to proceed with minimum hindrance.
2. Some increase in instrumentation and telemetry automatic testing, but this will be limited because of the use of the separate CIF for data acquisition.
3. In the non-electrical area, there may be some increase in tests involving discrete events, such as valve signatures, but the major efforts probably will be concentrated in eventually achieving automatic propellant loading. How far this progresses will depend to some extent upon the results of similar efforts at the static firing test sites.
4. A substantial increase in automatic GSE/ESE self-test and verification routines, including some diagnostic and fault isolation programs. This is a high priority requirement to minimize the overall decrease in GSE reliability that results from the substantial increase in equipment.

From a somewhat longer range point of view, it is expected that the growth in assignment of tasks to the checkout computers will also strain both hardware and software capability to achieve the desired results, at least on a real time, on-line basis. In this event, serious consideration probably will be given to the following:

1. A real time link between the DEE and the checkout computers. This will permit on-line monitoring and evaluation of rapid discrete signal transitions, and expand the overall test capability, at the cost, however, of an additional hardware item in the "launch-critical" category.*
2. The introduction of multiprogramming as a means of time sharing computer capability and permitting parallel operations. This would require a different programming language, such as the contemplated ATOLL 2, and would be restricted by equipment speed limitations.

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*"Launch critical" is used here as defined by the Astrionics Laboratory, MSFC.

3. A real time link between the CIF computers and the checkout complex. Although requiring a substantial programming effort and some hardware modification, this would permit a much higher degree of automation in instrumentation and telemetry testing. Since a good portion of these tests are essentially high volume, repetitive scans with variations only in parameter values, they offer promise of considerable time savings with automation.

The above comment applies in general to Saturn V prelaunch procedures as well as to Saturn IB. Apart from the requirements imposed by the addition of the S-II stage, the larger S-IC booster and the expanded site facilities, the major change will be the incorporation of the new Saturn V display system. With the DDP-224 display computer, a significant advance is possible in the use of the checkout complex, since there is much greater flexibility for using the display as a control and imprint device to meet unexpected test conditions.

The extent to which this is realizable again may be limited by the "non-launch-critical" assignment of the display system, which inherently is reflected in a less than maximum programming effort.

ESTIMATE OF FUTURE STATUS

Because of the greater complexity of vehicle prelaunch checkout as compared to stage acceptance testing, and also the intense launch schedule pressures, the increase of automation at KSC will, for the foreseeable future, continue to lag the various stage checkout facilities. Personnel retraining requirements, technical and psychological, are also a major factor that necessitate a slower, phased automation program concurrent with development of user confidence.

With achievement of this confidence, and also since the computer data link is an integral part of even manual tasks, there probably will be a sharp influx of additional or new test tasks for the computers to perform in those areas where the advantages of computer control are most evident or the manual testing excessively cumbersome.

This period probably will occur after about four or five vehicle checkouts have been performed.

At this point the limitations imposed by the checkout equipment and associated software will become the governing restraints upon further increase in automation. Careful tradeoff studies will be necessary to determine the relative benefits of additional checkout automation against the cost of major modifications in both hardware and programming. With the presently scheduled Saturn/Apollo program, major modification appears dubious but any increase in quantity of vehicles or schedule stretchout may well affect this estimate.

The Saturn V display system will offer the possibility of a substantial improvement in man-machine communications, and use of the display consoles in a flexible, real time control mode. Since possibly the most important single factor in the use of automation in a highly fluid test environment such as at KSC is the efficiency of the interface between equipment and human judgments, a full utilization of this added capability is highly desirable. As noted, however, a limitation on this utilization may be the non-launch-critical classification of this equipment.

Over the presently scheduled life of the Saturn IB/V program, it is not estimated that increase in checkout automation over that planned for SA-501 will result in any overall cost or even time savings. However it is expected that the following benefits will ensue:

1. Performance of more thorough, in-depth checkout
2. Acquisition of more test data in a format facilitating quick and thorough analysis
3. Better test repeatability, and minimization of human error
4. Training of test personnel, not only in computer hardware and software, but in interdisciplinary, system-oriented test planning.

Appendixes

SATURN I/IB/V LAUNCH VEHICLES VEHICLE PRELAUNCH CHECKOUT SYSTEM DETAILS

A. FUNCTIONAL BLOCK DIAGRAM OF THE ON-LINE SYSTEM[3]

Figure G-3 provides a functional block diagram of the major on-line components of the Saturn IB/V launch vehicle checkout system.

In addition to the on-line equipment, off-line IBM-360-40 and RCA-110A computers and peripheral input-output equipment are available at IBM, Huntsville, as support to assist in preparing and verifying checkout programs.

B. DESCRIPTION--MAJOR COMPONENTS AND FUNCTIONS

Checkout equipment is located in two areas, (1) the Launch Control Center (LCC) for Saturn V or Blockhouse for Saturn IB, and (2) the Launch Umbilical Tower (LUT) for Saturn V or Automatic Ground Control System (AGCS) complex below the mobile launcher for Saturn IB. Data link distances between areas vary from about one-half mile for Saturn IB to over six miles for Saturn V.

LCC (OR BLOCKHOUSE) EQUIPMENT

1. Blockhouse or LCC Computer--RCA-110A

Input - card reader, paper tape reader, display, console, I/O channels

Output - line printer, card punch, paper tape punch, display, console, I/O channels

Memory - 32,768 word core
- 32,768 word drum

Word Length - 24 bits

Input/Output Capabilities -

(a) Six I/O Data Channels (IODC)

IODC 1 - paper tape reader/punch, mag. tape units 1 and 2

IODC 2 - card reader, card punch, line printer, mag. tape units 3, 4, and 5

IODC 3 - data link to and from IU

IODC 4 - analog input/output to and from IU

IODC 5 - discrete input/output to and from IU

IODC 6 - display consoles

(b) Six I/O Control Channels (IOCC)

(c) 192 I/O Sense Lines (IOS)

(d) 192 I/O Address Lines (IOA)

(e) Eight I/O Buffer Registers (IOR)

(f) Eight Priority Request Lines

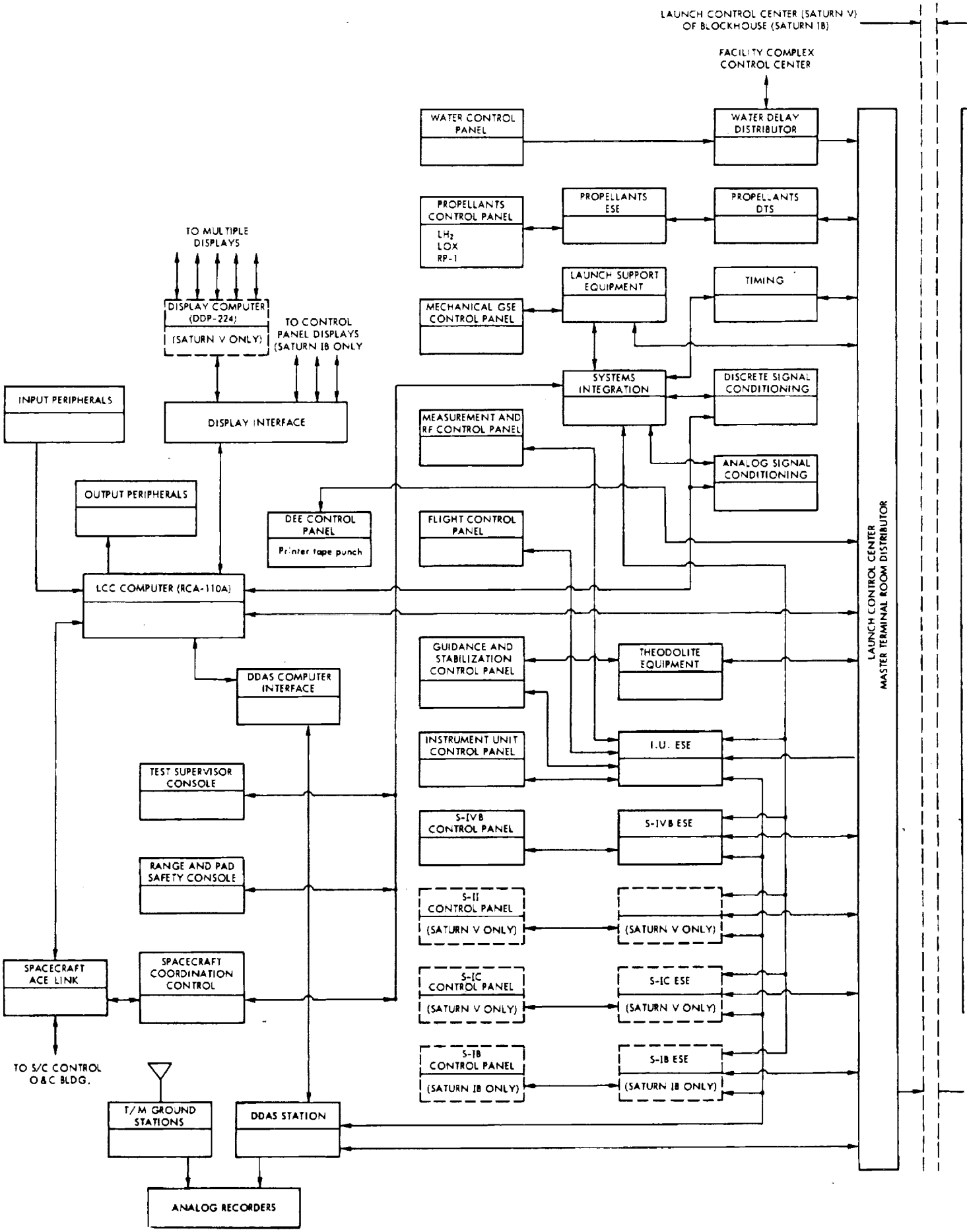
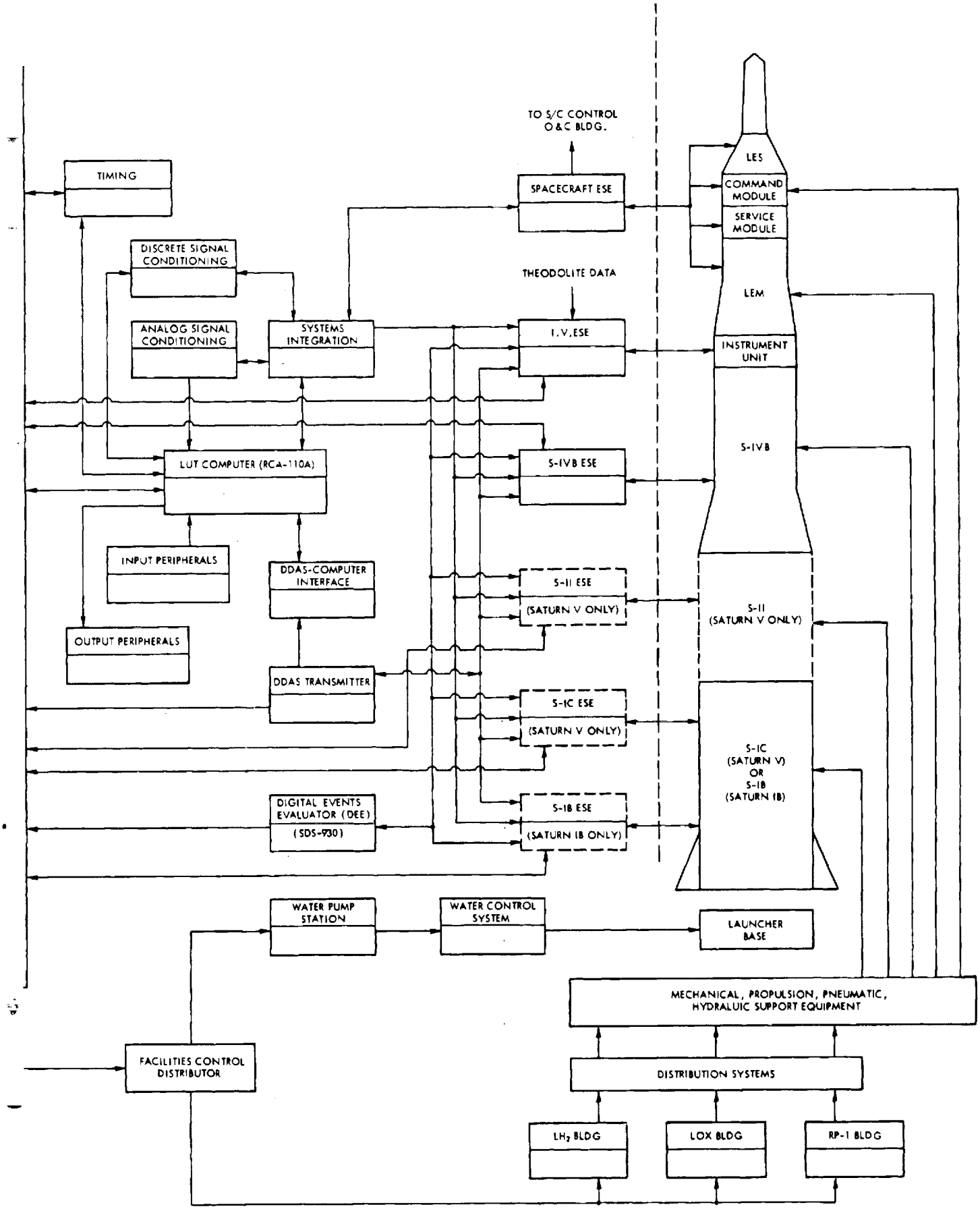


Fig. G-3—Saturn IB/V



inch checkout system

Function - Maintains control of the checkout software Operating System, which processes ESE panel switch position changes, services requests from Display Control Consoles, and controls data link transmissions

- Records test results
- Monitors control consoles for instructions
- Updates indicators and displays
- Maintains link to ACE-S/C system

2. Display System

(a) For Saturn IB only - Consists of 6 Display Control Consoles, each displaying alphanumeric data on Typotron memory-type CRT

Function - Permits data requests via DCC keyboard

- Accepts data inputs from Control Computer

(b) For Saturn V only - Consists of a separate Computer Controls DDP-224 display computer and up to 20 multi-mode CRT display stations

Function - Permits data requests via keyboard at any CRT station

- Processes displayed data for limits, scaling, linearization, etc.
- Controls display data traffic
- Provides capability for alphanumeric data, graphical data, TV data, fixed slide data, TV retransmission, editing and erasing

3. Test Supervisor's Console

Function - Permits monitoring and enabling of all subsystem and system control consoles

- Provides control and display of overall test status
- Provides checkout system intercommunications

4. Range and Pad Safety Console

Function - Provides indication of hazardous conditions affecting launch pad or range area safety

- Provides control capability for vehicle destruct

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5. Test Control Panels

Function - Provide capability for control of specific vehicle stage or subsystem ESE and tests (in most cases independent of other subsystem checkout)

Includes - DEE Control Panel (controls remote DEE)
- S-IVB Control Panel and S-IVB ESE
- S-IB Control Panel and S-IB ESE (Saturn IB only)
- S-II Control Panel and S-II ESE (Saturn V only)
- S-IC Control Panel and S-IC ESE (Saturn V only)
- IU Control Panel and IU ESE
- Guidance and Stabilization Control Panel, with ESE and theodolitic equipment
- Flight Control Panel
- Measurement and RF Control Panel
- Mechanical GSE Control Panel
- Propellant Control Panel and ESE
- Water Control Panel and Distributor

6. System Integration Equipment

Function - Interfaces Control Consoles, launch support equipment, timing data, stimuli-response information, and S/C linkage

Includes - Discrete signal conditioning and input-output equipment
- Analog signal conditioning and input-output equipment
- Prelaunch and range timing data
- ESE/GSE control and monitor equipment

7. DDAS Receiving Station

Function - Receives DDAS signal (600 kc carrier, frequency modulated by data pulse train) from remote DDAS transmitter
- Provides capability for selecting and/or recording specific data channels
- Demodulates, demultiplexes, resynchronizes data words for transmission to computer through DDAS-computer interface

8. Telemetry Ground Stations

Function - Accepts RF or composite signals from all PAM/FM/FM, SSB/FM and PCM/FM stage telemetry systems, either via air link or coaxial cable

- Demodulates and records data
- Converts selected data to computer-compatible form for evaluation
- Provides capability to measure RF parameters
- Provides timing signals for reference and synchronization
- Provides T/M calibration equipment
- Provides capability to adjust and calibrate input channel transducers and signal conditioners

9. Analog Recorder

Function - Records analog data, either from T/M ground stations or DDAS

Includes - Magnetic tape recorders for raw T/M data

- Oscillographs and meters for selected channels

10. Terminal Room Distributor

Function - Provides junction points and interconnection capability for all LCC or Blockhouse equipment electrical connections to stage

- Provides impedance level matching, and driving power interfaces as necessary

LUT (OR AGCS) EQUIPMENT

11. LUT (or AGCS) Distributor

Function - Accepts incoming lines from LCC (or Blockhouse) and provides interconnection points to LUT (or AGCS) lines

- Provides impedance level matching and driving power interface as necessary

12. LUT or AGCS Computer--RCA-110A

(Computer and peripheral equipment same as Item 1)

Function - Executes specific test programs, under control of Item 1

- Monitors and retransmits status of vehicle discrete signals
- Reads DDAS at request of test programs
- Transmits display data to Item 1
- Logs information for post-processing

13. Digital Events Evaluator

Function - Monitors and records discrete events (bi-level or "on-off" signals) together with reference time data so that a permanent record of time-critical test events is maintained

Consists of - A Scientific Data Systems SDS-930 computer with output typewriter and paper tape punch

14. DDAS Transmitting Station

Function - Accepts DDAS data from each of the vehicle stages and retransmits to DDAS Receiving Station

- Communicates selected DDAS data, in proper form, to LUT computer

15. System Integration Equipment

Function - Interfaces Stage ESE/MSE, timing and control data, stimuli-response information, and S/C linkage

Includes - Discrete signal conditioning and input-output equipment

- Analog signal conditioning and input-output equipment
- Timing synchronization
- ESE/MSE control and monitor equipment

16. Local ESE/MSE

Function - Under computer or manual control, provides stimuli to LV and accepts response data in return

Includes - IU ESE/MSE
- S-IVB ESE/MSE
- S-IB ESE/MSE (Saturn IB only)
- S-II ESE/MSE (Saturn V only)
- S-IC ESE/MSE (Saturn V only)

17. Facilities Equipment

Function - Provides necessary propellant servicing and control facilities for vehicle fueling and launch operations

Includes - LH_2 facility
- LOX facility
- RP-1 facility
- Water control facility
- Distribution systems
- Associated propulsion, mechanical, pneumatic, hydraulic support equipment

C. BASIC SOFTWARE

GENERAL

The operating system for the two-computer Cape Kennedy Saturn IB*(4,5) checkout system provides: (1) the general purpose operator control for sequencing automatic test programs, requesting and executing monitoring functions, and performing manual control and display functions, (2) the necessary subroutines for input-output control from machine-language programs and for execution of a limited subset of ATOLL statements, and (3) the general purpose programs associated with the data link between the two computers. These programs are called collectively by IBM the Operating System, and are specified in preliminary fashion in Ref. 5. They occupy about 25,000 words of the BHC (blockhouse computer) memory, and the abbreviated functions at the LUT occupy about 15,000 words of the AGCS (Automatic Ground Control System) computer memory, including tables.

IBM uses the RCA-110A and an IBM-360-40 for preparing programs written in assembly language.** The 360 assembler is compatible with SLAP-II. The 360-40 will also be programmed to provide the small amount of preprocessing required for ATOLL operations in the system. The operating system will be run on the MSFC Breadboard as soon as possible, but the GETS check at KSC, about July 1, is expected to be the final proof of its operation.

In general, schedule pressures have had strong effects on the amount of sophistication planned for the operating system.

No software simulation is included in the system. (Partial simulation of the RCA-110A was performed off-line on an IBM-7094, but merely to help check out the assembly program.)

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*Saturn V plans at present are to use the same system; however, this may change.

**Assembly language is a language in which computer words (and some subroutines) are written in a mnemonic, symbolic form. References to "machine language" usually mean "assembly language"--the slight inaccuracy is sanctioned by common usage.

Figure G-4 shows the basic operating system in the BHC. (The AGCS system is approximately a subset of this, with some variations.) The "operational control" block was originally intended to be a separate subprogram, but will actually be performed almost entirely by the interrupt processor and test program control. (It is left as a "subprogram" on the diagram for conceptual clarity.) A remnant of the operational control program is found in the timing interrupts, and analog or discrete input scan interrupts, which will cause automatic initiation of new operations. New operations may also be initiated as a result of operator commands, or by a specific test program.

On the present schedule, little in the way of automatic software controls are provided to ensure compatibility of interrupt conditions. Instead, the four priority levels are arranged in logical order, and programming supervision planning will ensure against improper use of inhibition of interrupts, and against intolerably long delays in response to lower priority action requirements. (Full inhibition is permitted only in the Operating System, although there is provision for a partial inhibition by test programs, which has an automatic 1-second interrupt to avoid error loop damage. There is a minor exception also in the on-board computer test programs.) At present, the fastest required sampling rate anticipated is 10 per second, and the longest true operating-system interrupt inhibition anticipated is one or two milliseconds.

Although these statements say nothing about interruption times of lower priority items by higher priority ones, such times are also expected to be tolerable. One way to make them tolerable is to avoid programming functions that cannot tolerate them. The specification states, "The programmer must be cognizant of the ability of the Operating System to interrupt the programs at any time and for any length of time." This is not as bad as it sounds, because (1) most interrupts are expected to be of short duration, and (2) any time-critical test program will have a special "time-critical interrupt routine" and special reentry point after interrupt, to permit compensating for interrupt delays. Figure G-5 shows more detail.

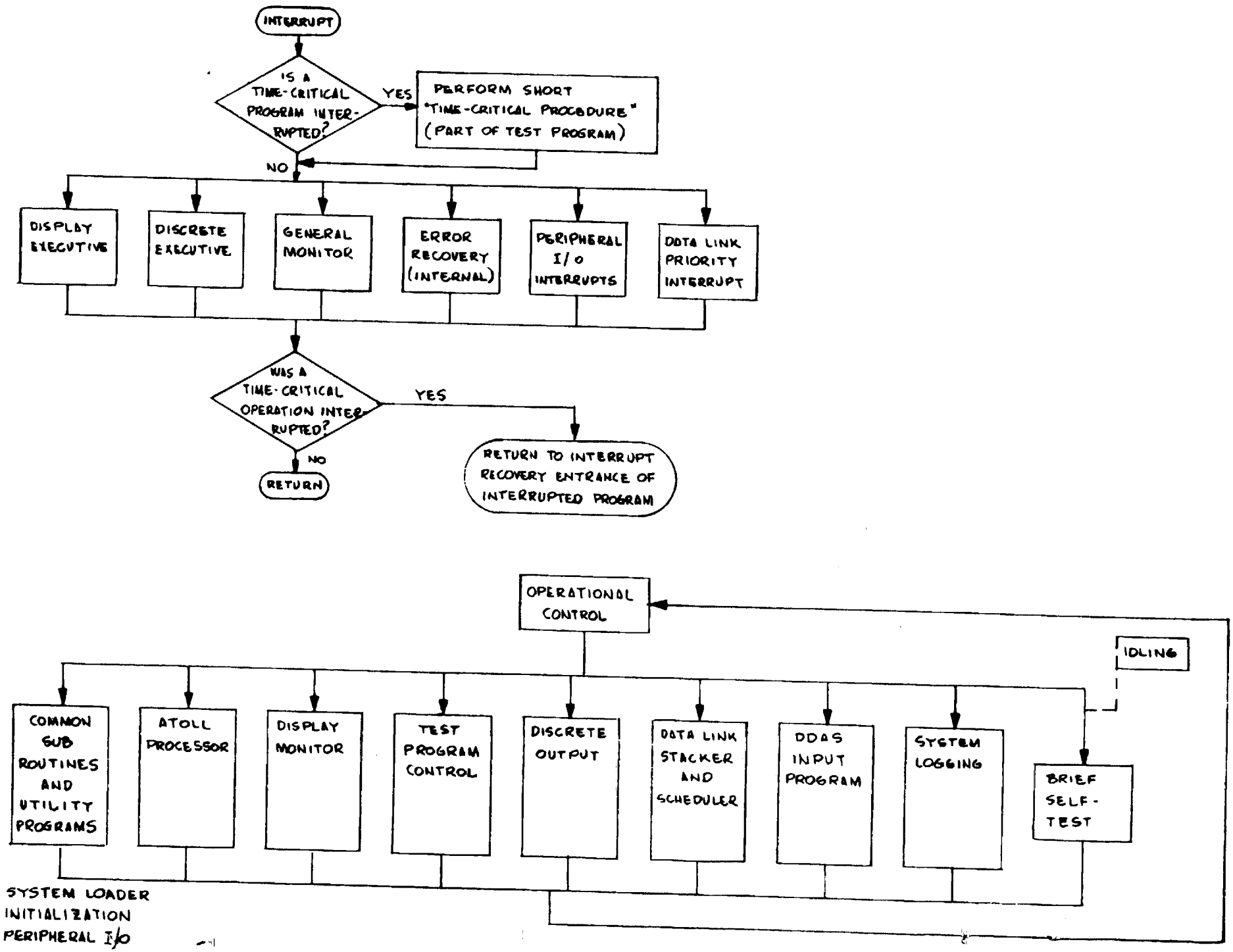
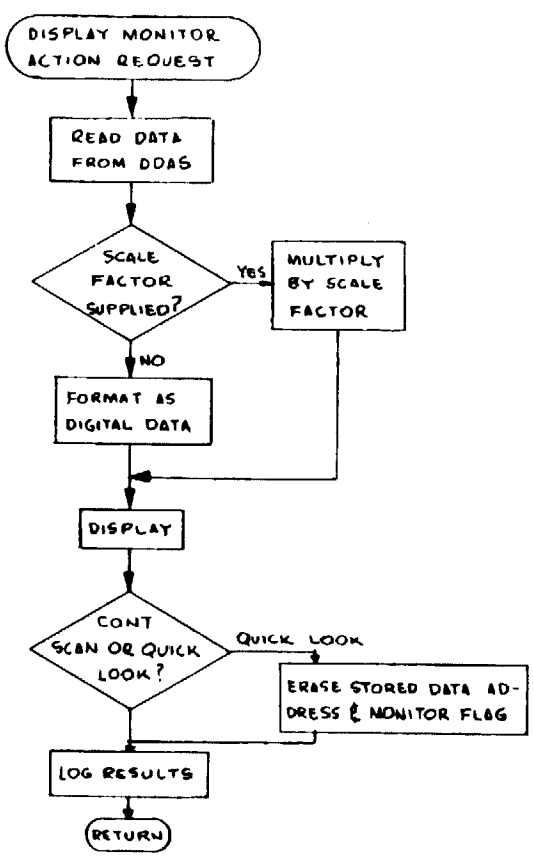
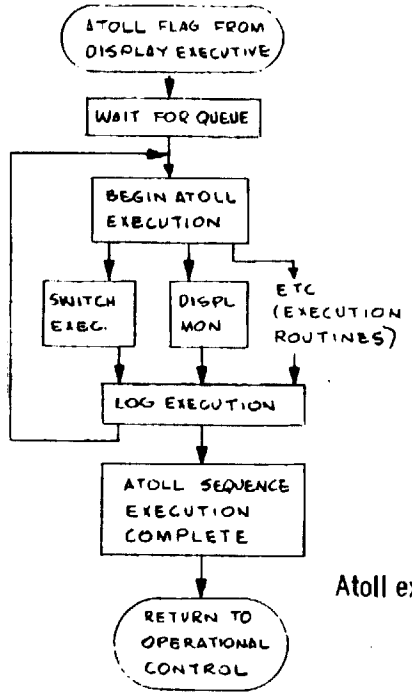


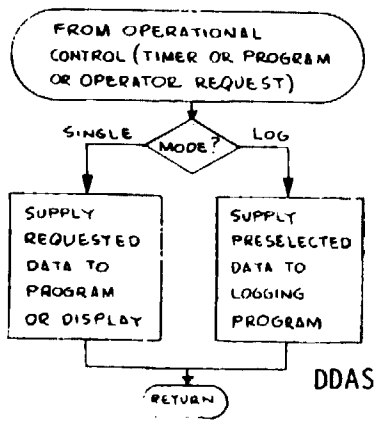
Fig G-4—Blockhouse computer



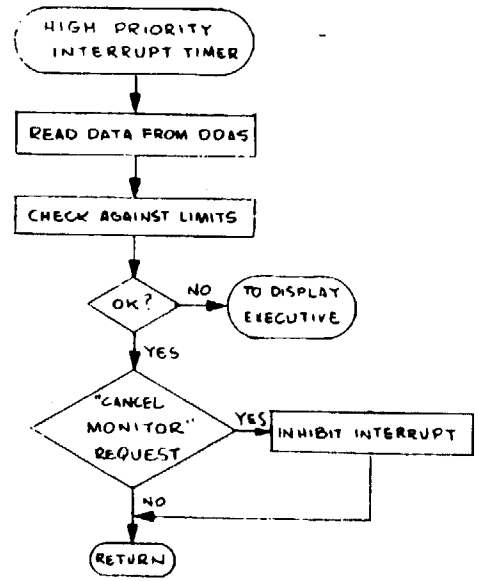
Display monitor



Atoll executive



DDAS input



General monitor

Fig. G-5—Miscellaneous programs, LV

MONITOR, DISPLAY, DATA LINK, AND HOUSEKEEPING FUNCTIONS

Three monitoring modes are provided: General Monitor, Continuous Display Monitor, and Quick-look Display Monitor. Because it is necessary to erase the entire CRT to edit it, no attempt is made to provide rapid "continuous" display. Instead, the three modes have the following characteristics:

General Monitor. This reads in a pre-chosen set (up to 100 total for all consoles) of analog and discrete measurements at the BHC (DDAS quantities or discretes), and compares them with desired values. Out-of-tolerance values cause an alarm display on the CRT, written on the next available empty line, or other programmed action. All General Monitor items and their sample rate must be pre-defined by the program. The fastest sample rate is 5 per second.

Continuous Display Monitor. Approximately every 15 seconds (per console), this monitor, controlled by low priority interrupt, reads-in a pre-chosen set (up to 20 per console, up to 75 total) of analog and discrete measurements at the BHC (DDAS quantities or discretes), and displays them on the CRT. The Operating System uses the next available line on the CRT. If the tube is full, the Operating System erases the tube (after the last line has been displayed for 15 seconds) and writes the new item on the first line. An alternative permits the quantity to be displayed only when it is out of tolerance. The operator may add items to or delete items from the list at will.

Quick-look Display Monitor. The operator may request a one-time display of any quantity available at the BHC (DDAS quantities or discretes).

Arbitrarily displayed quantities are not linearized, although the operator may insert a constant scale factor and bias at the beginning of a test or when he calls for a measurement. If the need for display is anticipated, the programmer may pre-choose scale factor and bias, and may insert special linearizing routines. No full table of measurement conversions will be programmed at first, although this may be added later. No procedure has yet been completed for routine entry of calibration data into a display conversion program.

The Display Executive processes inputs to the Display Control Console from the operator, and outputs to the Display Control Console for CRT presentation. Requests are made by typing in commands and data on the keyboard. No summary function keys are provided; in general, functions are commanded by four-letter mnemonic codes plus program labels.

The program start-stop control is developed from one designed to handle short, separable specific test programs that are individually selected by the operators. A program may be initiated or terminated, and "terminate" means "stop now and enter the Test End routine, without waiting for a suitable stopping place." (The Test End routine, a specially programmed part of each program, is expected to cancel any unsafe conditions resulting from sudden terminations.) There is no provision for Hold or Stop (within a program) in the Operating System, although of course the equivalents of these could be specially programmed as part of a specific test program. There is no general provision for recycle to a previous intermediate point or for Backup in the Operating System, although these theoretically also could be written as ordinary "test" programs, to be called up by the operator when he wanted them. There is no provision in the Operating System for restart after "termination," or for multiple entry points to a program. The provisions for emergency stop and emergency contingency action are:

(1) the Terminate-to-test-end sequence, manually initiated by typing in eight characters, including the program label

(2) a pre-coded no-go exit from General Monitor, and

(3) the high-priority Activity Indicator interrupt, resulting in some specially pre-coded action. (No such interrupts have yet been defined.)

Instead of having multiple entry points, the IBM system permits the operator to call for a predetermined sequence of tests, each of which can also be called for separately. This sequence may be defined from the card reader at run time. Instead of having a Breakpoint mode, it lets the operator delete specific tests from the sequence list before they have been performed. (This has the same effect,

except the "breakpoint" is at the major-test level, not the test-step level, and it is necessary to delete specifically all tests after the desired breakpoint.)

TEST PROGRAM OPERATIONS[1]

To request a test program, the operator types in a request and the computer adds his request to a queue. When his turn comes up, the operator types a request to execute the program, and execution begins. The program has complete control of the AGCS complex (and BHC when necessary), as shown in Fig. G-6, except for interrupts, until it is completed or the operator requests termination.

The operator may ask for a number of programs before executing any, to make a stack of programs. Requests are serviced in the order entered. He may cancel a request before execution.

The operator may also request a "sequence" of test programs to be run automatically with a single request. Normally, such sequences will be treated by the interleaver (see below) as a stack of separately entered programs, but the programmer may call the stack non-interleavable, in which case all members of the sequence will be completed before control is turned over to the next station.

The six operator consoles will be serviced in turn. The Operating System will execute a program from the stack of the first operator. Upon completion, if the next operator has requested execution, the system will begin immediately the program at the next console in line, and so on in round-robin fashion. Meanwhile, the first operator may add to his stack. Thus there may be some time between a request for execution and the time at which the request is honored. The IBM people do not expect most single tests to require much over 30 seconds, and they feel that the normal test planning will prevent serious delays due to competition for the computer's attention. (These assumptions are probably true, at the present stage of KSC automation, and are probably necessitated by schedule pressures. However, this simple approximation to multiprogramming may possibly break down later if automation increases considerably.)

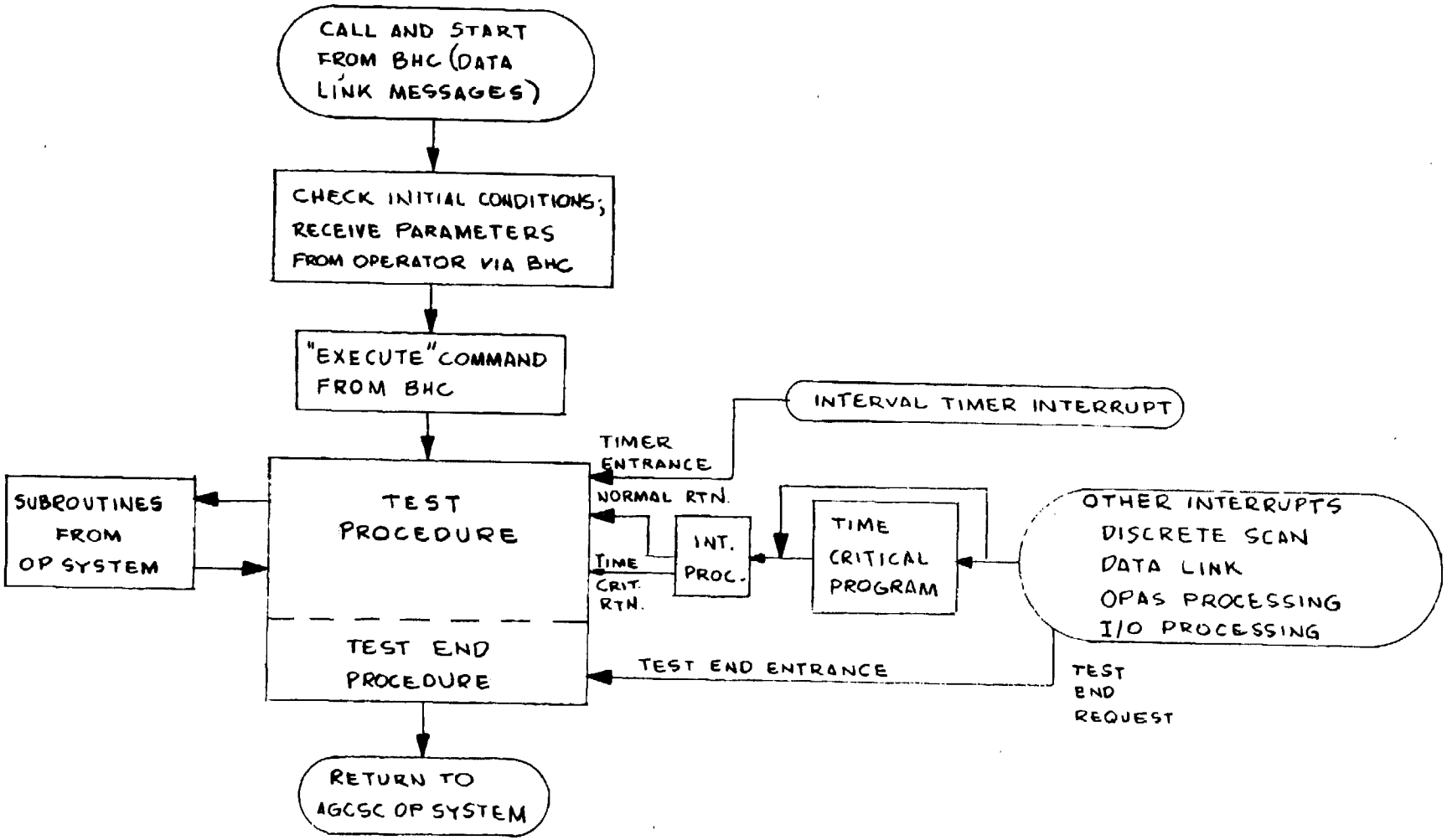


Fig. G-6—AGCS complex test program operation, LV

Test program control will require coordination between the BHC and the AGCS complex. The AGCS complex will normally contain the test program (except for those tests that use telemetry data available at the BHC).

Although an operator may request any display or monitoring function, he can call for only certain test programs. Each test program contains a code telling which operator card validates a request for the program, and each operator has a card with the corresponding code, which he must insert at the console he is using.

The present system has only an elementary subset of ATOLL, which cannot loop or perform any arithmetic, and which is probably useful only for certain network tasks. This ATOLL subset was implemented as a test engineer's tool. Programs coded by the programming organization will be largely in machine (assembly) language.

DATA LINK CONTROL

The simplex data link* is a vital portion of the Saturn IB checkout control. Command words and three types of messages are provided, in both directions. The messages are:

1. Flash Messages, in which the message is contained within the single command word (e.g., "transmission error detected, cancel information just received")
2. High-priority Messages
3. Normal-priority Messages

Control of sequencing is always in the BHC, and the BHC program can sense queues both in itself and in the AGCS complex.

The data link is attached to an Input-output Data Channel (IODC), which communicates directly with memory, so program participation is required only to initiate messages and give other commands. Once the IODC has been ordered to transmit a message of (say) X words starting at location Y, further operation is automatic.

The Operating System provides for continuous automatic transmission of messages stacked up in each computer, in order of priority, until all

*A simplex data link is one which passes information in either direction, but not both directions at once.

queues are empty. Erroneous transmitted parity causes a Flash Message to cancel the reception, and a re-try at transmission. Erroneous received parity causes a message repeat. Three unsuccessful automatic attempts cause the program to give up and assume a failure in the data link.

IBM personnel have not yet analyzed data link traffic, although they feel from preliminary looks that queue lengths will not become intolerably long.

MANUAL CONTROLS AND USE OF INTERRUPTS

For some time, the principal mode of the KSC installation will be manual, in which one manual switch at the Blockhouse causes one discrete or switch-selector action at the vehicle, and visual displays provide status information. The Operating System is designed to facilitate this.

Each Blockhouse switch has three positions: Off, Automatic, and On. In the Off and On positions, the corresponding vehicle or ESE condition is "frozen in," and the computer is inhibited from changing it. If the test program tries to change it away from the chosen condition while running an automatic program, the attempt is sensed by the Operating System. In such a case, the test program will branch to a pre-chosen alternative action, which may be (1) continue with a preprogrammed alternative procedure, (2) terminate the automatic test, or (3) display and hold for manual decision.

When the Blockhouse switch is returned to Automatic, the inhibition is removed, and the test program may then control the condition. However, removal of the inhibition may not change the condition. If the condition has been changed manually to one not anticipated by the program, it will remain in this state. If this can affect program operation, either (1) the program must check or repeatedly set the states of such discrete outputs whenever they are important, or (2) the operator must manually exercise care not to set up an anomalous situation.

The three major simultaneous functions are:

1. Running the test program
2. Servicing manual switch actions
3. Running the display and general monitor programs

The degree of simultaneity and complication of interruptions is reduced by the two-computer nature of the system. For example, the AGCS complex may be running a test program at the LUT while the BHC is performing critical and display monitor functions at the Blockhouse. (Monitor programs have access to data at the Blockhouse, such as BHC discrete signals, DDAS quantities, and AGCS complex data sent up the data line, such as vehicle digital computer information and vehicle discrete inputs to GSE.)

The priority level structure is shown in the following table.

The reverse path for manual operation--Blockhouse indication of VDI states--begins at the AGCS complex discrete-input IODC. The IODC repetitively and continually scans the DIs and updates the DI profile in the AGCS complex memory, without program participation. Every 500 milliseconds, a timer interrupts the AGCS complex to initiate a data-link message, which sends the DI profile (from AGCS complex memory) to the BHC. At the BHC, the received profile is compared with the previous profile, and the discrete-indicator panel lights are updated.

INTERRUPT PRIORITY LEVEL ASSIGNMENT, LAUNCH VEHICLE

Level	Line	BHC	AGCS Complex
4	8	Activity Indicator	Activity Indicator
4	7	Interval Timer 1	LVDC Interrupt
3	6	Data Link Command Word Receipt	Interval Timer 1
3	5	IODC Terminations	Discrete Changes
2	4	SDI Changes	Data Link Command Word Receipt
2	3	Display (Keyboard Request)	IODC Terminations
1	2	Interval Timer 2	Interval Timer 2
1	1	Interval Timer 3	Interval Timer 3

NOTE:

BHC

Interval Timer 1 used by Test Programs
Interval Timer 2 used by General Monitor
Interval Timer 3 used by Display Monitor

AGCS Complex

Interval Timer 1 used by Test Programs
Interval Timer 2 used to transmit VDI Status to BHC
Interval Timer 3 used by Switch Selector Routine

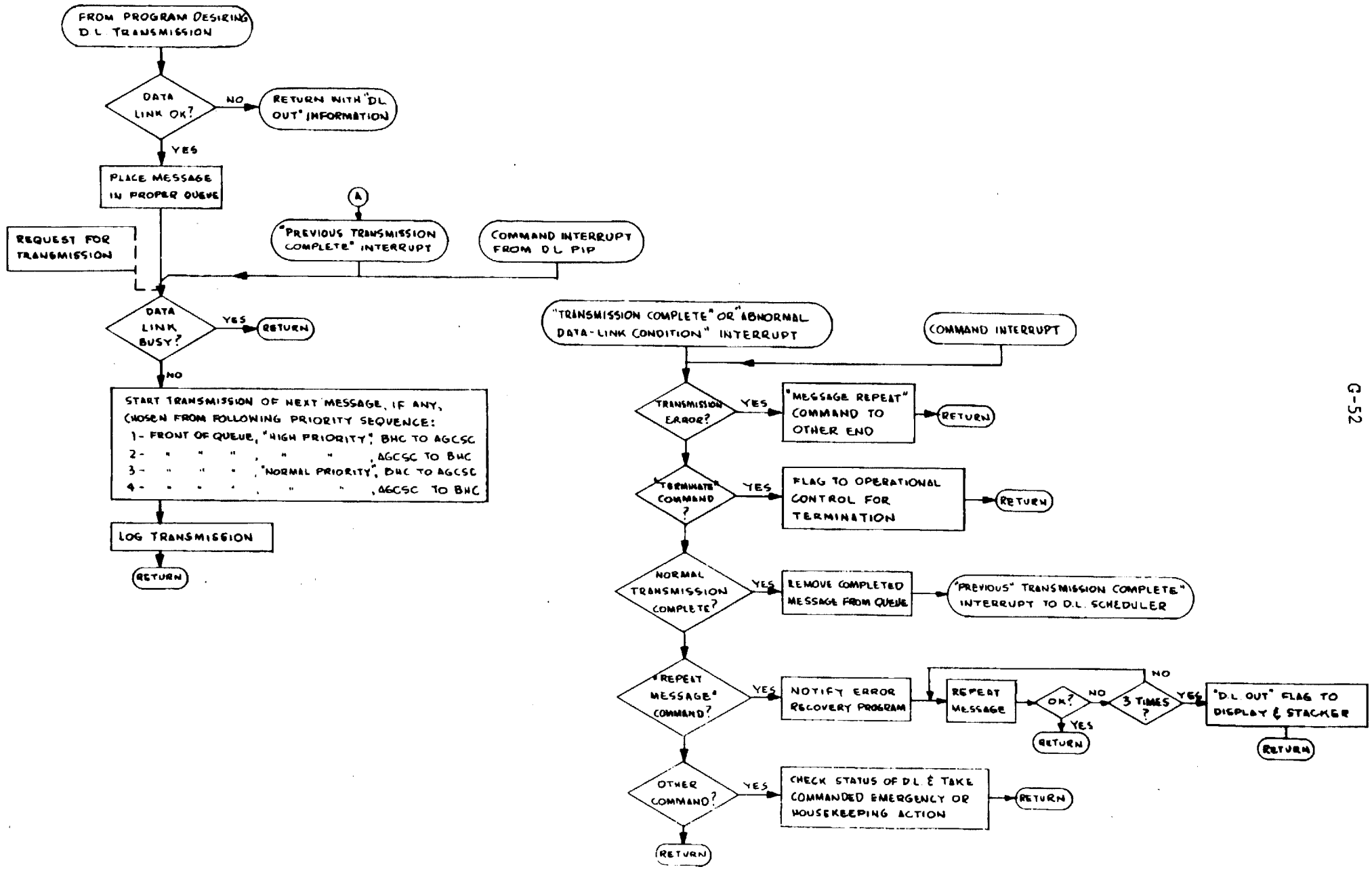


Fig. G-7—"Display/interrogate" and execution

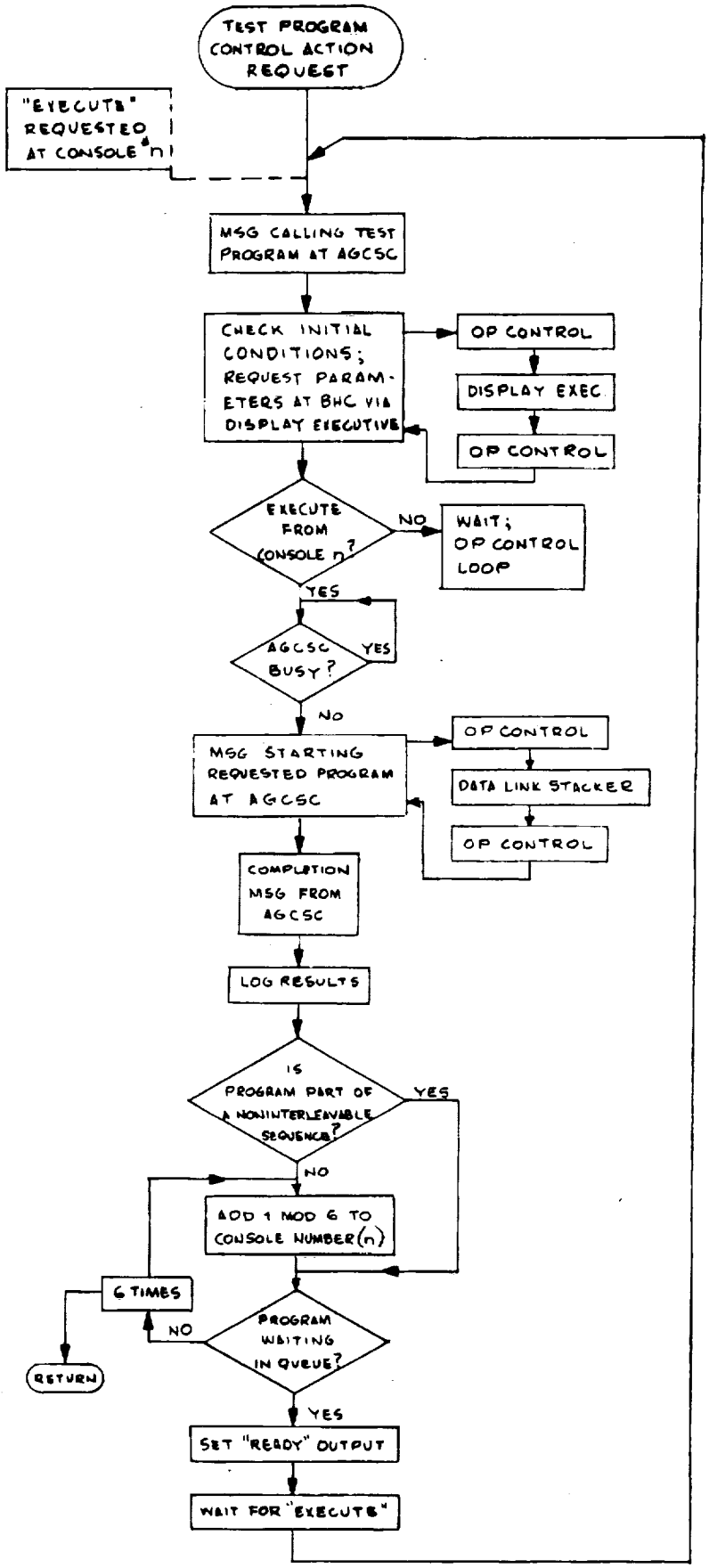
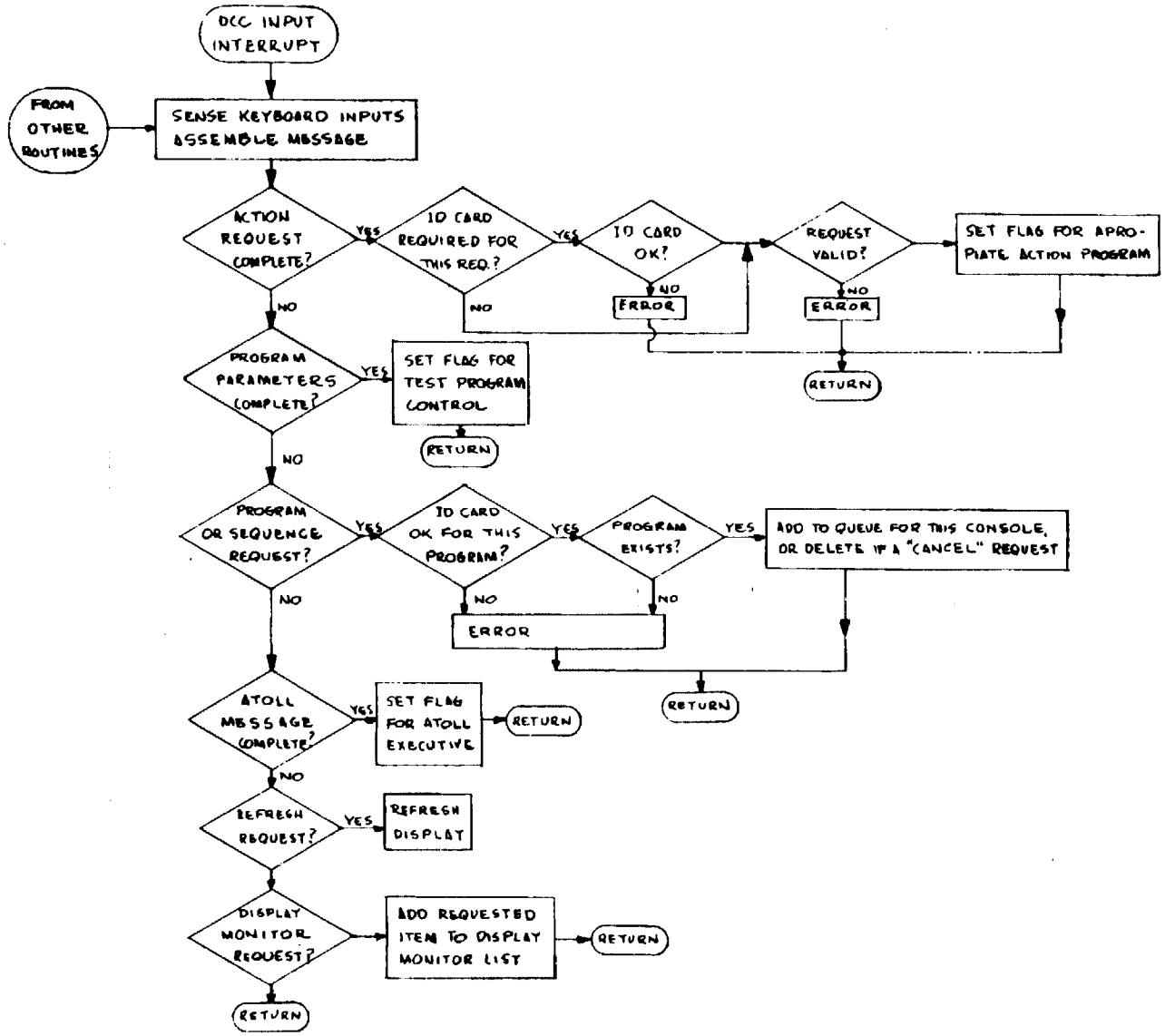
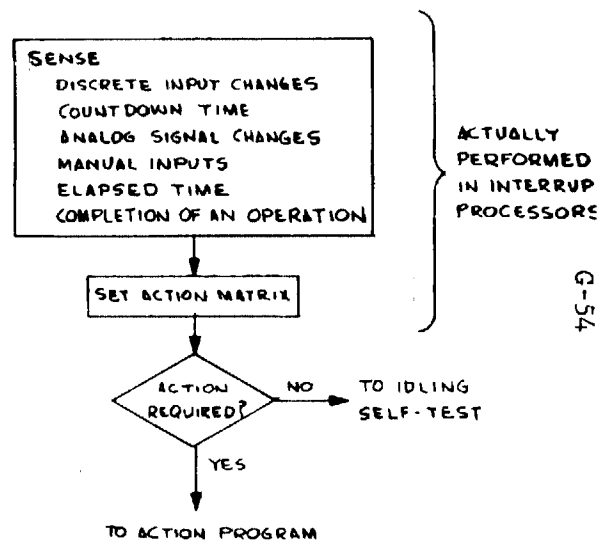


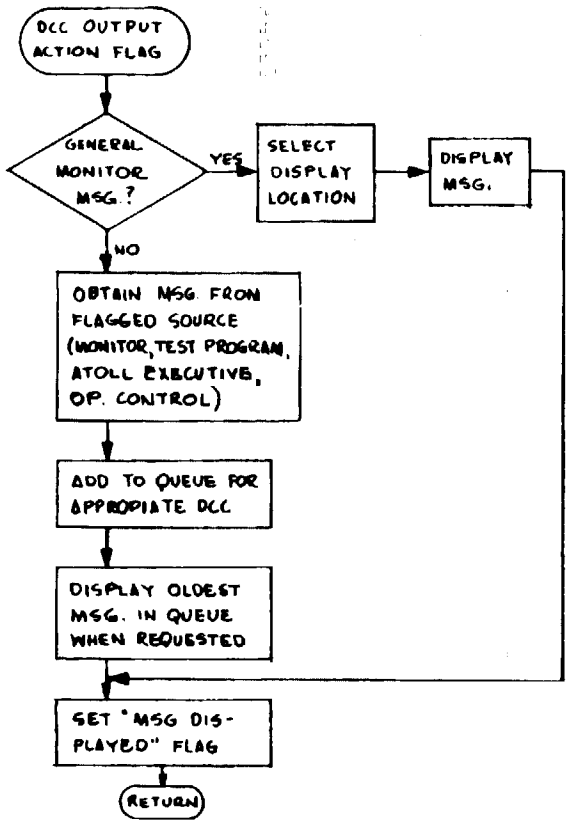
Fig. G-8—Test program control, LV



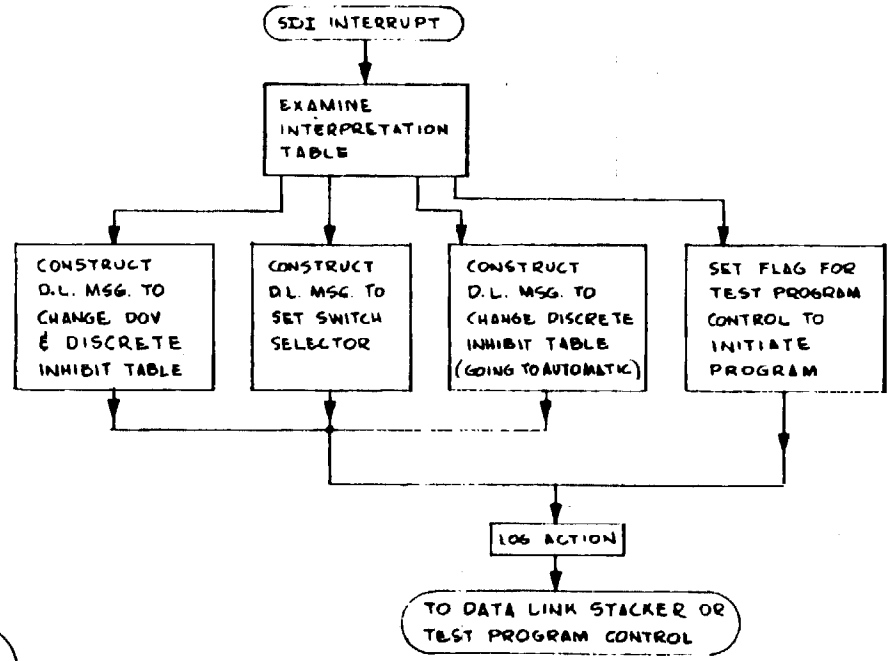


Operation control—launch vehicle

Fig. G-9—Display executive (inputs), LV



Display executive (outputs)—launch vehicle



Discrete executive—launch vehicle

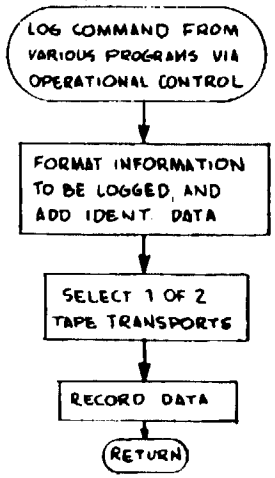


Fig. G-10—System logging, LV

D. SATURN V DISPLAY[6,7]

The display system scheduled for incorporation into the KSC checkout complex (39) for the Saturn V LV is now under construction by Sanders Associates, the system contractor.

The Saturn V Operational Display System, as it is termed, is designed to provide a real time monitoring, command, and emergency control capability during checkout operations. Its major features include:

1. A separate digital computer, the Computer Control Corp. DDP-224, utilized as a display processor providing centralized system logic and control.
2. Simultaneous computer control of up to 20 CRT display consoles with the ability to display:
   (a) Tabular alphanumeric data (up to 2,028 characters per page)
   (b) Graphical data (on a 512 x 512 matrix)
   (c) Closed circuit TV (from any of 10 video channels)
   (d) Slides (any of 512) and/or mixed slide/alphanumeric data
3. Capability to produce hard-copy (photographic form) of CRT data, and to generate a TV picture for retransmission.
4. Capability of any console operator to initiate a test or request specific test data via a console keyboard.
5. Capability of any console operator to edit, erase, or add data to display (via the keyboard or a photo pen).
6. Ability to monitor any console display from any other console.
7. Individual refresh memory (4,096 word core) per console.
8. Ability to select any of 10 prestored formats for convenient tabulation of the displayed data.
9. Ability to flash any character or line of characters under program control.
10. Operational interface with the RCA-110A checkout computer complex.
11. Modular construction to permit future addition of memory storage or consoles.

In operation, the Saturn V Operational Display System interfaces with the RCA-110A computer through an IODC that provides buffering and

control for data transfer. Under RCA-110A program control, the IO data-transfer operation between the RCA-110A and display unit is set up, after which the RCA-110A returns to its normal operation. The IODC then executes the data transfer and terminates the operation.

The DDP-224 display processor computer, acting in concert with the RCA-110A control program will perform any of the following functions:

1. Control the distribution of data to up to 20 display consoles.
2. Accept data from the RCA-110A in raw binary form and convert this data into console-compatible format.
3. Control the memory distribution switching.
4. Select projector slides.
5. Accept and process requests from the console operators.
6. Control hard-copy and TV camera converter operations.
7. Send test status response data to consoles.
8. Queue on console priority according to the waiting list of interrupts.
9. Erase data selected by a console operator through his photo pen or keyboard space bar.
10. Generate page and test formats (up to 10 preselected formats stored in a format band).
11. Switch data from the console keyboards into the refresh memory.
12. Exercise lock-out or security control over console operations.
13. Provide alternative routes for monitor and control functions.
14. Format console commands intended for the RCA-110A computer into compatible form.
15. Self-check display system and major components.
16. Format tabular to graphic presentation.
17. Convert data into engineering units and check against limits, where so programmed.

With this range of capability, the console operators are provided with more powerful and convenient means not only to observe test data, but to use the system as a two-way, real time command/control element which, in addition to preprogrammed operations, can also be used to meet unexpected or non-programmed checkout conditions.

Annex G

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6. NASA, George C. Marshall Space Flight Center, Saturn V Operational Display System, Exhibit "A".

7. Sanders Associates, Saturn V Operational Display System Block Diagram, Drawing 38156, January 15, 1965.

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