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ANALYSIS OF A DISPLAY AND CONTROL SYSTEM MAN-MACHINE INTERFACE CONCEPT

FINAL REPORT

VOLUME I

FINAL TECHNICAL REPORT

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FOREWORD

This final report covers the work performed by Autonetics Division of North American Rockwell Corporation under a study contract entitled Analysis of a Display and Control System Man-Machine Interface Concept. The report is submitted to the National Aeronautics and Space Administration Manned Spacecraft Center under the requirements of Contract NAS 9-12266. The study program covered the period from October 1, 1971 through August 31, 1972. The NASA technical monitor was Mr. G. K. Raines.

The final report consists of four (4) volumes:

→Volume I.	Final Technical Report
Volume II.	Appendix A. Principal Subsystems of Phase B Orbital Vehicle used in the Analysis.
	Appendix B. Control and Display Data Required for Crew Operations.
Volume III.	Appendix C. Formats and Format Trees
	Appendix D. Coding of Sample Format
	Appendix E. Principal Subsystems of NR-SD Winning Proposal Orbital Vehicle
Volume IV.	Appendix F. Control/Display Sequences for Four Mission Phases

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1.0 INTRODUCTION

1.1 OBJECTIVE

The objective of this study was to evaluate the feasibility of utilizing a simplified man-machine interface concept to manage and control a complex space system involving multiple redundant computers that control multiple redundant subsystems. The concept under evaluation involved the use of a CRT for display and a simple keyboard (numerics and function switches, no alphabetics) for control, with a tree-type control logic for accessing and controlling mission, system and subsystem elements.

Demonstration of concept feasibility was contingent upon preliminary definition of display formats and keyboard functions required, the control logic tree to be utilized, control and display software needed and potential problem areas encountered with this approach. Additional support was required through demonstration that the crew could effectively monitor and manage the system during critical mission phases without compromising mission success or crew safety.

To provide an effective test of the concept, the Orbital Vehicle of the Space Shuttle System was selected for analysis. The concept was evaluated in terms of the Phase B Space Shuttle System Design Study Orbital Vehicle, to utilize the wide scope of data management and subsystem control inherent in the central data management subsystem provided by the Phase B design philosophy. Following evaluation of the feasibility of the control/display concept with that system, a limited supplemental study was performed to evaluate feasibility with the North American Rockwell Space Division (NR-SD) winning proposal configuration. This was to determine the effectiveness of the concept with a system exhibiting much more limited central data management and control and providing a much greater utilization of dedicated cockpit instrumentation.

1.2 WORK ACCOMPLISHED

The study was performed in five phases: (1) establishment of control/display functional requirements, (2) development of control logic concepts, (3) preliminary design of control/display processor/software , (4) determination of concept impact on the DMS and problem identification, and (5) application of concept to the NR-SD winning Shuttle design. The following is a brief summary of the work performed during each phase.

1.2.1 Control/Display Functional Requirements

Phase B Space Shuttle Orbital Vehicle design specifications and descriptions were utilized to identify (1) mission characterisitcs, including a detailed mission time schedule, (2) vehicle/subsystem characteristics requiring control and display interfaces, (3) total information and control requirements, and (4) mission-specific crew tasks, for both nominal and non-nominal mission phases. A preliminary control and display logic concept was developed. Utilizing this and the information and control requirements, sample display formats were developed for mission and subsystem management. Approximately 100 formats were developed, representing 20 percent of the estimated total format requirement. Crew workload requirements were estimated, based on timeline analyses of selected mission phases, with the crew utilizing the preliminary control and display design concepts and sample display formats. Total display and control requirements were estimated on the basis of the above analyses.

1.2.2 Control Logic Concepts

A control logic tree was developed, to permit crew access to any display format in the system, utilizing no more than two indexes. Control and display sequencing for both crew members, utilizing all five CRT displays and three keyboards, was diagrammed step-by-step for four mission phases, to illustrate how data and commands are entered into the computer and to verify the utility of the control and display concept to the crew. Keyboard functions were completely defined.

1.2.3 Preliminary Design

Two alternate display/processor/software designs were developed and defined in detail, including mechanization, hardware requirements. The major difference between the two design concepts was in the method of display generation -- one utilizing a complex random stroke generation technique, the other using a less complex dot matrix generation technique. Estimates of mass-memory and processor storage and speed requirements were generated for each of the two design concepts. Program modules for all display and control operations were identified and described. Feasibility of both design concepts was verified.

1.2.4 Impact and Problem Areas

The impact of the two alternate design concepts on the central Data Management System was assessed and found to be primarily in the area of mass memory requirements. Problems associated with the implementation of the design concepts were identified, as well as problems associated with crew utilization.

1.2.5 Application to NR-SD Winning Shuttle Design

In a limited supplemental study following completion of the main study work described above, the NR-SD winning proposal configuration and the NASA proposal mission were reviewed to select representative subsystems for concept application evaluations. A mechanization approach and a preliminary design for concept application were defined. Three computers, two mass memories and a large number of command decoders were added to incorporate the concept. These additions were required since the NR-SD design utilizes dedicated controls and displays and does not include a central data management system.

Due to the significant quantity of added hardware/software, the control and display concept does not appear attractive for the NR-SD design.

This supplemental study is reported in Section 7.0 of this report.

1.3 REPORT CONTENT

Sections 2.0 through 6.0 report only the main study (Phase B shuttle configuration). Section 2.0 presents summary and conclusions. Section 3.0 describes the control and display functional requirements. Section 4.0 covers control logic. Section 5.0 covers preliminary design and Section 6.0 describes DMS impact and problem identification.

Section 7.0 reports only the supplemental study (NR-SD winning shuttle configuration).

2.0 SUMMARY AND CONCLUSIONS

2.1 BASELINE ASSUMPTIONS

Assumptions made concerning the baseline system design fall within three major areas: (1) human performance capabilities and limitations, (2) SSV program, mission and vehicle constraints, and (3) control and display guidelines.

2.1.1 Human Performance Capabilities and Limitations

Design of SSV system and subsystem equipment, GSE and component arrangement was assumed to be in conformance with established human engineering design criteria. Design of the DMS control and display concept used in the study, and the logic and procedures for its utilization, conform also to established human engineering design criteria.

Primary source for established human engineering design criteria was MIL-STD-1472, Human Engineering Design Criteria for Military Systems, Equipment and Facilities. Performance data relating to human capabilities and limitations not covered by applicable portions of MIL-STD-1472 were obtained from standard human engineering texts, MSC inhouse and sponsored studies and from Autonetics human engineering experiments and studies.

2.1.2 SSV Program, Mission and Vehicle Constraints

The Phase B Space Shuttle Orbital Vehicle design was selected as the baseline system for evaluating the control and display concept. The only changes made in the Phase B design were those necessary for incorporation of the control and display concept.

The orbiter was assumed to have a two-man flight crew, to be flyable under emergency conditions by a single crewman, and to have landing characteristics and handling qualities requiring no more demanding skills than those required for operational land-based aircraft. Normal operation was considered automatic, but the flight crew was provided the capability to control the space shuttle through all flight phases.

The MSS Logistic Resupply Mission was selected for the detailed analysis. Functions relating to docking and cargo handling were not included in the analysis because they are performed from a separate crew station. It was concluded that the MSS Logistic Resupply Mission is completely representative of all other Space Shuttle Missions with respect to its control/display requirements.

2.1.3 Control and Display Guidelines

The baseline control and display subsystem used in the study consists of 5 CRTs and 3 keyboards, with a limited number of dedicated displays and controls identified by the study. With the exception of the few dedicated displays and controls, all information necessary to the monitoring and control of the mission, vehicle and subsystems is available for display on the CRTs and all control actions involved in selecting displays, entering data, initiating control sequences and controlling discretes can be performed from the numeric keyboard and its associated function keys.

The CRT display system is capable of displaying computer generated alphanumerics and graphics, including (1) primary and secondary flight displays for all vehicle modes, i.e., attitude, air data, horizontal situation, GN&C and GCS, communication control, engine data, (2) subsystem status and control, (3) dedicated display backups, and (4) checklists, mission rules, texts, etc. The display generator accepts data from an I/O controller, transforms this data into a form suitable for use by the CRT monitors, and refreshes the display at a rate sufficient to produce flicker-free display on the CRT.

No memorization of operational codes is required of the crew; the control functions available in any configuration are adequately displayed on the associated CRT. The multipurpose keyboard panels provide the capability for controlling all subsystem functions, including communication and navigation frequency selection, IMU control, GN&C control, auto-pilot control backup and display accessing.

2.2 CONTROL AND DISPLAY CONCEPT

The control and display concept developed during the study permits the crew to monitor and control nearly all mission operations using only the CRTs and keyboards. Operations performed at remote stations and certain non-nominal activities (e.g., manual flight control) require dedicated controls, but all nominal and most non-nominal tasks utilize the control and display concept described below.

All information pertaining to mission, vehicle and subsystem operation is contained in at least one of an estimated 500 specially designed display formats. Each format contains numeric codes necessary for exercising control over the system element with which it deals as well as accessing codes for calling up other formats. Display formats are of three basic types: (1) operational procedures, (2) mission timelines, and (3) system management.

Operational procedure formats are checklists, displaying task-relevant quantitative data, instructions and options. The checklists are sequenced by numeric keyboard entries used to perform each task.

Mission timeline formats assist the crew in pacing checklist operations, permit integration of the two crew members task activities and provide overall visibility of mission operations as a function of time. Mission timeline formats are automatically displayed, as a function of mission time, during nominal mission operations.

System management formats include subsystem schematics, tabular control formats, tabular status formats, data entry formats and vehicle management formats. Subsystem schematics are diagrammatic representations of all components operable by the crew, as well as other important components necessary for crew understanding of the working of each subsystem element. Tabular control and status formats are tabular listings of available control commands and system status, unsuitable for schematic representation, but grouped according to functions or subsystem. Data entry formats permit the entry of numeric data into the computer, e.g., alternate landing site coordinates, navigation data, etc. Vehicle management formats provide monitoring and control of vehicle flight parameters, modeled after standard aircraft instrumentation and Apollo instruments.

Access to individual formats is provided by a control logic tree consisting of a master index and groups of sub-indexes. The logic tree is designed to provide access to any format by reference to no more than two indexes. Rapid access features are provided to permit direct accessing of related or important formats from any single format.

All control operations (except those few requiring dedicated controls) are performed with the 0-9 keyboard and a limited number of special function keys. Five special function keys permit connecting any keyboard to any of the CRTs, although no two keyboards may be connected simultaneously to a single display and no keyboard may be connected to two displays at one time. Additional special function keys permit entering and clearing commands, increasing and decreasing variable functions, designating data sign or direction (navigation coordinates) and authorizing a computer-recommended display shift.

Control commands and display accessing commands are entered by numeric codes -- 1-digit codes for rapid access commands, 2-digit codes for control commands and 3-digit codes for display format call-up. Control command codes are displayed next to the components they control on subsystem schematic formats or next to the component or function name on tabular formats. The displayed codes are brightness-coded to indicate the last transmitted command and component symbols are position-coded (or size-coded) to indicate their present sensed state; thus, diagnostic capabilities are inherent in the concept design.

2.3 PRELIMINARY DESIGN

Two alternate display techniques were mechanized and evaluated for application to the control and display concept under study. Both approaches were designed to interface with the Phase B integrated Data Management System (DMS) concept; i.e., a centralized computing complex interconnected with the various onboard subsystems by a data bus subsystem. Additionally, the centralized mass memory was used for the off-line storage medium. Both techniques are considered to be feasible.

The major difference between the two approaches is in the method of display generation. The first method used the more sophisticated random stroke technique while the second method used a less complex dot matrix approach. Additionally, the second method used a 16-bit display control word structure, as opposed to the first method which used a 32-bit control word structure.

Both designs were evaluated to a level of detail sufficient to establish feasibility. Neither design was completely optimized; however, examination of two approaches provides increased data for the conclusions.

As a result of the preliminary design effort and analyses, relative differences between the approaches are apparent. The dot matrix method eliminates the electrostatic deflection (superimposed on electromagnetic deflection) of the random stroke technique. The need for multiplexing at the interface between the display processors and the display controller is more critical for the dot matrix method. This is primarily attributable to the increase in the number of control words required because 16 bits rather than 32 bits are used. A 12 percent savings (approximately 200,000 32-bit words including allowance for 100 percent design reserve and triple redundancy) is realized with the 16-bit dot matrix structure in comparison with the 32-bit design.

Conversely, a definite savings in the number of instructions per format is realized using the 32-bit control word. This would normally translate directly into a savings of programming dollars. A complete tradeoff between the two design approaches is beyond the scope of this study.

The most significant impact on the DMS, of the control/display design concept, is the increase in mass memory sizing, from the 400K 32-bit words of the Phase B design to 800K 32-bit words. This sizing includes a 100 percent reserve allowance and is for each of the three storage units of the triple redundant storage system. An additional, but less important, impact is the need for a direct access channel between the mass memory and the display processor. This is required primarily to reduce the response time between selecting a format and having it displayed. A definite software impact is realized due to the increase in the programming requirements demonstrated by the large number of formats required; i.e., approximately 500.

The results and conclusions stated above are based on having automated the on-board operational checklist. It is interesting to point out the differences in requirements had the checklist been contained in a printed manual typical of the Apollo program, but instrumented through the use of the operator to keyboard interface. First, a reduction of approximately 160K 32-bit words would be realized. This translates directly into a 50 percent reduction in the mass memory add-on and a reduction of approximately 40 percent in the programming requirements. On the other hand, little or no reduction is realized in the display hardware itself. The actual merit of automating the checklist is out of scope of this study.

The evaluated control and display concept is feasible and desirable for a shuttle vehicle of the Phase B design philosophy which features an integrated control data management system.

(The summary and conclusions of the supplemental study to examine feasibility of concept application to the NR-SD winning proposal configuration are reported in Section 7.6.)

3.0 CONTROL AND DISPLAY FUNCTIONAL REQUIREMENTS

3.1 OVERVIEW

The purpose of this analysis phase was to develop control and display requirements in sufficient detail to permit (1) verification of crew capability to handle nominal and non-nominal operations during selected mission phases, (2) estimation of total quantities and types of control and display requirements during an entire mission, and (3) development and validation of a display logic concept using the proposed keyboard-CRT control/display subsystem. This section describes the procedures and results of the control and display functional analysis.

The steps described herein include development of a baseline mission, together with mission timelines, determination of vehicle and subsystem characteristics, establishment of mission functions, definition of crew information/action requirements, development of control and display requirements, selection of mission phases for detailed analyses, workload analysis and total requirements estimation.

The analysis utilized contractor-furnished descriptions of the missions, vehicle and subsystem characteristics for the Orbital Vehicle resulting from the Phase B Space Shuttle System Design Study. The only changes made in the Phase B design were those necessary for implementation of the Display and Control System design concept.

3.2 BASELINE MISSION

Space shuttle missions were examined to identify a representative mission suitable for the determination of control/display requirements. Missions examined included (1) Modular Space Station (MSS) Operations, (2) Earth Resources Survey, (3) Geosynchronous Satellite Emplacement, (4) Sun-synchronous Satellite Operations and (5) Space Station Rescue. The MSS Logistic Resupply Mission was selected for analysis. As shown in Figure 3-1, it includes the functions of ascent, rendezvous, docking, on-orbit resupply, deorbit, entry and landing.

Each of the other missions was reviewed to determine whether it requires functions or tasks not required by the MSS Logistics Resupply Mission. During the review, functions relating to docking and cargo handling were ruled out since, in the Phase B design, they are performed from a separate crew station and do not directly impact the main control/display subsystem. The other missions, with the exception of Space Station Rescue, differ from the MSS Operations primarily in orbital inclination, number of phasing burns required, orbital altitude and types of payload to be handled. Tasks required for establishing the orbital parameters are the same as for the MSS Logistics Resupply Mission, although they may be performed more or less frequently, and they will use the same data parameters, although with different parametric values.

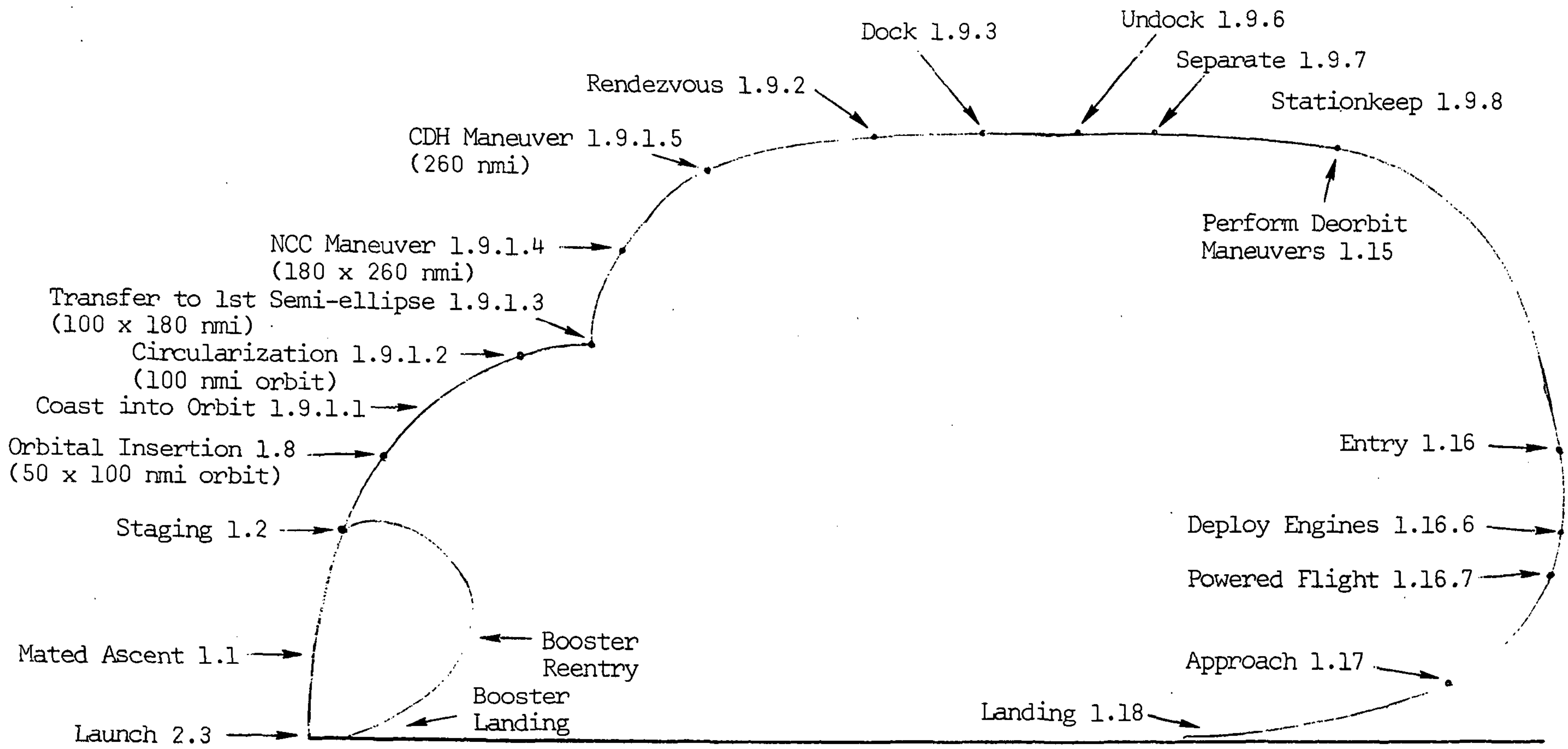


Figure 3-1. MSS Logistic Resupply Mission Selected for Analysis

Thus, it was concluded that satisfaction of the control and display requirements of the baseline MSS Logistics Resupply Mission would also satisfy the requirements for all other shuttle orbital missions.

3.3 MISSION TIMELINE

A mission timeline was developed for the baseline mission based on elapsed time estimates provided in the Phase B study for each of the mission phases. The timeline, shown in Figure 3-2, shows major events programmed for each mission phase. The time between each of these events was assumed to be the time available for the crew to perform necessary manual control tasks and to monitor system performance. During later analysis tasks (critical phase selection, workload analysis), these timelines were used to determine the mission phases involving the heaviest crew workloads and to verify that adequate time would be available to use the control and display design concept.

In constructing the timelines, no delays or stopover times were considered, such as the payload transfer period at the space station or the waiting period during stationkeeping. During these periods, it was assumed that the control and display subsystem would be in operation only for periodic status checks, and thus these periods would not materially impact control/display design. Under this constraint, total mission time is 33 hours.

Each event on the timelines represents a point in the mission at which one series of operator tasks must be completed and a new series begun. In general, major events, such as Delta V burns, are preceded by a series of configuration tasks and followed by a series of reconfiguration tasks. It is assumed that all tasks between two events must be completed by the crew for the later event to take place. Thus, to be feasible for the mission operations considered, the display and control concept must enable the crew to perform all assigned tasks within an event pair. Demonstration of this feasibility is described in Section 3.9, Workload Analysis.

3.4 VEHICLE AND SUBSYSTEM CHARACTERISTICS

The Phase B orbiter, as described in Report MSC-0037, "Phase B Final Report, Volume II Technical Summary, Book 2, Orbiter Vehicle Definition" (SD 71-114-2), was used as the basic vehicle configuration. Diagrams of the principle subsystems are provided in Appendix A.

Certain constraints were observed during the study, aimed at circumscribing the scope of the analysis within reasonable limits. The constraints are described below.

Only orbiter vehicle functions are included in the analysis. It was assumed that the booster vehicle would be manned and that during mated ascent only monitoring and staging preparation tasks would be performed by the orbiter crew.

Within the orbiter, only functions associated with the main cockpit controls and displays were analyzed. It was assumed that docking and payload

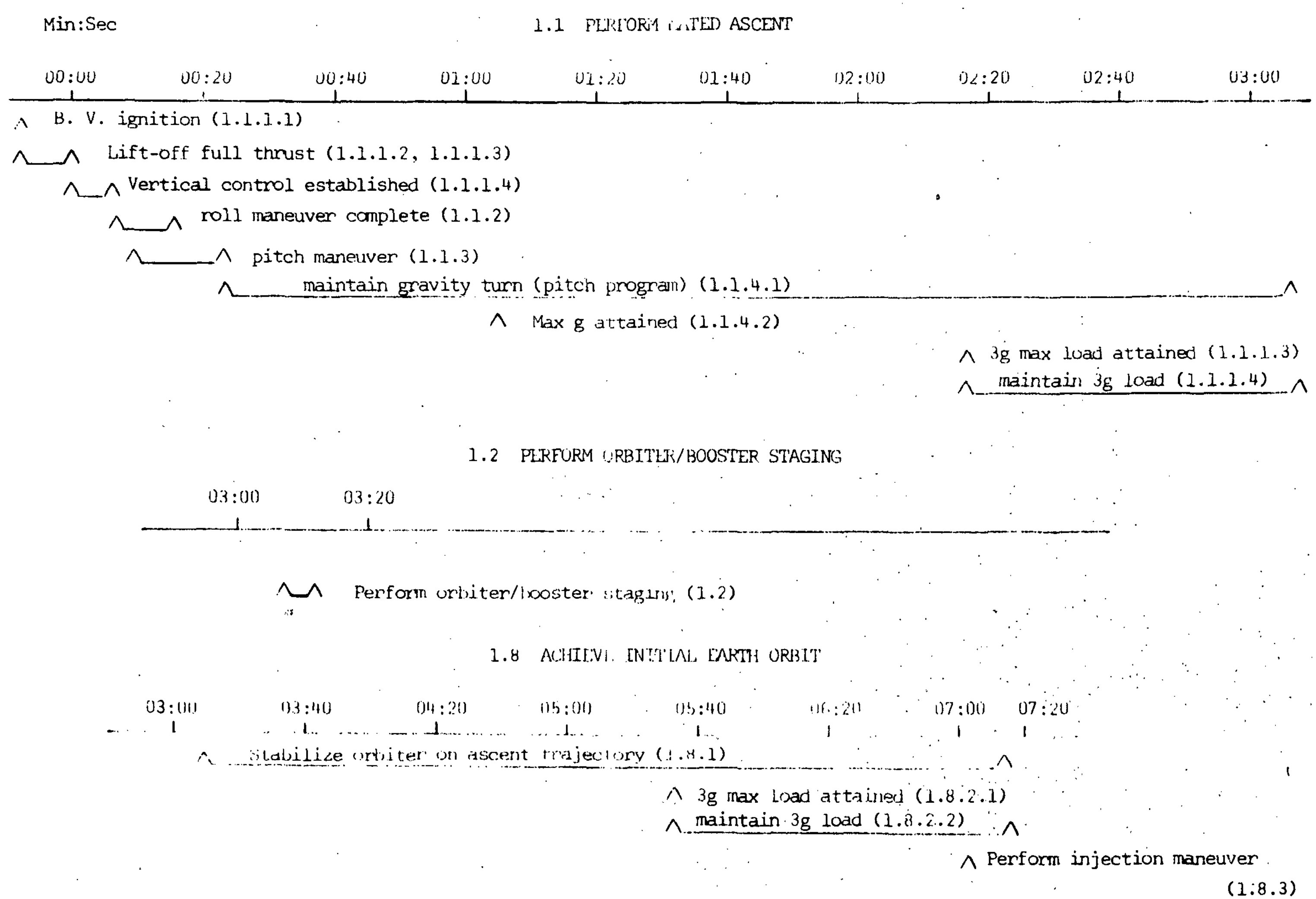
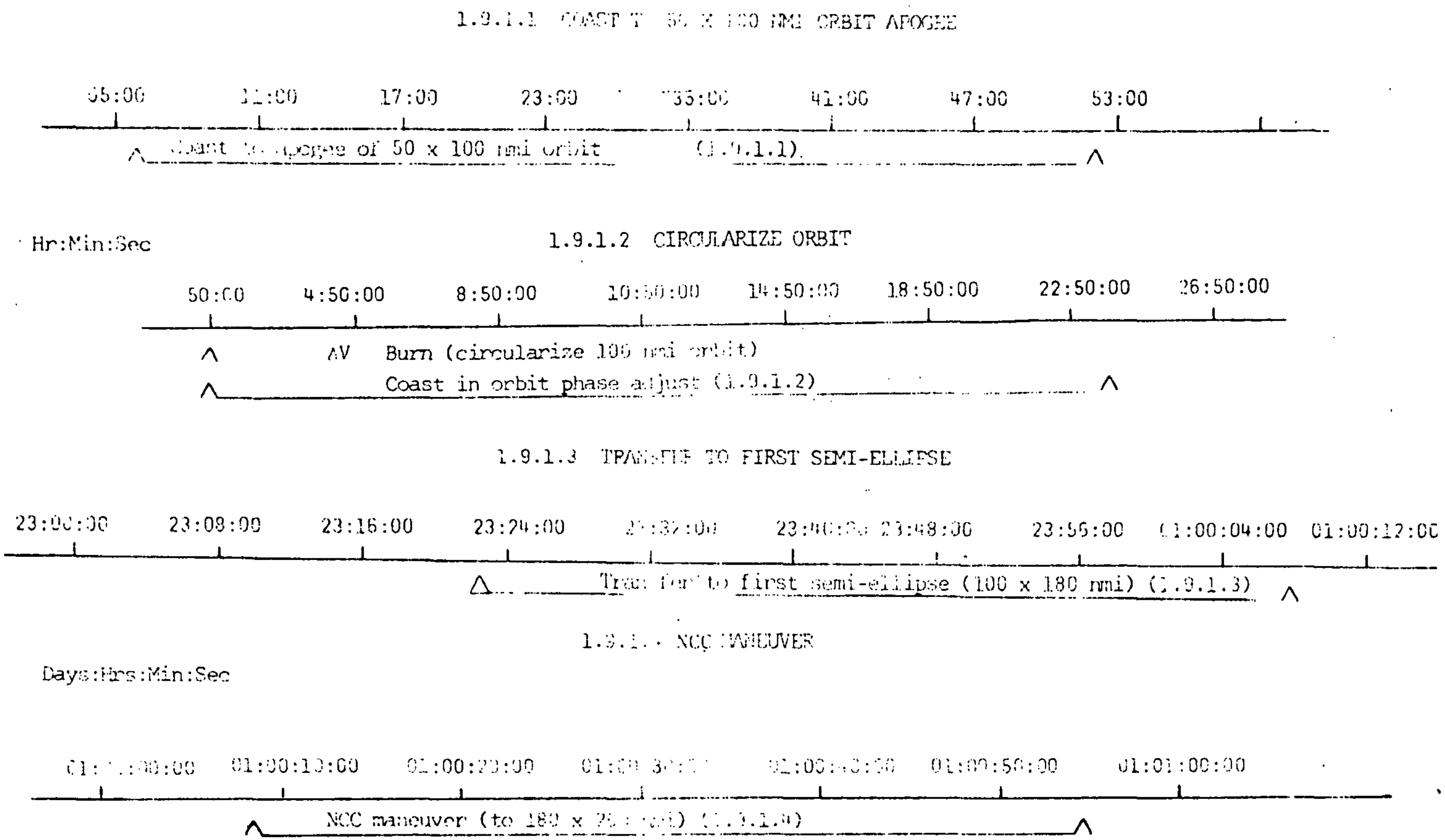


Figure 3-2. Orbiter Timeline with Mission Events Assumed for Analysis


ORBIT APOGEE
Hr:Min:Sec
17:00
23:00
41:00
47:00
53:00
of 50 x 100 nmi orbit
1.9.1.2 CIRCULARIZE ORBIT
50:00
4:50:00
8:50:00
14:50:00
18:50:00
22:50:00
26:50:00
ΔV Burn (circularize 100 nmi orbit)
Coast in orbit phase adjust (1.9.1.2)
TO FIRST SEMI-ELLIPSE
23:00:00
23:08:00
23:16:00
23:24:00
23:48:00
23:56:00
01:00:04:00
01:00:12:00
first semi-ellipse (100 x 180 nmi)
Days:Hrs:Min:Sec
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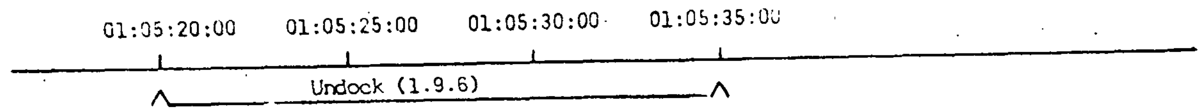
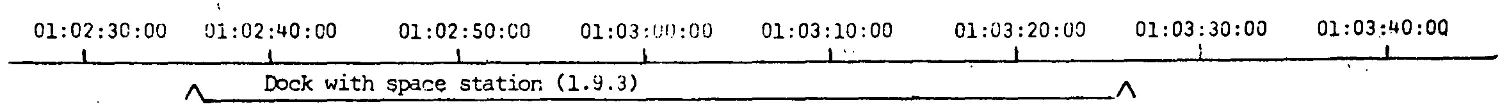
NCC maneuver

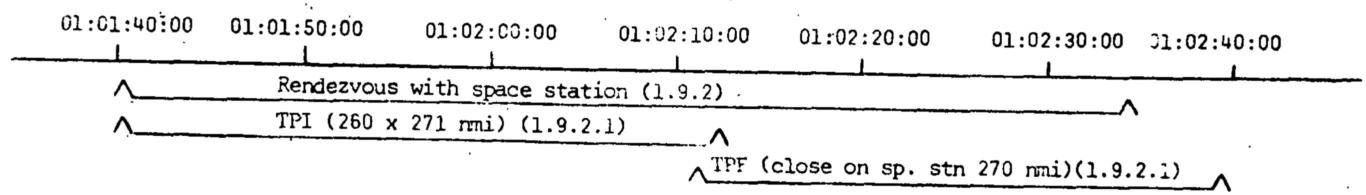
1.9.6 UNDOCK



1.9.3 DOCK



1.9.2 RENDEZVOUS WITH SPACE STATION



1.9.1.5 CDH MANEUVER

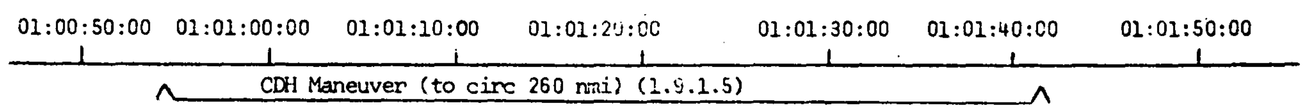


Figure 3-2. (Cont.)

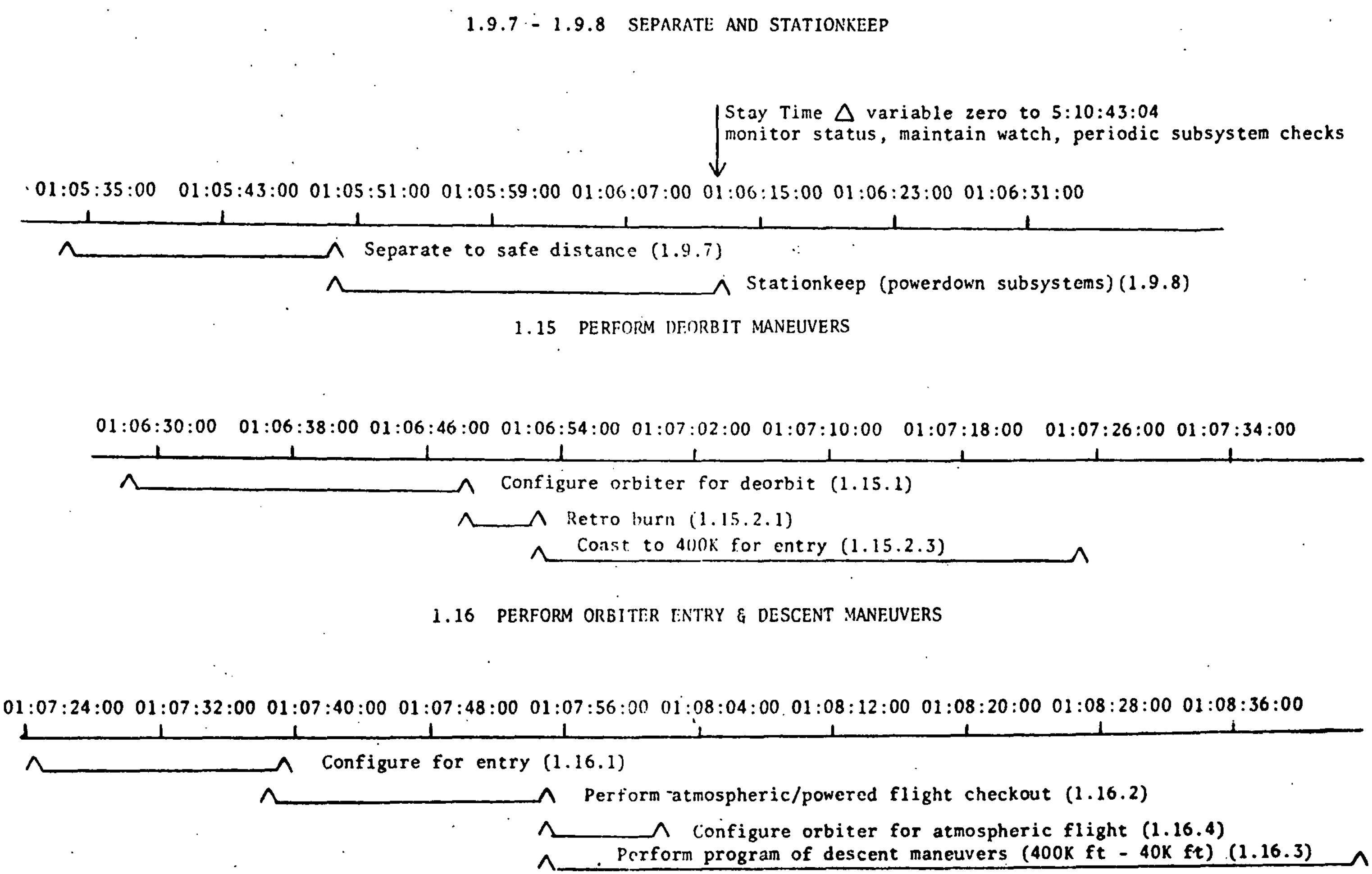


Figure 3-2. (Cont.)

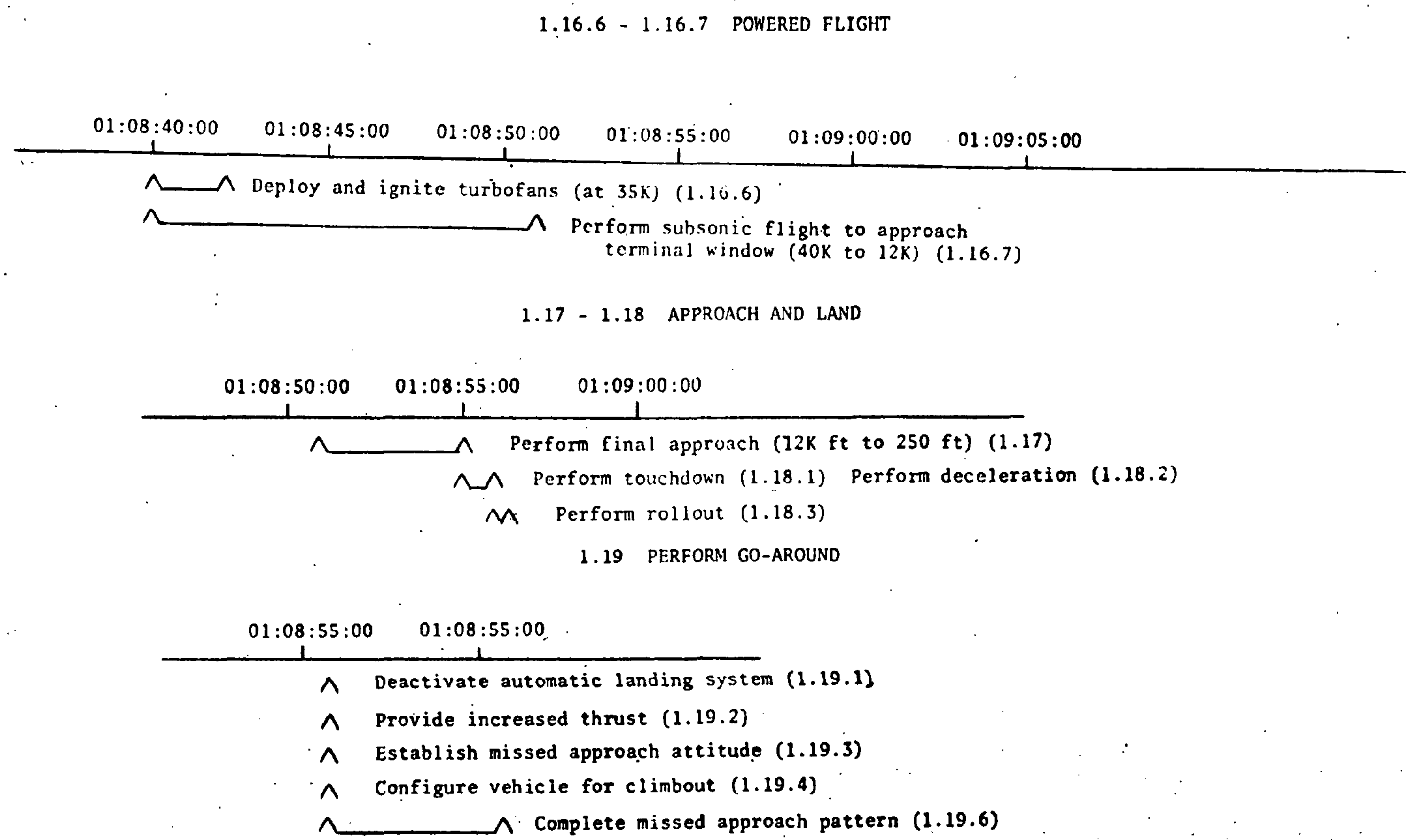


Figure 3-2. (Cont.)

management functions would be performed at a separate crew station; therefore, these functions were not included in the analysis.

The orbiter was assumed to have a two-man flight crew and to be flyable under emergency conditions by a single crewman.

Landing characteristics and handling qualities were assumed to require skills no more demanding than those required for operational land-based aircraft.

Provisions were made for crew-initiated override of all automated critical control functions.

Provisions were made for crew initiation of all abort modes.

The orbiter was assumed to have powered go-around capability and to be capable of making either a powered or unpowered approach and landing. For purposes of the analysis, the more highly task-loaded powered flight configuration was assumed.

In-flight maintenance was assumed not to be required although checkout and fault isolation capabilities of the Phase B concept were incorporated in the study.

Reliability requirements for the overall system were assumed to be .999 probability of crew safety, 0.9 minimum probability of completing the design reference mission.

No single point failures were permitted which would result in loss of the vehicle or crew.

All subsystems, as a minimum, were assumed to be designed to fail operational after the failure of the most critical component and to fail safe for crew survival after the second failure. This assumption was met with the control and display subsystem concept design.

In systems where redundancy is needed, the space shuttle system was assumed to provide redundancy within the system itself rather than providing degraded performance backup system concepts.

The control and display system was designed to support vertical launch as well as typical aircraft horizontal takeoff and landing.

Within the DMS, automatic failure isolation and recovery was assumed to not require coping with the problem of two or more simultaneous failures.

The DMS was assumed to be designed to allow manual specification of the level of redundancy within the computer system. Provisions for this were incorporated into the control and display concept design.

Provisions were made for the crew to manually specify the DMS configuration and thus override all automatic fault isolation and switching functions.

Normal operation was assumed to be automatic through all mission phases, but the flight crew was provided the capability to control the orbiter through all flight phases. When required, the flight crew would be able to participate in navigation, control, monitoring, computing, and observation of all subsystems. Status of subsystems would be displayed for crew monitoring, failure detection and operational mode selection.

The crew environment was assumed to be shirtsleeve. Therefore, no provisions were made in the displays and controls for operation with pressure suit on.

The overall system design provides the capability to display to the crew independent information from redundant data sources and selected data processing.

The subsystems to be monitored and controlled by the control and display system concept include (1) Environment Control and Life Support, (2) Power Generation Distribution and Control, (3) Propulsion, (4) Data Control and Management, (5) Guidance, Navigation and Control, (6) Communications, (7) Displays and Controls, (8) Caution and Warning, (9) Checkout and Fault Isolation, and (1) Consumables.

3.5 MISSION FUNCTIONS AND ALLOCATION TO CREW

The Phase B orbiter mission descriptions in MSC-03310, "Operations Plan for Phase C/D" (SD 71-103-2) were used as a source document for selecting mission functions. Selected mission functions are listed in Table 3-1. Each function retains the number designation used in the Phase B functional flow charts to permit cross reference between the data source and the analysis. Only functions involving crew/system interfaces were selected and only those functions dealing with orbiter vehicle control and management wereconsidered.

Mission functions/subfunctions were examined to determine the degree of crew participation planned for in the Phase B design. This level of crew participation was adhered to throughout the analysis, with the exception of functions relating directly to the control/display concept under study. Preliminary assignments of crew functions to the Commander (CDR) and Pilot (PLT) were made to assist in subsequent task analyses. However, these preliminary allocations were deviated from in the final task timelines whenever such changes would result in better utilization of available time. No effort was made to conform to any set pattern of function allocations to either crew member because it was assumed that each crew member must be competent to perform all mission tasks (one-man emergency operation ground rule). The preliminary crew allocation is listed in Table 3-2.

3.6 INFORMATION/ACTION REQUIREMENTS

Crew requirements for mission, system and subsystem data and for control capabilities were derived from an information/decision/action analysis developed mainly from two sources. Each primary subsystem was analyzed to determine what controllable elements are available within the subsystems (switches, valves, etc.) and what sensor or status data are available from

Table 3-1. Mission Functions Selected for Analysis

PHASE	
I. Pre-mission Preparation	
A. Perform premate checkout	2.4
1. Insert software	2.4.1
2. Energize systems	2.4.2
3. Perform checkout	2.4.3
B. Perform vehicle erection and assembly	2.1
1. Prepare orbiter for mating	2.1.2
a. load flight program	2.1.2.2
b. verify flight program operation	2.1.2.3
c. clear flight and engine recorders	2.1.2.5
2. Mate orbiter to booster	2.1.4
a. verify orbiter to booster interfaces	2.1.4.2
b. verify orbiter/launcher interfaces	2.1.4.3
C. Transfer and install at pad	2.2
1. Conduct launch readiness checkout	2.2.3
a. check out flight control systems	2.2.3.1
b. check out GN&C systems	2.2.3.2
c. check out power systems	2.2.3.3
d. check out communications systems	2.2.3.4
e. check out propulsion systems	2.2.3.5
f. perform switch scan	2.2.3.7
2. Attain standby status	2.2.4
a. place flight systems in standby	2.2.4.1
b. monitor shuttle status	2.2.4.2
c. activate flight systems	2.2.4.8
d. update software with final parameters	2.2.4.9
e. verify circuits and arm ordinance	2.2.4.10
II. Launch	
A. Perform launch operations	2.3
1. Perform propellant loading	2.3.1
a. monitor vehicle systems	2.3.1.2
2. Complete final system activation	2.3.5
3. Perform launch countdown	2.3.4
a. verify displayed checklist	2.3.4.1
b. verify GN&C alignment	2.3.4.2
c. transfer to internal power	2.3.4.4
d. verify all subsystems ready	2.3.4.5
e. verify shuttle ready for launch	2.3.4.9
f. perform launch program	2.3.4.10
B. Perform mated ascent	1.1
1. Perform initial ascent maneuver	1.1.1

Table 3-1. (Cont.)

PHASE	
a. monitor engine performance	1.1.1.6
b. monitor orbiter vehicle propellant pressures	1.1.1.7
c. monitor lift-off	1.1.1.1
d. monitor time from lift-off	1.1.1.5
2. Perform roll maneuver	1.1.2
a. maintain pitch and yaw null attitude	1.1.2.1
b. monitor roll program	1.1.2.2
c. determine roll rate	1.1.2.3
d. determine roll error	1.1.2.4
e. generate roll command	1.1.2.5
f. execute roll command	1.1.2.6
g. monitor time from lift-off	1.1.2.7
3. Perform pitch maneuver	1.1.3
a. maintain roll and yaw null attitude	1.1.3.1
b. monitor pitch program	1.1.3.2
c. determine pitch rate	1.1.3.3
d. determine pitch error	1.1.3.4
e. generate pitch command	1.1.3.5
f. execute pitch command	1.1.3.6
4. Maintain ascent profile	1.1.4
a. maintain gravity turn	1.1.4.1
b. maintain 3-g axial acceleration limit	1.1.4.2
c. maintain roll and yaw null attitude	1.1.4.3
d. activate booster attitude control propusion system	1.1.4.4
C. Perform booster/orbiter staging	1.2
1. Sense booster propellant depletion	1.2.1
a. transmit signal to booster and orbiter DCM	1.2.1.3
2. Configure vehicles for staging	1.2.2
a. initiate stagin sequence	1.2.2.1
b. perform orbiter engine stagin program	1.2.2.4
c. activate orbiter attitude control propulsion subsystem	1.2.2.5
B. Perform separation	1.2.3
1. Increase orbiter thrust to 100% nominal power	1.2.3.4
2. Maintain orbiter attitude	1.2.3.5
3. Perform physical separation	1.2.3.6
III. Orbital Insertion	
A. Achieve initial earth orbit	1.8
1. Stabilize orbiter on ascent trajectory	1.8.1
2. Control trajectory to injection	1.8.2
3. Perform injection maneuver	1.8.3

Table 3-1. (Cont.)

PHASE	
IV. Rendezvous	
A. Perform Space Station/base logistics support	1.9
1. Perform orbit and phase changes	1.9.1
2. Rendezvous with Space Station	1.9.2
B. Perform placement and retrieval of payload	1.10
1. Perform orbit and phase changes	1.10.1
2. Maneuver to emplace payload	1.10.2
3. Configure shuttle for alternate mission	1.10.12
4. Perform orbit and phase change	1.10.13
5. Rendezvous with payload	1.10.20
C. Perform delivery of propellants	1.11
1. Perform orbit and phase change	1.11.1
2. Rendezvous with other orbiting body	1.11.2
D. Perform short duration orbital mission	1.12
1. Perform orbit and phase changes	1.12.1
2. Configure shuttle for alternate mission	1.12.7
3. Perform orbit and phase change	1.12.8
V. Dock	
A. Perform Space Station/base logistics support	1.9
1. Dock with Space Station	1.9.3
B. Perform placement and retrieval of payload	1.10
1. Couple/dock to payload	1.10.24
C. Perform delivery of propellants	1.11
1. Dock with orbiting body	1.11.4
VI. Undock	
A. Perform Space Station/base logistics support	1.9
1. Undock	1.9.6
B. Perform placement and retrieval of payload	1.10
1. Uncouple/undock from payload	1.10.6
C. Perform delivery of propellants	1.11
1. Undock from other orbiting body	1.11.7
VII. Stationkeep	
A. Perform Space Station/base logistics support	1.9

Table 3-1. (Cont.)

PHASE			
		1. Separate to safe distance for stay	1.9.7
		2. Stationkeep during stay	1.9.8
		3. Separate to safe distance from space station	1.9.11
	B.	Perform placement and retrieval of payload	1.10
		1. Separate safe distance from payload	1.10.7
	C.	Perform delivery of propellants	1.11
		1. Separate safe distance from other orbiting body	1.11.8
	D.	Perform short-duration orbital mission	1.12
		1. Configure shuttle for earth resource survey	1.12.4
		2. Configure shuttle for equipment tests	1.12.3
VIII.	Deorbit		
	A.	Perform Space Station/base logistics support	1.9
		1. Perform on-orbit phasing	1.9.12
	B.	Perform placement and retrieval of payload	1.10
		1. Configure shuttle for earth return	1.10.27
		2. Perform on-orbit phasing	1.10.28
	C.	Perform delivery of propellants	1.11
		1. Configure shuttle for earth return	1.11.9
		2. Perform on-orbit phasing	1.11.10
	D.	Perform short-duration orbital mission	1.12
		1. Configure shuttle for earth return	1.12.5
		2. Perform on-orbit phasing	1.12.6
	E.	Perform deorbit maneuvers	1.15
		1. Configure orbiter for deorbit	1.15.1
		2. Perform retro maneuver	1.15.2
IX.	Entry		
	A.	Perform orbiter entry	1.16
		1. Establish entry and maintain desired entry	1.16.1
		2. Perform program of entry maneuvers	1.16.3
		3. Configure orbiter for subsonic flight	1.16.4
		4. Perform atmospheric flight subsystems checkout	1.16.2
X.	Powered Flight		
	A.	Deploy and ignite turbofans	1.16.6
		1. Descent to ABES deployment altitude and velocity	1.16.6.1
		2. Deploy air breathing engines	1.16.6.2

Table 3-1. (Cont.)

PHASE	
3. Verify deployment	1.16.6.3
4. Start ABES	1.16.6.4
a. perform engine start checklist	1.16.6.4.1
b. spin-up engines	1.16.6.4.2
c. provide fuel	1.16.6.4.3
d. ignite engines	1.16.6.4.4
5. Perform post-engine start checklist	1.16.6.5
B. Perform subsonic flight to approach terminal window	1.16.7
1. Perform energy management maneuvers	1.16.7.1
2. Perform descent approach maneuvers	1.16.7.2
a. perform landing checklist	1.16.7.2.1
b. accomplish approach checklist	1.16.7.2.2
c. obtain clearance for approach	1.16.7.2.3
d. perform flight to initial approach fix (IAF)	1.16.7.2.4
e. report position at IAF	1.16.7.2.5
f. activate automatic landing system	1.16.7.2.6
g. perform descent and intercept initial penetration course	1.16.7.2.7
XI. Approach and Lanc	
A. Perform final approach	1.17
1. Establish landing configuration	1.17.1
a. maintain approach air speed	1.17.1.1
b. lower landing gear	1.17.1.2
c. perform flight to FAF	1.17.1.3
d. report position at FAF	1.17.1.4
e. transition to final approach course	1.17.1.5
f. maintain glide slope and approach course	1.17.1.6
g. acquire visual references	1.17.1.7
h. perform visual correction	1.17.1.8
B. Establish landing velocity and attitude	1.17.2
1. Assume manual control	1.17.2.1
2. Align vehicle guidance approach with visual flight path	1.17.2.2
3. Verify landing checklist complete	1.17.2.3
4. Maintain descent rate	1.17.2.4
5. Perform flare	1.17.2.5
6. Monitor automatic landing system performance	1.17.2.6
C. Perform landing	1.18
1. Perform touchdown	1.18.1
a. maintain runway alignment	1.18.1.4

Table 3-1. (Cont.)

PHASE	
b. touchdown main landing wheels	1.18.1.1
c. perform decrab maneuvers	1.18.1.2
d. touchdown nose wheel	1.18.1.3
e. deactivate automatic landing system	1.18.1.5
2. Perform deceleration	1.18.2
a. deploy deceleration devices	1.18.2.1
b. apply brakes	1.18.2.2
c. maintain runway alignment	1.18.2.3
3. Perform rollout	1.18.3
a. secure deceleration devices	1.18.3.1
b. perform post-landing checklist	1.18.3.2
c. taxi vehicle to safing area	1.18.3.4
d. park vehicle	1.18.3.5
e. perform safing checklist	1.18.3.6
f. deactivate vehicle flight system	1.18.3.7
XII. Go-around	
A. Perform go-around	1.19
1. Deactivate automatic landing system	1.19.1
2. Provide increased thrust	1.19.2
a. Set throttle levers for takeoff thrust	1.19.2.1
3. Establish missed approach attitude	1.19.3
a. rotate vehicle to maintain approach attitude	1.19.3.1
b. verify positive climb rate	1.19.3.3
4. Establish climb-out configuration	1.19.4
a. perform speed brake retraction	1.19.4.1
b. continue climb	1.19.4.2
5. Complete missed approach pattern	1.19.5
a. climb to missed approach altitude	1.19.5.1
b. follow missed approach flight path	1.19.5.5
c. perform missed approach checklist	1.19.5.6
d. perform transition from climb to level flight	1.19.5.3
e. reduce engine thrust	1.19.5.2
f. perform turn maneuvers to approach path	1.19.5.4
XIII. Mission Abort	
A. Perform mission abort operations	5.0
1. Perform orbiter pad abort	5.2
a. egress orbiter crew and passengers	5.2.2
b. safe critical orbiter systems	5.2.4

Table 3-1. (Cont.)

PHASE	
2. Perform orbiter mated ascent abort	5.4
a. perform solo orbiter ascent entry	5.4.1
b. perform launch site orbiter landing	5.4.2
c. perform down-range orbiter landing	5.4.3
d. perform once-around orbiter landing	5.4.5
e. perform orbiter mission	5.4.6
f. establish orbiter mission status	5.4.7
3. Perform orbiter ascent abort	5.6
a. establish orbiter ascent, failure & performance capability	5.6.1
b. perform down-range landing & recovery	5.6.3
c. continue mission	5.6.4
4. Perform abort from orbit	5.7
a. establish orbit parameters	5.7.1
b. determine landing site availability & return time	5.7.2
5. Perform orbiter landing abort	5.8
a. establish reduced turbo-jet thrust	5.8.1
b. perform emergency landing procedures	5.8.2
XIV. Ferry Mission	
A. Perform ferry mission	6.0
1. Perform post-flight safing and servicing	6.1
2. Prepare for ferry operations	6.3
3. Perform ferry flight	6.4
XV. Turnaround	
A. Perform turnaround maintenance operations	3.0
1. Perform post-landing safing and securing	3.1
2. Perform hangar operations	3.2

Table 3-2. Preliminary Allocation of Functions/Subfunctions to Crew

Function No.	Function/Subfunction	Crew
1.1	Perform mated ascent	
1.1.1	Perform initial ascent maneuver	
1.1.1.1	Monitor liftoff	CDR
1.1.1.5	Monitor time from liftoff	CDR
1.1.1.6	Monitor BV engine performance	PLT
1.1.1.7	Monitor OV propellant pressures	PLT
1.1.2	Perform roll maneuver	
1.1.2.1	Monitor pitch and yaw null attitude	CDR
1.1.2.2	Monitor roll parameters (rate, error)	CDR
1.1.2.6	Monitor time from liftoff	CDR
1.1.1.6	Monitor BV engine performance	PLT
1.1.1.7	Monitor OV propellant pressures	PLT
1.1.3	Perform pitch maneuver	
1.1.3.1	Monitor roll and yaw null attitude	CDR
1.1.3.2	Monitor pitch parameters (rate, error)	CDR
1.1.3.7	Monitor time from liftoff	CDR
1.1.1.6	Monitor BV engine performance	PLT
1.1.1.7	Monitor OV propellant pressures	PLT
1.1.4	Maintain ascent profile	
1.1.4.1	Monitor gravity turn profile	CDR
1.1.4.2	Monitor 3g axial acceleration limit	PLT
1.1.4.3	Monitor roll and yaw null attitude	CDR
1.2	Perform booster/orbiter staging	
1.2.1	Monitor booster propellant depletion	PLT
1.2.2	Configure orbiter vehicle for staging	
1.2.2.1	Enable staging sequence	CDR
1.2.2.4	Activate orbiter attitude control propulsion subsystem	PLT
1.2.3	Perform separation	
1.2.3.1	Monitor orbiter thrust	PLT
1.2.3.2	Monitor orbiter attitude	CDR

Table 3-2. (Cont.)

Function No.	Function/Subfunction	Crew
1.8	Achieve initial earth orbit	
1.8.1	Monitor ascent trajectory	CDR
1.8.3	Monitor MPS cutoff	PLT
1.9	Perform space station/base logistics support	
1.9.1	Perform orbit and phase changes	
1.9.1.1	Coast to 50 x 100 nmi orbit apogee	
1.9.1.1.1	Deactivate MPS	PLT
1.9.1.1.2	Configure for space flight	CDR
1.9.1.1.3	Determine O/V attitude	CDR
1.9.1.1.4	Enable platform alignment	PLT
1.9.1.1.5	Configure for Delta V	PLT
1.9.1.1.6	Enable Delta V	CDR
1.9.1.2	Circularize orbit	
1.9.1.2.1	Monitor Delta V	CDR
1.9.1.2.2	Monitor ACPS	PLT
1.9.1.2.3	Perform post-burn reconfiguration	PLT
1.9.1.2.4	Determine O/V attitude	CDR
1.9.1.2.5	Enable platform alignment	PLT
1.9.1.2.6	Configure for Delta V	PLT
1.9.1.2.7	Enable Delta V	CDR
1.9.1.3	Transfer to 1st semi-elipse	
1.9.1.3.1	Monitor Delta V	PLT
1.9.1.3.2	Monitor ACPS	CDR
1.9.1.3.3	Perform post-burn reconfiguration	CDR
1.9.1.3.4	Determine O/V attitude	PLT
1.9.1.3.5	Enable platform alignment	CDR
1.9.1.3.6	Configure for Delta V	CDR
1.9.1.3.7	Enable Delta V	PLT
1.9.1.4	Perform NCC maneuver	
1.9.1.4.1	Monitor Delta V	CDR
1.9.1.4.2	Monitor ACPS	PLT
1.9.1.4.3	Perform post-burn reconfiguration	PLT
1.9.1.4.4	Determine O/V attitude	CDR
1.9.1.4.5	Enable platform alignment	PLT

Table 3-2. (Cont.)

Function No.	Function/Subfunction	Crew
1.9.1.4.6	Configure for Delta V	PLT
1.9.1.4.7	Enable Delta V	CDR
1.9.1.5	Perform CDH Maneuver	
1.9.1.5.1	Monitor Delta V	PLT
1.9.1.5.2	Monitor ACPS	CDR
1.9.1.5.3	Perform post-burn reconfiguration	CDR
1.9.1.5.4	Determine O/V attitude	PLT
1.9.1.5.5	Enable platform alignment	CDR
1.9.1.5.6	Configure for Delta V	CDR
1.9.1.5.7	Enable Delta V	PLT
1.9.2	Rendezvous with space station	
1.9.2.1	Monitor Delta V	CDR
1.9.2.2	Configure for rendezvous	PLT
1.9.2.3	Visually acquire space station	PLT/CDR
1.9.2.4	Enable rendezvous	PLT
1.9.2.5	Control (translate) vehicle, as required	CDR
1.9.3	Dock	
1.9.3.1	Configure for docking	PLT
1.9.3.2	Control (translate) vehicle, as required	PLT
1.9.3.3	Transfer control to docking station	CDR
1.9.3.4	Power down O/V	PLT
1.9.6	Undock	
1.9.6.1	Power up O/V	PLT
1.9.6.2	Receive control from docking station	CDR
1.9.7	Separate from space station	
1.9.7.1	Control (translate) vehicle, as required	CDR
1.9.7.2	Configure for stationkeeping	PLT
1.9.8	Stationkeep	
1.9.8.1	Power down O/V	PLT
1.9.8.2	Enable stationkeeping mode	CDR
1.9.8.3	Monitor system/subsystem status, periodically	CDR/PLT
1.9.8.4	Power up O/V	PLT
1.9.8.5	Configure for space flight	CDR
1.15	Perform deorbit maneuvers	
1.15.1	Configure for deorbit	PLT

Table 3-2. (Cont.)

Function No.	Function/Subfunction	Crew
1.15.2	Determine vehicle attitude	CDR
1.15.3	Enable platform alignment	PLT
1.15.4	Select landing site	CDR
1.15.5	Configure for Delta V	PLT
1.15.6	Enable Delta V	CDR
1.15.7	Monitor Delta V	CDR
1.15.8	Perform post-burn reconfiguration	PLT
1.16	Perform entry and descent maneuvers	
1.16.1	Configure for entry	PLT
1.16.2	Monitor trajectory	CDR
1.16.3	Configure for atmospheric flight	PLT
1.16.4	Monitor descent maneuvers	CDR
1.16.6	Deploy and ignit turbofans	PLT
1.16.7	Monitor subsonic flight to approach terminal window	CDR
1.17	Approach	
1.17.1	Configure for landing	PLT
1.17.2	Monitor approach	CDR
1.18	Land	
1.18.1	Monitor landing	CDR
1.18.2	Initiate drag chute	PLT
1.18.3	Initiate braking	CDR
1.18.4	Taxi to terminal	CDR
1.18.5	Deactivate critical O/V subsystems	PLT

each subsystem. In addition, detailed timelines were developed showing all control actions required during each mission phase, from which associated display requirements were derived.

Primary sources of subsystem control and sensor data were (1) the Phase B computer-compiled signal lists, which describe each planned input and output signal interfacing between the primary subsystems and the DCM, (2) subsystem drawings showing controllable components, (3) Phase B reports describing the operation of each subsystem, and (4) discussions with Phase B contractor engineers responsible for design of each subsystem. Control and display data accumulated from these sources were refined to provide a listing, by subsystem, of necessary and sufficient control and display signals for crew monitoring and control of all subsystems during both nominal and non-nominal operations. In general, completely automated functions (i.e., those permitting no direct crew interaction) were omitted from the listings.

The complete listing is provided in Appendix B. Each item in the list is categorized according to whether it is a control or a display function and whether it would be necessary to crew operation during nominal missions or non-nominal situations.

Detailed task timelines were developed for each mission phase showing each required crew action, the general sequence of actions and the approximate time at which each action should be performed. In general, it was found that, with the exception of a few time-critical tasks (e.g., initiation of Delta V), the sequence of actions was more important that the time of performance.

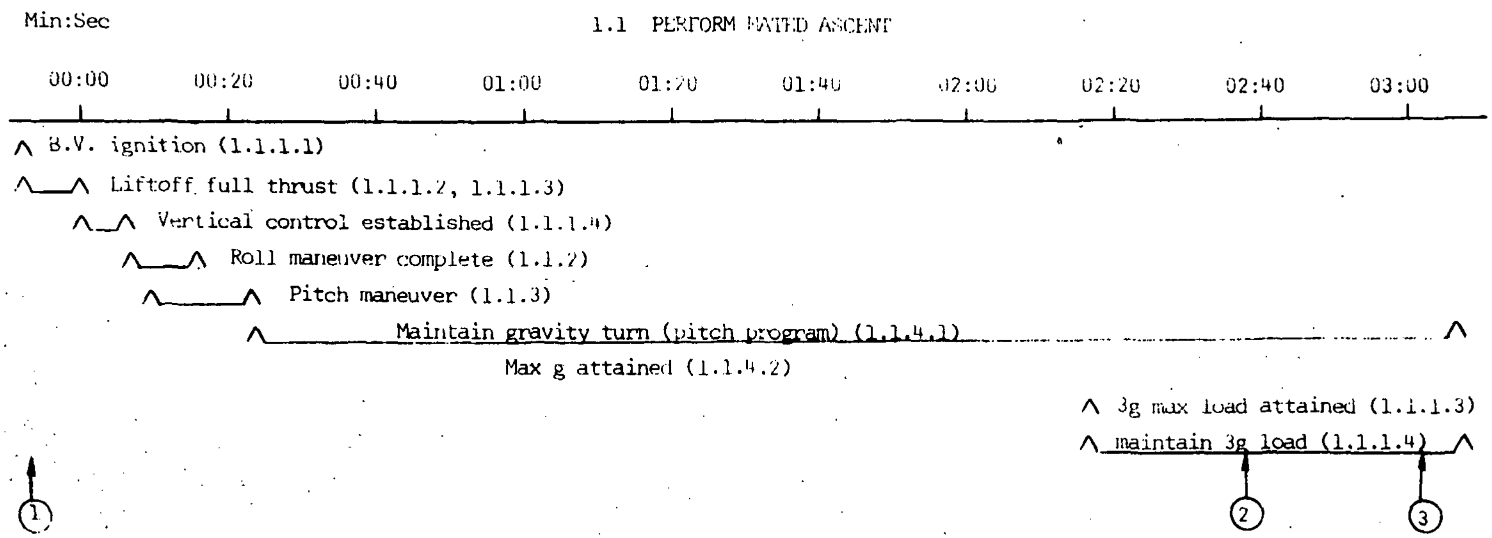
Figure 3-3 shows the task sequences, superimposed on the mission timelines. Position of each task on the timeline is approximate and sequence-dependent. Tasks were not divided between Commander and Pilot for this timeline, providing some indication of the relative loading during each mission phase for wrost-case, one-man crew operation.

3.7 DISPLAY/CONTROL CHARACTERISTICS

A preliminary control/display layout was selected for use in the development of format concepts and for the crew workload analysis. This baseline concept was intended to be modified as alternative logic concepts were evaluated.

3.7.1 Preliminary Design

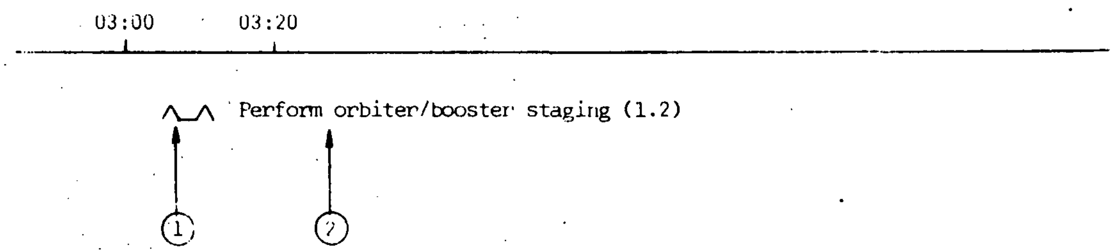
The baseline layout, shown in Figure 3-4, is comprised of 5 CRT's and 3 keyboards. Each crew member is provided with a primary and a secondary CRT. The fifth CRT is shared between the two crewmen. Each crew member is also provided with a keyboard from which he can exercise control of the mission/system/subsystems through any of the displays. The third keyboard, located between the crew members, serves as backup in the event of a keyboard failure.



1. MONITOR GNC AND VEHICLE DATA
2. SET MAIN ENGINE 1 & 2 NOZZLES TO 'EXTEND'
3. SET STAGE INITIATE TO 'PUSH ON'

Figure 3-3. Task Sequences

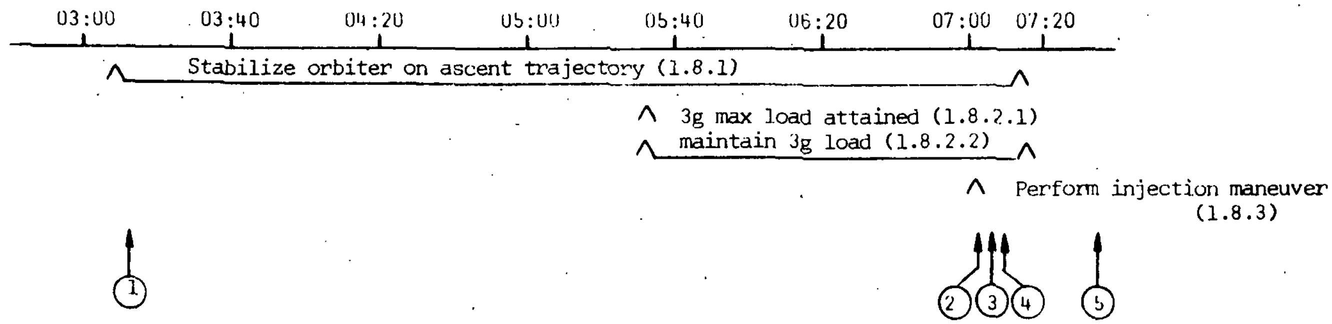
1.2 PERFORM ORBITER/BOOSTER STAGING



1. MONITOR GN&C AND VEHICLE PERFORMANCE
2. SELECT SEQUENCER BUS 'OFF'

Figure 3-3. (Cont.)

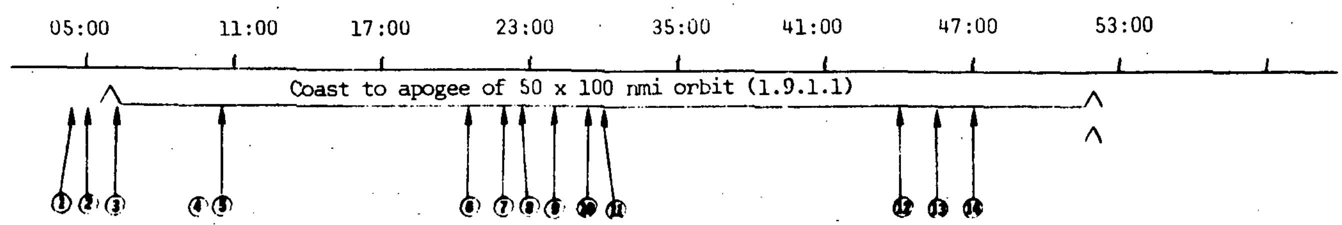
1.8 ACHIEVE INITIAL EARTH ORBIT



1. MONITOR GN&C AND VEHICLE PERFORMANCE
2. SELECT TIE BUS SOURCE 'AC1'
3. ACTUATE 'TIE'
4. SELECT AC BUS AC2 'TIE'

Figure 3-3. (Cont.)

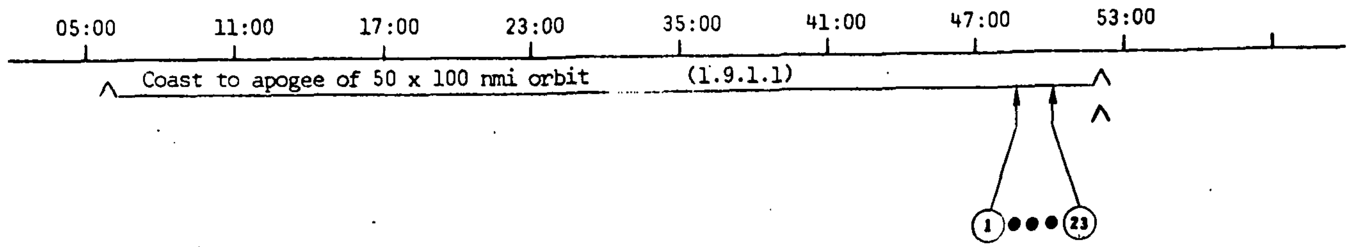
1.9.1.1 COAST TO 50 x 100 NMI ORBIT APOGEE



1. Monitor GN&C and vehicle performance
2. Select hydraulic circ pumps 1, 2, 3, 4, 'ON'
3. Select cargo bay doors 'OPEN'
4. Select radiator flow 'ON' (primary & secondary)
5. Select evap H_2O flow 'OFF' (primary & secondary)
6. Select AC bus 'AC1' & 'AC3' 'OFF'
7. Select 'STOP' APU 1 & 3
8. Depressurize hydraulic bypass 1 & 3
9. Close APU reactant supply (1, 2, 3, 4)
10. Select helium circul 'OFF' ($H_2$1 & 2) (O_2 1&2)
11. Close helium isolation (H_2 1 & 2((O_2 1 & 2)
12. Select pot H_2O HTR 'AUTO'
13. Select H_2O dump htr 'ON'
14. Adjust cabin temp as desired

Figure 3-3. (Cont.)

1.9.1.1 COAST TO 50 X 100 NMI ORBIT APOGEE

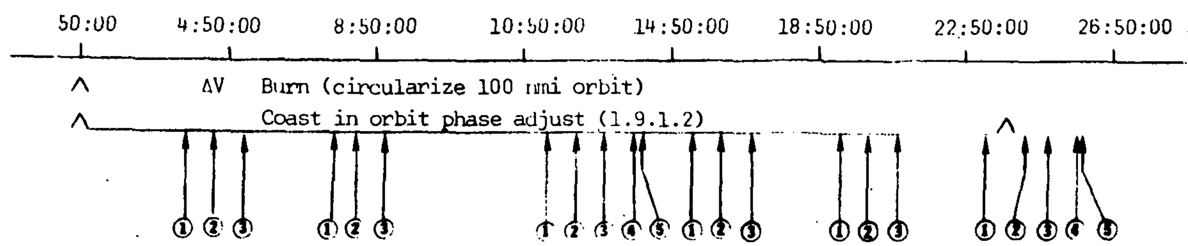


1. ENABLE ATTITUDE CONTROL DRIVERS
2. SELECT LOCAL VERTICAL ATTIT REF
3. SELECT AUTO-LO RATE-MIN DB
4. STAR TRACKER TO 'ON'
5. SELECT VERIFY STAR THRESHOLD
6. SELECT ATTITUDE DETERMIN PROGRAM
7. STAR TRACKER TO 'SEARCH'
8. VERIFY ACCEPTABLE STARS
9. EVALUATE MEASURED VS CALCULATED ATTITUDE
10. PRS POWER TO 'ON'
11. PRS MODE TO 'RANGING'
12. SELECT/VERIFY TARGET SITE
13. SELECT ORBIT PARAMETER DETERMIN PROGRAM
14. EVALUATE CALCULATED VS MEASURED ORBIT DATA
15. UPDATE STATE VECTOR
16. SELECT PLATFORM ALIGNMENT PROGRAM
17. INITIATE PLATFORM ALIGNMENT
18. SELECT ΔV CALCULATION PROGRAM
19. SELECT AUTO MANEUVER TO BURN ATTITUDE
20. ATTITUDE CONTROL MODE TO 'MAX DB'
21. PRS TO 'OFF'
22. STAR TRACKER TO 'OFF'
23. SELECT ΔV PROGRAM

Figure 3-3. (Cont.)

Hr:Min:Sec

1.9.1.2 CIRCULARIZE ORBIT

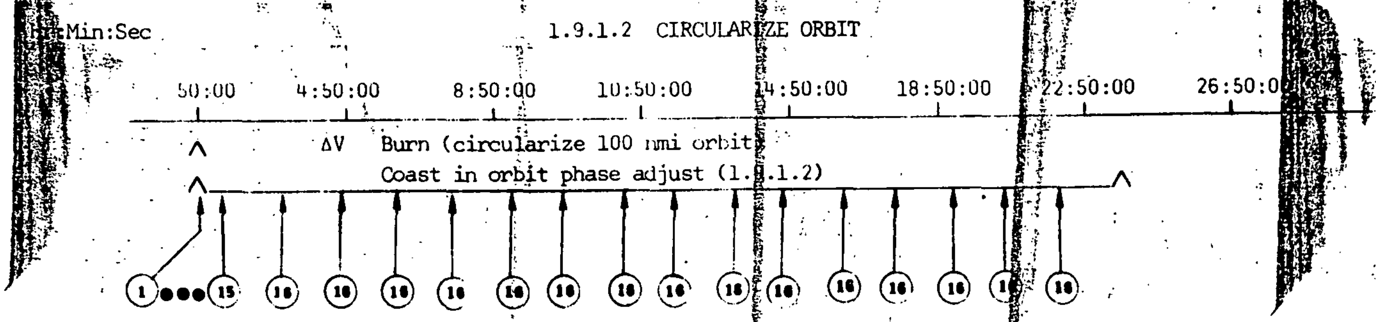


1. SELECT WASTE MGMT FAN #1
2. SELECT URINE DUMP HTR 'ON'
3. SELECT URINE DUMP HTR 'OFF'
4. SELECT ALTERNATE N_2 TANKS
5. SELECT ALTERNATE O_2 TANKS

Items 1–3: SELECTED PERIODICALLY BY CREW DURING NON TIME CRITICAL MISSION PHASES

Items 4–5: OCCURS APPROXIMATELY EVERY 12 HRS TO EQUALIZE CONSUMPTION

Figure 3-3. (Cont.)

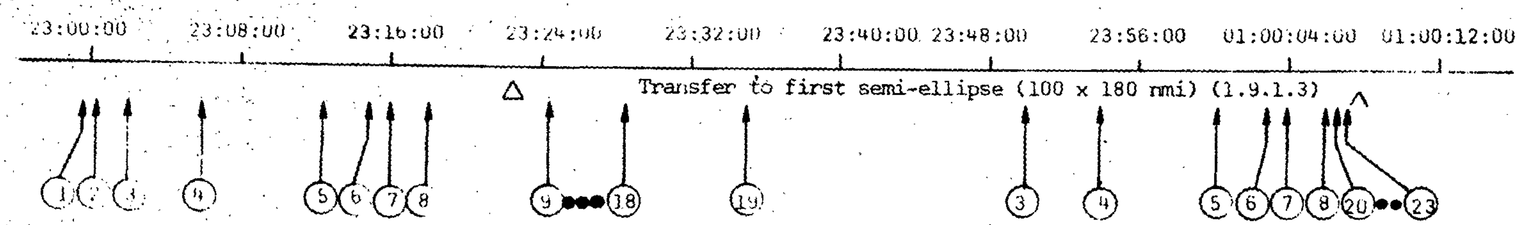


1. ENABLE ATTITUDE CONTROL DRIVERS
2. SELECT LOCAL VERTICAL ATTIT REF
3. SELECT 'AUTO-LO RATE-MIN DB'
4. STAR TRACKER TO 'ON'
5. SELECT/VERIFY STAR THRESHOLD
6. SELECT ATTITUDE DETERMINATION PROGRAM
7. STAR TRACKER TO 'SEARCH'
8. VERIFY ACCEPTABLE STARS
9. EVALUATE MEASURED VS CALCULATED ATTITUDE
10. PRS POWER TO 'ON'
11. PRS MODE TO 'RANGING'
12. SELECT/VERIFY TARGET SITE
13. SELECT ORBIT PARAMETER DETERMINATION PROGRAM
14. EVALUATE MEASURED VS CALCULATED DATA
15. UPDATE STATE VECTOR
16. A. SELECT S/C ATTITUDE DETERMIN PROGRAM
    B. SELECT ORBIT PARAMETER DETERMIN PROGRAM
    C. UPDATE STATE VECTOR

} REPEATED EACH ORBIT

Figure 3-3. (Cont.)

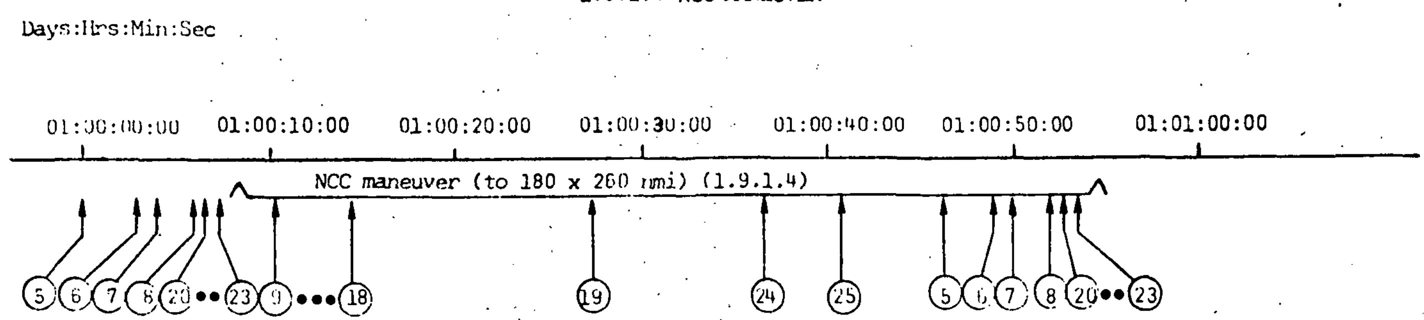
1.9.1.3 TRANSFER TO FIRST SEMI-ELLIPSE



1. SELECT PLATFORM ALIGN PROGRAM
2. INITIATE PLATFORM ALIGNMENT
3. SELECT ΔV CALCULATION PROGRAM
4. SELECT AUTO MANEUVER TO BURN ATTITUDE
5. ATTITUDE CONTROL MODE TO 'MAX DB'
6. PRS TO 'OFF'
7. STAR TRACKER TO 'OFF'
8. SELECT ΔV PROGRAM
9. ATTITUDE CONTROL TO 'MIN DB'
10. SET SPACE FLIGHT MODE TO 'ORB ATT'
11. SET PROP MODE SELECT (1,2,3) TO 'ACPS'
12. SET ΔV THRUST ENABLE TO 'OFF'
13. SET HOT GAS VENT MODE TO 'NON-PROPULSION'
14. STAR TRACKER TO 'ON'
15. PRS TO 'ON'
16. SET STAR TRACKER TO 'SEARCH'
17. SELECT ATTITUDE DETERMIN PROGRAM
18. SELECT ORBITAL PARAMETER DETERMIN PROG
19. UPDATE STATE VECTOR
20. PROPEL MODE SELECT (1,2,3) TO 'OMS'
21. SET SPACE FLIGHT MODE TO 'ΔV'
22. SET HOT GAS VENT MODE TO 'PROPULSION'
23. SET ΔV THRUST TO 'ENABLE'

Figure 3-3. (Cont.)

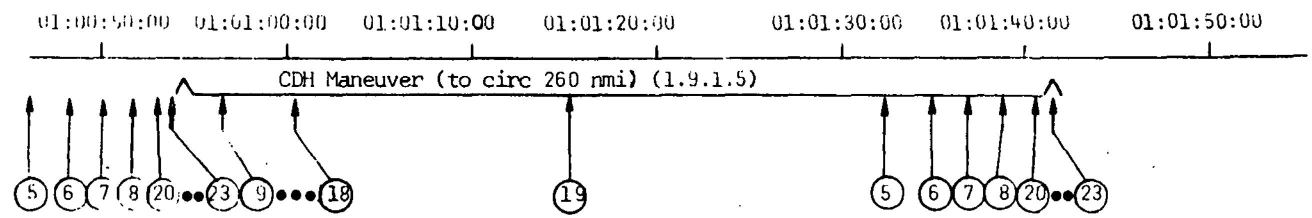
1.9.1.4 NCC MANEUVER



5. ATTITUDE CONTROL MODE TO 'MAX DB'
6. PMS TO OFF
7. STAR TRACKER TO 'OFF'
8. SELECT ΔV PROGRAM
9. ATTITUDE CONTROL TO 'MIN DB'
10. SET SPACE FLIGHT MODE TO 'ORB ATT'
11. SET PROPELL MODE SELECT (1,2,3) TO 'ACPS'
12. SET ΔV THRUST TO 'OFF'
13. SET HOT GAS VENT MODE TO 'NONPROPULSION'
14. STAR TRACKER TO 'ON'
15. PMS TO 'ON'
16. SET STAR TRACKER TO 'SEARCH'
17. SELECT ATTITUDE DETERMIN PROGRAM
18. SELECT ORBITAL PARAMETER DETERMIN PROGRAM
19. UPDATE STATE VECTOR
20. PROPELL MODE SELECT (1,2,3) TO 'OMS'
21. SET SPACE FLIGHT MODE TO 'ΔV'
22. SET HOT GAS VENT MODE TO 'PROPULSION'
23. SET ΔV THRUST TO 'ENABLE'
24. SELECT ΔV CALCULATION PROGRAM
25. SELECT AUTO MANEUVER TO BURN ATTITUDE

Figure 3-3. (Cont.)

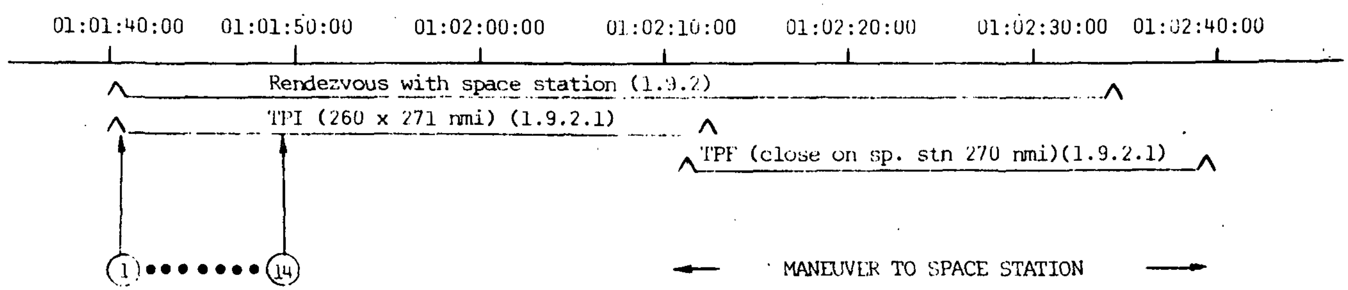
1.9.1.5 CDH MANEUVER



5. ATTITUDE CONTROL MODE TO 'MAX DB'
6. PRS TO 'OFF'
7. STAR TRACKER TO 'OFF'
8. SELECT ΔV PROGRAM
9. ATTITUDE CONTROL MODE TO 'MIN DB'
10. SET SPACE FLIGHT MODE TO 'ORB ATT'
11. SET PROPELL MODE SELECT (1,2,3) TO 'ACPS'
12. SET ΔV THRUST TO 'OFF'
13. SET HOT GAS VENT MODE TO 'NONPROPULSION'
14. STAR TRACKER TO 'ON'
15. PRS TO 'ON'
16. SET STAR TRACKER TO SEARCH
17. SELECT ATTITUDE DETERMIN PROGRAM
18. SELECT ORBITAL PARAMETER DETERMIN PROGRAM
19. UPDATE STATE VECTOR
20. SET PROPELL MODE SELECT (1,2,3) TO 'OMS'
21. SET SPACE FLIGHT MODE TO ΔV
22. SET HOT GAS VENT MODE TO 'PROPULSION'
23. SET ΔV THRUST TO 'ENABLE'

Figure 3-3. (Cont.)

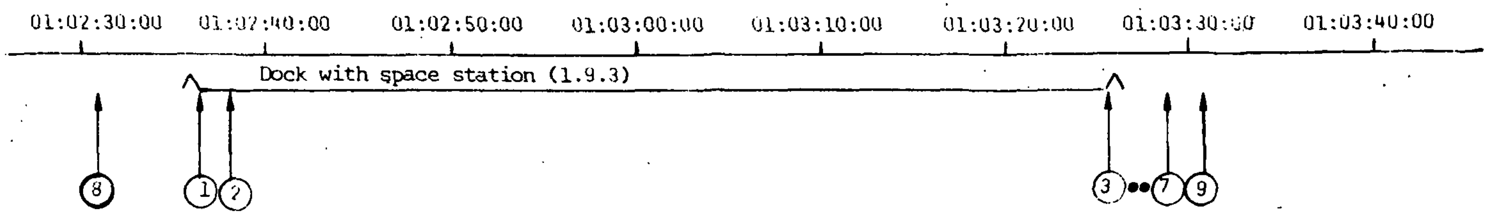
1.9.2 RENDEZVOUS WITH SPACE STATION



1. SET SPACE FLIGHT MODE TO 'ORB ATT'
2. SET PROPELL MODE SELECT (1,2,3) TO 'ACPS'
3. SET V THRUST TO 'OFF'
4. SET HOT GAS VENT MODE TO 'NONPROPULSION'
5. ATTITUDE MODE 'TO MANUAL'
6. ATTITUDE CONTROL TO 'RATE COMMAND'
7. STAR TRACKER TO 'ON'
8. PRS TO 'ON'
9. VISUALLY ACQUIRE SPACE STATION
10. SET STAR TRACKER TO 'RENDEZVOUS'
11. SET PRS TO 'RENDEZVOUS'
12. SELECT RENDEZVOUS PROGRAM
13. TRACK SPACE STATION
14. TRANSLATION CONTROLLER 'ON'

Figure 3-3. (Cont.)

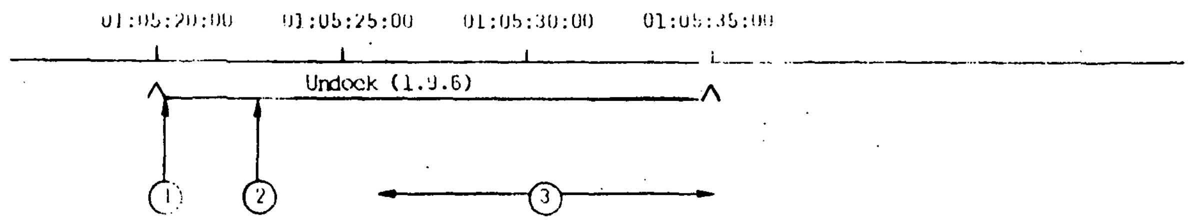
1.9.3 DOCK



1. SET ATTITUDE CONTROL RATE
2. SET ATTITUDE DEADBAND
3. GN&C SYSTEMS TO 'OFF'
4. SET GH_2 ACCUMULATOR PRESSURE TO 'OFF'
5. SET GO_2 ACCUMULATOR PRESSURE TO 'OFF'
6. SET THERMO VENT SYSTEM MODE TO 'MANUAL'
7. SET THERMO VENT SYSTEM ISOLATION VALVE TO 'OPEN'
8. TOP OFF CHARGE BAT 'B'
9. TOP OFF CHARGE BAT 'A'

Figure 3-3. (Cont.)

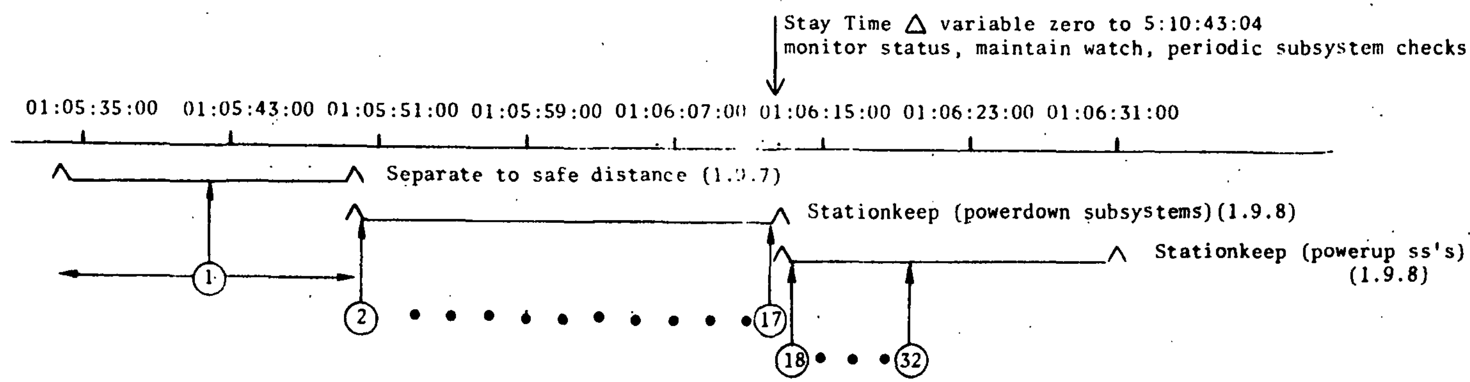
1.9.6 UNDOCK



1. ENABLE DOCKING MECHANISM
2. OPERATE DOCKING MECHANISM FOR DISENGAGEMENT
3. TRANSLATE FROM SPACE STATION

Figure 3-3. (Cont.)

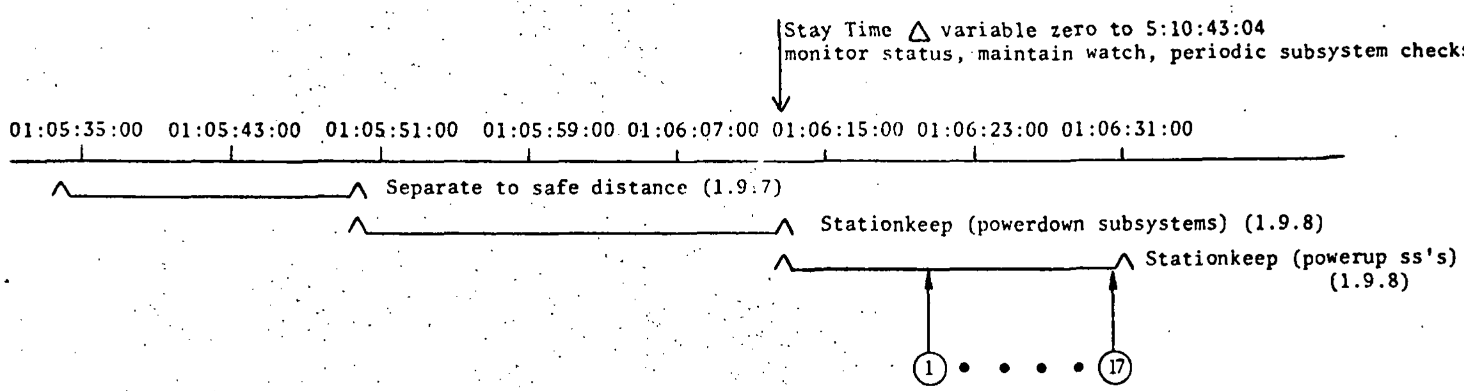
1.9.7 - 1.9.8 SEPARATE AND STATIONKEEP



1. PERFORM MANUAL SEPARATION
2. SET MANUAL ATTITUDE MODE TO ATT HOLD
3. PRS TO OFF
4. STAR TRACKER TO OFF
5. IMU TO OFF
6. ATTITUDE CONTROL DRIVERS TO OFF
7. HAND CONTROLLERS TO OFF
8. DISCONNECT FCI FROM DC BUS MNA
9. SHUT DOWN FUEL CELL #1
10. SELECT FCI O_2 REACTANT OFF
11. SELECT FCI H_2 REACTANT OFF
12. SELECT FCI H O DELIVERY CLOSE
13. CLOSE FCI REACTANT SUPPLY
14. SELECT CPU 3 TO STANDBY
15. SELECT CPU 4 TO STANDBY
16. SELECT D&C PROCESSOR 2 & 3 OFF

Figure 3-?. (Cont.)

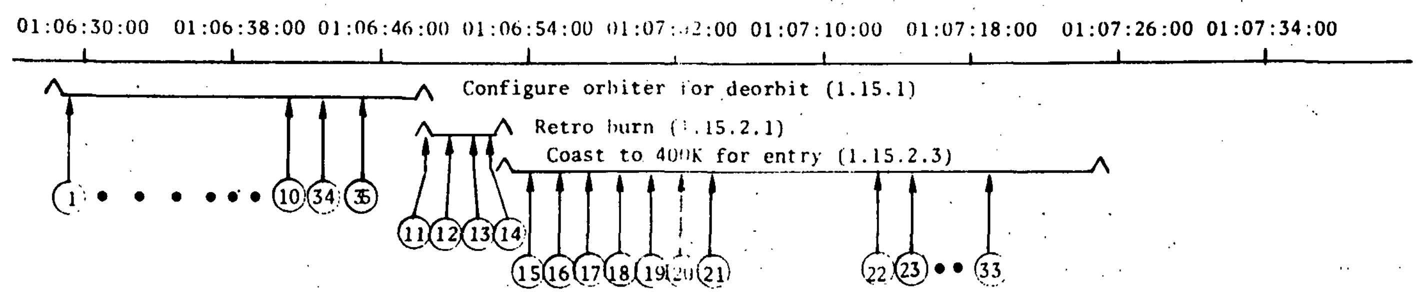
1.9.7 - 1.9.8 SEPARATE AND STATIONKEEP



1. TRANSLATION CONTROLLER TO ON
2. ROTATION CONTROLLER TO ON
3. ATTITUDE CONTROL TO MANUAL
4. SET ATTITUDE CONTROL RATE
5. SET ATTITUDE CONTROL DEADBAND
6. MANUAL ATTITUDE MODE TO RATE COMMAND
7. ATTITUDE CONTROL DRIVERS TO ENABLE
8. IMU POWER TO STANDBY
9. STAR TRACKER TO ON
10. PRS TO ON
11. SELECT ATTITUDE DETERMIN PROGRAM
12. STAR TRACKER TO SEARCH
13. IMU TO ON
14. SELECT PLATFORM ALIGN PROGRAM
15. SELECT ORBIT PARAMETER DETERMIN PROG.
16. PRS TO RANGING
17. PRS TO RENDEZVOUS

Figure 3-5. (Cont.)

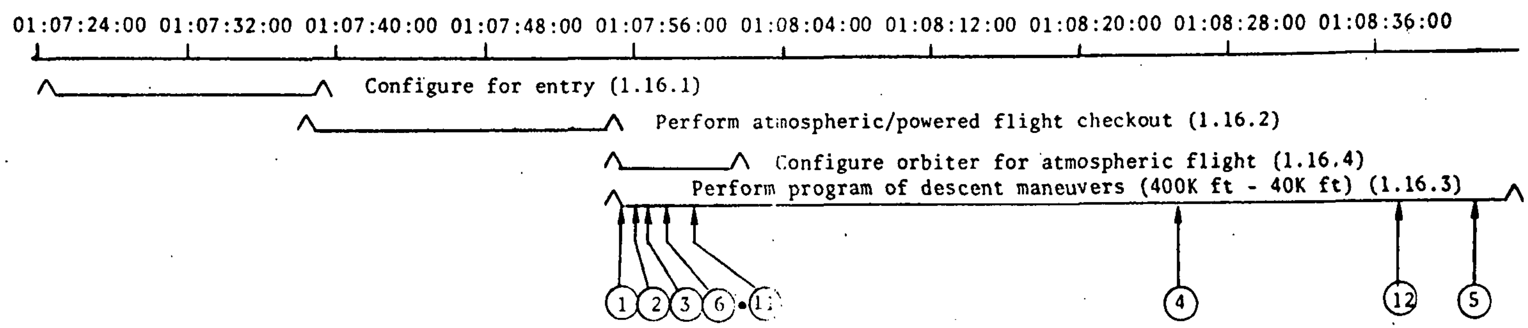
1.15 PERFORM DEORBIT MANEUVERS



1. ATTITUDE CONTROL TO AUTO
2. SELECT PRIMARY/ALTERNATE LANDING SITES
3. SELECT ΔV CALCULATION PROGRAM
4. SELECT AUTO SC MANEUVER
5. SET SPACE FLIGHT MODE TO ENTRY
6. SELECT ΔV PROGRAM
7. APS ΔV DRIVERS TO ENABLE
8. SELECT EVAP H_2O FLOW 'AUTO' (PRI & SEC)
9. SELECT RADIATOR FLOW 'BY PASS' (PRI & SEC)
10. SELECT CARGO BAY DOORS 'CLOSE'
11. SET ΔV THRUST TO ON
12. ΔV SET TO INCREASE OR DECREASE
13. SET APS GIMBAL TRIM TO ENG 1,2, OR 3
14. SET APS GIMBAL TRIM PITCH AND YAW
15. APS ΔV DRIVERS OFF
16. SELECT ENTRY CALCULATION PROGRAM
17. APS GIMBAL TRIM TO OFF P&Y
18. ΔV THRUST TO OFF
19. SET PROPEL MODE SELECT (1,2,3) TO ACPS
20. SET HOT GAS DOORS TO CLOSE
21. SELECT AUTO MANEUVER TO ENTRY ATTITUDE
22. SELECT ENTRY PROGRAM
23. SELECT HELIUM ISOLAT VALVES OPEN (H_2,O_2)(1 & 2)
24. SELECT HELIUM CIRCULATION AUTO (H_2,O_2)(1 & 2)
25. SELECT APU REACTANT SUPPLY OPEN (1,2,3,4)
26. SELECT START APU (1,2,3,4)
27. SELECT H_2 HEAT EX 1 'AUTO'
28. SELECT H_2 HEAT EX 2 'AUTO'
29. SELECT H HEAT EX AUTO
30. SELECT HYD BYPASS PRESS (1,2,3,4)
31. SELECT AC BUS AC1 TO GEN
32. SELECT AC BUS AC2 TO GEN
33. SELECT AC BUS AC3 TO GEN
34. SET PROPEL MODE SELECT TO OMS
35. SET HOT GAS VENT MODE TO PROPULSION

Figure 3-3. (Cont.)

1.16 PERFORM ORBITER ENTRY & DESCENT MANEUVERS



1. SET UHF 1 OR 2 TO ON
2. SET UHF ANT TO AUTO
3. SET UHF CHANNEL TO ATC
4. SET ATC XPONDER TO A OR B
5. SET PRS MODE TO APPR/LDG
6. SET AERO FLIGHT MODE TO AUTOPILOT
7. SET LUBOIL ISOLATION (1,2,3,4) TO AUTO
8. SET FUEL TANK VENT ISOLATION TO OPEN
9. SET FUEL MODE TO HORIZONTAL
10. SET FUEL TANK TO MAIN
11. SET BOOST DUMPS (MAIN & AUX) TO 'AUTO'
12. SELECT COLLISION AVOIDANCE LITE 'ON'

Figure 3-3. (Cont.)

1.16.6 - 1.16.7 POWERED FLIGHT

01:08:40:00	01:08:45:00	01:08:50:00	01:08:55:00	01:09:00:00	01:09:05:00

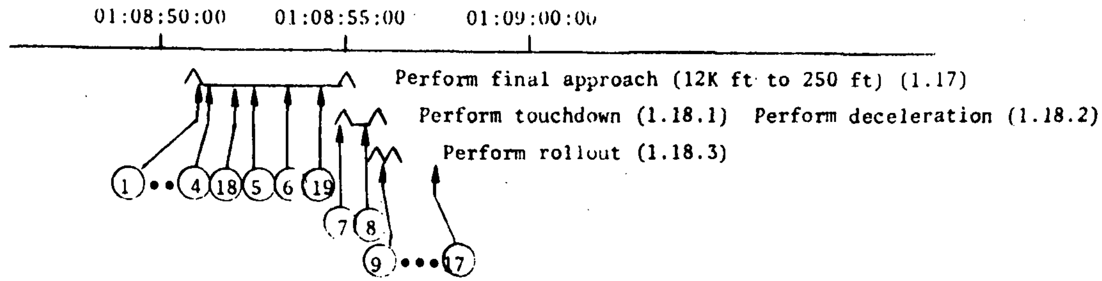
Deploy and ignite turbofans (at 35K) (1.16.6)

Perform subsonic flight to approach terminal window (40K to 12K) (1.16.7)

1. SET RADAR ALTIM TO AUTO
2. SET RADAR ALTIM SCALE TO HI
3. SET ATC TO ALT RPTG
4. SET ENGINE DEPLOYMENT (2,3) TO DEPLOY
5. SET ENGINE DEPLOYMENT (1,4) TO DEPLOY
6. SET ENGINE START MODE TO AIR
7. SET FUEL TANK SHUTOFF (1,2,3) TO OPEN
8. SET ENGINE START (2,3) TO ON
9. SET ENGINE THRUST CONTROL LEVER (2,3) TO IDLE
10. SET ENGINE START (1,4) TO ON
11. SET ENGINE THRUST CONTROL LEVER (1,4) TO IDLE
12. SET ENGINE THRUST CONTROL LEVER (2,3) TO MAX
13. SET ENGINE THRUST CONTROL LEVER (1,4) TO MAX
14. SET ENGINE THRUST CONTROL LEVER (1,4) TO IDLE
15. SET ABES THRUST CONTROL AUTO ENABLE TO ENABLE

Figure 3-3. (Cont.)

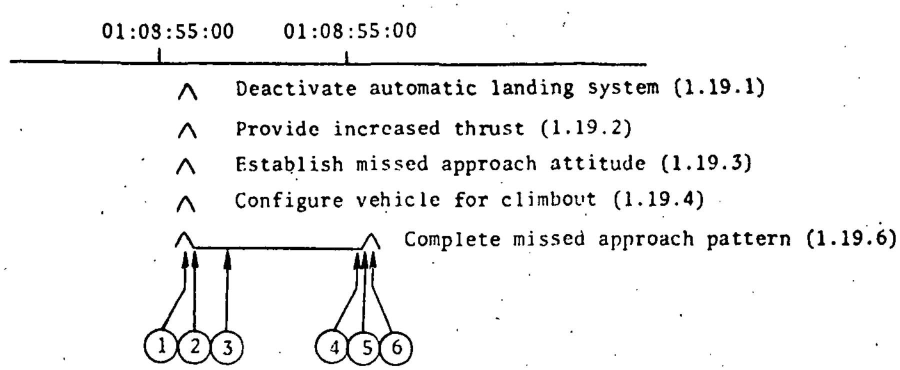
1.17 - 1.18 APPROACH AND LAND



1. SET AERO FLIGHT MODE TO 'AUTO LAND'
2. SET LANDING GEAR TO 'DOWN'
3. SET THROTTLE TO 'AUTO'
4. SET SPEED BRAKE TO 'AUTO'
5. SET NOSE WHEEL LOCK TO 'ON'
6. SET NOTE WHEEL STEERING TO 'OFF'
7. DEPLOY DRAG CHUTE
8. INITIATE BREAKING
9. SELECT AUTO LAND 'OFF'
10. SET NOSE WHEEL LOCK TO 'OFF'
11. SET NOSE WHEEL STEERING TO 'ON'
12. SET ENGINE THRUST CONTROL LEVER 1 2 3 4 TO 'OFF'
13. SET FUEL TANK SHUTOFF (1,2,3) TO 'CLOSE'
14. SET BOOST PUMPS (MAIN & AUX) TO 'OFF'
15. SET LUBOIL ISOLATION TO 'CLOSE'
16. SET ENGINE DEPLOY (2,3) TO 'RETRACT'
17. SET ENGINE DEPLOY (1,4) TO 'RETRACT'
18. SET RADAR ALTIM SCALE TO 'HI'
19. SET RADAR ALTIM SCALE TO 'LO'
20. SET LANDING LITES TO 'ON'

Figure 3-3. (Cont.)

1.19 PERFORM GO-AROUND



1. SET AUTO THROTTLE DISENGAGE TO 'PUSH ON'
2. SET ENGINE THRUST CONTROL LEVER (1, 2, 3, 4) TO 'MAX'
3. OPERATE ENGINE THRUST CONTROL LEVER TO POWER (AS REQ'D)
4. SET ENGINE THRUST CONTROL LEVER (1, 2, 3, 4) TO 'IDLE'
5. SET ABES THRUST CONTROL AUTO ENABLE TO 'ENABLE'
6. SET AERO FLIGHT MODE TO 'AUTO LAND'

Figure 3-3. (Cont.)

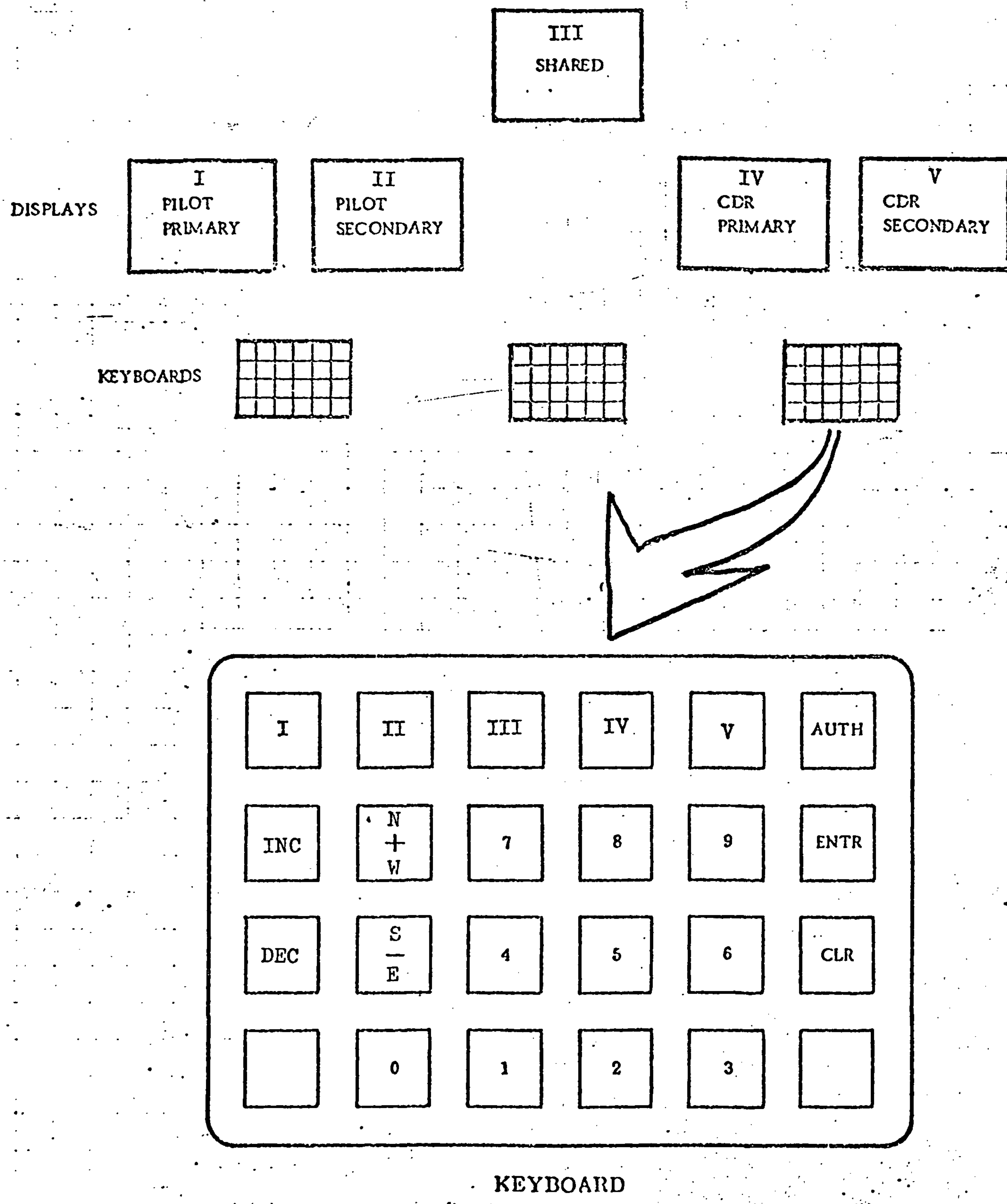


Figure 3-4. Control/Display Layout Assumed for Workload Analysis

Each CRT provides a 6 x 8 inch usable display surface. Two alphanumeric character sizes, 7/32 inch and 1/8 inch, were assumed for major titles and the remainder of the format, respectively. A basic format skeleton, shown in Figure 3-5, was developed. This skeleton reserves certain display surface areas for information common to all formats. These include GMT (or MET) and event time, format title and code number and special quick-access codes for other frequently required formats. Standard symbols and conventions were also developed and are shown in Table 3-3. The primary objectives in developing these symbol conventions were to use familiar component symbols, taken from standard usage within the professional disciplines represented in each subsystem (e.g., electrical, hydraulics, etc.), and to use symbols which can readily display the states of the components they represent (e.g., on/off, open/closed, etc.).

The keyboard contains a set of 0 through 9 numeric keys, with which the crew member will perform most of his control actions. Associated with the numeric keys is a limited number of special function keys which were tentatively identified during preliminary format concept development. Five of the special function keys are labeled with Roman numerals and represent the five CRT displays which may be controlled from that keyboard. These keys are interlocked to prevent tying more than one display to a keyboard at a time.

In addition to the standard ENTER and CLEAR keys, an AUTHORIZE key was provided to permit the crew member to authorize the computer to perform a function it has recommended. For example, if a Caution and Warning light is displayed for which a different display format would be appropriate for operator evaluation of the trouble, the computer would recommend the format and the operator would need only to actuate the AUTHORIZE key to permit a display format shift.

Plus, minus, E, N, S, and W key functions are provided on two special function keys. These functions will be used to enter special qualifiers with numeric data inputs, like latitude, longitude, gimbal angles, etc. The display format will determine the meaning of the key.

Two additional keys, INCREASE and DECREASE, are provided for continuously variable functions like volume controls, flow rates, etc. To use these controls, the operator must first select and enter the code of the function to be controlled, after which he can increase or decrease the parameter while watching the displayed quantitative variation.

3.7.2 Operating Procedure

For purposes of workload analysis, a preliminary operating procedure using the control/display concept was developed; the operator would use the keyboard/display subsystem in the following manner. The operator would first select the display surface for which he desires keyboard control by selecting the appropriate Roman-numeraled key. The selected key would remain depressed throughout all subsequent operations until deselected by selecting another display surface to indicate the active keyboard-display interface (the active display also shows a symbol to indicate that it is active). To display a format on the selected display surface, the operator

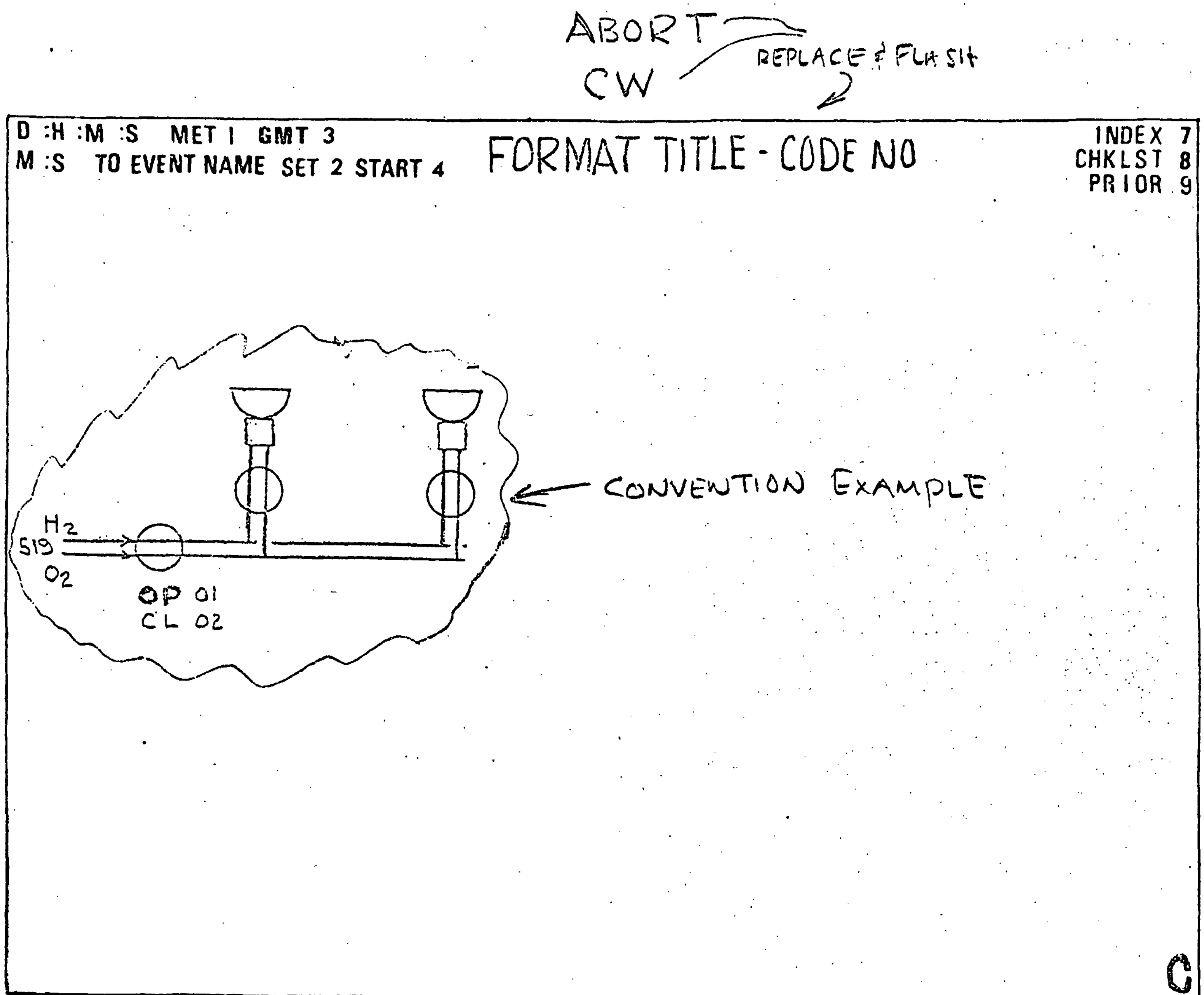
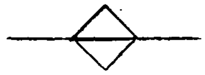
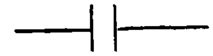
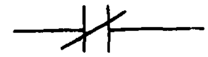
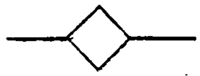
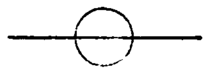
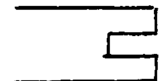
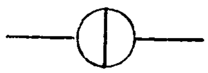
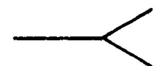
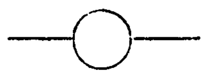
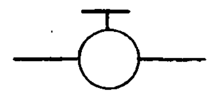
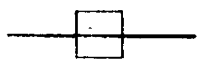
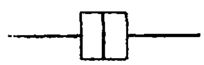
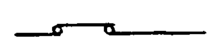
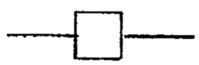
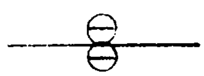
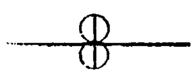
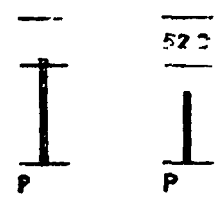
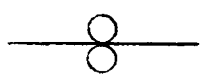


Figure 3-5. Basic Format Skeleton

Table 3-3. Standard Character Conventions

	Function	Symbol		Function	Symbol
1.	Pump On		13.	Elec Pwr Cont Open	
2.	Pump Off		14.	Elec Pwr Cont Closed	
3.	Pump Unknown		15.	Check Valve	
4.	Solenoid Valve Open		16.	Heater	
5.	Solenoid Valve Closed		17.	Vent	
6.	Solenoid Valve Unknown		18.	Manually Controlled Element	
7.	Pressure Regulator Flowing		19.	Switch Open	
8.	Pressure Regulator Closed		20.	Switch Closed	
9.	Pressure Regulator Unknown		21.	Jet Engine	
10.	Fan On		22.	Rocket Engine	
11.	Fan Off		23.	In-Tolerance, Out-of-Tolerance Quantities (Pressure, Flow, etc.)	
12.	Fan Unknown				

Abbreviations

24.	Open	OP	28.	Down	DN	32.	Quantity	Q
25.	Close	CL	29.	Pressure	P	33.	Voltage	V
26.	Automatic	AUTO	30.	Flow	F	34.	Amperes	A
27.	Manual	MAN	31.	Temperature	T			

Table 3-3. (Cont.)

CONVENTIONS

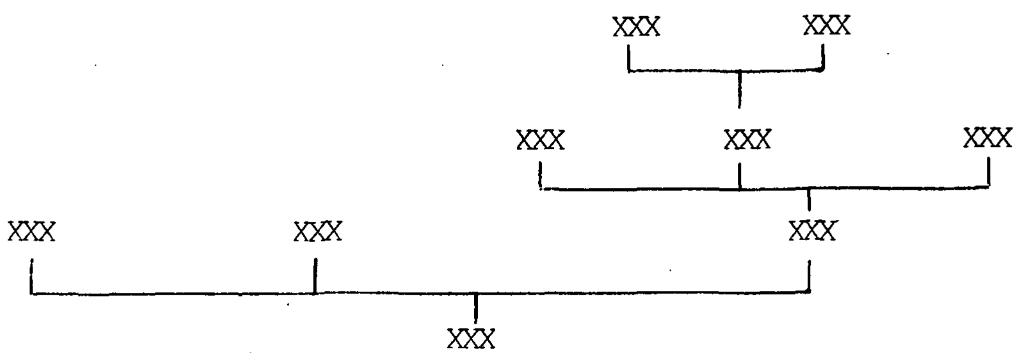
35. Reserve one-digit numbers for special usage.

36. Within a format, use two-digit numbers, the meanings of which are unique to that format only but, when used with other formats, may have other meanings.

37. Each format will be identified by a three-digit number which is reserved for that format only.

38. When a control action is performed, the control code will appear in the data entry verification window of the CRT. After visual verification, selection of the ENTER key will cause the control action to occur and will brighten the action word and code number; the previously commanded action word and code number will be reset to normal brightness.

39. Format trees will use the following diagrammatic convention:



40. Alphanumeric characters will be used in two sizes: 7/32" and 1/8". This will provide two display densities when the characters are used as follows:

20 Lines High x 40 Characters Long

7/32" high x .132" wide character; 1/16" line space; .065 character space

30 Lines High x 60 Characters Long

1/8" high x .089" wide character; 1/16" line space; .044 character space would enter a three-digit number representing that format, taken from an index or from a format reference or he would use one of the one-digit codes presented in the upper right corner of the display (Figure 3-5). The selected format would remain on the designated display until deliberately removed, regardless of subsequent keyboard-display linkage; however, a keyboard can control only through the format on the display it is linked to.

To perform a control action within a specific format, assuming the correct keyboard-display linkage, the operator would observe the display, locate the correct control action, either on a checklist or within a subsystem diagram, and enter the two-digit code number shown on the display next to the component to be controlled. As the code digits are selected on the numeric keyboard, they appear in the verification area of the lower right corner of the display. After visual verification, the code would be entered into the computer by pressing the ENTER key. If visual verification indicates an entry error, the operator would clear the digits from the verification area with the CLEAR key.

The crew member may, at his discretion, display GMT on one of his main displays and Mission Elapsed Time (MET) on the other by selecting the proper display surface and entering the code of the desired time mode. Event time will normally be displayed automatically below elapsed time, counting down to the next major event in the mission. The crewman may reset the event timer on any display and start it timing from zero time as a special event timer by using an appropriate code. This would not affect the event timers on any of the other displays.

If a Caution and Warning or Abort signal is received at any point in the mission, the format title on each display will be replaced by either a CW or ABORT character word. This word will flash until acknowledged by one of the crewmen activating a CW panel switch or the Master Abort indicator.

3.7.3 Dedicated Controls/Displays

Although an objective of the study was to provide as complete a management capability through the CRT/keyboard concept as possible, it was recognized that there would be a need for some minimum number of dedicated controls and displays to satisfy startup, safety and operator flight control requirements. Therefore, each subsystem control/display requirements list was evaluated to identify functions requiring dedicated controls and displays based on the following criteria:

1. Requires immediate time-critical crew activation and/or recognition
2. Is necessary for in-flight startup from battery power only
3. Is a basic design of the subsystem and forces dedicated controls/displays
4. A continuous manual control task is required.

A complete list of dedicated controls and displays is given in Table 3-4. The fact that these controls and displays are identified as dedicated

Table 3-4.

DEDICATED CONTROLS/DISPLAYS

SUBSYSTEM Elec. Power Distribution

TASK	CONTROLS & DISPLAYS	RATIONALE
Power up after temporary loss of all electrical power except batteries	Controls (RPC's) DC Bus Tie (3) Fuel Cell Bus Tie (3) Transformer Rect Tie to DC Buses (3) AC Gen Bus Tie (3) AC Gen Tie to AC Bus (3) Transformer Rect Tie to AC Bus (3) APU "Start" "Stop" Emerg Cockpit Lights Displays Fuel Cell Voltage DC Bus Voltage APU Run Status AC Gen Voltage AC Bus Voltage	Loss of control capability through DMC and integ D&C when elec power lost

Table 3-4. (Cont.)

DEDICATED CONTROLS/DISPLAYS

SUBSYSTEM Atmospheric Pressure Control

TASK	CONTROLS & DISPLAYS	RATIONALE
All Control Functions of Emergency O_2 System	All Controls Shutoff Regulator Select (2) Flow Control Displays Cabin Pressure (Direct Reading Mechanical)	System designed all mechanical (No electrical control functions)

Table 3-4. (Cont.)

DEDICATED CONTROLS/DISPLAYS

SUBSYSTEM Waste Management & Hygiene

TASK	CONTROLS & DISPLAYS	RATIONALE
All	All Controls All Displays for Nominal Operation (Displays for non-nominal and COFI compatible with CRT presentation remote location not significant)	Waste management and hygiene Station Remote from Flight Station

Table 3-4. (Cont.)

DEDICATED CONTROLS/DISPLAYS

SUBSYSTEM Food Management

TASK	CONTROLS & DISPLAYS	RATIONALE
All Hot & Cold Water Dispensing	2 Hot and 2 Cold Water Taps	Food and water management station remote from flight station

Table 3-4. (Cont.)

DEDICATED CONTROLS/DISPLAYS

SUBSYSTEM GN&C Space Flight Control

TASK	CONTROLS & DISPLAYS	RATIONALE
Manual Vehicle Rotation	Rotation Controller	. Quick control of vehicle because of multi-axis simultaneous control . Quick manual takeover in event of failure in automatic system . Req'd for docking . Pilot preference for 'feel' of vehicle
Manual Vehicle Translation	Translation Controller	. Same as rotation controller
Manual Takeover of Vehicle Attitude Control	Attitude Control (Manual/Auto)	. Quick disconnect of computer inputs to ACPS and TVC in case of failure in automatic system
Abort Enable	Single Stroke Control	Time Critical
Manual Stage	Single Stroke Control	Time Critical
Manual Separation	Single Stroke Control	Time Critical
Manual Dock Cont Xfer	Single Stroke Control	Time Critical
Manual Main Thrust On	Single Stroke Control	Time Critical
Manual ΔV Thrust On	Single Stroke Control	Time Critical

Table 3-4. (Cont.)

DEDICATED CONTROLS/DISPLAYS

SUBSYSTEM GN&C Atmospheric Flight & Ground Control

TASK	CONTROLS & DISPLAYS	RATIONALE
Directional Control	Rudder Pedals	Continuous Control and time critical access
Pitch & Roll Control	Stick	" " " " " "
3 Axis Trim Control	Pitch & Roll on Stick	Crew member flying vehicle should trim out force as desired. Trim thru CRT is backup to trim on stick.
Manual Drag Control	Speed Brake UP/DN Switch	Time critical manual go-around control thru CRT is backup.
Nose Wheel Steering & Brakes	Rudder Pedals	Continuous control & time critical access.
Manual Takeover Select	On Stick	Time Critical
Landing Gear Emergency Lower	Manual Release	Emergency down is mech system.
Parking Brake	"T" Handle	Parking brake is mech system.

Table 3-4. (Cont.)

DEDICATED CONTROLS/DISPLAYS

SUBSYSTEM GN&C Atmospheric Flight & Ground Control

TASK	CONTROLS & DISPLAYS	RATIONALE
Directional Control	Rudder Pedals	Continuous Control and time critical access
Pitch & Roll Control	Stick	" " " " " "
3 Axis Trim Control	Pitch & Roll on Stick	Crew member flying vehicle should trim out force as desired. Trim thru CRT is backup to trim on stick.
Manual Drag Control	Speed Brake UP/DN Switch	Time critical manual go-around control thru CRT is backup.
Nose Wheel Steering & Brakes	Rudder Pedals	Continuous control & time critical access.
Manual Takeover Select	On Stick	Time Critical
Landing Gear Emergency Lower	Manual Release	Emergency down is mech system.
Parking Brake	"T" Handle	Parking brake is mech system.

Table 3-4. (Cont.)

DEDICATED CONTROLS/DISPLAYS

SUBSYSTEM DCM

TASK	CONTROLS & DISPLAYS	RATIONALE
Power Up & Initialize Computers	Controls START  AUTO OFF START MODE SET  CLEAR	DCM not operating until power applied

Table 3-4. (Cont.)

DEDICATED CONTROLS/DISPLAYS

SUBSYSTEM Integrated D&C

TASK	CONTROLS & DISPLAYS	RATIONALE
Power Up Integ D&C	Controls "OFF" "START" "AUTO" NOTE: "START" - applies power to all ID&C LRU's and enables all channels. "AUTO" - reverts control to ID&C.	Integ D&C not available for control actions until powered up

Table 3-4. (Cont.)

DEDICATED CONTROLS/DISPLAYS

SUBSYSTEM Comm

TASK	CONTROLS & DISPLAYS		RATIONALE
1. Set Intercom Volume (CDR & PLT)	Volume Control		Need for rapid change to offset loud or soft input.
2. Set Master Sound Input (CDR & PLT)	Three Position Switch	AUDIO/TONE OFF AUDIO	Need for rapid access to prevent loss of voice message when tone occurs.
3. Set Master Volume (CDR & PLT)	Volume Control		Need for fine setting without lookup delay.
4. Intercom Selector	Three position Swith	T/R OFF RCV	Need for frequent nonscheduled rapid utilization.

Table 3-4. (Cont.)

DEDICATED CONTROLS/DISPLAYS

SUBSYSTEM ABES

TASK	CONTROLS & DISPLAYS	RATIONALE
Control ABES Engine Thrust	Manual Throttles - backup toggle thrust controllers - manual mode switch - auto enable	During manual operations, continuous control is required - manual takeover of control may require instant takeover (e.g., landing abort)
Detect Fire & Initiate ABES Engine Fire Extinguisher	Fire switch, 2 agent discharge switches per engine, 2 fire sensor lights per engine	Emergency switching function
Enable fire detection Sensors & Test	Enable switch for sensors A and B, test switch for sensors A and B, 2 fire sensor lights per engine	Uses same lights to verify as the emergency warning; no need for redundant switching & reading on CRT

Table 3-4. (Cont.)

DEDICATED CONTROLS/DISPLAYS

SUBSYSTEM Power Generation

TASK	CONTROLS & DISPLAYS	RATIONALE
Power Up After Temporary Loss of All Electrical Power Except Batteries	Controls APU "START" "STOP" (4) APU Reactant Supply Valves ($4\ H_2$, $4\ O_2$) Displays APU Run Status	Loss of control capability thru DMC & integ D&C when elec power lost

does not preclude redundant provisions in the formats for alternate use by the crew under certain conditions. Dedicated controls and displays are listed by subsystem. No effort was made to design control/display panels or to establish optimum locations for dedicated controls and displays since this was outside the scope of the analysis.

3.7.4 Formats

Utilizing the control/display requirements, the format conventions and symbols and the subsystem schematics, sample formats were developed for management of each of the subsystems and for monitoring and control of system and mission functions. The objectives were (1) to demonstrate the feasibility of incorporating all non-dedicated control and monitoring requirements into a limited number of format types, (2) to provide sufficient format samples to permit verification of their utility during normal mission operations and contingency situations, and (3) to provide a basis for estimating total program and computer storage requirements for complete mission operations.

Approximately 100 individual formats, 70 of which are shown in Appendix C, were developed, ranging from a complete set of formats for the propulsion subsystem to single samples for other subsystems. Complete indexes for all required formats within each subsystem and for normal operating procedures during the entire mission were prepared as a basis for estimating total requirements. These are shown in Appendix C.

Five separate types of formats were developed, each having different utilization and display characteristics. These types are briefly described below, with references to examples in Appendix C.

Indexes - Primary access to individual formats by the crew will be by indexes (format trees). It is anticipated that at startup the first format to be displayed will be the master index. Including the master index, no more than two indexes are required to locate any format in the repertoire. Indexes are characterized as fixed format displays (no variable data), using alphanumerics and horizontal and vertical vector generation and referencing only 3-digit format selection control operations. Format 100 is the master index, and normal operational procedure checklists are indexed in Formats 101, 102, and 103.

Subsystem Management - Theoretically, complete control of the entire mission could be exercised using only the subsystem management formats (with the exception of dedicated controls and displays), although these formats are designed primarily for contingency activities like override of automated functions, reconfiguration of subsystems and in-flight procedural changes. Subsystem management formats are either schematic or tabular in form, reference 2-digit discrete control commands, enable keyboard data entry and display variable data. Tabular formats are, in general, entirely alphanumeric, with variable data displayed as digital numerics. Schematic formats contain both numeric and graphic variable data and a high degree of graphic symbology. Format 601 is a representative sample of tabular formats showing variable status data and Format 764 is representative of tabular formats permitting data entry. Format 507 is illustrative of schematic formats with both graphic and digital variable data.

Vehicle Management - Vehicle management formats are primarily graphic displays of vehicle and mission profile data, such as vehicle flight profile, flight director information and horizontal situation data. These formats are characterized by providing virtually no control capability, displaying largely variable data, and, unlike the other display formats, requiring symbol rotation capability in the display mechanization. It is anticipated that one or another of these formats will be displayed on each crew member's secondary CRT throughout most of the mission. Format 721 is representative of this type of display format.

Operational Procedure Checklists - During the analysis, it became apparent that a major factor in operator performance of the mission tasks, within the available time, would be the crew's ability to follow the sequences of tasks through each mission phase. Possible approaches, within the context of the control and display concept under evaluation, were narrowed to two alternatives. In one approach, the crew would be provided a carry-on-board checklist, similar to that used in the Apollo missions. The checklists would reference the appropriate subsystem format wherein the necessary control for performing each task would be found. This approach, while the least expensive from a computer/storage standpoint, would be the most time-consuming for the operator, necessitating frequent display format switching operations.

The second approach would program each checklist for display on the CRT and would incorporate, for each task listing, such information as the action to be performed, the present state of the control, the alternative control modes and their associated codes, and, where appropriate, quantitative data relating to the status of the subsystem under control. The task would be performed directly from the checklist without necessity for referring to the individual subsystem formats. This latter approach, illustrated in Format 131, Appendix C, would require considerably greater computer storage capacity but was adopted for this study because it minimizes crew performance time, reduces possibilities for operator error and simplifies the crew's task of keeping track of operating sequences.

The checklists, which would each consist of from 6 to 30 task events, would be displayed two events at a time. The task event to be performed next would be displayed in the primary location just below the related quantitative data. The task event last performed would be displayed below the event to be performed next. As each task is performed, the task list would sequence down, permitting the operator to observe the effect of the last command.

To assist the operator in pacing his task performance, each checklist would be assigned an arbitrary time-to-completion of 15 seconds per event. At the start of the checklist, a cumulative timer would credit the operator with time remaining if the event is completed in less than the allotted time and would charge him if more than the allotted time is used. Thus, the operator could determine whether he is falling behind the event schedule.

The cumulative timer would be reset at the beginning of each checklist.

Three event-hold conditions are also provided on the checklist. A TIME HOLD would be displayed if the next event should not be performed until a specified time in the mission. For example, after initiating the platform alignment program during the IMU ALIGN checklist, the next scheduled event would be to evaluate platform gimbal angles and calculated corrections. A time hold would be displayed for the 10-minute period required for platform alignment. Removal of the displayed TIME HOLD would inform the operator that platform alignment is complete and data are available for performing the next event. A SEQUENCE HOLD would be displayed if the next event should not be performed until the other crewman has performed a constraining event in his checklist. For example, the platform alignment program of the IMU ALIGN checklist should not be initiated until the orbit data has been verified by the other crewman performing the DETERMINE ORBIT checklist. If the other crewman is falling behind his performance schedule, a SEQUENCE HOLD displayed on the IMU ALIGN checklist would warn the operator to wait until orbit data are available. A CW HOLD would be displayed if a CW condition has been detected but not yet acknowledged by the crew. Acknowledgment would remove the hold display.

The above HOLD conditions may be programmed to prevent the operator from performing the next event or they may serve only as warnings, depending on the criticality of the hold situation. In general, the interlock would be preferable to prevent inadvertent program mixups.

Mission Timelines - To aid the crew in overall mission management, particularly in coordinating individual checklists within each mission phase, mission timeline formats were developed. These are illustrated by Format 203, Appendix C. Each timeline represents a period between major mission events and includes from four to a dozen checklists of operator activities. Each timeline (mission phase) consists of a time scale representing the total time for that phase with time blocks for each checklist appearing at the scheduled intervals along the time scale. A pointer moves along the time scale at a real-time rate indicating the passage of mission time. As checklist events are completed by the operators, the appropriate checklist blocks would be shaded. By visually correlating the position of the shaded area on the checklist blocks with the time scale pointer, the operator could determine the completion and timing status of mission events and the future procedures to be performed during the mission phase.

The timeline for each phase would be called up automatically at the conclusion of the last checklist for the preceding phase. In addition, the timeline for any phase could be called up by either operator for display on any CRT. Since the mission timeline would normally be displayed on the fifth (center) CRT, if any other CRT fails, the center CRT could be time-shared between the mission timeline and any other display format, including checklists, by using the single digit commands 8 (checklist) and 9 (prior) in the upper right corner of every display format.

3.8 SELECTION OF MISSION PHASES FOR DETAILED ANALYSIS

Based on the mission/task timelines shown in Figure 3-3, four mission phases were selected for detailed timeline analysis. The four selected phases were: Coast Into Orbit (1.9.1.1), Deorbit (1.15), Powered Flight (1.16) and Approach and Land (1.17). These phases were selected as being most heavily task-loaded for the crew based on preliminary inspections of the tasks required for each mission phase.

During the Coast Into Orbit phase, operator tasks involve shutting down and dumping residual fuel from the main propulsion system, spacecraft reconfiguration for space flight, determination of vehicle attitude, target state vectors and orbit, IMU alignment and configuration and calculation for Delta V. With the exception of shutting down and dumping residual fuel from the main propulsion system, all of these tasks are repeated during successive orbital changes prior to Rendezvous.

During Deorbit, the crew must configure for retrofire, activate the ACPS, select a landing site, initiate and monitor retrofire Delta V, configure for reentry, deactivate the OMS, initiate reentry maneuvers and monitor reentry trajectory and attitude.

During the Powered Flight phase, operator procedures include configuring for powered flight, deploying and starting ABES engines, and monitoring powered flight maneuvers.

During Approach and Landing, crew tasks involve configuration for approach and landing, monitoring approach and landing and configuration for shutdown.

In selecting these mission phases for detailed analysis, both the number of tasks to be performed by the crew and the time available for their performance were used as selection criteria.

3.9 WORKLOAD ANALYSIS

A workload analysis was performed, for the four selected mission phases, to determine whether the use of the keyboard/CRT approach would be likely to require more operating time than is available within each mission phase. Both nominal and non-nominal operating conditions were considered, and keyboard operating procedures requiring both minimal and maximal access times to subsystem controls were analyzed. The analysis and results are described below.

3.9.1 Nominal

Subsystem, vehicle and mission management tasks were detailed for each phase and allocated to either the Commander (CDR) or the Pilot (PLT). In general, tasks involving vehicle and mission control were allocated to the Commander and tasks involving subsystem management were assigned to the Pilot although this could not be adhered to constantly throughout the mission without a resultant disproportionate assignment of tasks to one crewman.

Time available for each phase was diagrammed on a timeline which permitted allotting task times in increments of 15 seconds. A 15-second minimum increment was selected to represent the amount of time required for a crewman to perform a typical task involving (1) reading from a checklist the task to be performed, (2) evaluating whether conditions are suitable for performing the task, (3) reading out the code number of the task to be entered on the keyboard, (4) setting in the code number on the keyboard, (5) verifying the correctness of the entry, (6) pushing the ENTER button, and (7) verifying that the task action resulted in the desired change. Although time estimation procedures indicate that the crewman could probably complete this type of task in less time, the selection of 15 seconds per task may be expected to result in careful, unhurried performance with minimum error rates. If the time available is sufficient for completion of all tasks with this performance time allocation, it may be concluded that the operations involved are not time critical.

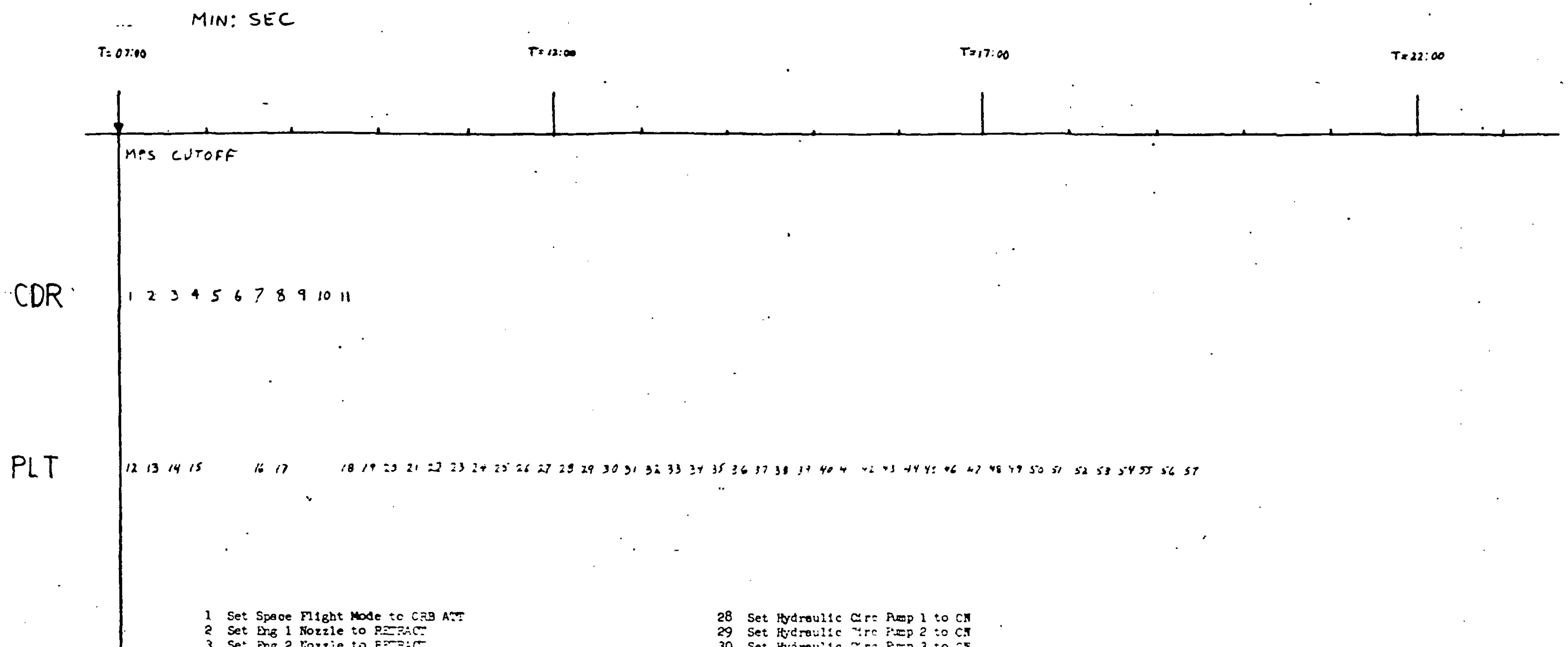
Tasks were entered on the timeline at the appropriate time of occurrence, separately for each crewman, with appropriate delays for such activities as waiting for completion of alignment, evaluating status, etc. Results, shown on the timelines (Figures 3-6, 3-7, 3-8, and 3-9) indicate that at no point in the mission will the crewmen be overloaded nor will they be performing time-critical operations during a nominal mission. The evaluation is based on the assumption that each crew member will be operating primarily from a CRT-presented checklist, with occasional reference to other display formats for short term operations. The absence of time-critical tasks results from the basic Phase B design in which time-critical tasks are automated in most cases by basic provisions built into each subsystem.

It is evident from the timelines that considerable leeway exists for alternate approaches to using the CRT/keyboard control and display subsystem. The timeline assumes that each crewman operates from a CRT presented checklist appropriate to the mission segment, wherein alternative command actions and present status are provided as part of the checklist; references to other formats are infrequent and display switching is minimized. As an alternative, virtually all of the control actions assumed for the checklists can be made from subsystem and vehicle control formats, providing the crewman with greater overall visibility of configuration status, but requiring more display switching functions. Sufficient time is available throughout the mission phases for this latter approach also. For example, the largest number of subsystem reconfiguration tasks are required just after completion of the main engine burn following separation. On the timeline (Coast Into Orbit Phase), these activities are assigned mostly to the Pilot, in keeping with the task assignment philosophy, while the Commander monitors trajectory and mission parameters. During the first 20 minutes after engine shutdown, the Pilot would have available seven minutes of slack time. If the subsystem control tasks were performed from individual subsystem formats, rather than from a checklist display, the Pilot would be required to switch formats 12 times using three of the available seven minutes of slack time. No other series of tasks approaches that degree of format switching complexity.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TIMELINE COAST INTO ORBIT (1.9.1.1)



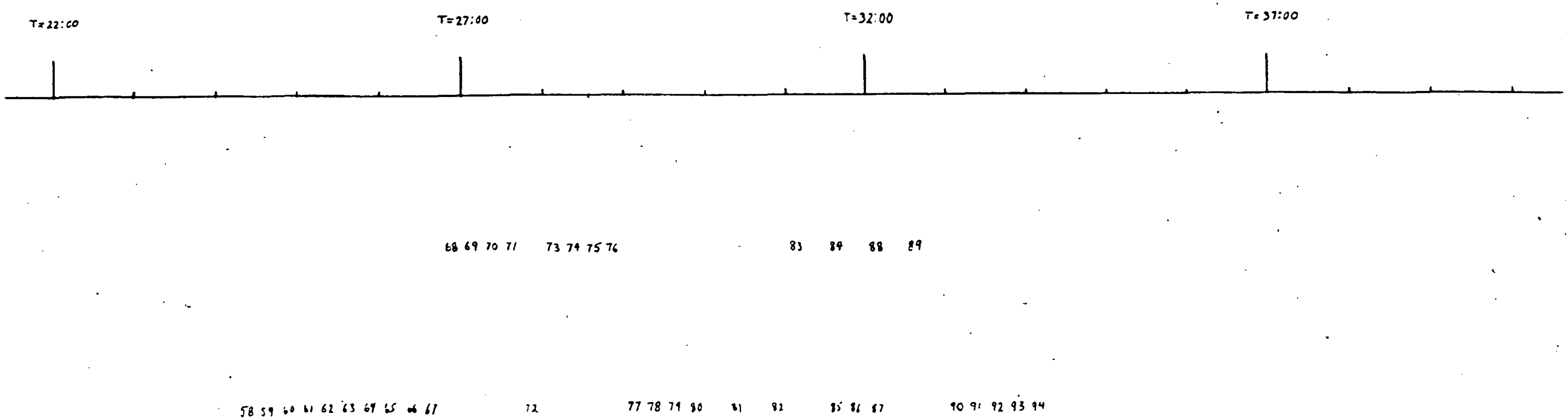
1 Set Space Flight Mode to ORB ATT
2 Set Eng 1 Nozzle to RETRACT
3 Set Eng 2 Nozzle to RETRACT
4 Set Propellant Mode Select to ACPS
5 Set Hot Gas Doors to OPEN
6 Set Hot Gas Vent Mode to PROP
7 Set Delta V Thrust Enable 1 to OFF
8 Set Delta V Thrust Enable 2 to OFF
9 Set Delta V Thrust Enable 3 to OFF
10 Set Ascent TVC Drivers to OFF
11 Set Ascent Thrust Enable to OFF
12 Set Eng 1 Prevalve to OPEN
13 Set Eng 2 Prevalve to OPEN
14 Set Eng 1 Propellant Dump Valve to OXID
15 Set Eng 2 Propellant Dump Valve to OXID
16 Set Eng 1 Propellant Dump Valve to FUEL
17 Set Eng 2 Propellant Dump Valve to FUEL
18 Set Eng 1 Propellant Dump Valve to OFF
19 Set Eng 2 Propellant Dump Valve to OFF
20 Set Eng 1 Prevalve to CLOSE
21 Set Eng 2 Prevalve to CLOSE
22 Set Helium Isolation Valve 1 to OPEN
23 Set Helium Isolation Valve 2 to OPEN
24 Set LH_2 Boiloff Isolation Valve to OPEN
25 Set LO_2 Boiloff Isolation Valve to OPEN
26 Set LH_2 Tankage Isolation Valve to OPEN
27 Set LO_2 Tankage Isolation Valve to OPEN
28 Set Hydraulic Circ Pump 1 to ON
29 Set Hydraulic Circ Pump 2 to ON
30 Set Hydraulic Circ Pump 3 to ON
31 Set Hydraulic Circ Pump 4 to ON
32 Depressurize Hydraulic Bypess 1
33 Depressurize Hydraulic Bypess 2
34 Set AC Bus 1 to OFF
35 Set AC Bus 2 to OFF
36 Set APU 1 to OFF
37 Set APU 3 to OFF
38 Set APU Reactant Supply 1 to CLOSE
39 Set APU Reactant Supply 3 to CLOSE
40 Set H_2 He Circ 1 to OFF
41 Set O_2 He Circ 1 to OFF
42 Set H_2 He Isol 1 to CLOSE
43 Set O_2 He Isol 1 to CLOSE
44 Set APU Reactant Supply 2 to CLOSE
45 Set APU Reactant Supply 4 to CLOSE
46 Set H_2 He Circ 2 to OFF
47 Set O_2 He Circ 2 to OFF
48 Set H_2 He Isol 2 to OFF
49 Set O_2 He Isol 2 to OFF
50 Set Cargo Bay Doors to OPEN
51 Set Radiator Flow Primary to ON
52 Set Radiator Flow Secondary to ON
53 Set Evap H_2O Flow Primary to OFF
54 Set Evap H_2O Flow Secondary to OFF
55 Set Pot H_2O Htr to AUTO
56 Set H_2O Pump Htr to ON
57 Adjust Cabin Temp as required

Figure 3-6. Coast Into Orbit Workload Timeline

FOLDOUT FRAME 1

FOLDOUT FRAME 2

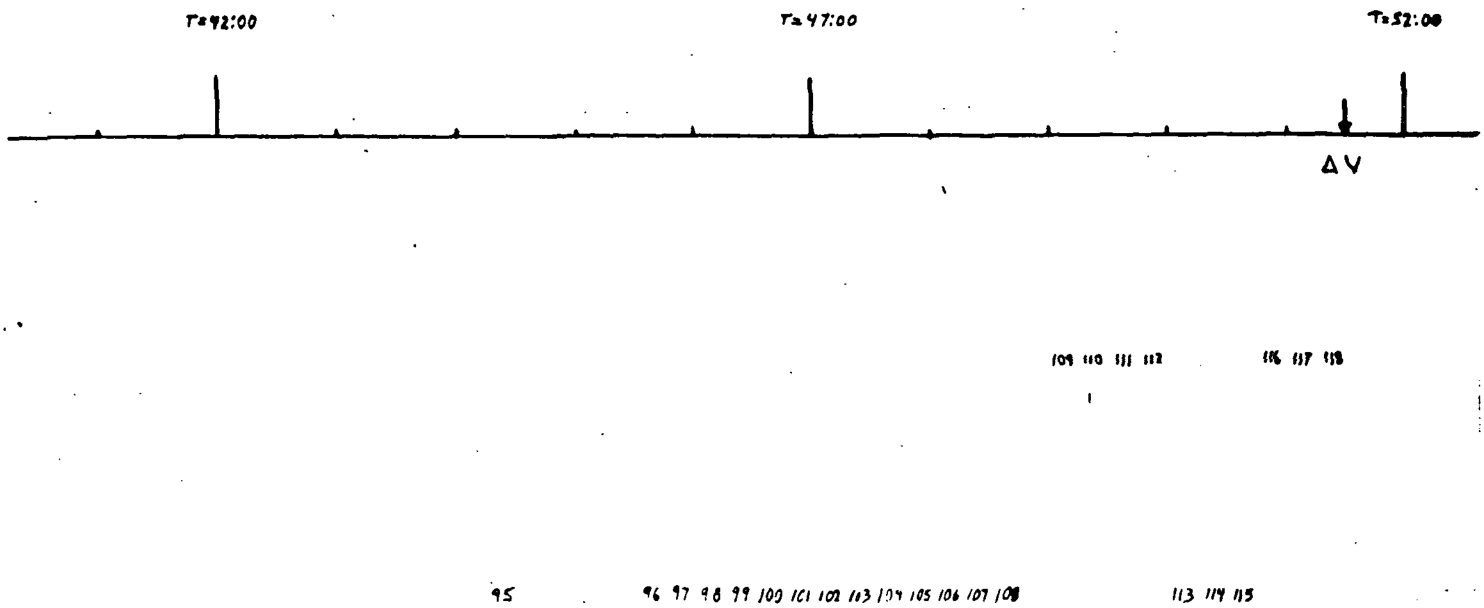
TIMELINE COAST INTO ORBIT (1.9.1.1)



58 Call up FCS Display
59 Set Attitude Control Driver 1 to ENABLE
60 Set Attitude Control Driver 2 to ENABLE
61 Set Attitude Control Driver 3 to ENABLE
62 Set Attitude Control Driver 4 to ENABLE
63 Set Attitude Reference to LOCAL VERT
64 Set Attitude Control Mode to AUTO
65 Set Attitude Control Rate to LO RATE
66 Set Attitude Control Deadband to MIN DB
67 Evaluate FCS Display
68 Call up Star Tracker Display
69 Set Star Tracker Power to ON
70 Set/Verify Star Tracker Threshold
71 Evaluate Star Tracker Display
72 Set Keyboard Code for Attitude Determination Program
73 Set Star Tracker Mode to SEARCH
74 Verify Star Acceptability
75 Compare Calculated vs Measured S/C Attitude
76 Enter S/C Attitude
77 Call up PRS Display
78 Set PRS Power to ON
79 Set PRS Mode
80 Set PRS Range
81 Set PRS Target Site
82 Evaluate PRS Display
83 Call up Orbit Parameter Display
84 Set Keyboard Code for Orbit Parameter Determination Program
85 Monitor Displayed Range and Range Rate
86 Verify Ground Station Sequencing
87 Monitor PRS Subsystem Data
88 Evaluate Calculated and Measured Orbit Data
89 Enter Preferred Orbit Data
90 Call up IMU Display
91 Set Keyboard Code for Platform Alignment Program
92 Monitor IMU Display
93 Evaluate Platform Gimbal Angles and Calculated Corrections
94 Initiate Platform Alignment
95 Verify Proper Platform Alignment

Figure 3-6. Coast into Orbit Workload Timeline (Cont.)

TIMELINE COAST INTO ORBIT (1.9.1.1)



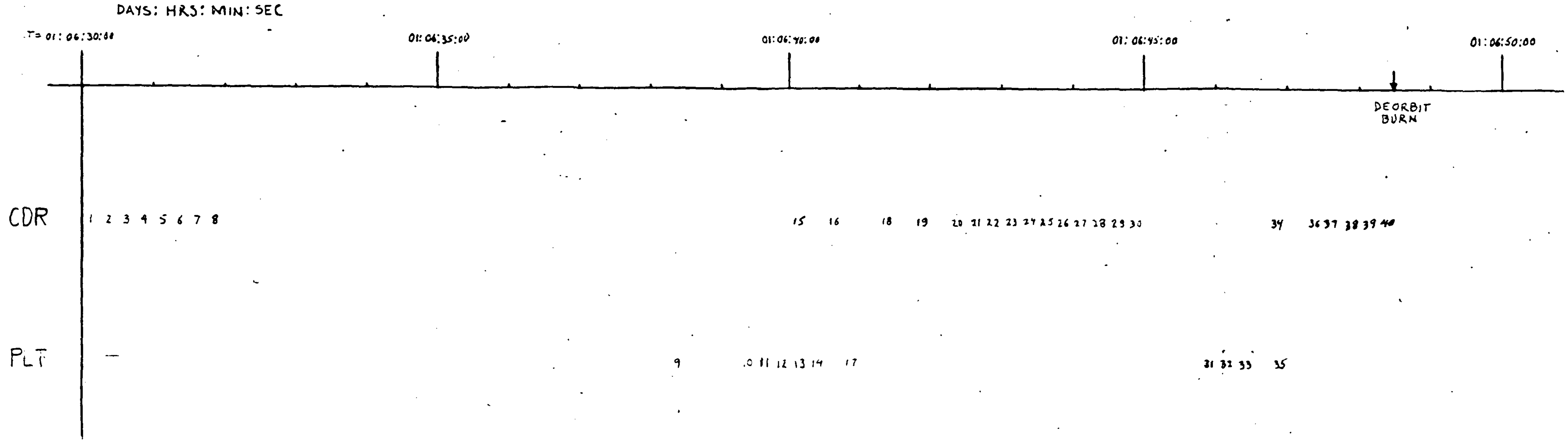
96 Set APS Delta V Driver 1 to ENABLE
97 Set APS Delta V Driver 2 to ENABLE
98 Set APS Delta V Driver 3 to ENABLE
99 Set APS Delta V Driver 4 to ENABLE
100 Set TVC Mode to AUTO
101 Set Attitude Control Driver 1 to ENABLE
102 Set Attitude Control Driver 2 to ENABLE
103 Set Attitude Control Driver 3 to ENABLE
104 Set Attitude Control Driver 4 to ENABLE
105 Set Attitude Reference to LOC VERT
106 Set Attitude Control Mode to AUTO
107 Set Attitude Control Rate to LO RATE
108 Set Attitude Control Deadband to MIN DB
109 Call up Delta V Program Display
110 Enter Keyboard Code for Delta V Calculation Program
111 Enter Desired IMU Gimbal Angles
112 Enter Keyboard Code for AUTO MANEUVER
113 Set Attitude Control Mode to AUTO
114 Set Attitude Control Rate to LO RATE
115 Set Attitude Control Deadband to MAX DB
116 Verify Delta V Parameters
117 Enter Keyboard Code for Delta V program
118 Set Delta V Thrust Enable to ENABLE

Figure 3-6. Coast Into Orbit Workload Timeline (Cont.)

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TIMELINE DEORBIT (1.15)



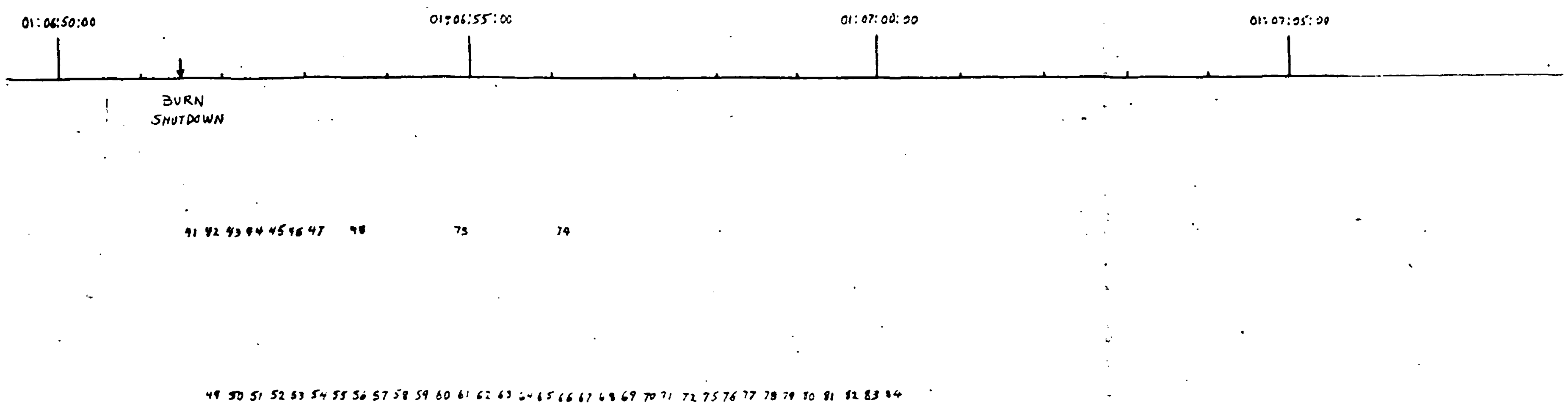
1 Set Attitude Control Driver 1 to ENABLE
2 Set Attitude Control Driver 2 to ENABLE
3 Set Attitude Control Driver 3 to ENABLE
4 Set Attitude Control Driver 4 to ENABLE
5 Set Translation Control Enable to ENABLE
6 Set Attitude Control Mode to AUTO
7 Set Attitude Control Rate to HI
8 Set Attitude Control Deadband to MIN

9 Enter Keyboard Code for Orbit Determination Program
10 Set Evap H_2O Flow Primary to AUTO
11 Set Evap H_2O Flow Secondary to AUTO
12 Set Radiator Flow Primary to BYPASS
13 Set Radiator Flow Secondary to BYPASS
14 Set Cargo Bay Doors to CLOSE
15 Monitor Range and Range Rate Display
16 Verify Ground Station Sequencing
17 Enter Keyboard Code for Orbit Parameter Display
18 Enter Keyboard Code for Landing Site Display
19 Set in Keyboard Code for Selected Landing Site
20 Enter Keyboard Code for Delta V Calculation Program
21 Enter Keyboard Code for FCS Display
22 Set/verify Attitude Control Driver 1 to ENABLE
23 Set/verify Attitude Control Driver 2 to ENABLE
24 Set/verify Attitude Control Driver 3 to ENABLE
25 Set/verify Attitude Control Driver 4 to ENABLE
26 Set/verify Attitude Reference to LOCAL VERT
27 Set/verify Attitude Control Mode to AUTO
28 Set/verify Attitude Control Rate to LO RATE
29 Set/verify Attitude Control Deadband to MAX DB
30 Enter Keyboard Code for AUTO MANEUVER

31. Set Propellant Mode Select 1 to CMS
32 Set Propellant Mode Select 2 to CMS
33 Set Propellant Mode Select 3 to CMS
34 Set Space Flight Mode to ENTRY
35 Set Hot Gas Vent Mode to PROPULSION
36 Enter Keyboard Code for Delta V Program
37 Set TVC Mode to AUTO
38 Set Delta V Thrust Enable 1 to ENABLE
39 Set Delta V Thrust Enable 2 to ENABLE
40 Set Delta V Thrust Enable 3 to ENABLE

Figure 3-7. Deorbit Workload Timeline

TIMELINE DEORBIT (1.15)



41 Set Delta V Thrust Enable 1 to OFF
42 Set Delta V Thrust Enable 2 to OFF
43 Set Delta V Thrust Enable 3 to OFF
44 Set Delta V Drivers Enable 1 to OFF
45 Set Delta V Drivers Enable 2 to OFF
46 Set Delta V Drivers Enable 3 to OFF
47 Set Delta V Drivers Enable 4 to OFF
48 Set Translation Control Enable to OFF
49 Set Hot Gas Doors to CLOSE
50 Set Propellant Mode Select 1 to ACPS
51 Set Propellant Mode Select 2 to ACPS
52 Set Propellant Mode Select 3 to ACPS
53 Set Helium Isolation Valve 1 (H_2) to OPEN
54 Set Helium Isolation Valve 2 (H_2) to OPEN
55 Set Helium Circ Loop 1 (H_2) to AUTO
56 Set Helium Circ Loop 2 (H_2) to AUTO
57 Set APU 1 H_2 Reactant Supply to OPEN
58 Set APU 2 H_2 Reactant Supply to OPEN
59 Set APU 3 H_2 Reactant Supply to OPEN
60 Set APU 4 H_2 Reactant Supply to OPEN
61 Set Helium Isolation Valve 1 (O_2) to OPEN
62 Set Helium Isolation Valve 2 (O_2) to OPEN
63 Set Helium Circ Loop 1 (O_2) to AUTO
64 Set Helium Circ Loop 2 (O_2) to AUTO
65 Set APU 1 O_2 Reactant Supply to OPEN
66 Set APU 2 O_2 Reactant Supply to OPEN
67 Set APU 3 O_2 Reactant Supply to OPEN
68 Set APU 4 O_2 Reactant Supply to OPEN
69 Set APU 1 to START
70 Set APU 2 to START
71 Set APU 3 to START
72 Set APU 4 to START
73 Enter Keyboard Code for Entry Calculation Program
74 Enter Keyboard Code for Automatic Spacecraft Maneuver
75 Set Hydraulic Bypass 1 to PRESS
76 Set Hydraulic Bypass 2 to PRESS
77 Set Hydraulic Bypass 3 to PRESS
78 Set Hydraulic Bypass 4 to PRESS
79 Set H_2 Heat Exchanger 1 to AUTO
80 Set H_2 Heat Exchanger 2 to AUTO
81 Set H_2 Heat Exchanger 3 to AUTO
82 Set AC Bus 1 to GEN
83 Set AC Bus 2 to GEN
84 Set AC Bus 3 to GEN

Figure 3-7. Deorbit Workload Timeline (Cont.)

TIMELINE POWERED FLIGHT (1.16.6-1.16.7)

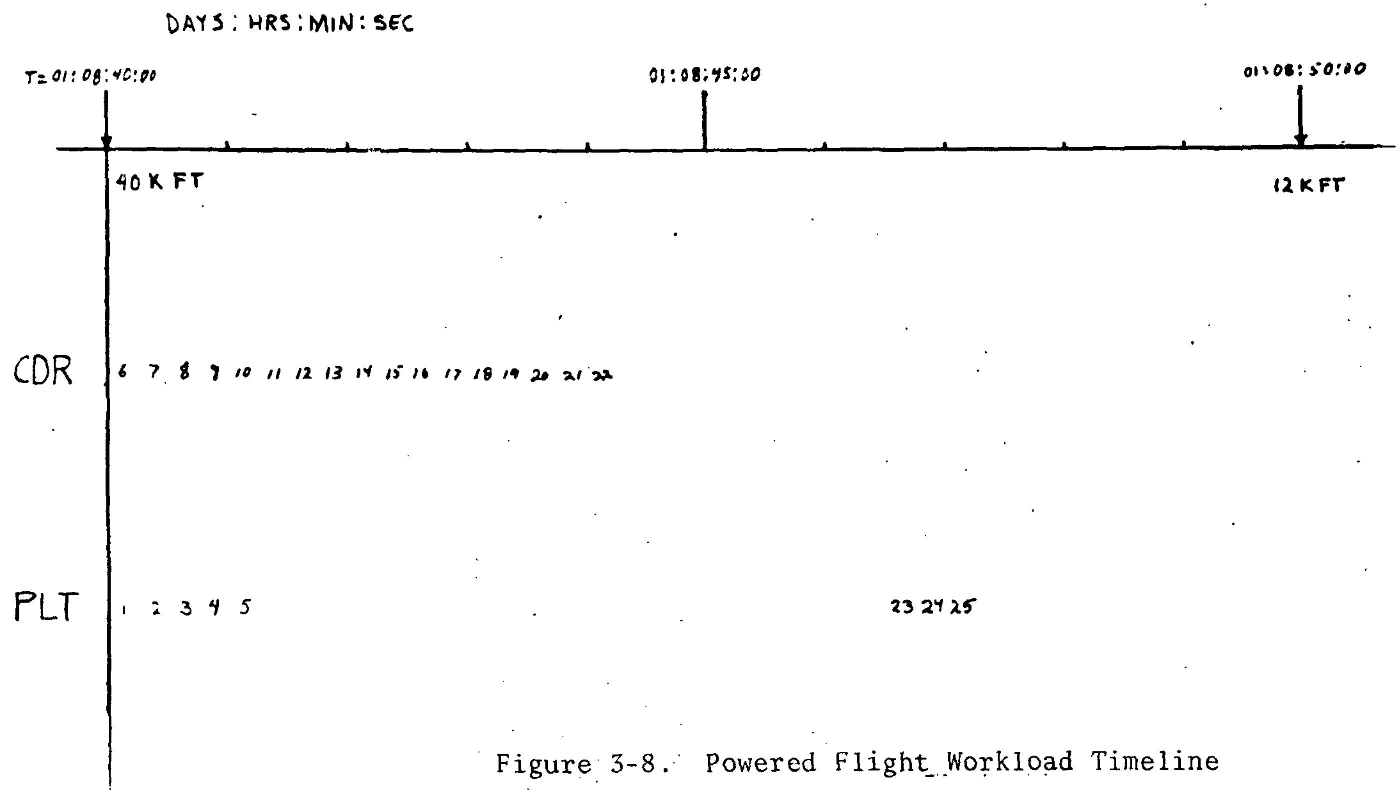
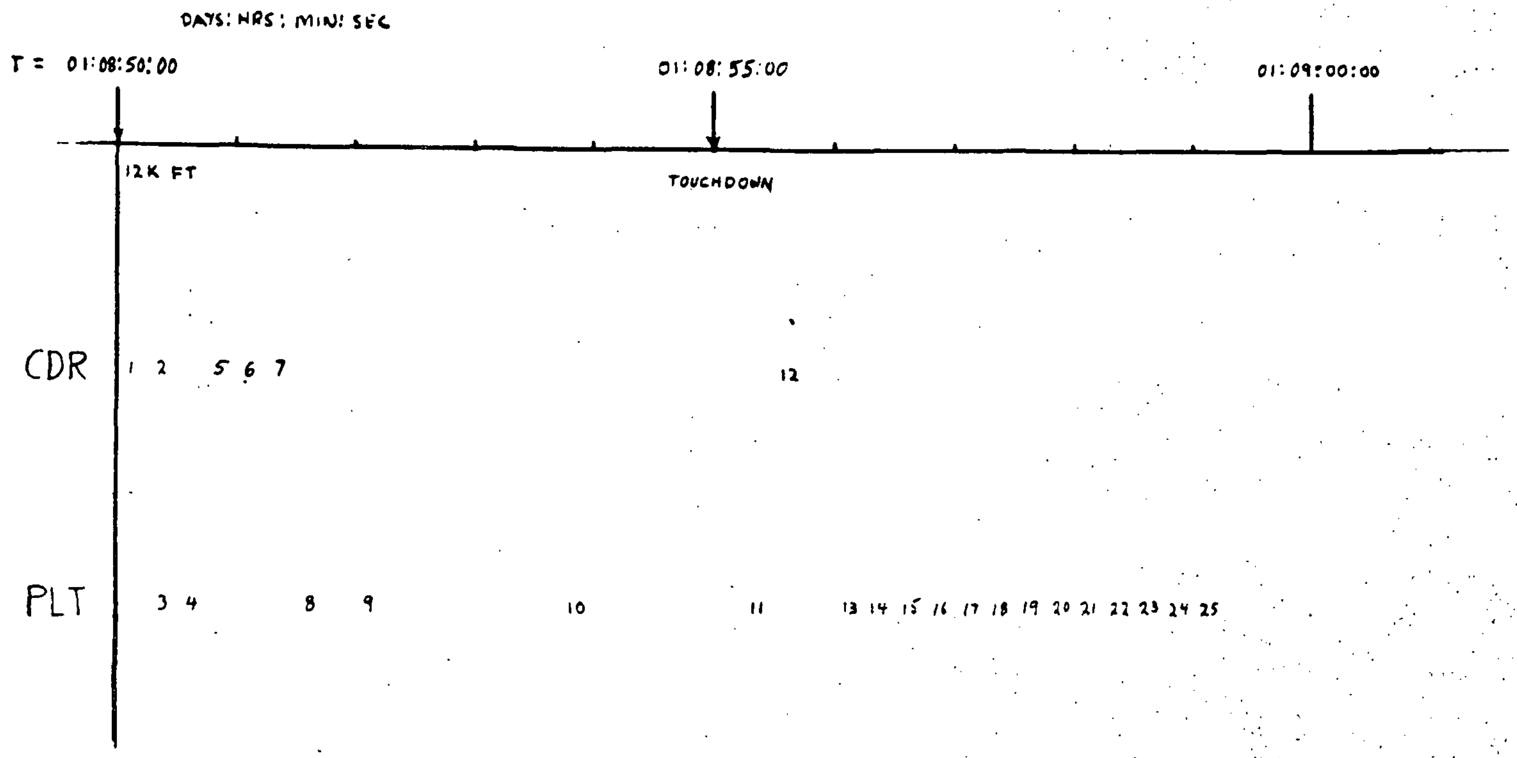


Figure 3-8. Powered Flight Workload Timeline

1 Set Eng Start Mode to AIR
2 Set Fuel Tank Shutoff 1 to OPEN
3 Set Fuel Tank Shutoff 2 to OPEN
4 Set Fuel Tank Shutoff 3 to OPEN
5 Set Anti-collision Light to ON
6 Set Eng 2 to DEPLOY
7 Set Eng 3 to DEPLOY
8 Set Eng 1 to DEPLOY
9 Set Eng 4 to DEPLOY
10 Set Eng 2 Start to ON
11 Set Eng 3 Start to ON
12 Set Eng 2 Thrust Control Lever to IDLE
13 Set Eng 3 Thrust Control Lever to IDLE
14 Set Eng 1 Start to ON
15 Set Eng 4 Start to ON
16 Set Eng 1 Thrust Control Lever to IDLE
17 Set Eng 4 Thrust Control Lever to IDLE
18 Set Eng's 2,3 Thrust Control Levers to MAX
19 Set Eng's 2,3 Thrust Control Levers to IDLE
20 Set Eng's 1,4 Thrust Control Levers to MAX
21 Set Eng's 1,4 Thrust Control Levers to IDLE
22 Set ABES Thrust Control Auto Enable to ENABLE
23 Set Radar Altimeter to AUTO
24 Set Radar Altimeter Scale to HI
25 Set ATC to ALT RPTG

TIMELINE APPROACH AND LAND (1.17-1.18)



1 Set App/Land Seq to ON
2 Set Landing Mode to AUTO LAND
3 Set Landing Gear to DN
4 Set Throttle to AUTO
5 Set Speed Brake to AUTO
6 Set Nose Wheel Lock to ON
7 Set Nose Wheel Steering to OFF
8 Set Altimeter to RADAR
9 Set/verify RDR Altimeter Scale to HI
10 Set RDR Altimeter Scale to LO
11 Set Drag Chute to DEPLOY
12 Set Foot Brakes to ON
13 Set Landing Mode to OFF
14 Set Nose Wheel Steering to ON
15 Set Eng's 1,2,3,4 Thrust Control Levers to OFF
16 Set Fuel Tank Shutoff 1 to OFF
17 Set Fuel Tank Shutoff 2 to OFF
18 Set Fuel Tank Shutoff 3 to OFF
19 Set Boost Pump Main to OFF
20 Set Boost Pump Aux to OFF
21 Set Luboil Isolation to CLOSE
22 Set Eng 1 Deploy to RETRACT
23 Set Eng 4 Deploy to RETRACT
24 Set Eng 2 Deploy to RETRACT
25 Set Eng 3 Deploy to RETRACT

Figure 3-9. Approach & Land Workload Timeline

3.9.2 Non-nominal

The evaluation of non-nominal operations involves similar assumptions, in that special checklists would be available for all abort and major malfunction situations. As with nominal operation, time-critical reconfiguration requirements were automated by the basic Phase B design. Reconfiguration requirements, such as isolating a leaking valve or turning off a malfunctioning fuel cell, require location of the appropriate subsystem format for display and identification of the appropriate control input code. This should require no more than one to one and one-half minutes under present concepts.

The failure modes which potentially have the greatest impact on system operation for the CRT/keyboard approach are those involving failure of the displays or keyboards themselves. The critical question i whether scheduled operations and monitoring can be performed with fewer than the five CRT's and three keyboards assumed for the study. Therefore, failure modes involving loss of two of the five CRT's or two of the three keyboards were investigated.

2 CRT Failure Mode - The loss of two CRT's, whatever the combination, would result in one operator having two CRT's and the other only one. The worst case, assumed for the investigation, would occur if one operator lost both of his primary CRT's, forcing him to rely on the shared CRT as his primary display.

It was assumed that, during nominal operations, each crewman would use one of his primary CRT's for the display of the current checklist and the other primary display for major system or subsystem parameter displays, as required, to monitor mission progress and to verify the results of system operations. The fifth CRT could be used for format selection (usually unnecessary with the study concept) and for the display of supplementary information for either operator on a short-term basis, but normally would be used for mission timeline display. The loss of the two CRT's would restrict one operator to the display of either checklist or parametric data, but not both. Several alternatives are available for dealing with this situation.

One alternative would involve reassignment of checklist tasks. This could be accomplished either by combining (interleaving) tasks by computer control or by special checklists, stored for just this type of contingency. In either case, tasks would be reallocated to permit the crew member with two displays to handle those tasks requiring simultaneous display of two formats and the other crew member to perform routine control or monitoring tasks involving a single format or checklist display. From a time standpoint, the worst case would be to assign the crew member having two displays all checklist tasks. Referring to the Coast Into Orbit timeline, 118 tasks must be performed between the completion of main engine burn and the next phasing Delta burn. Using the unhurried task rate of 15 sec per task, these tasks could be completed in approximately 30 minutes; total time available is approximately 45 minutes. The timing of most tasks within a phase generally is not critical as long as the proper order of occurrence is maintained. Thus, it seems likely that one crewman could perform all or most of the checklist tasks without strain. The same relationship between time required and time available holds also for the other three mission phases.

A second alternative would be to require that the crewman having access to only one display time-share it between checklist display, system or parametric displays and the mission timeline. This would result in increased performance times due to the increased switching required. However, the need for other display access may be considered less critical under degraded conditions and some adjustment may be made in the checklist assignments of the two crewmen.

2-Keyboard Failure Mode - The loss of two of the three keyboards would require that one crewman perform all of the control tasks, as well as the selection of display formats for both crewmen. The foregoing analysis of the feasibility of a single crewman performing all checklist tasks is equally applicable to the loss of two keyboards. Although a greater workload for one crewman would result, the increase would be unlikely to overload him.

3.9.3 Conclusion

Based on the above analysis, it is concluded that the control/display concept under study is feasible from the standpoint of operator workload. During both nominal and non-nominal situations (other than those obviously requiring use of dedicated controls and displays), the crew will not be forced into a work overload situation resulting from characteristics of the keyboard-CRT approach either in accessing information or exercising control over the system.

3.10 TOTAL DISPLAY AND CONTROL REQUIREMENTS ESTIMATE

The preceding analyses of information and control requirements, format development techniques and operating procedures provide the basis for estimating total control and display requirements for the Orbiter Vehicle (omitting remote station operations). This estimate provided the basis for subsequent sizing and mechanization of preliminary design concepts developed and evaluated during later study phases.

The total quantity and types of data and formats required are summarized in Table 3-5. Formats were divided into seven classes. Representative samples (shown by the numbers in parentheses after each format group title) were examined to determine the numbers of alphanumeric and symbolic characters required for display of static and dynamic information. These numbers were adjusted by a weighting factor which represents the percentage of the sample format density judged to be found in the average format of that class. The adjusted character count per format, multiplied by the number of formats within the class, yields the total number of characters required for displaying that class of formats.

In estimating character requirements, alphanumeric characters included letters, numbers, decimal points and percentage notations. All other

Table 3-5.

Summary of Quantity and Types of Data and Formats Required for Orbiter Vehicle

Format Grouping	Weighting Factor %	Adjusted Characters Per Format				Total Number Formats	Total Characters/ Class
		Static		Dynamic			
		Alpha	Symbol	Alpha	Symbol		
Operational Checklists (131)*	50	1621	8	964	12	180	469 K
Subsystem Mgm't (304, 405, 507)	80	161	103	179	39	130	63 K
Vehicle Mgm't (721)	80	113	130	73	57	22	8 K
Checkout (979)	80	251	64	212	0	61	32 K
Caution & Warning (880)	100	147	3	135	0	60	17 K
Timeline (203)	90	221	46	39	61	22	8 K
Index (102)	60	392	25	39	0	24	11 K
				GRAND TOTAL		499	608 K

*Numbers in parentheses are formats sampled.

characters were counted as wymbols. A line segment was counted as a single symbol, regardless of its length, as long as it did not change direction or become interrupted. Characters were counted as dynamic if any change to the character could occur during system operation, such as a change in size, brightness, length or presence. Static characters are fixed in the format and never change.

The total number of characters that must be stored and programmed for display is approximately 608K. This number should not be confused with the total number of computer words required for storage (described in a later section) since techniques for compaction during programming cause the latter requirement to be considerably lower.

It should be noted that 3/4 of the character requirements result from the operational checklist formats. This indicates that a considerable reduction in display requirements could be achieved by the use of some other method for providing checklist information; e.g., carry-on-board printed books, etc. This saving must be balanced against the high degree of utility, procedural simplification and time saving which an integrated checklist would provide. For most system operations, the checklist formats appear to be far more valuable to the crew than the Subsystem Management formats, the next largest character requirement.

4.0 CONTROL LOGIC CONCEPTS

4.1 OVERVIEW

The purpose of this section is to describe the control logic concepts developed as a part of the CRT/keyboard control and display approach and to test the feasibility of these concepts analytically from the standpoint of the operation and mission requirements. The section will describe the overall control logic tree which will permit operator access to any display format in the system, as well as additional features provided to facilitate access based on operator need. Display sequencing and control sequencing will be described in detail. A series of diagrams is provided to describe the step-by-step sequencing of each display surface and the associated control actions during each of the selected mission phases. Finally, a description of keyboard switch functions required to permit implementation of the control logic concepts is provided.

4.2 CONTROL LOGIC TREE

Crew access to any mission procedure or system management format may be gained through a set of index formats, with access to the lowest format level available by reference to no more than two indexes: the Master Index, and one of the sub-indexes (categorized as Operational Procedures, Mission Timelines and System Management). Additional features which minimize access time include references within each format page to adjoining formats (as in flow charts), references to related but not adjoining formats likely to be needed for fault isolation, and references to contingency formats for each checklist task. A quick access method is provided for frequent or critical access requirements.

4.2.1 Access Tree

Figure 4-1 illustrates the control logic tree for accessing individual formats. The Master Index, which can be called for display by entering the three digit number 100, provides the access codes for all sub-indexes. The sub-indexes provide access codes to all individual formats. To use the indexing system to call up for display the Deactivate MPS checklist, the operator would call the Orbit Index by entering the access code 102. The displayed Orbit Index lists the Deactivate MPS checklist under the Orbital Transfer mission phase. Entering its access code, 131, would cause the display of the first task of the Deactivate MPS checklist, together with its associated checklist data.

If the operator wished to call up a subsystem diagram, starting from the Master Index, he would have followed the same procedure, illustrated in Figure 4-1. For example, to locate the liquid oxygen supply schematic for the Main Propulsion System, the operator would enter the Propulsion Index access code 500, then the MPS L02 Supply access code 504, shown on the Propulsion sub-index. Complete formats for all of the indexes are contained in the format layouts in Appendix C.

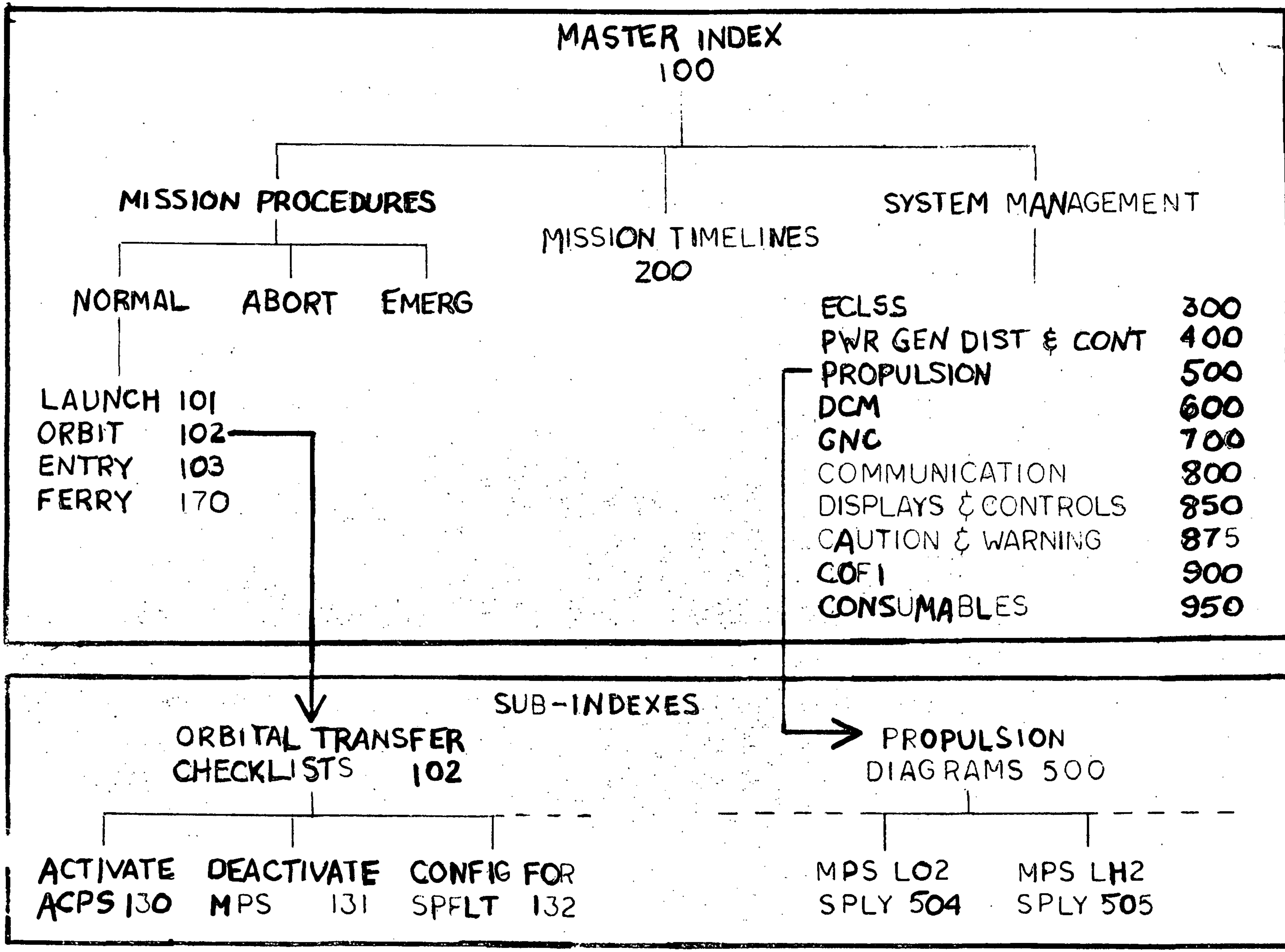


Fig. 4-1 Sample control logic tree, indicating access to individual formats through sub-indexes.

4.2.2 Intraformat Referencing

Normally, it would be unnecessary for the crew to use the indexing system to determine access codes for other formats, since advantage is taken of the interrelationships between formats and the probable accessing requirements of the crew during the design of the individual formats. Figure 4-2 illustrates two provisions for direct access. All lines leading into and out of format schematics, such as the MPS L02 Supply shown in the figure, are labeled with their source or destination access codes. For example, the oxygen supply line goes to the MPS engines, diagrammed on format 507, as indicated by the arrowhead leading from the LOX tanks. In addition, analysis indicates the likelihood that during fault isolation the operator may need access to subsystem displays that do not directly interface a particular format. These access codes would be displayed at the bottom of the format, as, for example, the Gimbal Hydraulics format 431, shown at the bottom of Figure 4-2.

4.2.3 Checklist Referencing

During normal mission operations, the crew will be using mission procedures (checklists) in a predetermined sequence. With the exception of initial selection, this will also be true of abort and emergency procedures. At the end of each checklist, the operator is required to select the next checklist to be performed. To avoid the necessity for returning to the index to determine its access code, the last task in each checklist is an instruction to the operator to call the next normally performed checklist and provides the access code for its retrieval. The operator, though normally expected to follow the predetermined sequence, may disregard this instruction and call a checklist out of sequence, in the event that some contingency requires repetition of a previously performed procedure or because a change is required to the normal mission sequencing. In the latter case, if the access code for the out-of-sequence checklist is not listed under Contingency formats, the operator would be required to return to the index for the correct access code.

The Contingency access codes listed with each task on the checklist format (see format 131, Appendix C) follow the same selection principle as access codes displayed on subsystem formats. They represent the three formats most likely to be selected by the operator if he feels the need for further information about subsystem status before performing the specified task.

4.2.4 Task Referencing

In addition to the checklist on his primary display, each crew member normally will need an additional monitor format on his secondary display. For example during ascent, following separation from the Booster Vehicle, the Commander will monitor the OV Ascent Monitor format (728, Appendix C). Although such display formats could be accessed from the indexes, this would normally be unnecessary because, at the appropriate point in the checklist, a task would be inserted instructing the operator to call the recommended display on the other CRT, together with its access code. Again, the operator may choose to access the index to locate the access code for another format he prefers.

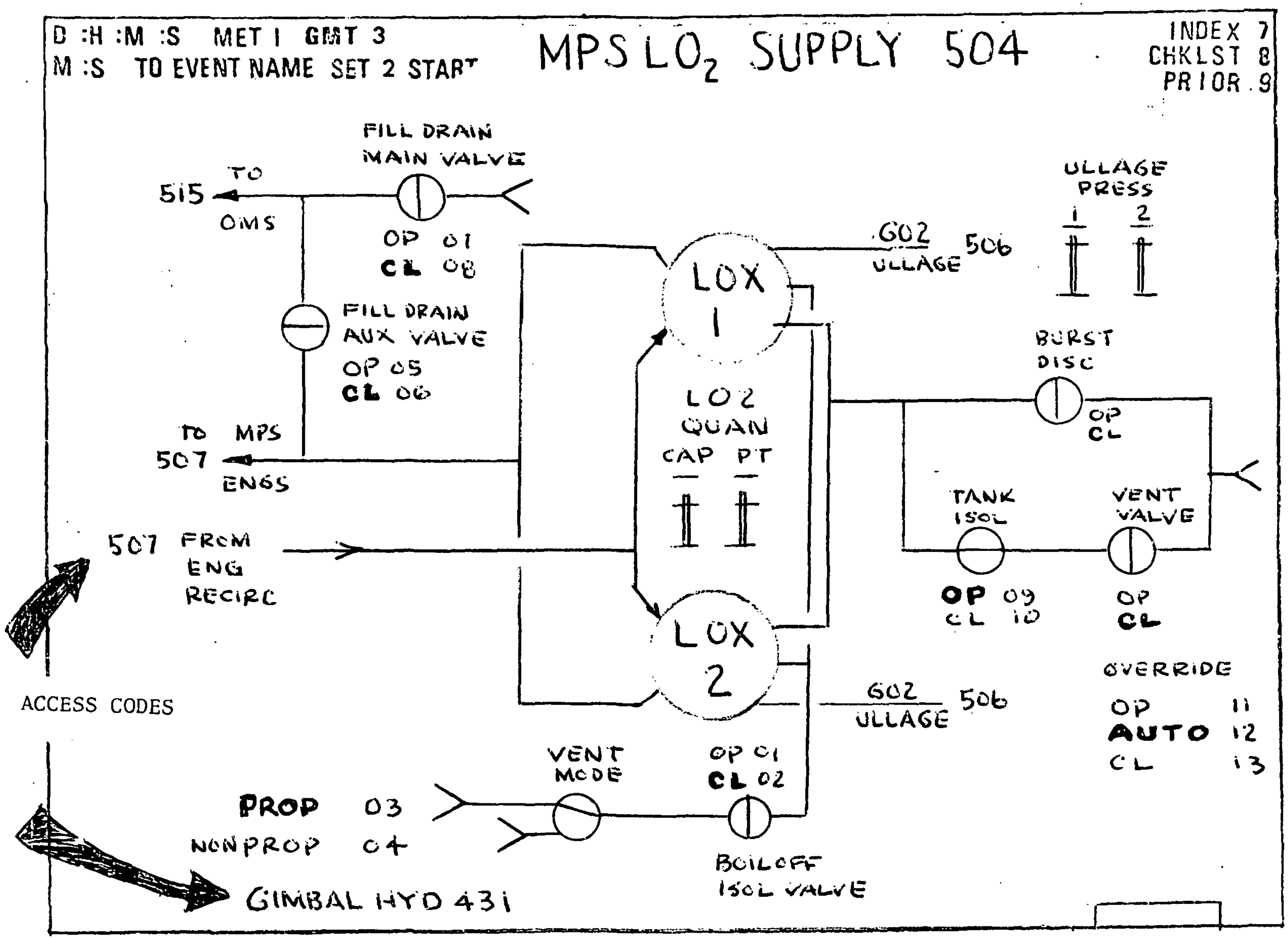


Figure 4-2 Subsystem format illustrating access codes for other related formats

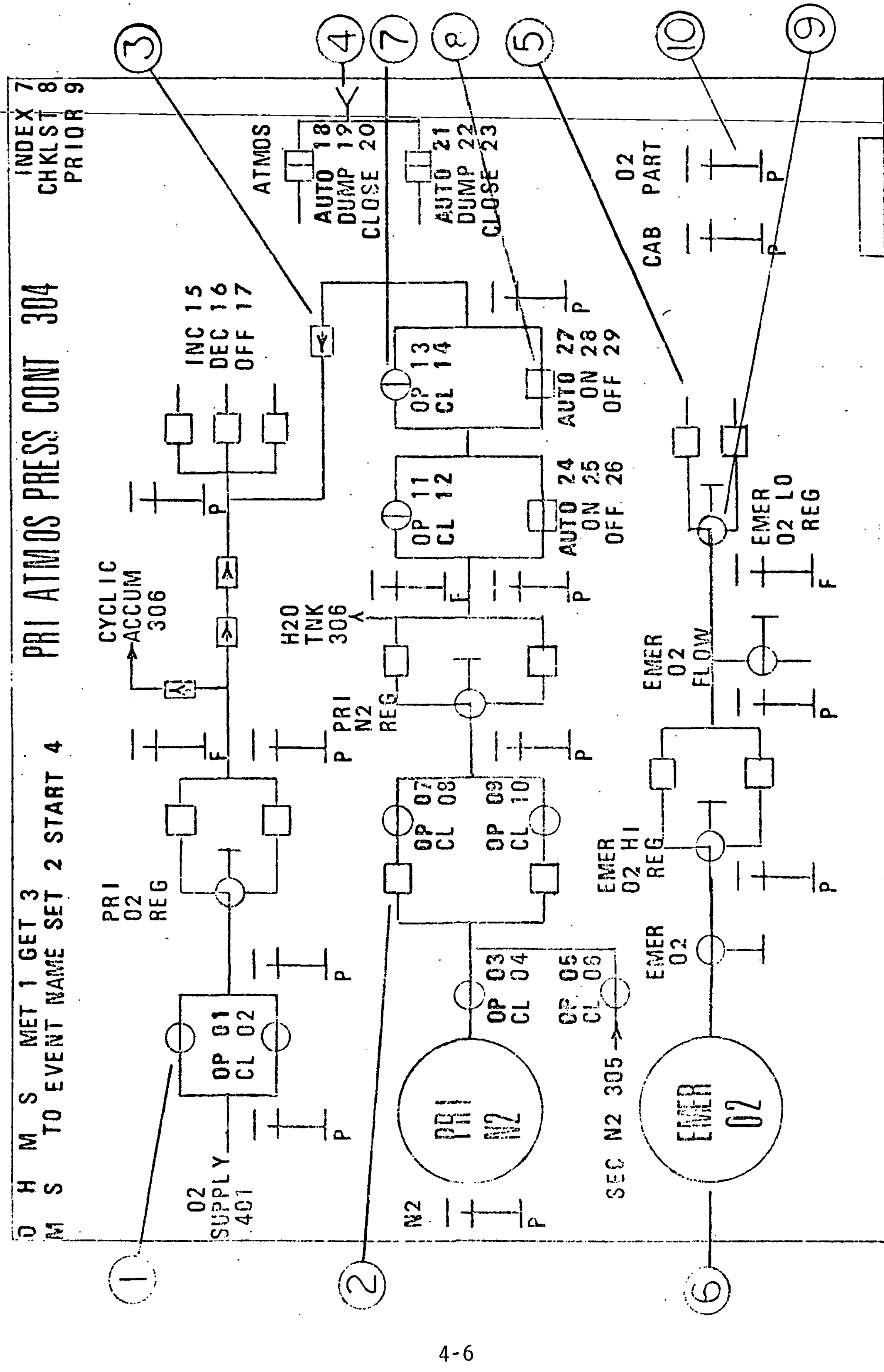


Figure 4-3 Sample subsystem schematic format

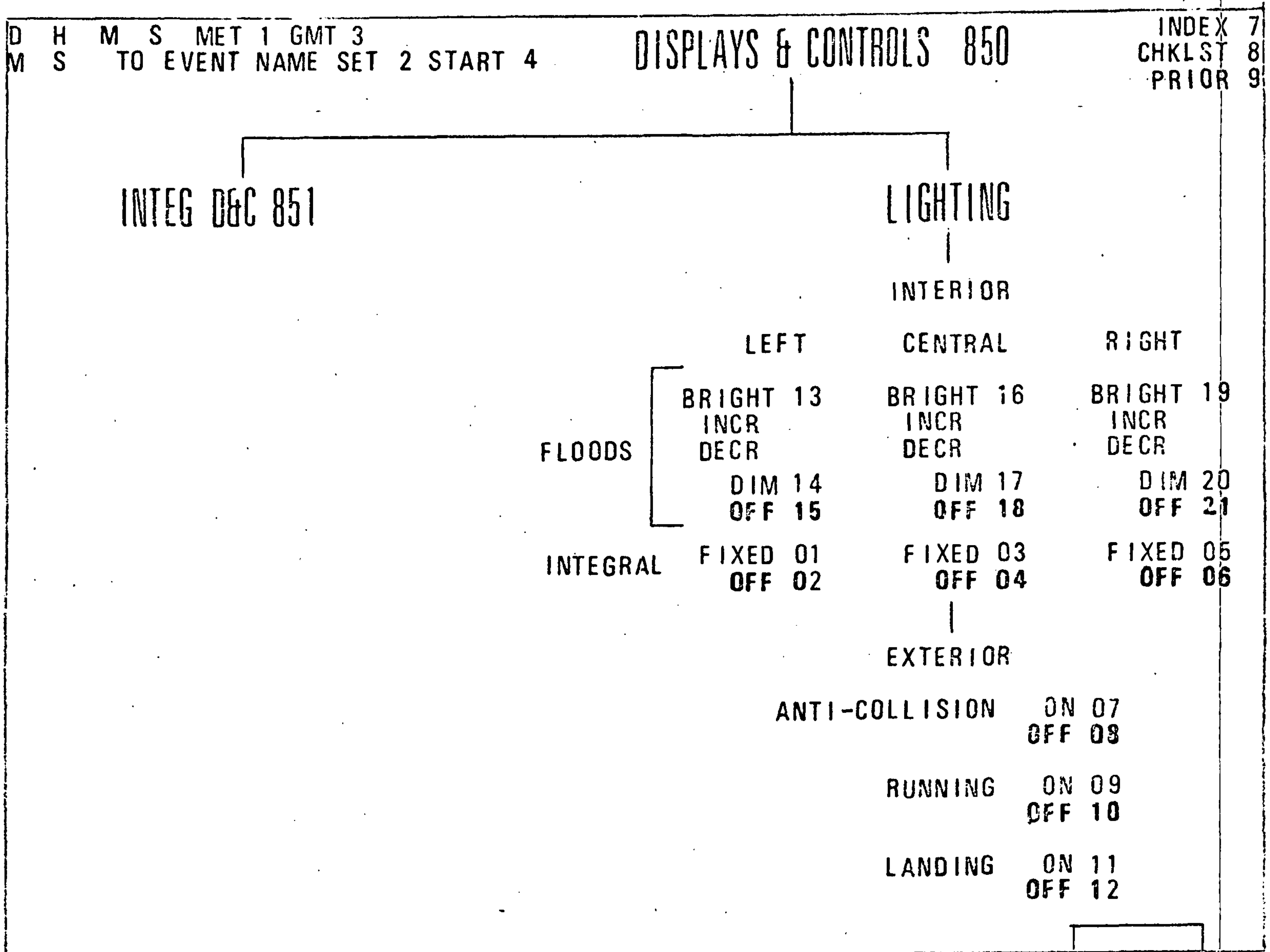


Figure 4-4 Sample tabular control list format

D H M S MET 1 GMT 3
M S TO EVENT NAME SET 2 START 4

GN&C LRU STATUS 979

INDEX 7
CHKLST 8
PRIOR 9

LRU		QTY	IN OPER	AVAIL	FAILED	
IMU	PLATFORM	3	1 3	2		
	POWER SUPPLY	3			2	
STAR TRACKER	UNIT	2	1		2	WARNING
	CONTROL UNIT	2	1	2		
SHUTTER-SHIELD ASSEMBLY		2	1	2		
PRECISION RANGING SYSTEM		3	123			
RADAR ALTIMETER		2		12		
AIR DATA PACKAGE		3	1 3		2	
ROTATION	CONTROLLER	2	12			
	CONTROLLER I/F UNIT	2	12			
TRANSLATION CONTROLLER		1	1			
PEDAL TRANSDUCER		2		12		
BODY RATE SENSOR	ROLL	3	1 3	2		
	PITCH	3	1 3	2		
	YAW	3	1 3		2	
ATT-TRANSL DRIVER	4-JET	6	12 456		3	
	2-JET	4	1234			
ABES THROTTLE CONTROL DRIVER		1		1		
AERO SURF-TVC DRIVER		4		1234		
TVC GIMBAL SERVO DRIVER		1		1		
GN&C CONTROLPANEL		1	1			
FLIGHT INSTRUMENT PANEL		1	1			

Figure 4-5 Sample tabular status listing

D :H :M :S MET 1 GMT 3 ALTERNATE LANDING SITE 764 INDEX 7
M :S TO EVENT NAME SFT 2 START 4 CHKLST 8
PRIOR 9

			LAT	LONG	SEL
PRIMARY SITE		FLORIDA	N 28° 28' 31"	W 080° 33' 45"	21
ALTERNATE	1	GUAM	N 13° 27' 15"	E 144° 37' 10"	22
	2	HAWAII	N 21° 16' 42"	W 157° 49' 17"	23
	3	CALIF	N 33° 14' 26"	W 119° 26' 58"	24

SITE OVERRIDE	ENTER	THEN	ENTER
PRIMARY	25		LAT ___° __' __" LONG ____° __' __"
ALT 1	26		LAT ___° __' __" LONG ____° __' __"
ALT 2	27		LAT ___° __' __" LONG ____° __' __"
ALT 3	28		LAT ___° __' __" LONG ____° __' __"

Figure 4-6 Sample data entry format

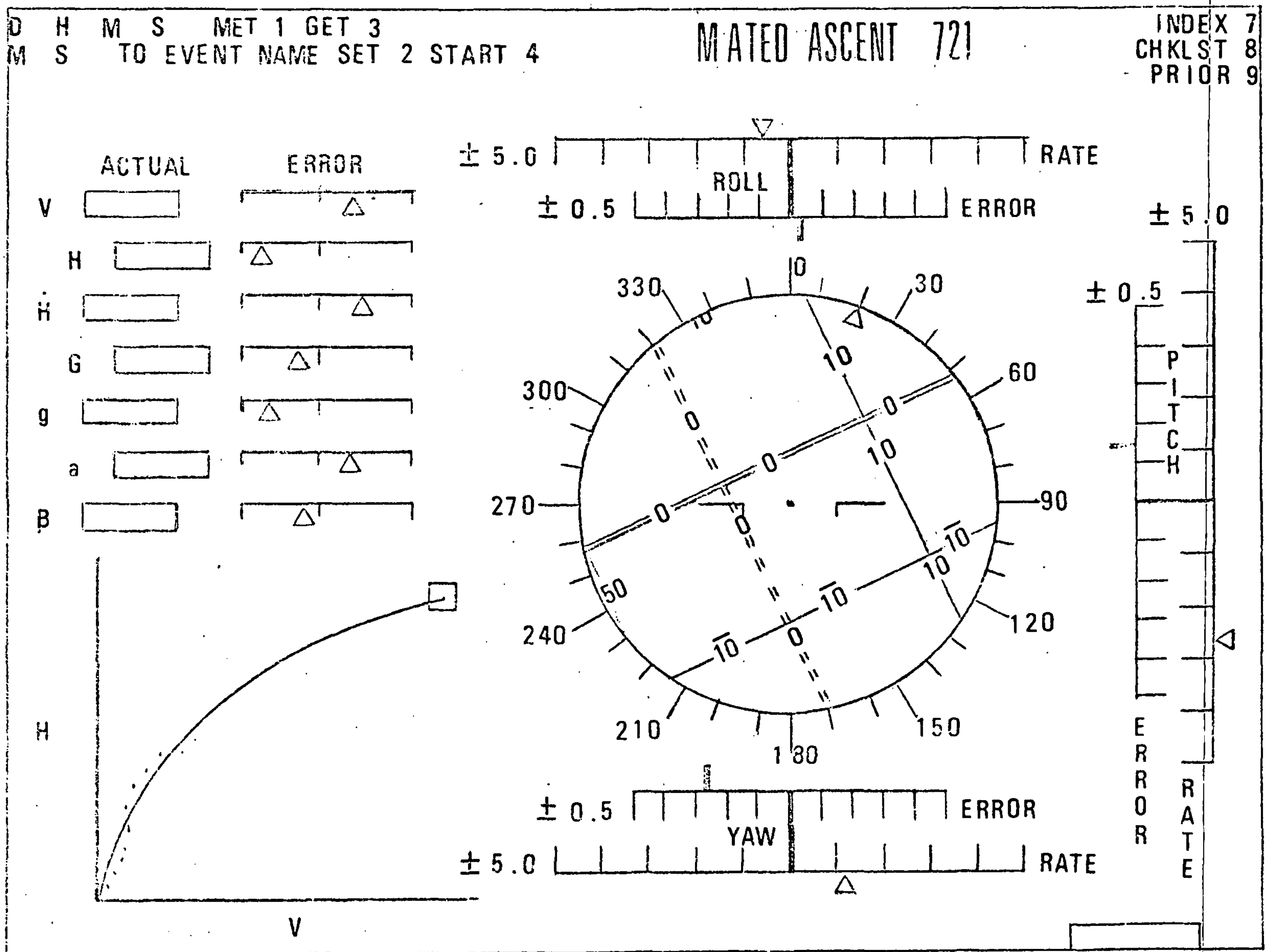


Figure 4-7 Sample vehicle management format

subsystem status and configuration verification. Each subsystem format contains diagramatic representations of all components operable by the crewmembers as well as other important components necessary for understanding the working of the subsystem element. Refering to Figure 4-3, symbols may be seen representing valves (1), pressure regulators (2), check valves (3), vents (4), cabin outlets (5), and supply tanks (6). Each component, for which information is available from data management concerning its status, i.e., open/closed, on/off, etc., is shown symbolically in its sensed state. For example, valve (1) is open, permitting oxygen flow through to the primary regulator, whereas valve (7) is closed, forcing N2 flow through the pressure regular (8) in parallel with it. Components which do not show status, e.g., pressure regulator (2), do not have sensors associated with them, so that their status cannot be determined; usually they cannot be controlled by the crew.

All components operable by the crew have indicators which tell the crew what the last commanded state of the component was. This is shown by a brightening of the command code (indicated on the drawing by heavier printing of the command code) associated with the component. For example, valve (1) (Figure 4-3) was last commanded open, as indicated by the heavily printed OP 01 associated with it. In some cases, such as pressure regulator (8), the component has three modes, one of which is automatic. As shown for (8), the last commanded status was AUTO. By comparing the commanded state with the actual state, the operator may perform one type of manual fault isolation. In the case of pressure regulator (8), the commanded state was AUTO and the system has set the regulator to ON. Whether that is the appropriate setting would depend upon the condition of the cabin atmosphere and the quantitative data also available on the format -- a determination to be made by the crew.

Certain of the controls were assumed, for purposes of the analysis, to be dedicated -- manually operable at a control external to the keyboard. An example, in Figure 4-3, is the Emergency 02 Low Pressure Regulator valve (9). Although the status of the valve is shown on the diagram, the operator must change the status by adjusting the valve elsewhere in the cabin.

In addition to component status, most subsystem schematic formats provide quantitative information concerning pressure, temperature, voltage, or other parameters relevant to subsystem status. Quantitative data are presented normally either in the form of graphic bar charts or as digital numbers. The choice of either type of display depends upon the degree of precision required by the crew when using the data.

Bar charts may take either of two forms. The most commonly used type displays the measured parameter as a vertical bar scaled in relationship to upper and lower tolerance limit markers (e.g., (10), Fig. 4-3). Both the upper and lower limits, as well as bar height may vary as conditions change. When the parameter value falls above or below the tolerance limits, the digital value of the parameter appears flashing between the tolerance limit lines. The second type of bar chart represents the parameter value as a percentage of total value permissable. This is used most often for parameters like fuel quantity, where the bar height indicates the percentage remaining of total fuel capacity. Limit lines are usually unnecessary with this type of bar chart.

In using subsystem schematics as monitoring and fault isolation displays, the operator would be expected to scan each element of the subsystem for discrepant quantitative readouts (bar charts and/or digital values). Discovery of a discrepancy would then require the use of standard troubleshooting logic to locate the responsible component and to formulate a workaround (e.g. bypassing a valve, isolating a fuel tank, etc.).

Tabular Control Formats

Certain subsystems or subsystem elements do not need schematic diagrams or graphic displays to enable the crew to use them effectively. In those cases, commands and control status are presented in tabular lists, designed to permit ease of location of control elements. An example of this type of format is shown in Figure 4-4. Both exterior and interior lighting control status is shown by the relative brightness (two-state) of the individual commands associzted with each lighting type and location. In the figure, all lighting controls are OFF.

Tabular Status Formats

A number of information parameters is needed by the crew to monitor system status, but they have no control functions associated with them. These parameters are found most often in system areas like configuration management, caution and warning and data management. Display of these parameters is most suitably presented in tabular formats, as in Figure 4-5. The format depicted lists all LRU's in the GN&C, the number of units on board, which of the units are in operation, which are available and which have failed. The operator would be able to determine when backup in any LRU category dwindled to a critical point. The WARNING in the last column of the figure indicates that only one Star Tracker Unit is left available because of the failure of Unit 2.

Data Entry Formats

Occasions requiring the crew to enter numeric data into the computer are rare, associated primarily with contingency situations, such as changed rendezvous assignments or altered mission profiles. A special display format for entering data is shown in Figure 4-6. Procedures for data entry are described in the Control Sequencing section below.

Vehicle Management Formats

Display formats for monitoring and control of vehicle flight parameters are modeled after standard aircraft instrumentation and instrumentation developed during the Apollo program. A sample vehicle management display is shown in Figure 4-7. With this display, present pitch and yaw angles are read out on the simulated attitude ball under the fixed vehicle symbol. Roll angle is indicated by the pointer on the inside edge of the calibrated circle. Roll, pitch and yaw rates are indicated by moving pointers on fixed scales, as are the error magnitudes for each axis. Vehicle flight parameters, such as velocity, altitude, altitude rate, etc., are digitally displayed in the boxes under the ACTUAL heading, while error direction and gross magnitude is indicated by moving pointers on the scales associated with each parameter. This display is used during ascent and includes a graph of the altitude versus velocity profile, with a "window" of the required H/V limits for desired orbit.

Permanent Format Data

As illustrated on Figures 4-3 through 4-7, time data and quick access codes are displayed with all formats. On the top left corner of the format is displayed either Mission Elapsed Time (MET) or Greenwich Mean Time (GMT), depending on operator selection. It is anticipated that each crew member would select GMT on one of his two CRT's and MET on the other. Below the clock readout is an event timer. Normally, it is set to display time to the next major event, e.g., Delta V, etc. At the option of the operator it may be reprogrammed to operate as an elapsed-time event timer. Procedures for this option are described in the Control Sequencing section below.

Quick access codes are displayed in the upper right corner of every format. INDEX Code 7 provides immediate access to the Master Index. CHKLST Code 8 accesses the next task to be performed on the checklist scheduled for the operator position from which the display is commanded. PRIOR Code 9 accesses the last format displayed on the CRT from which the code was commanded.

At the lower right margin of every format is a small box. This is the entry verification area reserved for display of the keyboard input characters prior to entry. By checking the characters in this box before pressing the ENTER key, the operator can verify that the numerics about to be entered are the same as those he intended to enter.

4.3.2 Operating Procedure Checklists

All operating procedures associated with normal operations, aborts and major emergency situations will be stored in the form of checklists for display and control by the crew using the keyboard/CRT control and display concept. Individual checklists will involve anywhere from four to thirty operator tasks. Checklists will be scheduled for each of the crew, as indicated by the C (Commander) or P (Pilot) after each checklist format number on the operating procedure indexes (101, 102, 103, 170, Appendix C), but they may be called and performed by either crew member. In the event that one crew member is incapacitated, an emergency procedure would provide a combined checklist format operable by a single crew member.

Figure 4-8 contains a sample checklist format. The following description of the information contained on the figure is representative of all checklists assumed for the study.

The checklist is divided into two sections. The upper section is reserved for quantitative data associated with the task to be performed. In the event that no data are available or needed, the data space is left empty.

The lower section of the checklist format contains two tasks, the task to be performed (directly under the task category headings) and the task last completed (below the task to be performed). The task description consists of an action verb, displayed in 1/4" bright letters, and the object of the verb written in 1/8" lower intensity letters. In the illustration, the action verb is OPEN and the verb object is ENG 2 PREVALVE. The present status consists of an adjective describing the present condition of the verb object, written in 1/4" bright letters. The options available to the operator are divided into normal and contingency alternatives. Normal options include all of the control actions associated with that task that the operator has available.

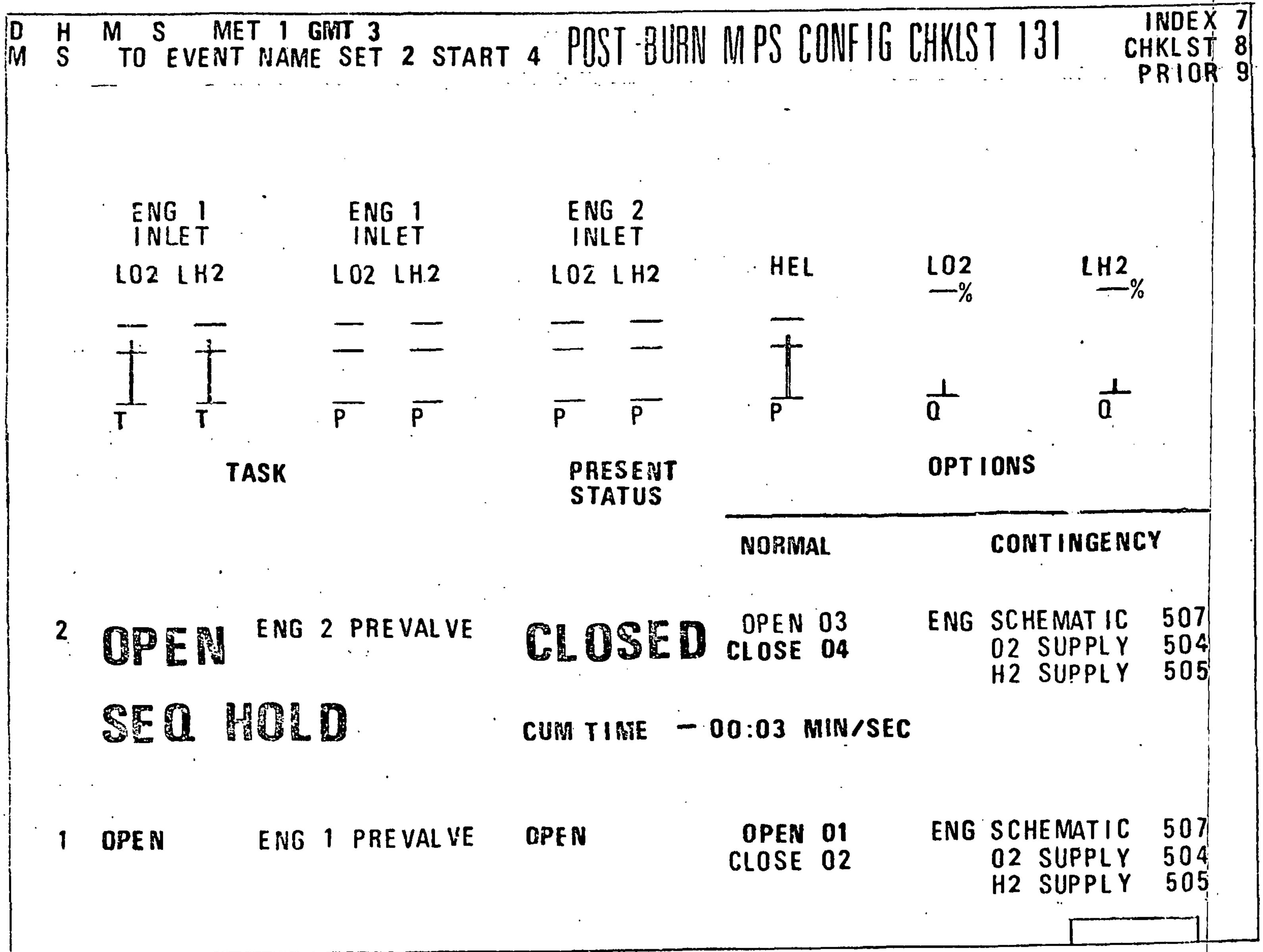


Figure 4-8 Sample Checklist Format

In the illustration, both OPEN and CLOSE are available options, even though the valve is already closed. Contingency options normally include System Management format numbers directly related to the assigned task.

Additional information associated with the description and options of the next task to be completed includes a cumulative time readout to assist the operator in pacing his task activities. Each task is assigned a nominal 15 second completion time. The cumulative timer credits the operator with positive (+) time if the task is completed in less than 15 seconds, negative (-) time if he takes longer than 15 seconds.

Too much positive or negative cumulative time may result in the display of a SEQUENCE HOLD or TIME HOLD warning. These indicate to the operator that he must delay his next task to (1) allow the other crew member to catch up in task sequencing or (2) permit mission time to catch up to the schedule task time, respectively.

4.3.3 Mission Timeline Data

Special mission timeline formats are provided for display on the shared CRT to facilitate coordination of individual checklists with mission time and to provide overall visibility of mission progress to the crew. An example is shown in Figure 4-9. Each timeline represents a subphase of the mission and is called for display automatically at the time designated as the scheduled start time of that phase. A pointer moves along the timeline scale at a real-time rate providing a reference index of the scheduled progress of the mission. Each checklist to be performed during that mission subphase is represented below the time scale by a rectangle whose length represents the scheduled completion time of the checklist and whose position under the scale represents the portion of the subphase in which the checklist should be completed. As each task of the checklist is completed, the rectangle is shaded by an amount proportional to the length of the rectangle and the total number of tasks in the checklist. By visually aligning the moving pointer with the shaded rectangles, the crew can determine the timelines with which the checklists are being completed.

The timeline formats may be removed and/or replaced by other formats by a keyboard procedure described in the Control Sequencing section below.

4.4 CONTROL SEQUENCING

In accordance with the study objective, all control sequencing for the entire Space Shuttle orbital vehicle, with the exception of dedicated controls described in Appendix B, is performed using the 0-9 keyboard and a limited number of special function keys. To meet this objective, a special numeric code was developed, consisting of one-, two-, and three-digit numerals, which, when entered on the keyboard, command control activities that are unique either to the code or to the code in relation to the format on the active CRT. The following is a description of the utilization of this code and the special function keys, in terms of the various system control functions available to the operator.

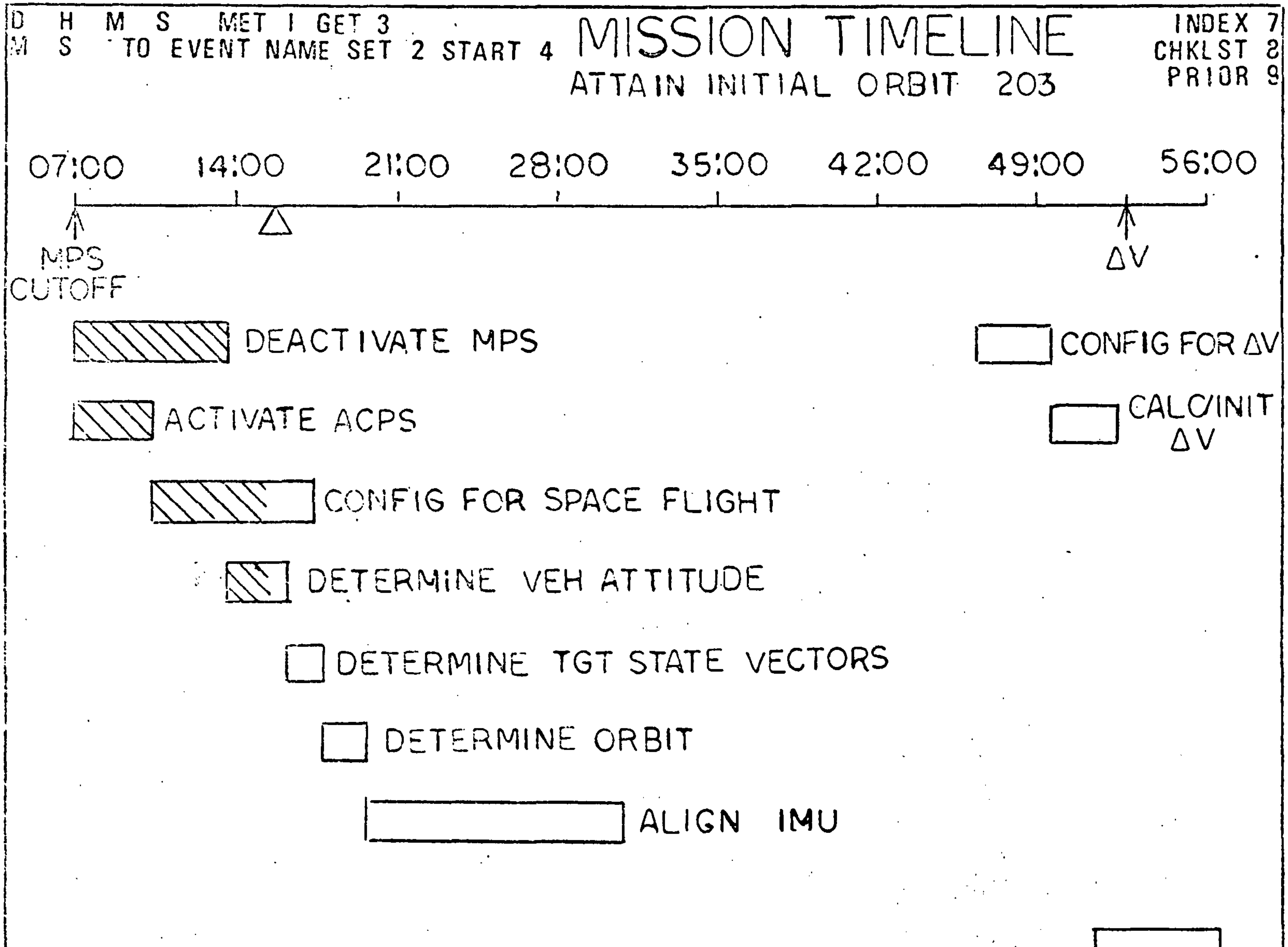


Figure 4-9 Sample Mission Timeline Format

4.4.1 CRT Control

Any of the three keyboards can be used to exercise control over system elements through any of the five CRTs. Selection of the CRT which is actively connected to each keyboard is made with special function keys labeled with ~~roman numerals I through V. Each CRT is designated by a roman numeral, with I~~ at the left of the cockpit across to V at the right side. Thus, the Pilot utilizes CRTs I and II, the Commander utilizes CRTs IV and V and the two share CRT III. When a roman numeraled key on a keyboard is depressed, a control interface is established between the keyboard and the corresponding CRT. As long as the key remains locked down the interface is retained. When a different roman numeraled key on the keyboard already interfacing with a CRT is depressed, the first interface is broken (the key is automatically released) and a new interface is established between the keyboard and the newly selected CRT. If a roman numeraled key on a keyboard is depressed, but represents a CRT already controlled by another keyboard, the requested interface is rejected (the key will not remain depressed) until the originally controlling keyboard relinquishes control of the CRT (the operator selects a different CRT for interface with the originally controlling keyboard).

4.4.2 Format Access Control

All formats are called for CRT display by their three-digit code designations. To call, for example, the Master Index for display on CRT II with the Pilot's keyboard, the special function key, II, is depressed, the code 100 is entered on the keyboard, verified in the digital entry box in the lower right corner of CRT II, and the ENTER key depressed. Subsequent format callups on CRT II may be made without re-depressing the special function key, II, because the control relationship between the keyboard and the CRT remains in effect until another CRT is selected from that keyboard.

4.4.3 System Control

All system control commands are issued with two-digit codes, in conjunction with a specific format. These commands may be issued as part of the individual checklist sequences or independently from System Management formats.

System Management Control

All control commands necessary to control the space shuttle vehicle through all mission phases may be made from System Management formats. However, the crew would require printed or optically displayed task lists referencing the correct formats to guide them through the task sequences. To avoid this necessity, normal control command sequencing was assumed to be performed from checklist formats. However, to control subsystem operation from System Management formats, the operator would use the following procedure. After calling to the display the format containing the components or functions to be controlled, the operator would determine the two-digit code representing the control action desired, enter the numerals on the keyboard, verify the code entry in the verification box on the lower right edge of the format and press the ENTER key.

As an example of this procedure, refer to Figure 4-3. Assume that format 304 is displayed on the CRT which is active with the keyboard. To close the

Oxygen Supply valves (1), the operator would enter 02 on the keyboard, verify the code in the verification box, and press the ENTER key. As a result, the 02 command would be decoded in the display processor as a command to initiate the closing of the oxygen supply valves. This command, sent to the central processor, would cause the processor to send a signal to the valve solenoid, causing it to close the valve. At the same time the display processor would change the display symbology by reducing the intensity of the previous command to the valve (OP 01) and increasing the brightness of the present command (CL 02). When the solenoid closes the valve, a signal is returned, via the central processor, to the display processor affirming that the valve is closed, causing the display processor to change the open-valve symbol to a closed-valve symbol. The brightness and symbol changes are stored for future display update.

Two types of system control actions require additional operations. One is the control of continuously variable components, like lighting. For these operations, the special function keys INC and DEC (increase and decrease, respectively) are used. Referring to Figure 4-4, incremental control of the interior flood lights may be achieved by first entering the control code for BRIGHT (example, 13 for the left interior flood), then actuating the special function key INC or DEC, depending on the brightness level desired (determination of the level achieved would result from observing the cabin floodlight being controlled). Incremental control would continue to be available until either (1) the operator enters another control code from that same format, or (2) the operator calls another format to display on that CRT.

The other type of system control requiring additional operations is data entry. Although rarely required, it is achieved through special format provisions. An example is shown in Figure 4-6. In the example, to enter new primary landing site latitude and longitude coordinates into the central processor (it is assumed the latitude and longitude coordinates are received from a ground station), the operator would first enter the PRIMARY code 25, verify and press the ENTER key. This would cause the display of the LAT and LONG underlined blanks shown in the figure. The operator would then enter appropriate data, filling in the blanks from left to right, top to bottom. As the operator keys in the numbers, they are displayed in the blanks, where they remain for verification until the operator again keys ENTER. The latitude and longitude figures will then appear at the top of the format in the row labeled PRIMARY SITE in place of the previous primary site (FLORIDA). Since no alpha-character input is available, the new site coordinates will not have a name label associated with them, unless this is a location previously stored in the computer. Similar procedures would be used for overriding 1st, 2nd or 3rd alternate site coordinates.

Two additional special function keys are used in conjunction with data entry: the one marked N+W and the one marked S-E. These keys are used to designate positive and negative numbers and to specify the earth hemisphere references for latitude and longitude. The identity of either key is determined by the control command code preceding its use. For example, referring to Figure 4-6, in entering the latitude figures for the primary site override, described above, the control code 25 specifies that the next set of entries to follow will be latitude data. The first character of the latitude input is designation of north or south hemisphere; thus, keying the N+W key at that point will be sensed as N. The same logic applies to the interpretation of these keys in other data entry modes -- they are identified in terms of what is expected from the control command code preceding them.

Checklist Control

All control command code operations are the same for checklist usage as for System Management format usage, described above. Referring to Figure 4-8, control commands available to the operator for each task are shown under OPTIONS - NORMAL. In the example, the operator's next scheduled task is to open the Eng 2 prevalve -- the valve is shown to be presently closed. When the operator enters the control command code 03, verifies the entry and keys ENTER, several changes occur: (1) the checklist advances one step, i.e., in the example, task 2 replaces task 1 at the bottom of the checklist and, in turn, is replaced by task 3 in the middle of the format, (2) the Present Status of the component (Eng 2 Prevalve) changes (to OPEN) following receipt of confirmation from the data processor, (3) the large symbol size of the task just completed changes to small size symbols, while the new task is displayed with large symbols, where appropriate, and (4) control command code brightness shifts from CLOSE 04 to OPEN 03, to indicate the most recent commanded state.

Certain task conditions may not require control command code inputs. If the task involves the manipulation of a dedicated control, no control command code is entered. Instead, the operator performs the task specified, using the dedicated control, then returns to the keyboard and keys ENTER. This advances the checklist one step, calling up the next task. If the task specifies putting a component into a state it is already in (e.g., opening a valve already open), the operator verifies that no control command code input is required and keys ENTER, calling the next checklist step.

If the operator wishes to sequence rapidly through a checklist in either direction, he may depress the special function keys INC or DEC to advance or return, respectively, at a rate of 2 steps/sec. Keying the single digit 8 will return the checklist to the next task to be performed (see Quick Accessing, Section 4.2.5).

Mission Timeline Control

In the event that a crew member wants to use the shared CRT, which normally displays the mission timeline, to display another format, he may do so by selecting CRT III on one of the keyboards, usually the central one, then keying the desired format access code. To timeshare the central CRT between the mission timeline format and the newly called format, the operator may key the single digit 9 (and ENTER) repeatedly. Each time the number is entered, the preceding format will be recalled, permitting the operator to "flip" between them. This procedure would be most useful in the event of a failure to one of the CRTs, permitting operations to continue with the same display accessibility, but slightly degraded availability.

4.5 CONTROL AND DISPLAY SEQUENCES

A series of diagrams have been prepared, illustrating the sequences in which displays will be called and control actions performed, relative to each of the five CRTs in the Space Shuttle cockpit. These diagrams are of the four mission phases selected for detailed analysis; (1) Coast Into Orbit, (2) Perform Deorbit Maneuvers, (3) Powered Flight, and (4) Approach and Land. Figure 4-10 shows selected diagrams from the series. The complete series for the four mission phases is Appendix F. Each sequence is diagrammed in 15 second time increments, equivalent to the arbitrary checklist performance times assumed for the workload analysis.

The first task of the first series is the last task (at time 06:45) of the Achieve Initial Earth Orbit phase, in which each of the operators (Pilot = PLT, Commander = CDR) call new checklists for the beginning of the Coast Into Orbit phase. The diagrams are read in the following manner:

At time 06:45, the Pilot's CRT I is displaying the Monitor MPS checlist, his CRT II is displaying the Achieve Initial Earth Orbit format 726 or 727. The Commander's primary CRT IV is displaying the Monitor Trajectory checklist and his secondary CRT V is displaying the OV Ascent Monitor format 728. The shared CRT III is displaying the mission timeline for Achieve Initial Earth Orbit phase, indicating the end of the phase, with all of the checklist nearly complete. On PLT I, the checklist instructs the operator to "call Deactivate MPS checklist on display." The operator's action is to key I, 131 (with ENTER understood on all subsequent diagrams, unless no control code is required). On CDR IV, the checklist instructs the operator to "call Activate ACPS checklist on display". The operator's action is to key IV, 130.

Fifteen seconds later, at time 07:00, PLT I shows the first task of the Deactivate MPS checklist (set Eng 1 prevalve to open) and the required action (key 01). The operator's option codes are shown below the display diagram. CDR IV shows the first task of the Activate ACPS checklist (set space flight mode to ORB ATT) and the required action (key 02). The mission timeline for the Coast Into Orbit phase is shown on COM III, indicating the timeline has just begun and showing the two checklists scheduled to be performed first.

Subsequent steps in the sequence are interpreted in the same manner. Note that at time 19:-0, the Commander's checklist shows a 15 second TIME HOLD to allow time for the calculated and measured orbit data to be made available by the system. At 19:15, the Pilot's checklist shows a SEQ HOLD, to permit the Commander to complete the Determine Orbit checklist before the Pilot initiates the platform alignment program. Similar hold conditions are shown throughout the sequences, when appropriate.

The control/display sequences diagrammed in Figure 4-10 indicate clearly the feasibility of controlling and monitoring system operations using the control and display concept under evaluation. At no point in the diagrammed phases are the two system operator's overloaded, or even hurried in performing scheduled tasks, and yet, all tasks are easily accomplished within the available mission time.

4.6 KEYBOARD SWITCH FUNCTIONS

The final keyboard design is shown in Figure 4-11. No additional functions were required beyond those originally assumed for the workload analysis. A description of the function of each key is provided below:

1. 0-9 Numeric Keys. Provide the means for all format accessing and system control commands through numeric codes and for all data entry.

2. I, II, III, IV, V Keys. Provide means for actively connecting the keyboard with one of the five CRTs similarly labeled. Keys are interlocked to prevent more than one CRT to be actively connected

TIME 06:45

PHASE 1.8 ACHIEVE INITIAL EARTH ORBIT

PLT I	PLT II	COM III	CDR IV	CDR V
MONITOR MPS CHKLST CALL DEACTIVATE MPS CHKLST ON DISPLAY KEY I 131	ACHIEVE INIT EARTH ORBIT 726/727	MISSION TIMELINE 1.8	MONITOR TRAJECT CHKLST CALL ACTIVATE ACPS CHECKLIST ON DISPLAY KEY IV 130	OV ASCENT MONITOR 728

TIME 07:00

PHASE 1.9.1.1 COAST INTO ORBIT

PLT I	PLT II	COM III	CDR IV	CDR V
DEACTIVATE MPS CHKLST SET ENG I PREVALVE TO OPEN KEY 01	ACHIEVE INIT EARTH ORBIT 726/727	MISSION TIMELINE 1.9.1.1 DEACT MPS ACT ACPS	ACTIVATE ACPS CHKLST SET SPACEFLIGHT MODE TO ORB ATT KEY 02	OV ASCENT MONITOR 728
OPTIONS 01, 02			OPTIONS 01, 02, 03, 04	

FIGURE 4-10. CONTROL/DISPLAY SEQUENCES

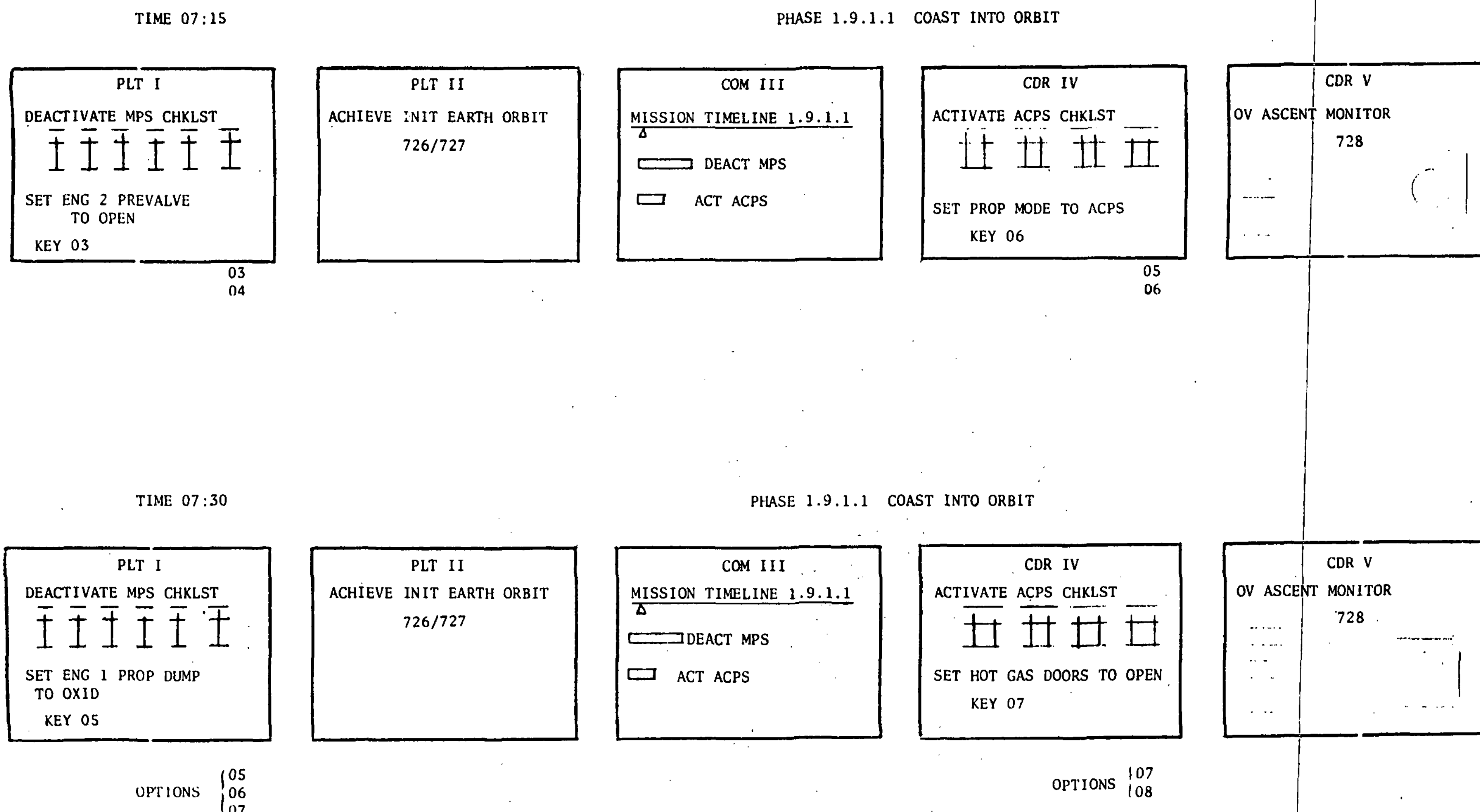


FIGURE 4-10. CONTROL/DISPLAY SEQUENCES (CONT.)

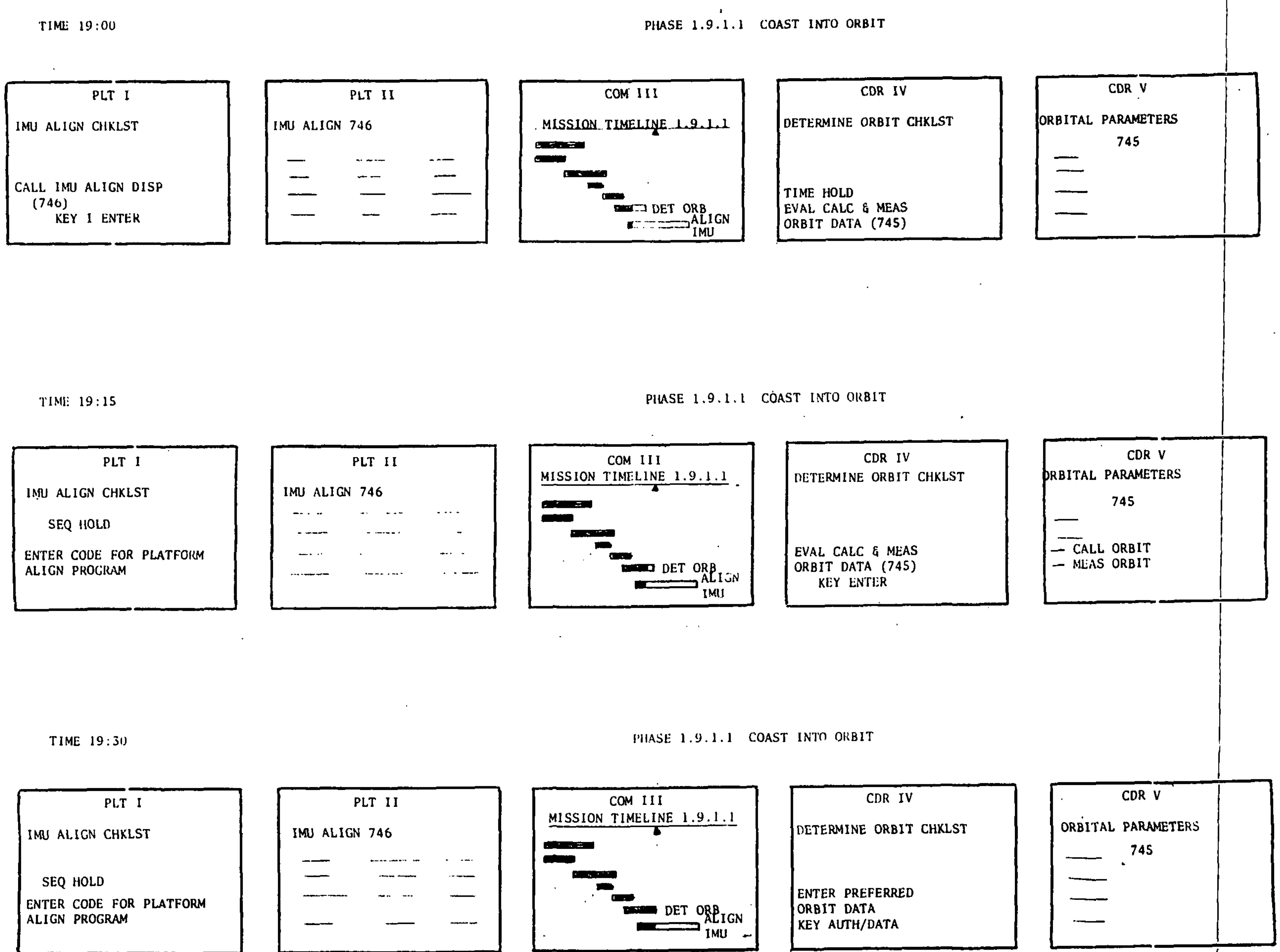


FIGURE 4-10. CONTROL DISPLAY SEQUENCES (CONT.)

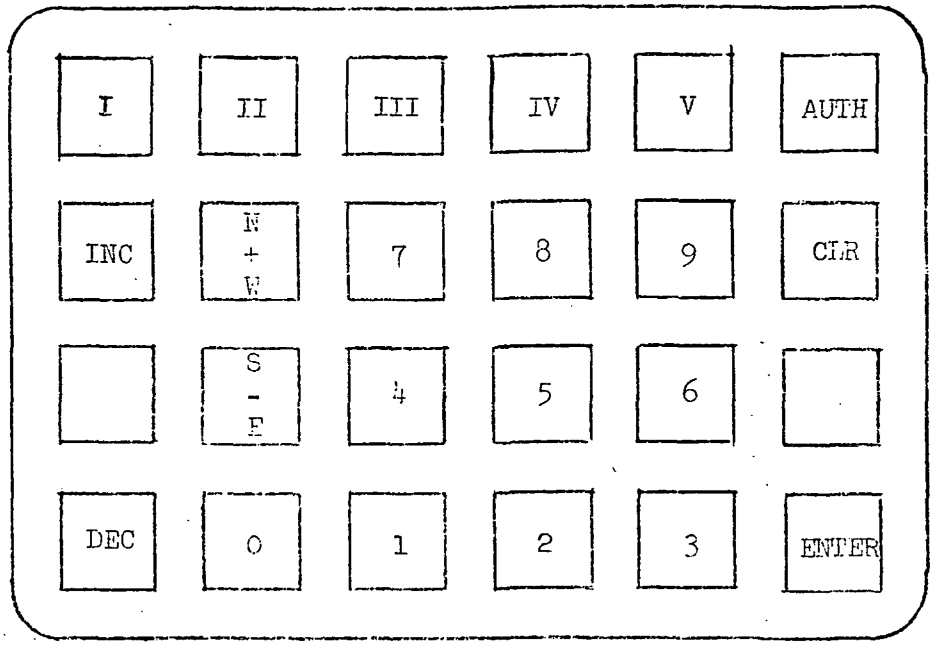


Figure 4-11 Final Keyboard Layout

to a single keyboard at one time and to prevent another keyboard from assuming command of a CRT already controlled by a keyboard.

3. INC Key. Provides means to control (increase) variable components, when used following specific control command codes. Otherwise, causes "scrolling" advance of checklist format at 2 steps/sec rate.

4. DEC Key. Provides means to control (decrease) variable components, when used following specific control command codes. Otherwise, causes "scrolling" backwards stepping of checklist format at 2 steps/sec rate.

5. AUTH Key. Provides a means for the operator to authorize the substitution of a display format recommended by the data processor as a result of an abort or emergency situation.

6. N+W Key. Permits entering North, West, or positive designation during data entry, when used with special data entry formats.

7. S-E Key. Permits entering South, East, or negative designation during data entry, when used with special data entry formats.

8. ENTER Key. Used to signal display processor that preceding numerics have been verified and should be processed and transferred. When active CRT is displaying a checklist, ENTER command causes the checklist to advance one step, whether control command numerics preceded it or not.

9. CLEAR Key. When entering numerics prior to keying the ENTER key, the CLEAR key may be used to clear the contents of the entry verification box in the lower right corner of the format. It may also be used to clear the entire data entry format prior to final entry.

5.0 PRELIMINARY DESIGN

5.1 INTRODUCTION

This section provides the technical descriptions of two alternate designs developed during the study, both considered feasible for implementing the control/display concept described in the preceding sections. The primary difference between the two alternates lies in the architecture of the display system itself. In one case, Concept A, the display system uses a relatively sophisticated random stroke technique. Concept B utilizes a dot matrix technique and is somewhat less complex.

Before going into the details of the two concepts, a number of general considerations are reviewed below. The purpose of this review is to establish the various ground rules, constraints and driving functions assumed for the designs.

5.1.1 General Considerations

The display system alternate designs (A and B) are in conformance with the operational procedures described in Section 4.0, Control Logic Concepts. The designs were also shaped by the following assumptions derived from previous studies.

Guidelines

Documented in the proposal and described in Section 3.0 of this report are a number of guidelines covering (1) human performance capabilities and limitations, (2) SSV program, mission and vehicle constraints, and, (3) controls and displays. All of those guidelines are applicable to these design alternates, but particular attention was given to those items listed under (3).

The controls and displays guidelines were, in general, results from previous studies and were in keeping with the state-of-the-art technology. Of the composite, those which explicitly affect either the design of the display system or establish the baseline configuration are restated below:

(A) Five CRTs (selectable from any keyboard)

(1)	Usable Area:	6 x 8 inches
(2)	Writing Speed:	250,000 inches/second
(3)	Intensity Levels:	2
(4)	Character Sizes:	2
(5)	Spot Size:	10 mils
(6)	Position Accuracy:	1 part in 1,024
(7)	Refresh Rate:	50 times/second

(8) Flash Rate: 1 Hz

(9) Contrast Ratio: 2.5/1 (8,000 foot lamberts)

(B) Three Keyboards

(1) Numeric and function keys only (no alpha)

(2) No self-display capability

(C) Update Rates

(1) Dynamic: 20 times/second

(2) Quasi-static: 1 time/second

Other guidelines which affect the design implicitly will be mentioned throughout this section. Normally, that type of guideline affects the format structure, which in turn may affect the design of hardware or software or both, e.g., the capability to initiate a control sequence. This requirement is structured in the format but is actually executed through the organization of the software.

DMS Configuration

The Data Management System (DMS) selected for application of this concept was the North American Rockwell SSV Phase B configuration. The Phase B configuration is an integrated concept using a central processor interconnected to all of the various subsystems via a data bus. In this manner, all subsystems are under control of the central processor: a Data Management System. For purposes of integrating the display and control subsystem into the DMS, only the central processor, the data bus subsystem, the mass memory and the DMS software organization are of concern. Given that the display and control subsystem will consist of five CRTs, three keyboards and the electronics to process and control the displays, the baseline configuration, including the DMS interface, is depicted in Figure 5-1. The Acquisition, Control and Test (ACT) units, as shown, are assumed to be part of the data bus subsystem.

The two major driving functions produced by the DMS are the information transfer rates between the central processor and the display interface and the temporary storage capacity provided by the ACT units. These characteristics were determined from Phase B studies to be as follows:

(A) Information Transfer Rate

(1) Input: 25 times/second

(2) Output: 25 times/second

(B) ACT Storage Capacity

(1) Input 124 32-bit data words

(2) Output: 31 32-bit data words

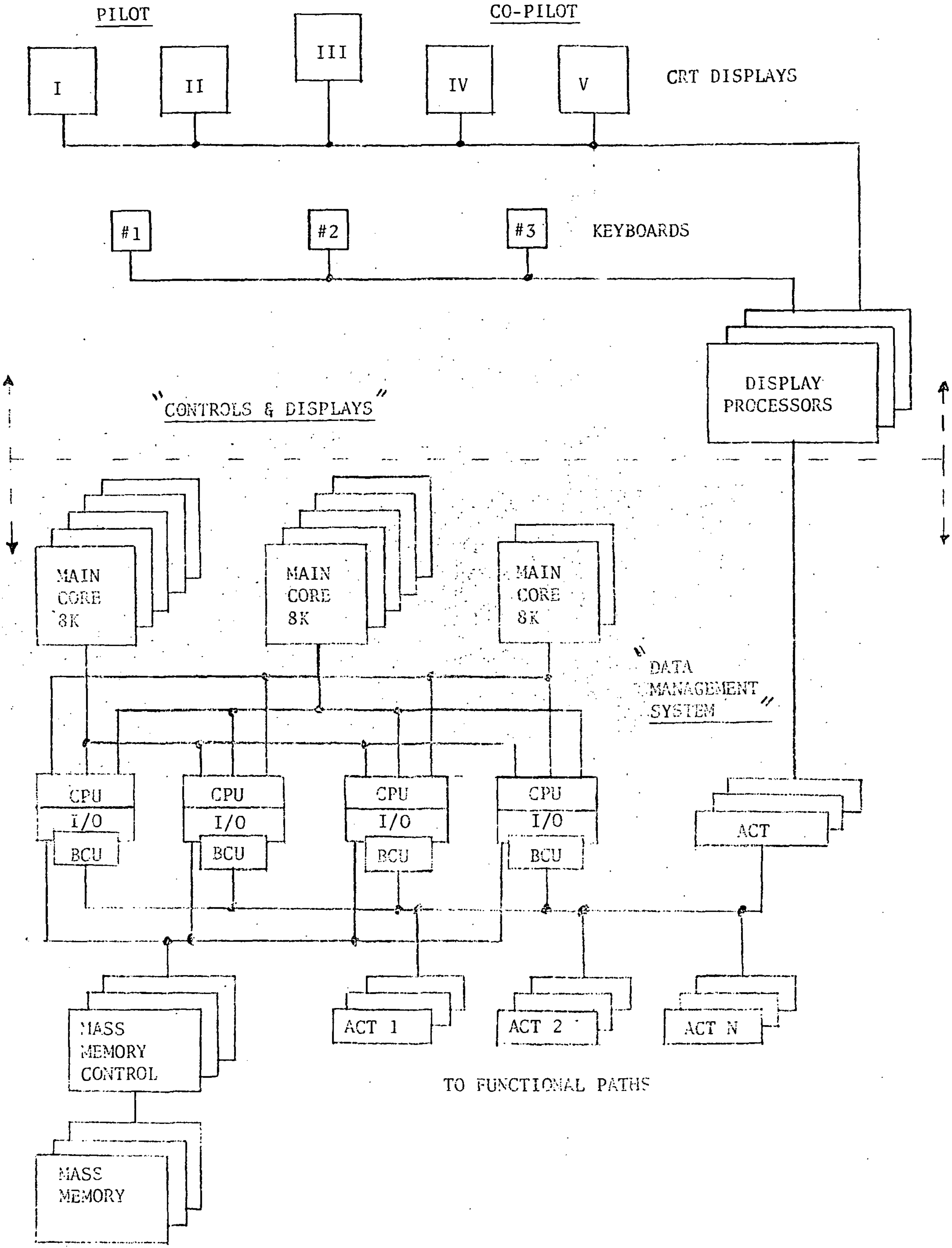


Figure 5-1. Baseline System Configuration

(C) Maximum Information Rate

(1) Input: 3100 32-bit data words/second

(2) Output: 775 32-bit data words/second

Control Logic Concepts

The Control Logic concepts described in Section 4.0 provide much of the man-machine communications and as such establish many of the software display requirements. A typical example would be the relationship of keyboard inputs to the expected system responses. This is primarily a software driving function and thus provides the basis for the structure of the keyboard program module. Additionally, these requirements define many of the one- and two-digit routines, some of which are common to all of the formats (e.g., the header), and many of which are unique to a given format.

Display Formats

The display formats (Appendix C) impose the greatest number of driving functions upon the design of the display system and the organization of the display software. This results from the variety of operational procedures performed by the crew by viewing formats and initiating simplified keyboard commands. The procedures are discussed in detail in Section 4.0.

The driving functions resulting from format designs are discussed below in terms of their implications for design of the control and display system.

Complexity

The term "complexity" pertains to the variety of data contained in the many formats and the manner in which the data must be displayed. The basic format scheme requires that the data be displayed in all or any combination of:

(A) Alphanumerics and special characters

(B) Vectors

(C) Graphics

(D) Conics

The design obviously must include the appropriate function generators.

Additional complexities include the requirement to rotate a portion of the format about a given point (e.g., Format #721), which calls for the generation of the sine/cosine functions and multiplication to resolve the X, Y deflection voltages, together with holding registers for the initial positioning, since only a portion of the display is rotated. Also, the requirement to scroll the checklists (e.g., the 100 series formats) imposes special requirements on the organization of the software. There are several special requirements of this nature which are mentioned in the section on software.

Dynamic Data

The term "dynamic data" involves those data which are variable with time and are required for display. The data can include either analog or discrete information or both. The point of concern here is the update rates required for this type of data. For this study, two rates were selected:

Rate (1): 20 times/second

Rate (2): 1 time/second

Briefly what this information implies is that the routines operating on these data must operate at the frequency of the update rate and that the information transfer rates must be compatible. Furthermore, the dynamic data must be organized within the refresh buffers in such a manner as not to disturb the refresh cycle during updates.

Man-Machine Communications

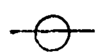
This paragraph is intended to point out that the various keyboard inputs by the crew impact the software design. For example, a three digit input (followed by the "ENTER" key) is a format request, a two digit input is a system command, and a one digit input is a rapid access request. In essence, the driving function is the man-machine interface, i.e., the response of the system to the crew's input (see Section 4.0).

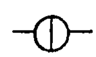
Histroical Content

The term "historical content" refers to the state or condition of the variables last commanded by the crew. This is best illustrated by the following example:

Given a two-state variable (e.g., valve) the formats are designed to provide the following information:

(A) The state of the valve as measured by the system

ON: 

OFF: 

(B) The last commanded state of the valve

(This condition is displayed by setting either the "ON" or "OFF" to a higher level of brilliance respectively).

The actual state of the variable can be instrumented by simply sampling the variable. The last command which is analogous to a switch position must have been recorded previously. This could be done in at least one of two ways:

(A) Writing the format back into mass memory

(B) Storing the information locally in some sort of matrix

For this study the matrix method was selected for two basic reasons:

(A) Writing back into mass memory increases data bus rates and is subject to error

(B) The formats, because of control sequences, are so organized as to produce certain redundancies for many variables. Consequently, for each input command, more than one format may be involved, thus causing chaos on the data bus in attempting to update the various formats, if the format were to be rewritten into mass memory.

Quantity

Quantity as a driving function affects local memory size and software only to the extent of having to keep track of more of the same things. This is not a significant problem in the design. The greatest impact due to quantity (number of formats) is the mass memory (e.g., 400 formats at 400 words per format would imply 160,000 words of storage required). The actual estimate is provided in later paragraphs on memory storage estimates.

Fault Tolerance

The reliability requirement for the Space Shuttle has been given as fail operational-fail safe. This is an obvious hardware driving function, since a minimum of three elements are normally required to meet this constraint. Those requirements which are not so obvious include the means for detecting and isolating faults to insure failing operational or safe. Certain techniques are discussed further in this section.

For purposes of this study, control/display system fail safe is defined as three displays and one keyboard operational.

5.1.2 Design Objectives

The primary goal of this study was to determine the feasibility of the concept identified for study. To achieve this goal, the following design objectives were adhered to during the course of the study.

Hardware

State-of-the-art technology was applied to arrive at a baseline system. Through a process of iterations, the baseline system was subjected to the various driving functions and optimized within the time available. To provide a level of confidence and a point for trade, an alternate scheme was designed.

Software

A working program structure was organized to a level sufficient to demonstrate feasibility and to aid in estimating the computer size, including local and central processing. In addition, a cross section of formats was programmed, based on the display control word structure, from which the mass memory was estimated. Coding of a typical format is given in Appendix D.

Man-Machine Communications

Provisions for a highly flexible operator-oriented system were made to allow crew participation in the overall system procedures.

5.1.3 Mechanization Trade-Offs

A number of mechanization trade-offs were conducted in the process of establishing the preliminary design. In most cases, because of the time limit, the trade-offs were based on results gained from similar studies and/or actual experience. In certain cases, however, a survey and/or detailed analyses was performed in support of the trade-off.

Central vs. Local Processing

There are two basic approaches to implementing the displays and controls in the shuttle. The first utilizes the central computer to call and control the formats and provide the display system with the selected format structure and all of the required supporting data. This approach is not suitable for the concept being studied due to the excessive requirements on the data bus and the degree of involvement needed for handling up to five active CRTs.

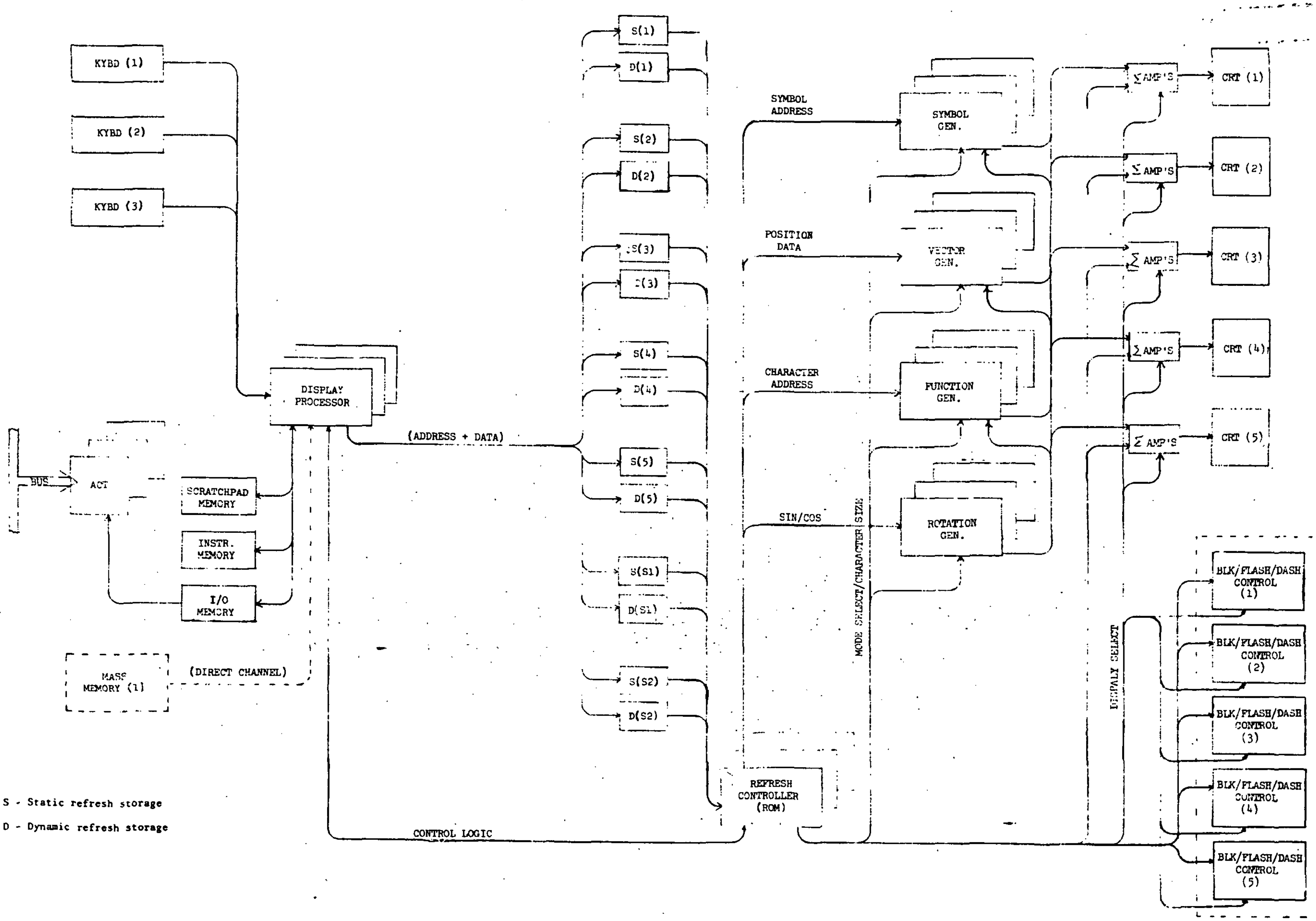
The second, more suitable, approach is that of utilizing local processing with smaller computers assigned to control the displays. These processors communicate with the central computer for system information and receive general format structures from mass memory. The number and size of the local processors needed is dependent upon reliability dictates and processing loads, respectively.

The second approach was selected for implementing the preliminary design.

Dedicated vs. Integrated Display System

The reliability dictate (fail-op, fail-safe) requires that a minimum of three local processors be used in the design. Immediately the question arises, "Can a savings be achieved through integration?". An integrated display system was considered and a baseline was designed (Figure 5-2). In this particular design, the refresh memory storage buffers were the logical elements for integration. Rather than three independent (dedicated) buffer groupings, one grouping of five (one per CRT) with two spares was provided, wherein either spare could replace any one of the operating five.

The problem with this organization is the existence of too many independent elements and thereby a complex multipath system. Whenever this occurs, an excessive amount of monitoring and switching is required which reduces the desired gain. A second problem with this particular mechanization, and one which leads to the selection of Concept A, is the speed requirement; i.e., operation of five independent CRTs using one refresh controller is very marginal. Updating five memory refresh buffers through the use of a single processor is very marginal, which leads to a need to divide the work load between the various elements. In so doing, the system begins to take the form of a dedicated system, i.e., Concept A, which is described later in this section and which is selected over that of the integrated design.



S - Static refresh storage

D - Dynamic refresh storage

FIGURE 5-2 INTEGRATED DISPLAY AND CONTROL SYSTEM

Stroke vs. Dot Matrix

There are many pros and cons throughout industry concerning the use of stroke over the dot matrix technique and vice-versa.

In the past, the random stroke method has been recommended because of its performance and versatility. The dot matrix (and raster) has been recommended because of its low cost and reduced power. Recent advances in writing technology indicate that there is no reason for poor quality writing, whether the random stroke or the dot matrix technique is used. The trade-offs thus become versatility, cost, and power. Other trade-offs of concern include reliability and simplicity, which normally go hand-in-hand with cost and power, and software (complexity and magnitude).

To perform all these trade-offs and select an optimum system is beyond the scope of this study. Of concern here is the feasibility of design, using either the random stroke or dot matrix techniques. However, to develop a confidence level in the overall concept, both techniques were designed to the level of determining feasibility and are discussed in the following sections.

5.2 CONCEPT A

Concept A is one of two preliminary designs considered feasible for application of the control and display concept evaluated under this study. The design, including both the hardware and software, is in conformance with the operational procedures described in Section 4.0 and the general considerations outlined in this section.

The basic design for Concept A is a dedicated system using local processing and a random stroke writing technology. The reliability requirement has been given as fail-operational fail-safe. The final state, fail-safe, is defined as three displays and one keyboard operational. This, together with physical location considerations and crew requirements, determines the need for the three keyboards and five displays described earlier. Any keyboard must be able to select any one of the five displays.

Concept A uses a basic 32-bit word structure over that of a 16-bit word for display and control for the following reasons:

A. The selected DMS, including the computing subsystem, data bus, and mass memory uses the 32-bit word structure; therefore matching the word structure will contribute to interface ease.

B. The technique used in this design is the random stroke method and requires a 10-bit resolution -- beam positioning can be achieved with only one word, thereby saving time.

C. Control can be accomplished simultaneously with data words.

D. Each processor must be capable of handling three CRT displays simultaneously; 32-bit words provide the required added speed efficiency using less hardware.

To meet the failure dictate, a minimum of three local processors is required. A further requirement for an overlap of one of the five displays to be controlled by two operating processors leads to the processor-display assignment provided in the following table 5-A.

Display Processor	Displays				
	I	II	III	IV	V
1	X	X	X	X	X
2			X	X	X
3a*	X	X	X		
3b*			X	X	X

*Either or

Table 5-A. Processor-Display Assignment

As a result of the design and analysis described below, it was concluded that configuration of Concept A diagrammed in Figure 5-3 is sound and meets the requirements.

5.2.1 Concept A Summary Description

A summary of the overall display characteristics is given in Table 5-1. The characteristics of the elements within the display system are provided in the following paragraphs.

Operation of the display system involves keyboard selection, which assigns a display to a particular local processor. That processor receives further information from the keyboard relating to a format call-up (3-digit request). The processor requests information to be sent from the mass memory, under control of the central processors, to both the central and the local processors. The information received by the central processors includes, as required, by each of the formats:

(A) Instructions for compacting measurement data

(B) Measurement data addresses for display updating

(C) Addresses for execution of certain 2-digit keyboard input commands.

The information received by the local processor includes:

(A) The display control words (format)

(B) Special 2-digit keyboard input interpreting routines, e.g., a routine for interpreting the difference between a normal 2-digit command and one followed by data.

(C) Special control words used for queuing the central processor in response to certain 2-digit input commands.

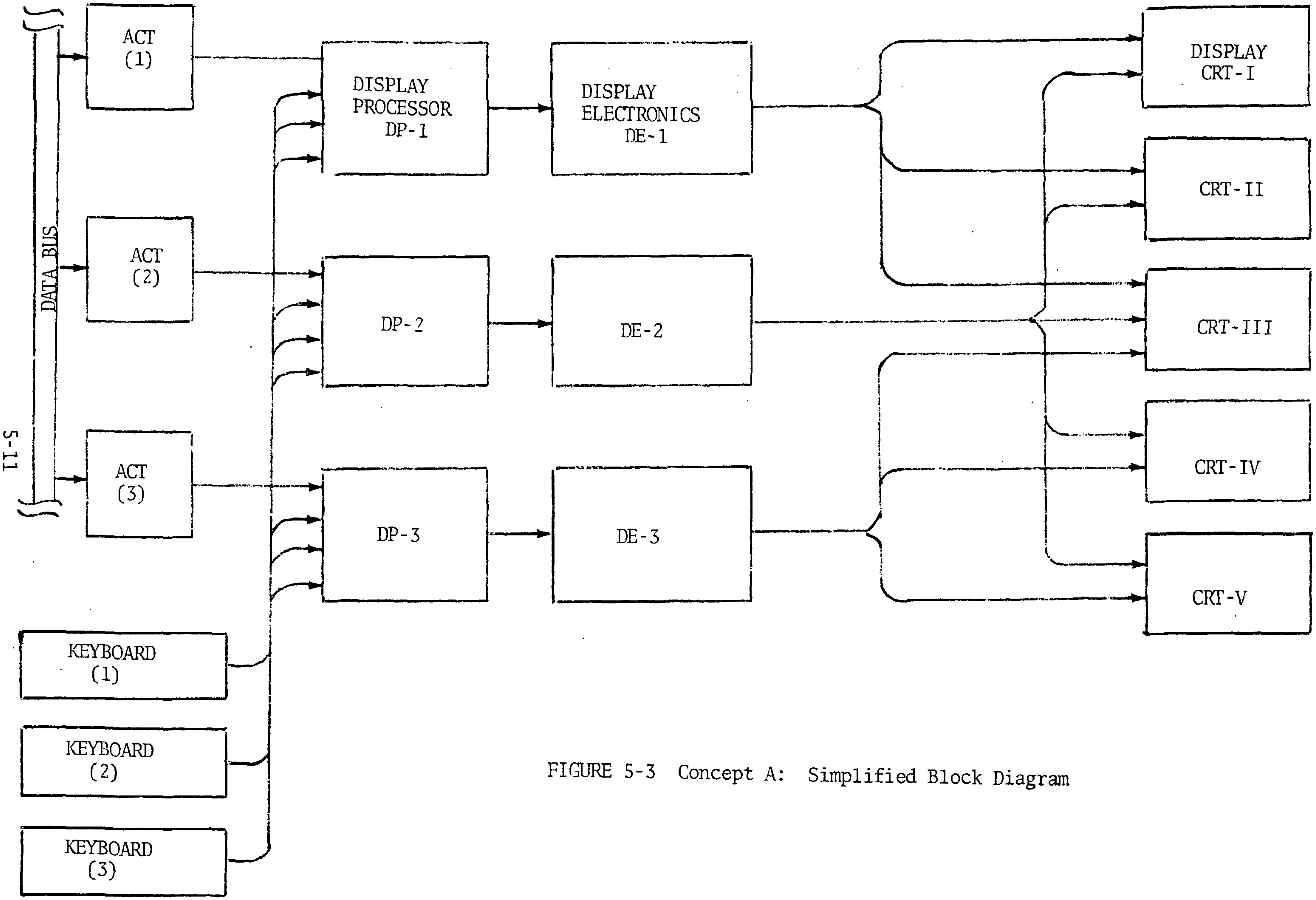


FIGURE 5-3 Concept A: Simplified Block Diagram

TABLE 5-1 - DISPLAY CHARACTERISTICS

Type	- Cathode Ray Tube - magnetic & electrostatic deflection
Area	- 6 x 8 inches
Resolution	- .010 inches spot size with 10 bit digital to analog positioning accuracy
Method	- Stroke
Refresh Rate	- 50 times/second
Update	- 24 times/second (dynamic), 1 time/second (quasi-static)
Characters -	- 36 alphanumeric 27 special symbols 1 space width

Character size and density	Size (inches) h x l	Density* (Char.) H x L	Space (inches) Line	Character
	1/8 x .089	20 x 40	1/16	.044
	7/32 x .132	30 x 60	1/16	.065

CRT Writing Speed	- 250,000 inches/second
Intensity	- Two intensity levels; blinking at 1Hz for caution and warning
Display Control	- 3 32-bit words, 7 modes of operation

*display maximum $\simeq$ 1/3 maximum density or 600 characters/display

Upon receipt of the above data the local processor requests and receives one update from the central processor. The local processor updates the dynamic memory bank and then commands the refresh controller to initiate reading the dedicated memory refresh buffers. The controller reads from memory, via a direct memory access channel, the interface logic defined by three control words, as shown in Table 5-2. The control words are stored in correct sequential fashion in the refresh memory banks and timed to provide a refresh every 20 milliseconds.

There are three sets of two refresh memory banks. The two banks are defined as static and dynamic. The static bank is reserved for non-varient control words, while the dynamic bank is reserved for those words requiring update information. In this manner the display processor can update the dynamic bank while the static bank is being read by the controller.

The basic control word, as noted in Table 5-2, provides ten bits of X and Y coordinate data or sine and cosine of the angle of rotation. Three bits are used to identify which of the following modes is commanded:

(A) Rotate
(B) Symbol
(C) Vector
(D) Circle
(E) Rectangle
(F) Vector Perturbation
(G) Spare

Four sizes of circles and rectangles are possible. The vector perturbation mode permits incrementing the X or Y positions, selected with the axis increment select bit, by the amount for the count indicated in the Data Word 1. A vector with a length equal to the other axis increment is written at each position.

The word type is identified by two bits in each control word. The other bits are used as follows. A bit permits definition of one of two intensity levels. The blank bit controls the video on the Z-axis of the CRT. The flash bit enables the blinking of the beam at a 1HZ rate as required for the caution and warning function. The dash bit permits the writing of broken line segments for vectors. A vector is expressed by the starting and final points given in the basic and Data Word 1, respectively. A bit is available for parity error checking.

The start-new-line bit permits the continuation of character writing in a page format by starting a new line at the initial x position with y decremented. As noted, Control Word 2 defines four characters which are written sequentially in text format. Table 5-3 indicates the 63 characters selected for writing.

Each local processor can control up to three displays. The maximum refresh frame time per display is based on a mix consisting of 600 symbols and 200 one inch vectors.

With the estimate of one inch per character, a display requires 800 inches of beam positioning for character writing. Since there are 30 lines and each is 8 inches in length, another 240 inches are estimated for positioning.

TABLE 5-2 - DISPLAY CONTROL WORDS

Bit Positions	Command Words		
	Basic	Data-1	Data-2
0	Parity	Parity	Parity
1			
2			
3			Symbol-1
4	X-Coordinate	X_i-Coordinate	
5	or	or	
6	$\sin\theta$	ΔX	
7			
8			
9			Symbol-2
10			
11			
12			
13			
14			
15	Y-Coordinate	Y_i-Coordinate	Symbol-3
16	or	or	
17	$\cos\theta$	ΔY	
18			
19			
20			
21	ΔX or ΔY		Symbol-4
22		Count	
23	Mode		
24			
25	Spare	Dash	New Line
26	Blank	Blank	Flash
27	Intensity	Intensity	Intensity
28	Size	Size	Size
29	Size	Size	Size
30	Word Type	Word Type	Word Type
31	Word Type	Word Type	Word Type

B-6 →			0	0	0	0	1	1	1	1
B-5 →			0	0	1	1	0	0	1	1
B-4 →			0	1	0	1	0	1	0	1
BITS	B B B 3 2 1	Row ↓ Column →	1	2	3	4	5	6	7	8
	0 0 0	1	Blank	H	P	X	5	⊟	♁	+
	0 0 1	2	A	I	Q	Y	6	◫	⊗	-
	0 1 0	3	B	J	R	Z	7	□	±	ε
	0 1 1	4	C	K	S	0	8	8	Δ	₵
	1 0 0	5	D	L	T	1	9	Y	▼	≀
	1 0 1	6	E	M	U	2	⦶	||	▩	°
	1 1 0	7	F	N	V	3	⊖	⧣	•	⊠
	1 1 1	8	G	Ø	W	4	○	⍰	%	⊓

(Selectable code is 6 bits: 64 selections)

TABLE 5-3. - SELECTABLE SYMBOLS

Further, the electronics requires time to settle from each step position command. This is estimated to be 2 microseconds per character or 1.6 milliseconds for the entire display. Using a conservative write rate of 250,000 inches per second, the time for character formation and positioning is approximately 4 milliseconds. Note that blanked positions normally are twice the unblanked rate. The total time is 5.6 milliseconds (1.6 + 4.0) per display.

Since three displays are to be controlled by one set of generators, the total time is 16.8 milliseconds. This value is within the 20 milliseconds required for a 50 times per second refresh.

The interface between the controller and processor is closed loop, using an interrupt scheme. Upon completion of each CRT frame (end-of-message), an interrupt is generated by the controller and issued to the processor. In this manner, the processor schedules the controller and updates the dynamic memories synchronously. The estimated time for servicing the interrups is approximately two percent of the duty cycle. This was computed based upon the processor having a 2.5 μsec equivalent add time (short operation).

Stroke generators were selected for Concept A. Analog signals are generated for the X and Y deflection voltages to produce line segments or strokes. Provisions have been incorporated for selective blanking of character(s) in local memory without affecting the remainder of the display.

The CRT beam is deflected by currents through the deflection yoke. (The display control words required for each mode type are discussed in Section 5.2.1). Utilization of function generators preserves time and reduces memory and, and in general, the amount of electronics required.

5.2.2 Display Elements

The display subsystem consists of the following major elements:

(A) Display Processors (3)

(B) Display Controller Electronics (3)

(C) CRT Displays (5)

(D) Keyboards (3)

The elements are interconnected so that no single failure is cause for a complete subsystem failure, Figure 5-4. The subsystem is designed for both automatic and manual reconfiguration. Automatic reconfiguration is under control of the central processor while manual reconfiguration can be initiated by the crew.

Display Processors

The general processor characteristics are listed in Table 5-4. The purpose of the display processor is to interpret keyboard inputs, convey the crew's commands, retain historical events, and display the desired data. In performing these functions, the processor is required to scale and convert

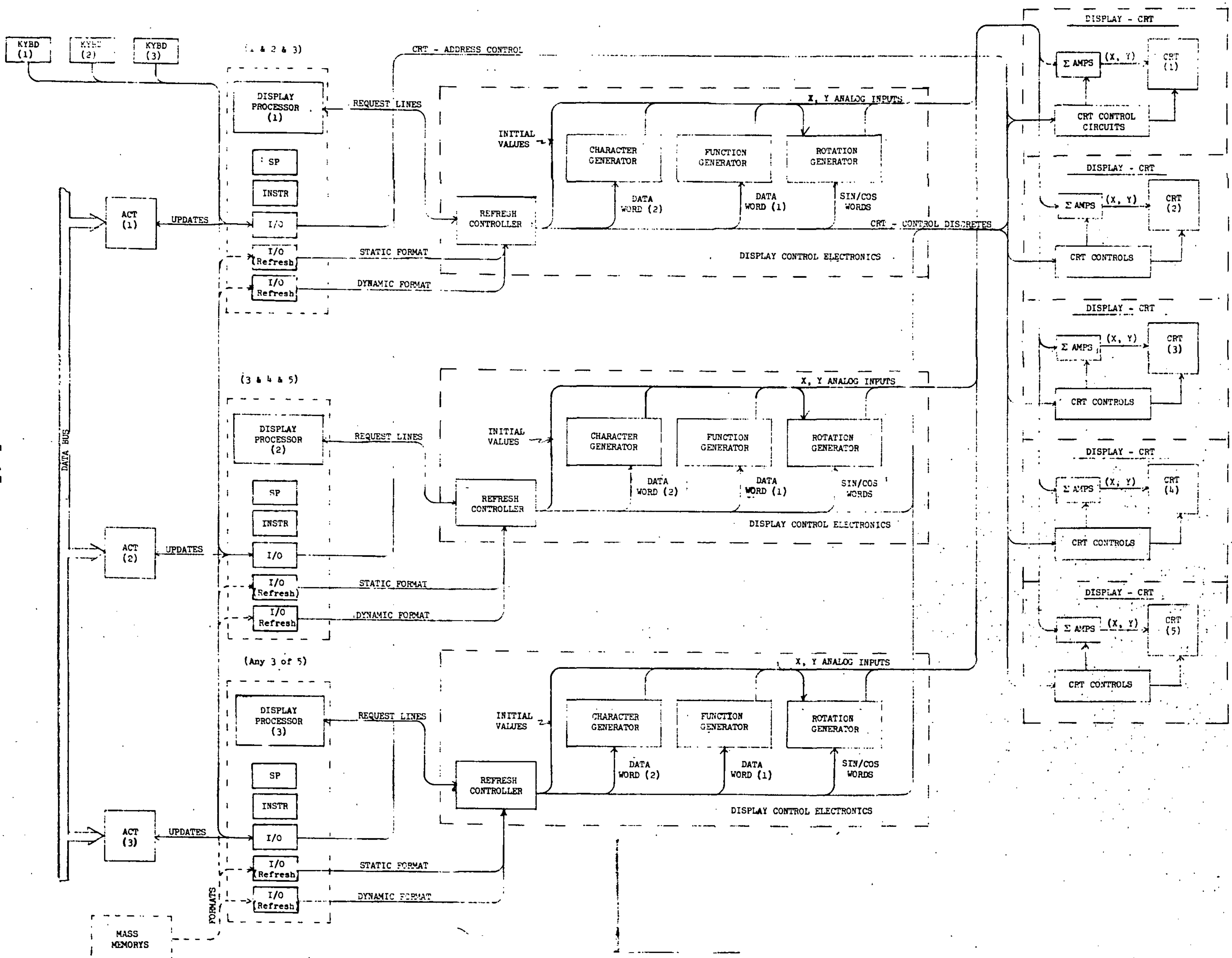


FIGURE 5-4 CONCEPT "A" DISPLAY & CONTROL SYSTEM

TABLE 5-4. - BASIC PROCESSOR CHARACTERISTICS

Type:	Digital, general purpose, stored program
Number System:	Binary, Fixed point, 2's complement
Memory Speed:	1.25 microsecond cycle time
Memory Capacity:	8K 32-bit words
CPU Registers:	o Accumulator - 16 bits o Lower Accumulator - 16 bits o Program Counter - 16 bits o Address Register - 16 bits
Interrupts:	Two Types: (1) External (2) Programmable
Typical Execution Times:	o Add/Substract/Load/Store 2.5 usec o Multiply 10.0 μsec o Divide 20.0 μsec o D.P. Add/Subtract 4.0 μsec o D.P. Load/Store 4.0 μsec
Input/Output:	o Parallel and serial inputs data channels o Parallel output data channel o Direct Memory Access Channel o At least 12 discretes
I/O Rates:	140 kHz - 32 bits parallel 3.2 megabits serial
Technology:	Arithmetic and Control Unit o MOS LSIC's Memory (NDRO Required) o Plated Wire I/O o MOS/Bipolar (hybrid)

the various input signals for display, perform various arithmetic operations, provide non-destruct storage, and establish synchronism between various interfaces.

Each processor controls three displays and communicates with one keyboard at a time. It contains the operating memory required for execution of the display programs and the memory required for refresh buffering. Prefresh buffering is classified as static (fixed format), and dynamic (that which varies). The display processors perform self test and, with the central processor and crew participation, perform other tests on the display subsystem, e.g., all characters can be displayed simultaneously under operator control.

The display processor is interfaced with the central processor through the parallel input/output channel interconnected to a standard ACT unit. For the preliminary design, it is recommended that the display processor have a direct channel with the mass memory. This channel (a serial channel) is necessary to retrieve the selected format skeletons for display. Access would be under control of the central processor thereby maintaining synchronism. This is an increase over the present DMS design but is warranted by having to handle the update requirements for three CRTs with any one ACT unit. Without this added interface, the retrieval of a format from mass memory could take on change to the present DMS configuration. If more time was allowed on the data bus and/or an increased ACT memory capacity was provided, there would be no need for the additional interface.

All three keyboards are seen by each of the processors. Any keyboard can select any display; however, only one keyboard can be in control of a given display at any one time. The priority is on a first-come, first-served basis.

The interface of the refresh controller with the refresh memory is through the parallel direct memory access channel. The frame time for refreshing each display is under control of the processor via a closed loop interrupt scheme. This allows the processor to address and present (blank or unblank) the data on the selected display(s).

Display Controller Electronics

The display controller electronics reads the format display control words from the refresh memory in the display processor and decodes these to drive the voltages for CRT control. It contains the digital and analog circuitry to convert the control words (three) to analog deflection and video intensity signals. The basic timing is contained in the display controller electronics. Refreshing at 50 times per second is performed under control of the display processor. Figure 5-5 presents a block diagram of the display controller electronics.

The CRT deflection amplifiers are supplied their signals from digital to analog converters. Either alphanumeric characters, symbols, or graphics can be displayed at any usable location on the CRT face by use of vector, character, and conic signal generators. Beam positioning, together with translations or rotation, is also programmed in the same manner.

A relationship between beam movement and intensity exists. To accommodate equal intensities for various displays, either constant write rates or beam

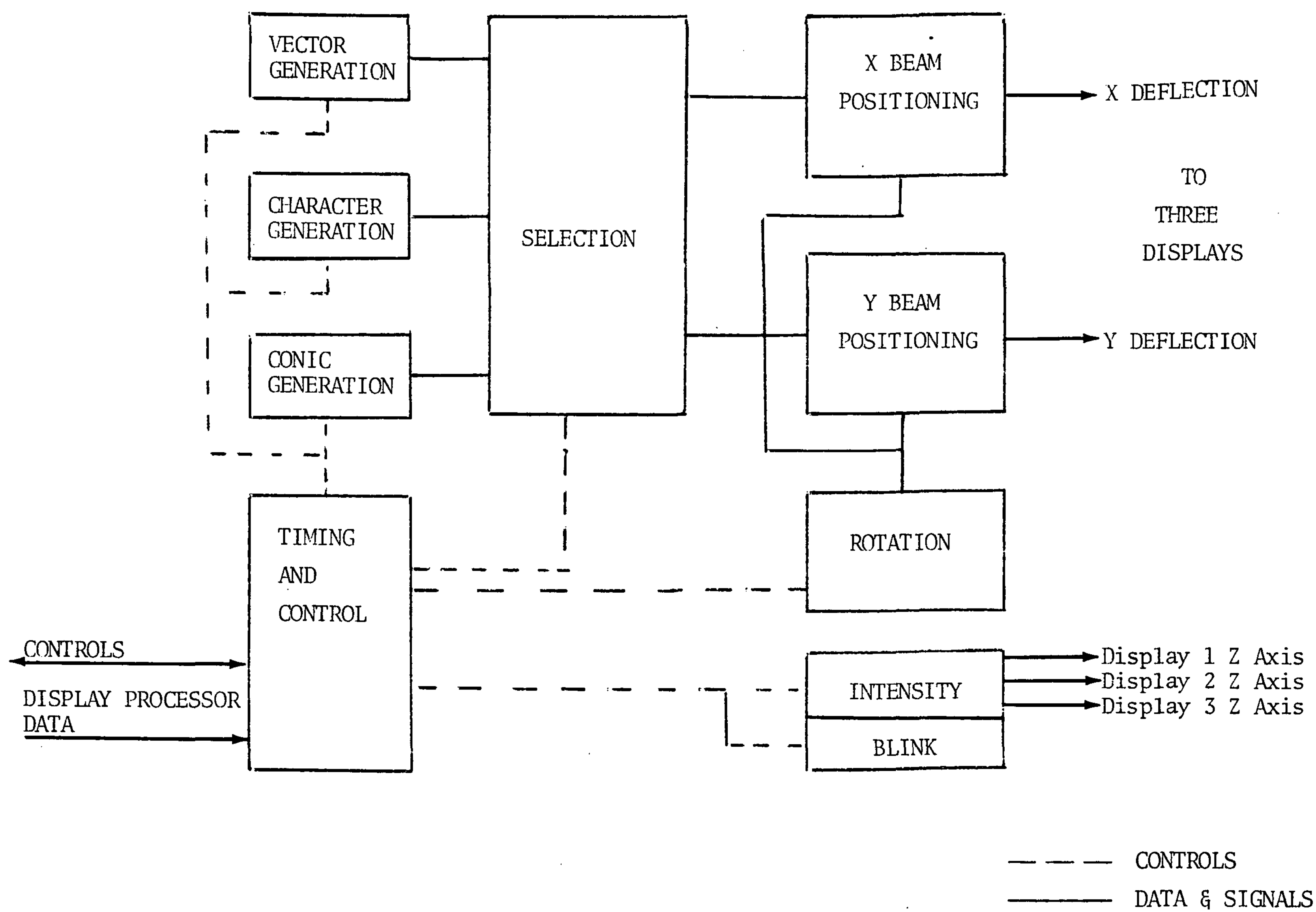


FIGURE 5-5 Display Controller Electronics

compensation is required. The relative merits of each of these for the shuttle application has not been evaluated.

Two methods of displaying graphical data by vectors are possible. The first uses point-to-point connection of line segments. With this method, the initial and final x and y points are given. Incremental changes in the x and y values continues until the final and incremented values are equal. Either up/down counters or adders/subtractors can be used.

The second methods uses vector magnitude and angle. The starting point of the vector is provided along with these. The vector can be drawn by using a ramp generator from the initial point with the direction controlled by the x and y digital to analog converters.

Constant writing speed is obtained using the ramp. The length of time to write a vector is proportional to its magnitude.

A solid state read-only memory provides the symbol library. It contains the stroke control bits/words to generate the x and y deflection and intensity controls. This digital information is used to control the line segments or strokes to form the symbols.

A number of ways exist to organize the symbol generator. One of these is to obtain the ROM symbol starting address by decoding the character field of the control word. This address can be placed in an address counter. The readout of the ROM would be the Δx, Δy, and intensity information. The address counter can be stepped at time intervals to read out the succeeding strokes. The various sized symbols and intensities can either be selected from the ROM word or by gain control of the deflection signals.

An alternate method requiring less ROM storage would be to time-scan each ROM word output in either a weighted or nonweighted manner and to derive the sequential strokes in this fashion.

Sine and cosine waveforms are used to generate different conics. These can be derived either digitally, using ROM's, or by analog means, as from system clocks and harmonics. Placing sine and cosine signals of equal amplitude into the x and y deflection circuits yields circles; unequal amplitudes give elipses. Various conic radii required in either symbols or graphics can be obtained by using attenuators or frequencies controlled by the decoding of the word format and display timing.

Rotation of elements of the display are accomplished through the implementation of the following equations:

$$X_1 = Y_0 \sin \theta + X_0 \cos \theta$$

$$Y_1 = Y_0 \cos \theta + X_0 \sin \theta$$

where X_1 and Y_1 are the rotated coordinates, X_o and Y_o are the initial coordinates, and θ is the angle of rotation.

The mechanics of obtaining this rotation is that of driving digital to analog converters with digital values of the sine and cosine of the desired angle of rotation as obtained from a ROM. The reference voltages for these converters are supplied from the x and y deflection voltages obtained from position and stroke information.

Intensity control circuitry provides intensity levels required by the display control words and a means by which uniform intensity or a change in brightness level can be obtained. Blinking at 1Hz, under control of the bit in the control word, is provided.

Operational amplifier summation of analog signals provides a means of combining the generated deflection voltages. In the baseline approach, depending upon CRT positioning capability, three display tubes are driven by one display generator by unblanking the addressed intensity circuits. The operation with the display processor is done synchronously such that the assignment of data words is performed according to a time staggered refresh method.

Various techniques utilizing electrostatic character formation or multiple digital-to-analog conversion channels, with possibly more generators, can reduce the logic speed and analog circuitry bandwidth. A cost effectiveness study to determine the optimum way is beyond the scope of the present effort.

Microprogram control is suggested in the display electronics control. Such an approach would offer advantages in the design including feasibility for changes and possible reduction in amount of logic and power. The format words could be examined, decoded and used to obtain micro-instructions necessary to perform the sequences attributed to each required action.

The operations involved in generating a symbol always involve the acquisition of a bsic control word type. In the case of a vector mode (3) or a vector perturbation mode (6) (see Section 5.2.1), the second control word type is additionally required. Symbol generation (mode 2) requires the third control word type in addition to the basic. As indicated earlier, up to four symbols can be generated with each third word type. Additional words are required for greater numbers of symbols. The display electronics steps one character position in the X axis upon completion of each character. Sufficient buffering is envisioned to ensure the availability of control words if needed on a look-ahead basis. Parity checking on the words is performed. Interrupts are used to alert the display processor to any errors detected, and/or end-of-message signals.

A typical mechanization for the display controller electronics is shown in Figure 5-6. The control is implemented through micro-programming involving the micro-operations shown in Figures 5-7, -8, and -9. The CRT display provides amplification of the signals to deflect and gate the cathode ray tube beam. It also contains the high voltage conversion and control circuitry needed for an electromagnetic, electrostatic system. Linearity correction is provided for both x and y deflection signals.

Built-in test capability is provided with photodiodes placed at the perimeter of the display. These diodes periodically receive the team and provide an indication of status of the beam and ability to position.

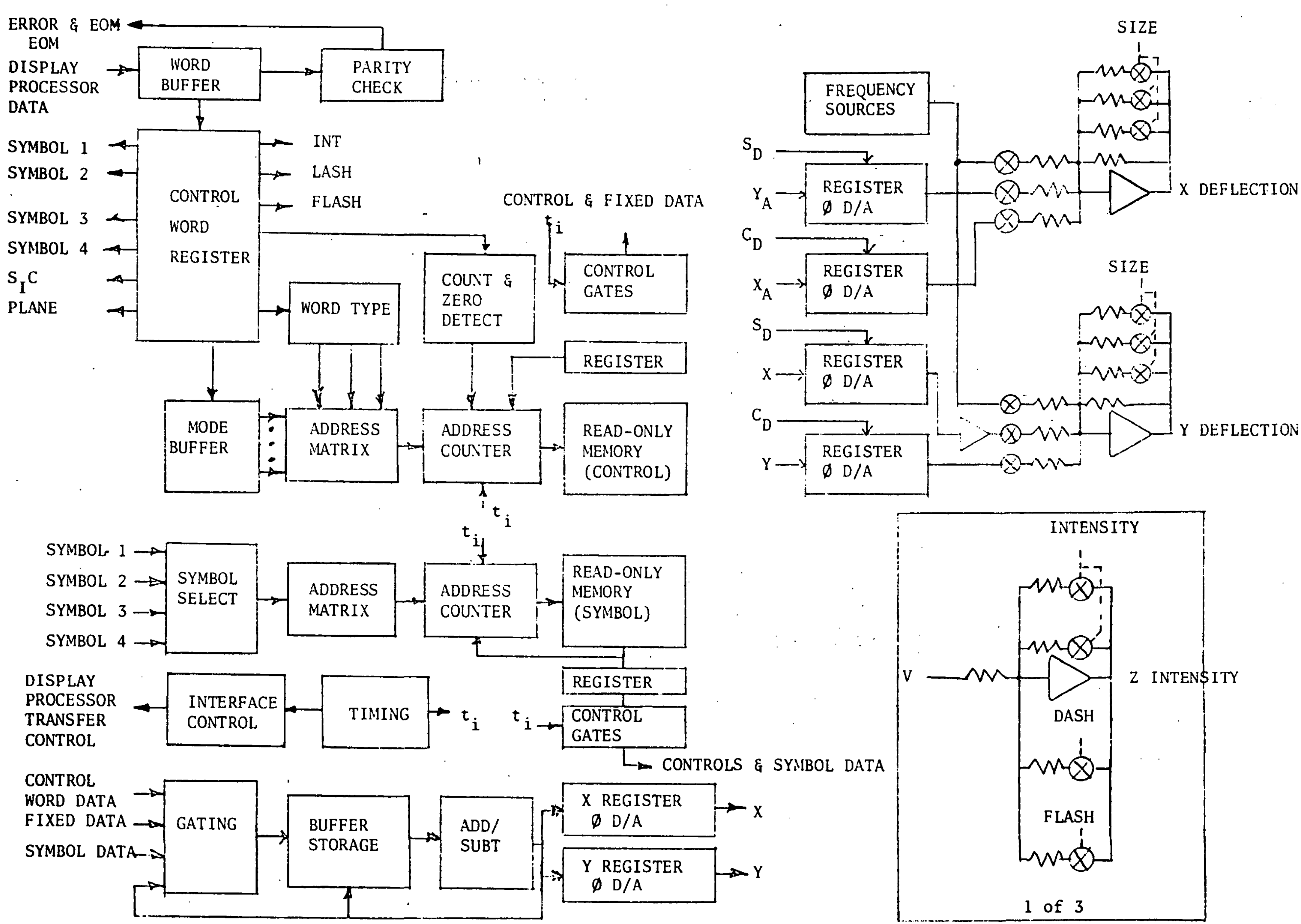


Figure 5-6. Typical Implementation of Display Controller Electronics

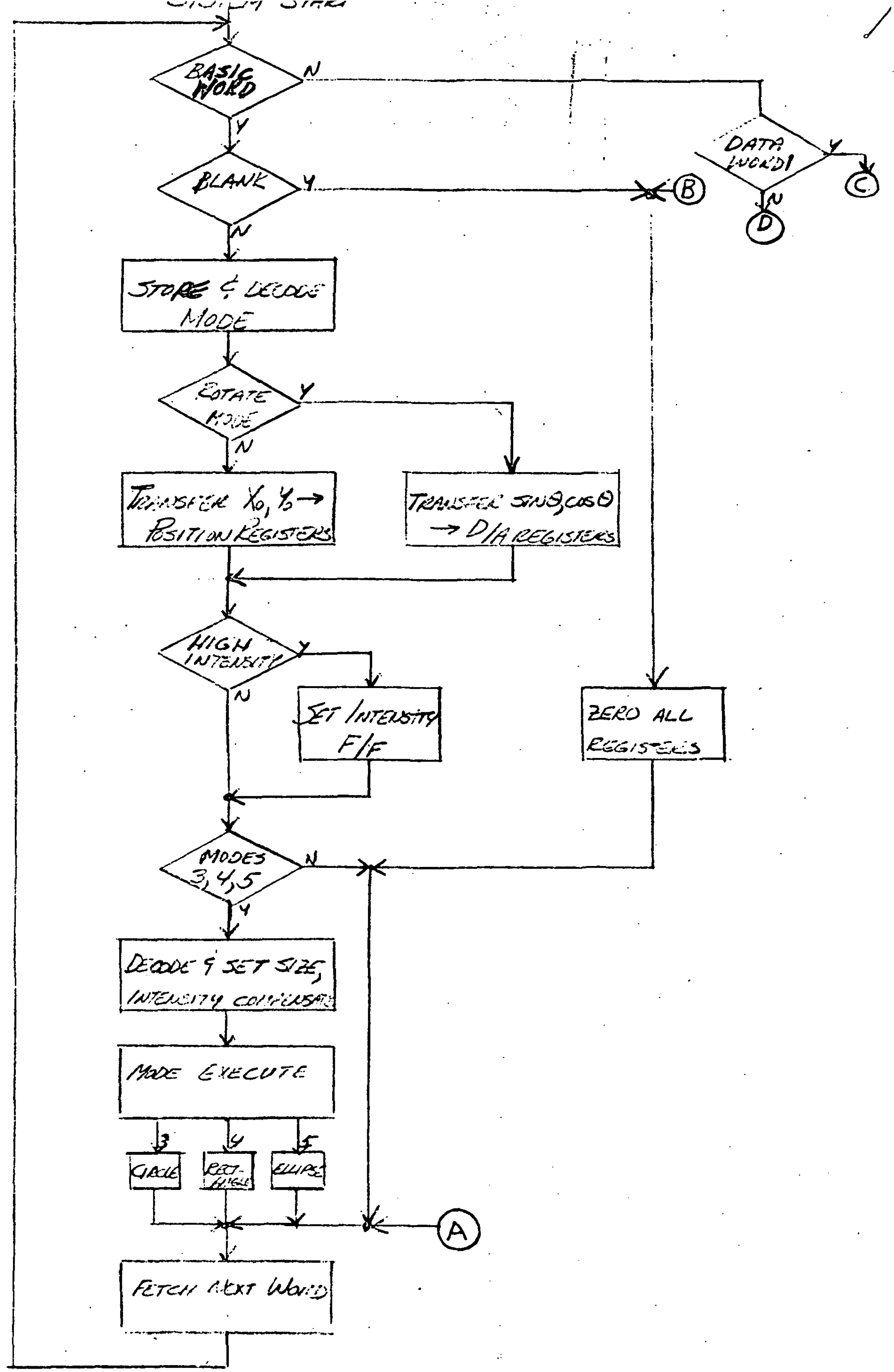


Figure 5-7. Basic Data Word Micro-Instructions Flow

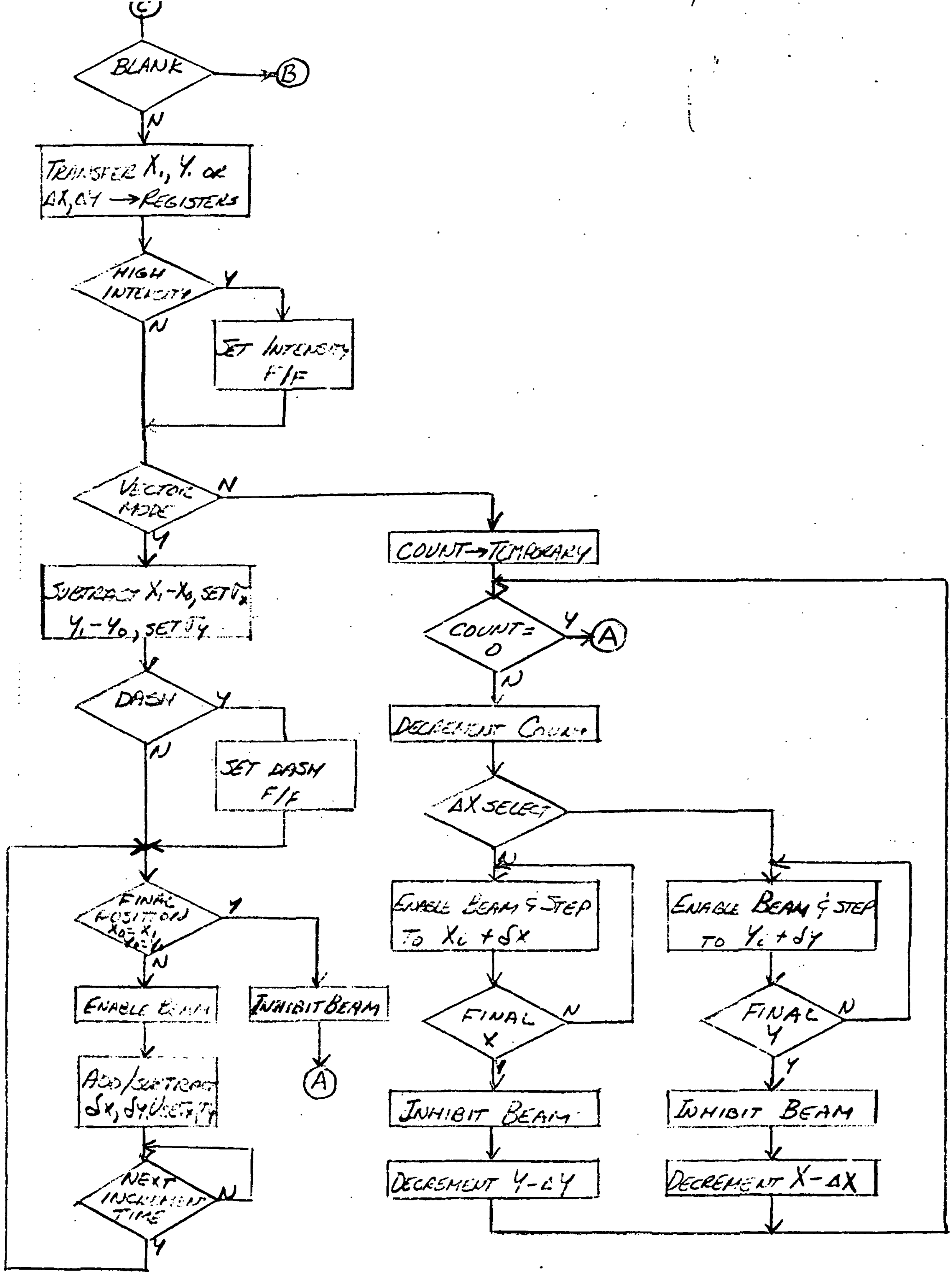


Figure 5-8. Data Word 1 Micro-Instructions Flow

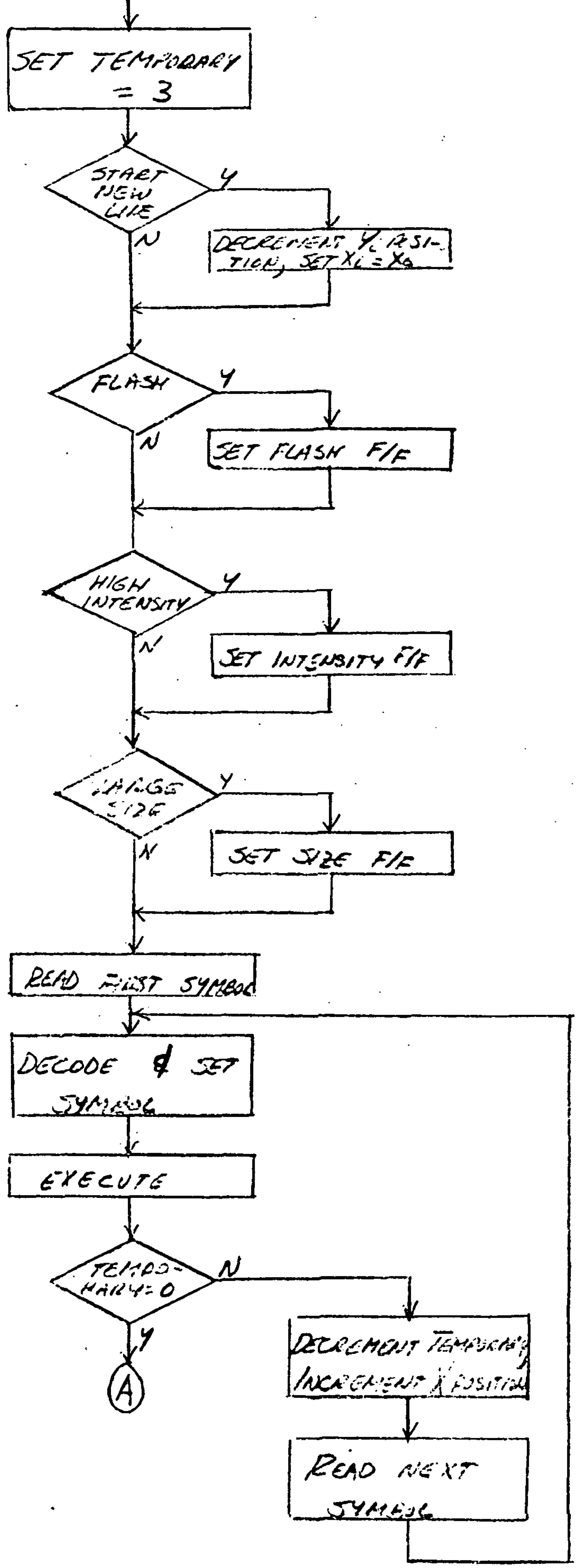


Figure 5-9. Data Word 2 Micro-Instructions Flow

Other failure detection methods involve both test patterns and the capability of multiple CRT display of identical information. These are accomplished on a demand basis with crew participation.

Keyboards

Each of the three keyboards (see Figure 4-11) provides the numeric and special keys by which the crew performs command and display actions. These keys enable the selection of a display and of display formats. One keyboard communicates with one display at a time. The functions of the keys are:

(A) 0-9 Numerics - Provides decimal data keys

(B) ENTER - Commands keyboard entry and/or advance checklist

(C) CLEAR - Clears latest keyboard entry

(D) AUTHORIZE - Enables display override to present a new display

(E) Plus, Minus, E. N, S, and W - Provides special keys for sign and direction

(F) INCREASE, DECREASE - Permits crew adjustment of variables, or slew of checklist

(G) Display Selector (I, II, III, IV, V) - Selects one of five displays

To provide these functions, no logic is required at the keyboard. The selection of a display CRT causes the linkage, if available, of a particular display processor to the keyboard. If not available, a CRT indication is provided. All required logic is contained in the processors.

A keyboard retains control of the last display selected. This approach does not require keyboard priorities.

Double pole switches are required to provide a dual, independent indication to the processors.

5.2.3 Software Organization

The information below has a twofold purpose: (1) to demonstrate software feasibility of the concept, based on the DMS configuration selected, and (2) to provide sufficient detail for computer sizing (speed and memory).

The DMS configuration along with the display processor permits storage in three unique locations: mass memory, central processor, and display processor. To organize the software and to estimate memory sizes resulting from display requirements, an allocation of the various functions was first performed (Figure 5-10). In tabulating these functions, a number of other functions were considered already resident in the central processor:

(A) All 2-digit command execution routines, e.g., the routines for opening and closing valves and/or switches.

MASS MEMORY

- Static Display Formats
- Dynamic Display Formats
- Format Tasking Routines
- Address Listings
- Address Tables

CENTRAL PROCESSOR

- Call Requested Formats
- Execute Requested Commands
- Transmit Required Format Measurement Data
- Transmit Caution and Warning Data
- Monitor Display BITE
- Provide Automatic Display Reconfiguration

DISPLAY PROCESSOR

- Monitor KYBD Inputs
- Interpret KYBD Inputs and Initiate Operator Commands:
  1) Select Display
  2) Format Requests
  3) System Commands
  4) Display Commands
  5) Manual Reconfiguration
- Provide Storage for Formats on Display
- Convert and Scale System Measurement Data for Display Updates
- Display and Log All Operator System Commands
- Provide CRT Command and Control Logic
- Provide Synchronization for Updating Refresh Memory
- Provide Real Time Clock Display Capability
- Provide System Interface Capability
- Provide BITE for Fault Isolation

FIGURE 5-10 - "Functional Allocations"

(B) All caution and warning routines.

(C) All routines for extracting measurements.

(D) Storage for all measurement data.

Furthermore, it was assumed that,

(A) All command execution routines are ordered, i.e., addressable given a start location and a delta.

(B) All measurement data are filed and addressable by subsystem.

The software organization is structured to be modular and consistent with the functions listed in Figure 5-10. Two types of modules were defined: resident and transient. The resident modules are those programs which are stored in the processor throughout the mission. The program modules and routines for both the display and central processors are listed in Table 5-5. The listing includes both the resident and transient program modules, routines, and tables; thereby including anywhere from one to five sets of approximately 500 transient data sets stored in mass memory.

To demonstrate feasibility, each of the program modules is discussed below in sufficient detail to show throughput and compatibility between modules and the various subsystems.

Display Processor

The preliminary design of the operational program for the display processors consists of the seven basic modules listed in Table 5-5.

Executive and I/O Modules

The executive module is relatively simple when compared to that required by the central processor. This results from the limited amount of real-time requirements. A real-time clocking function is used primarily to aid in self test and to provide a point of reference in the program. Mission timers may use this clocking function, however, long term synchronization will be under control of the central processor.

In general, the display program synchronization is provided via the interface. For this reason the I/O module is combined and presented with the executive (Figure 5-11).

The functions performed by the executive, as seen in Figure 5-11 are relatively straightforward. Typically the executive consists of a power-up routine with transient error checking, program and I/O initializations, and a simple job-tasking routine for completing initiated jobs and for the execution of routines other than those initiated by interrupts.

The I/O module consists of those functions initiated by interrupts. These interface functions and their organizations are discussed in the following paragraphs.

TABLE 5-5. - MODULAR SOFTWARE ORGANIZATION

Display Processor:

- Executive Module -
  - Power-On Sequence
  - Transient Recovery Sequence
  - Built-in-Test Monitoring Routine
  - Synchronization and Program Control
- Keyboard Module -
  - Input Decoder Routine
  - CRT Address and Control Routine
  - 2-Digit Input Tasking Routine
  - 3-Digit Format Requesting Routine
  - 1-Digit Header Control Routines
- Update Memory Module -
  - "Last" Command Update Routine
  - System Measurement Update Routines
- I/O Module -
  - ACT/CRT Interface Control
  - Mass Memory Interface Control
  - Refresh Controller Interface
  - Keyboard Interface Control
- Self-Test Module
- Utility Module
- Refresh Memory Modules

Central Processor:

- Display I/O Routine
- Decoding and Lock-Up Routine
- Format Fetch and Transmit Routine
- 2-Digit System Command Routine
- System Measurement Select Routine
- Display Monitor and Reconfiguration Routine

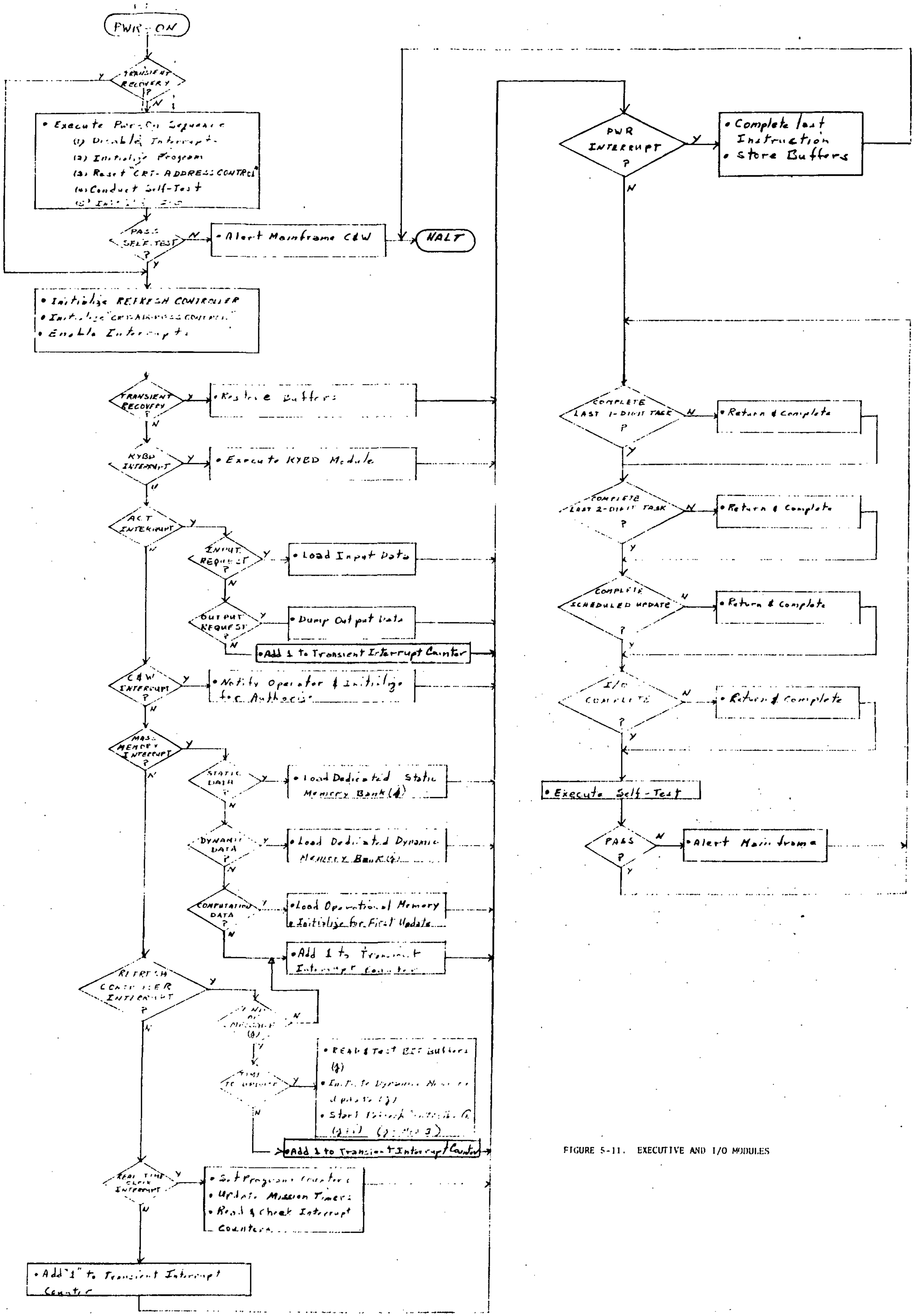


FIGURE 5-11. EXECUTIVE AND I/O MODULES

ACT Interface

Twenty-five times per second, the ACT, which is time-synchronized with the central processor, interrupts the display processor. Each time this occurs, I/O data (Input: 124 32-bit data word, Output: 31 32-bit data word) are transferred between the ACT and the operating memory. The input data are termed dynamic (24 times per second) or quasi-static (once per second). The output data, which consist of requests on the central processor, supporting data, and monitoring information, are interfaced at a constant rate (5 times per second).

To describe the organization of the input data, they are classified by rate:

Group A: Dynamic Data

Group B: Quasi-static Data.

Both groups consist of three sets of data, one set per display, 3 displays per processor.

With the exception of caution and warning information, Group A data are considered to be made up of all non-discrete signals. Each set of these measurements (3 in all) can consist of up to 60 15-bit words, although this word configuration is not mandatory (i.e., rather than 60-60-60, they could be grouped 40-30-110). The location of each signal within the data block corresponds to an address stored in the processor, although the addresses and the routines for scaling and updating the refresh memory to these data are transient. For purposes of this study, the remainder of the data words (44 32-bit words) are reserved for caution and warning, timing information and control.

The Group B data block also consists of three sets of data. Each of these sets is made up of two sub-sets, one representing discretes and the other non-discrete data. The organization of the quasi-static analog data is typical of that for Group A. In the case of discrete data, each word represents a class of discrete information, e.g., the first word represents a class of discrete information, e.g., the first word may represent solenoid valves (up to 30 valves per 32-bit word plus one bit for parity and one for noting subsequent changes). In this manner, the symbol corresponding to the state of the discrete can easily be changed, e.g., in the case of a valve:

one : Open : ⊖

zero : Closed : 1

In the next case the word may represent pressure regulators, i.e.,

one : Open : □

zero : Closed: : $\boxed{1}$

Seven words per set are reserved for discrete data of this type. This leaves 23 words for caution and warning information and control.

The output data are organized as follows:

A. One word for locating measurement data, per 2-digit request (this word plus the table location in the central processor sets a pointer to the measurement or to the routine for securing the measurement).

B. One word for locating the routine for executing a 2-digit command (typical of item (A)).

C. One word for locating the starting address in mass memory for retrieving format data.

D. Three words (one for each display) are reserved for discrete BIT (built-in-test) information.

E. Six words are reserved for analog BIT data.

The remainder of the words are used for control and to transfer various operator input data, e.g., a position update consisting of latitude and longitude. Based on the turn-around time, an output rate of five times per second was selected.

Caution and Warning Interface

The caution and warning interrupt is generated by the central processor and is considered asynchronous. In the event this interrupt occurs, the header changes and blinks and acceptance of an "Authorize" key-in for a format change-over is initiated.

Mass Memory Interface

Any mass memory interrupt is predictable (with the exception of a random error) and thus the loading of mass memory data is basically under control of the display processor. This limits the likelihood of loading errors. The input data are divided into three groups of information: static, dynamic, and operational. The static and dynamic data blocks consist of the display control words and the operational data block, the supporting routines and tables. The static and dynamic data are read into one of three dedicated memory banks (one per display), with the provision that these banks are overlapped with the CPU. The operational data are loaded in a common memory in which the resident programs reside. The initiation of a mass memory interrupt (format request by a crew member) is considered random with little or no affect on the duty cycle to the period between interrupts.

Refresh Controller Interface

The refresh controller interrupt is a feedback signal indicating that the controller has just completed a refresh cycle for one of the three displays. This interrupt is initiated whenever the controller has sensed an end-of-message display control word. Using this technique allows the processor to control the refresh frames and, moreover, provides the means for update synchronization (e.g., update every other frame permits 25 updates per second).

Keyboard Interface

Each processor is interfaced with three independent keyboards and consequently will receive three independent interrupts. These interrupts will occur asynchronously and could occur simultaneously. Priority is initially based on a firt-come, first-served assignment. Thereafter, the keyboard can relinquish control (assignment of a display) by a single command.

The occurrence of interrupts on these lines is considered relatively slow (one per second per keyboard) and, consequently, does not impact the duty cycle. Furthermore, it is assumed that all keys interrupt the processor, with the possible exception that the display select keys could be discrete lines.

Real Time Clock

The real time clock interrupt is considered part of the executive program. For lack of specific information, a 32 times/second interrupt is considered adequate. Transient interrupt counters are added to aid in the detection and isolation of noise on the interrupt lines.

Keyboard Module

A typical program module for the keyboard input is diagrammed and presented in Figure 5-12. Because of the requirement that any keyboard can select any display, three of these modules (or equivalent) are needed in each processor.

The functions performed by these modules are in conformance with the requirements outlined in Section 3.0. The data presented in the diagram are self-explanatory, with the possible exception of the 2-digit routine. This routine is used to determine if the input is to be transferred to the central processor (command execution routine) or to be used by the local processor (a special routine included with the format of interest). If the input is of the command execution type, the request is also logged in the "last command" (historical) data matrix.

Update Memory Module

The update memory module consists of those routines used to provide two types of updates. The first update type is the measurement of the variables with respect to time. This type of information is derived via the central processor and is used by the crew to determine the value or condition of the variable.

The other update type which is applicable to most variables is the value or state to which the measured variable was last commanded. This information can only be achieved through having recorded the crew's previous command. In this manner, the crew is able to compare the present measurements to the last commands. To accommodate this latter update type, a historical matrix is kept in the operational memory. The matrix is ordered by rows and columns corresponding to 3-digit format code and 2-digit command code, respectively. In some cases, redundancies appear between formats and for these, transient data in the form of addresses must accompany the formats. Otherwise, only the starting address in the dynamic memory is required for each variable type, i.e., two-state, three-state, etc.

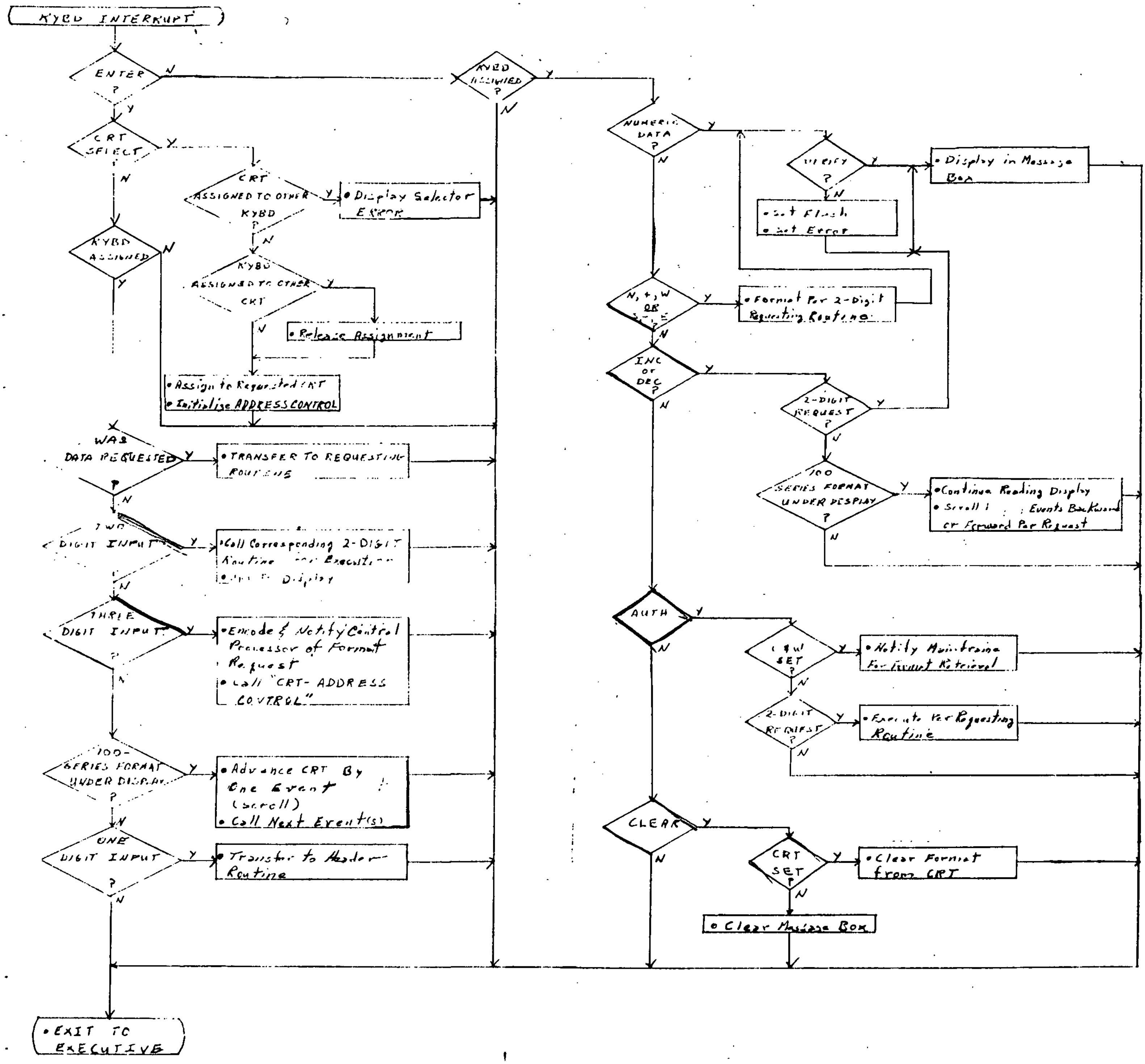


FIGURE 5-12. KEYBOARD MODULE

Self Test Module

Typical self test routines are scheduled, as well as the results of various throughput tests conducted in conjunction with the hardware. Note that some cross-monitoring is assumed between the processors for increased probability of error detection. Furthermore, automatic reconfiguration can only be instrumented via the central processor. Manual reconfiguration, however, can be performed by the operator.

Utility Module

This module contains all of the standard utility routines, e.g., binary-to-decimal conversion, sine, cosine, decimal-to-binary, etc. In addition, this module contains a variety of routines common to all or many of a series of formats, e.g., header changes and scaling routines. In effect, this is somewhat a "catch-all" module.

Refresh Memory Modules

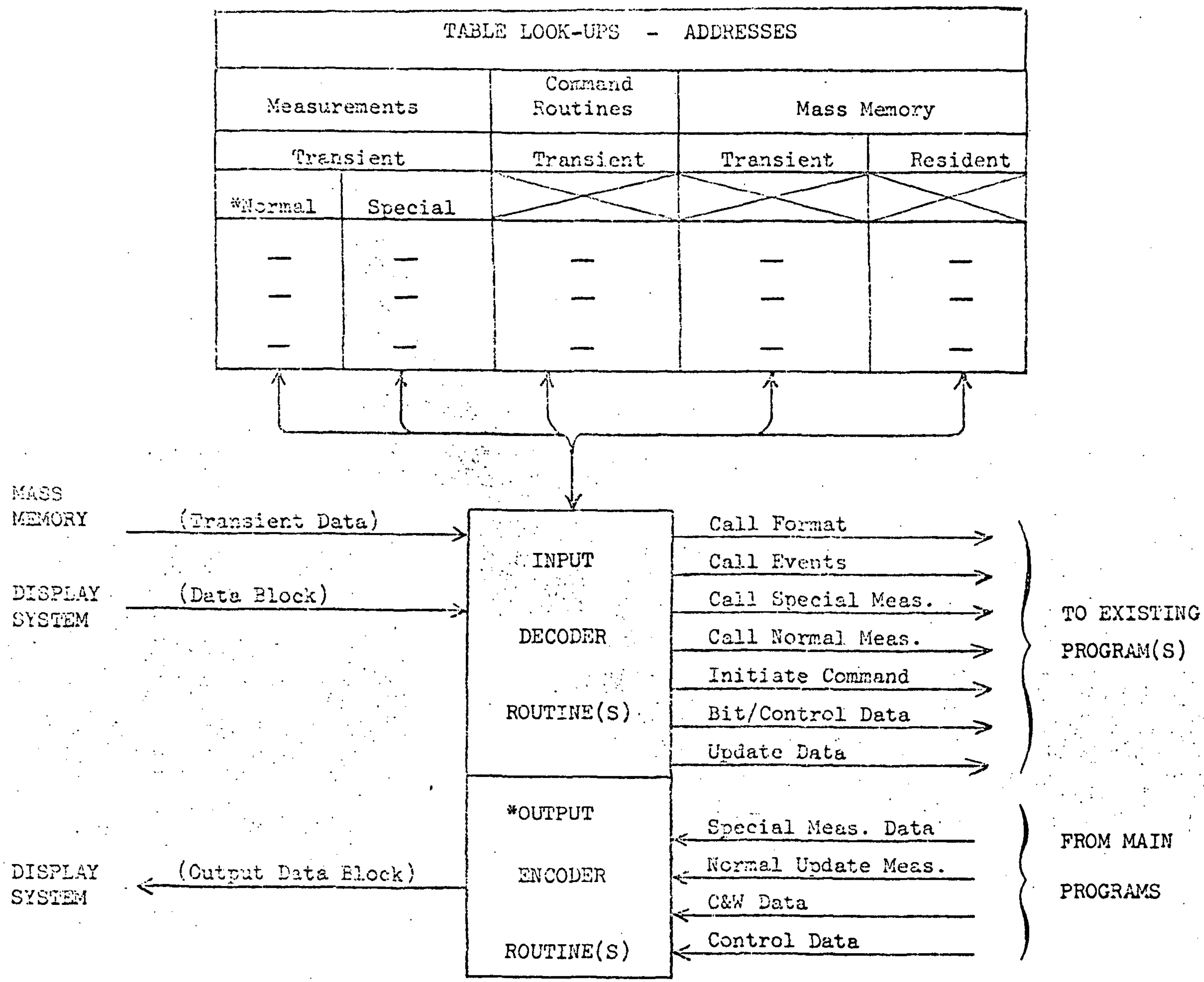
Refresh memory modules are simply dedicated memory banks (1 set per CRT) reserved for the display control words.

Central Processor

The organization of the display software in the central processor is given in Figure 5-13. The routines and various tables are both transient and resident. For this purpose, a mass memory input line is shown. Thus, whenever a new format is called for display, or whenever a 100 series format is scrolled, data will be received over this channel.

As previously described, the data block received from the display subsystem is encoded by its organization within the block. This is achieved by the magnitude of the 2-digit keyboard input. The input decoder then simply routes the crew updates, BIT data and control words to its destination routines, noting that crew updates include the destination address. Special measurements (if required) and command execution routines are called by combining the appropriate input word with the starting location of the corresponding table wherein the address is stored.

The output encoder is responsible for compacting the data and the control words necessary to the display subsystem. This information and its organization were discussed earlier in the paragraphs describing the I/O module. To compact the data as described, it is envisioned that the addresses for obtaining the measurement data are first grouped by the required rate: i.e., dynamic or quasi-static. Next, the execution of the routines for gathering the measurement data would be divided into discretes and analog measurements. The discrete data would then be separated by symbols and ordered in accordance with a starting location in the refresh buffer memory. The analog data would be ordered in accordance with a corresponding table look-up in the display operational memory, assuming that this table is ordered and transient. In this manner, the measurements are taken and compacted into the appropriate output data block.



*Assumes that the display subsystem receives data directly from mass memory

FIGURE 5-13. - CENTRAL PROCESSOR DISPLAY SOFTWARE

Mass Memory

The organization of the software in the mass memory is format-oriented. In general, each format used during the mission will be stored in mass memory and will consist of the following.

(A) Static Data Block - Display control words which are non-time-variant.

(B) Dynamic Data Block - Display control words in which the data vary with time.

(C) Tasking Routines - Special routines used to interpret and execute certain 2-digit keyboard commands.

(D) Address Listings - Includes starting addresses for tables and/or specific addresses when update measurements for more than one subsystem are involved and/or routing crew input data.

(E) Address Tables - Specific addresses where the order is proportional to the 2-digit request.

5.2.4 Memory Storage and Speed Estimates

Based on the described preliminary design, estimates were made of the memory capacity and speed required for the display processor. Additionally, the added display memory capacity requirements for both the mass memory and central processor were estimated. These estimates are described below.

Mass Memory

The mass memory was estimated first, since all display formats are stored in this subsystem and the formats are the basic driving functions. Since it was not possible to consider all of the formats individually, an alternate methods for estimating the size was used.

First, all of the formats were placed in the following groupings:

(A) Checklist Formats - These formats include the header, bar charts and n-successive events displayed two at a time.

(B) Subsystem Management Formats - These schematic formats include the header, pictorial and/or graphic descriptors, and subsystem commands and measurement data.

(C) Vehicle Management Formats - These formats include header, pictorial and/or graphic descriptors, and system commands and measurement data.

(D) Index, C/O and C&W Formats - All of these include both the header and text.

(E) Timeline Formats - These include header, bar charts, and text.

Having categorized the formats, at least one or two in each group was selected for coding. The selection was based on those formats having the highest density for display, both static and dynamic requirements considered.

The coding used the three, 32-bit display control words described earlier. An example of the coding used including both 16 and 32-bit control words is illustrated in Appendix D.

In addition to the static and dynamic memory requirements, an estimate of the maximum capacity for storing the associated tasking routines, address listings and address tables was made. These capacities are given in Figure 5-14.

Having estimated the storage requirements for those formats having the highest densities within each group, the total requirements was estimated. First, the requirement of the formats having the highest density was multiplied by the number of formats within each group. This figure represents the total number of words per group if all of the formats had the same density. To adjust this figure for the variation in densities, a weighting factor was used. This factor represents the percent of the high density format to be found in the average format.

The results of this procedure are shown in Figure 5-15. The results indicate that 302,000 32-bit words are required in mass memory for the total number of formats required for the control/display Concept A.

The mass memory speed requirements specified by the DMS (3.2×10^6 bits/second) are quite sufficient; however, the data should be channeled directly to the display processors rather than over the data bus.

Central Processor

The requirements for the central processor was based on assumptions made in previous paragraphs. Thus, only those resident and transient routines shown in Figure 5-13 were sized.

The speed requirements imposed on the central processor are well within those given for the DMS. This is logical, since much of the load has been taken up by the local processor.

There appear to be no added requirements for the data bus beyond those previously imposed by the DMS (Output: 3200 words/sec and Input: 800 words/second). The only added requirement is that direct channel between the mass memory and display processor be provided.

The storage requirements for the central processor are given in Figure 5-16. The estimates are based on servicing 5 CRTs simultaneously. Estimates are based on the assumption that the following are already in the central processor.

(A) Measurement Data

(B) Command Execution Routines

(C) Basic I/O (data bus) functions

(D) BIT Monitoring

(E) Caution and Warning routines

Format Grouping	Estimated Memory Capacity Per Highest Density Formats (32 Bits Per Word)				
	Static	Dynamic	Tasking Routines	Address Listings	Address Tables
*Checklist Format	100	120	64	64	64
Subsystem Mgmt Format	200	220	128	64	128
Vehicle Mgmt Format	190	230	256	64	128
C/O Formats	230	200	128	64	128
C/W Formats	90	90	128	32	64
Timeline Formats	120	90	64	16	16
Index Formats	210	40	--	--	--

*The static and dynamic capacities were based on 2 of n events only.

FIGURE 5-14 - ESTIMATED HIGH DENSITY FORMAT STORAGE CAPACITY

Format Grouping	# of Words Per High Density Format	# of Formats Per Group	Average % of High Density Formats	Est. No. of Words Per Group (32 Bits/Word)
*Checklist Formats	1510	180	60	163K
Subsystem Mgmt Formats	740	130	60	58K
Vehicle Mgmt Formats	868	22	80	15K
C/O Formats	750	61	80	37K
C/W Formats	404	60	80	19K
Timeline Formats	306	22	90	6K
Index Formats	250	24	60	4K

ESTIMATED MASS MEMORY REQUIREMENTS $= \sum$ Groups $=$ 302K

*The total number of words for the high density format was estimated, based on a total of 30 events, i.e.,

Total = (Bar Charts and Subtitles) + (30 events) = (Tasking Routines) + (Add. Lst.) + (Add. Tble)

= 82 + 1236 + 64 + 64 + 64

= 1510 Words

FIGURE 5-15 - ESTIMATED MASS MEMORY STORAGE CAPACITY

Functions	Resident Storage (32 bit words)	Transient Storage (32 bit words)
Input Decoder Routine	400	--
Output Encode Routine	340	--
Address Listings	120	160
Address Tables	1000	500
TOTALS	1860	660

FIGURE 5-16 - CENTRAL PROCESSOR STORAGE REQUIREMENTS

Display Processor

The estimates for both memory storage and percent duty cycle are given in Figure 5-17. These estimates take into account both the resident and transient requirements and are based on each display processor handling 3 of 5 CRTs simultaneously.

The duty cycle was based on a processor having a "short-op" (equivalent "add-time") of 2.5 microseconds and an interrupt breakdown as follows:

(A)	Real Time Clock	:	32 times/sec.
(B)	Refresh Controller	:	150 times/sec.
(C)	Data Bus	:	50 times/sec.
(D)	Keyboards	:	3 times/sec.
(E)	Mass Memory	:	1 time/sec.
(F)	C&W	:	1 time/sec.

This, coupled with the update rates required for the refresh buffers, produced the speed estimates given.

5.3 CONCEPT B

Concept B is the second of two preliminary designs considered feasible for implementation of the display concept under study. Although only one design was required, a quick-look into the application of the dot matrix method was made for the following reasons:

(A) Normally, dot matrix techniques are much simpler in mechanization.

(B) Typically they use less power.

(C) No electrostatic deflection (high voltage) requirements

(D) There is a possible reduction in memory requirements through the use of row-column positioning (i.e., 14 bits for beam positioning rather than 20 as in Concept A).

The basic B design is analogous to that of A. The design uses three local processors interfaced with the central processor, mass memory, and keyboards in nearly the same manner. The exception is in the structure of the display control words, i.e., 16 bits are used rather than 32 as in the A design. Based on the limited analysis, the interface between the processor and refresh controllers is more complex in Concept B, although functionally it is the same as A. In essence, the use of 16 bit control words increases the word count by a factor of approximately two (16 versus 32). Thus twice as many words must be operated on to display the same format in Concept B as is the case in Concept A. To overcome this the controllers in the B design multiplex their inputs on a word by word schedule rather than frame by frame as in A. Thus, each of the five displays has its own controller and all of its display electronics (Figure 5-18). In this manner, the design is able to meet the

Functions	Resident Storage (32 Bit Words)	Transient Storage (32 Bit Words)	Percent Duty Cycle
Executive Module	400	—	1
Keyboard Module	700	800	1
Update Module	600	100	30
I/O Module	600	100	30
Self-Test Module	300	—	1
Utility	600	—	—
Tables	1000	—	—
Refresh Buffers	100	1400	—
TOTALS	4300	2400	63%

FIGURE 5-17. - CENTRAL PROCESSOR MEMORY AND SPEED ESTIMATES

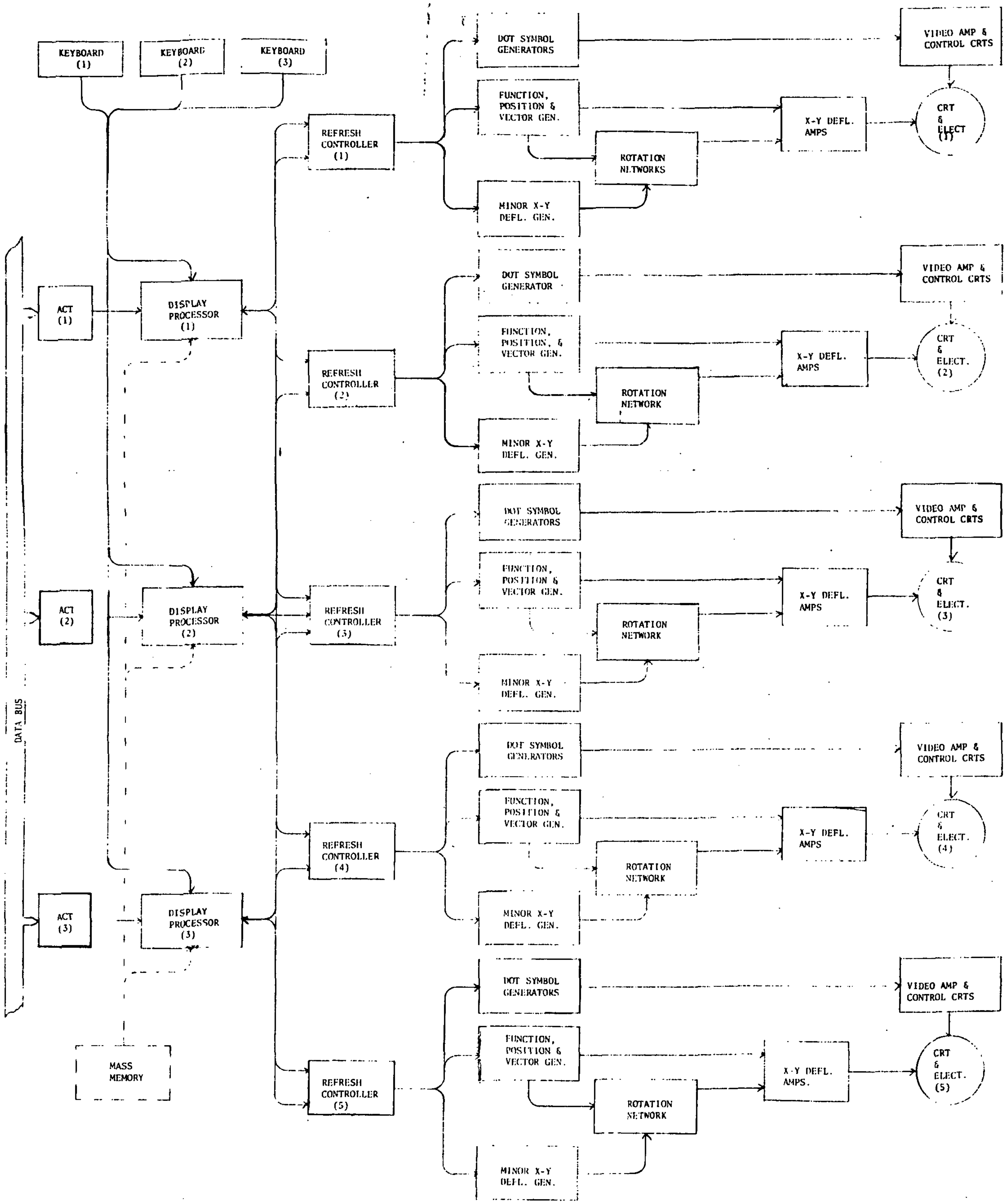


FIGURE 5-18. PRELIMINARY DESIGN - CONCEPT B

failure dictate using only three processors. The primary reason for word by word multiplexing is the added amount of time needed at the display using 16 bits rather than 32, e.g., twice as long to position the beam, or two control words. This requirement may be reduced with further study.

5.3.1 Concept B Summary Description

A summary of the display characteristics for this concept is provided in Table 5-6. It should be noted that the B concept is "hybrid" in that vector writing is provided; however, this writing uses magnetic deflection only, i.e., no superimposed electrostatic deflection is required.

The operation of the display system is considered basically the same as that for the A design, i.e., two processors on-line and one in standby. Each processor would be capable of handling up to three displays. The display-processor assignment is the same as in design A, i.e., any keyboard can select any display provided another keyboard is not in control. Typically, the information transferred and the mechanization between the display processor, the keyboard, central processor, and mass memory are the same. The information transfer between the refresh controller and the display processor and its interface is organized differently. Four of the five controllers have two 16-bit input buffers and the fifth has three. In this manner, the control words may be multiplexed from at least two different sources and in one case three, which is in conformance with the reliability constraints. Thus, refresh controllers 1 and 2 can receive and display data under control of processor 1, or, in the event of a processor 1 failure, processor 3 (typical of controllers 4 and 5 with processors 2 and 3 - but not both). Refresh controller 3 can receive and display data from either processor 1 or 2 (first-come, first-served), and, in the event of failure, either 1 and 3 or 2 and 3, depending on which failed.

The refresh controllers are designed to read alternately in sequence their appropriate memory banks within each processor by way of a direct memory access channel. With the exception of a 16-bit parallel interface between the processor and controller, rather than 32-bit, the display processor has the same features as those given in Table 5-4. Furthermore, the organization of the static and dynamic memories is assumed to be the same.

Primary differences between Concepts A and B are the display control words, 32-bits and 16-bits, respectively. The organization of the control words for the B design is given in Table 5-7. Two bits are used to differentiate between word types. The basic control word provides for the selection of the subsequent mode and the logic settings for the various control gates. Typical of Concept A also, the following modes are provided.

1. Symbol
2. Rotate
3. Circle
4. High Resolution
5. Vector Perturbation
6. Angle Perturbation
7. Spare

Three circle sizes are provided, two sizes of alphanumerics, and a selection of specially sized symbols (Table 5-6). The high resolution mode permits

TABLE 5-6. - DISPLAY CHARACTERISTICS

Type	Cathode Ray Tube - magnetic deflection
Area	6 x 8 inches (usable area)
Resolution	0.010 inches (10-bit D/A positioning)
Method	Dot Matrix
Refresh Rate	50 times/second
Update Rate	24/second (dynamic), 1/second (quasi-static)
White Lines	90 lines/inch Vertical Lines: 6 x 90 - 540 lines Horizontal Lines: 8 x 90 - 720 lines
Selectable Characters	Standard Size: *Up to 120 Double Size: Up to 120 Special: Up to 120
Character Size (hxw)	Standard: 9 x 7 dot grid Double: 18 x 7 dot grid Special: 18 x 14 dot grid
Selectable Character Positions (density)	2880 standard size characters Non-overlapping rows: 36 Non-overlapping columns: 80
Writing Speed	250,000 inches/second
Intensity	Two levels (8000 ft. Lambert environment)
Display Control	Three, 16-bit words, seven modes of operation
Special	Flashing at 1 Hz and line dashing capability

* 8 slots reserved for control

BIT POSITIONS	DISPLAY CONTROL WORDS			
	BASIC	**DATA WORD-1	**DATA WORD-2	DATA WORD-3
*P	*Parity	*Parity	*Parity	*Parity
0	ΔX or ΔY			
1				
2	No. of			
3	Increments			
4		Row	Row	Symbol-1
5	Blanking			
6	Intensity			
7	Dash			
8	Flash			
9	Size			
10	Size	Column	Column	Symbol-2
11				
12	Mode			
13				
14	Word Type	Word Type	Word Type	Word Type
15	Word Type	Word Type	Word Type	Word Type

*If this cannot be included separately from the 16 bits, control words 1, 2, and 3 will have to be merged, thereby significantly increasing the number of times the control word BASIC will be used in coding the formats.

**The difference being blanked and unblanked without the use of "basic".

TABLE 5-7 - ORGANIZATION OF THE CONTROL WORDS FOR B DESIGN the positioning and vectoring of the beam to a resolution accuracy of 10 bits, but requires two data words, one for X and one for Y. The vector perturbation mode increments the previous vector by a ΔX of ΔY amount equal to the count set in the No.-of-Increment bit positions. The angle increment mode will rotate about the last blanked position in increments of $\Delta\theta$ and draw the last unblanked vector. This is permissable since all of the data reside in different registers within the display electronics.

The word type (basic and data words 1, 2, and 3) is identified by the two bits shown in Table 5-7. The remaining bits in the basic word are typical of those described in Concept A. Data words 1 and 2 are normally used to position the beam in a row-column matrix (72 x 80). If, however, the high resolution mode is selected, data words 1 and 2 are used explicitly to position the beam in x and y, respectively with 10 bit resolution. Similarly, if the rotate mode is selected, data words 1 and 2 represent the sine and cosine of the argument. On the other hand, if the angle perturbation mode is selected, data word 1 is interpreted to be the incremental angle, in which case the sine and cosine values are derived from 2 ROMs. Data word 3 is used solely to select (address) the character within the chosen size: A, B, or C.

(A) A: Normal

(B) B: Double

(C) C: Special

As in Concept A, each processor can handle up to three displays. A quick-look estimate of the timing requirements to achieve this indicated that more words must be processed due simply to the reduction in the word size (32 bits to 16). This being the case, multiplexing the control words at the controller allows for overlapping the processing and should be sufficient to permit control of three displays. This area does require more study effort.

The interface between the processor and controller is closed-loop, using an interrupt scheme. An interrupt is initiated whenever an end-of-message occurs and the constant-block-size counter cycles through zero, i.e., the controller must cycle through identical block sizes for each display to maintain synchronization for updating the dynamic memory blanks (note that updating occurs any time the dynamic banks are not being read, which could be implemented using two interrupts or the same interrupt twice).

5.3.2 Display Elements

The display subsystem under the B design consists of the following major elements:

(A) Display Processors (3)

(B) Display Controller Electronics (5)

(C) CRT Displays (5)

(D) Keyboards (3)

As in the A design, these elements are interconnected such that no one single failure is cause for a complete subsystem failure (Figure 5-18). Both manual and automatic reconfiguration are provided.

Display Processors

The general characteristics of the display processor are the same here as those given in Table 5-4 with one exception. The direct memory access channel need only handle 16 bits parallel; however, the data rate for this channel must double, i.e., from 80 kHz - 32 bits parallel to 160 kHz - 16 bits parallel. The reader is referred to the display processor description in paragraph 5.2.2.

Display Controller Electronics

The display controller electronics reads the format display control words from the refresh memory located in the display processor. These data are then decoded and processed in accordance with the selected modes to derive the voltages required by the CRT electronics.

The preliminary design of this unit is shown in Figure 5-19. Microprogramming is recommended for control because of its flexibility and inherent physical advantages. For these same reasons, read-only-memory (ROM) devices are used to achieve accurate digital voltages for beam positioning and are also used to derive the pulse trains (video modulation) representing the various symbols which are used to drive the CRT video channels.

To illustrate the various operations involved within the controller, a simple microprogram sequence is illustrated, Figures 5-20 and 5-21.

In viewing these figures, it can be seen that certain control statements are examined whenever data word 3 is read in. This is explained by Figure 5-22, which demosntrates that, of the normal 7-bit code used to address symbols in data word 3, a few codes are used for internal control such as spacing, start new line, end-of-message, and test codes.

CRT Display

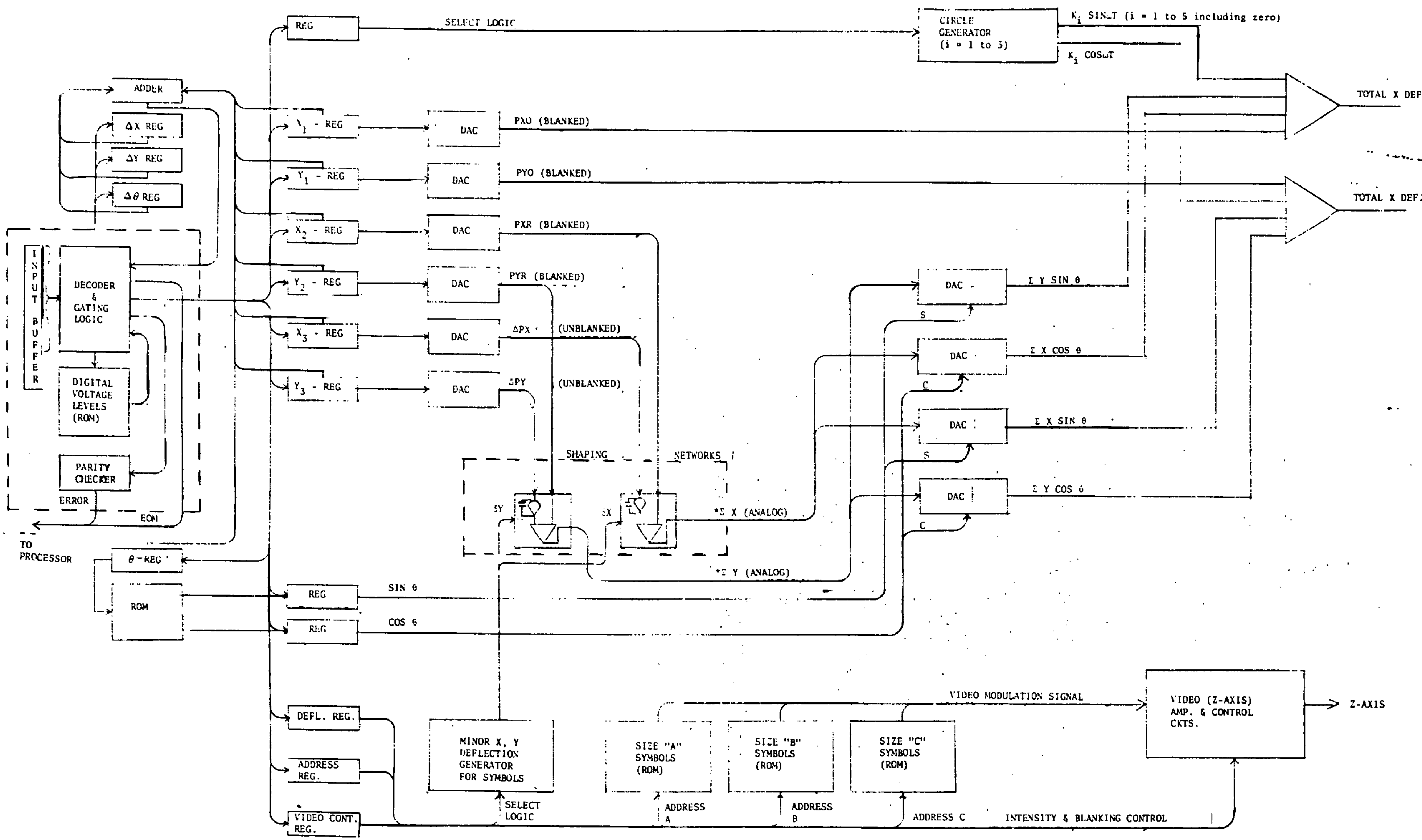
The primary difference between the A and B designs in the display electronics is that A uses electromagnetic beam positioning in conjunction with electrostatic deflection. In concept B, the latter is not required, thereby reducing deflection voltage requirements. However, because of the video multiplexing required for the dot matrix technique, the bandwidth on the z-channel is significantly increased and furthermore requires more sophisticated synchronization between all of the axes. Otherwise, both designs perform the same basic functions.

Keyboards

The keyboard design is the same as that described in paragraph 5.2.2.

5.3.3 Software Organization

With the exception of handling 16-bit words rather than 32-bit words, the basic structure of the software for Concept B is assumed to be the same as for A.



*APPLIED AS REFERENCE VOLTAGE

FIGURE 5-19. REFRESH CONTROLLER ELECTRONICS AND GENERATORS

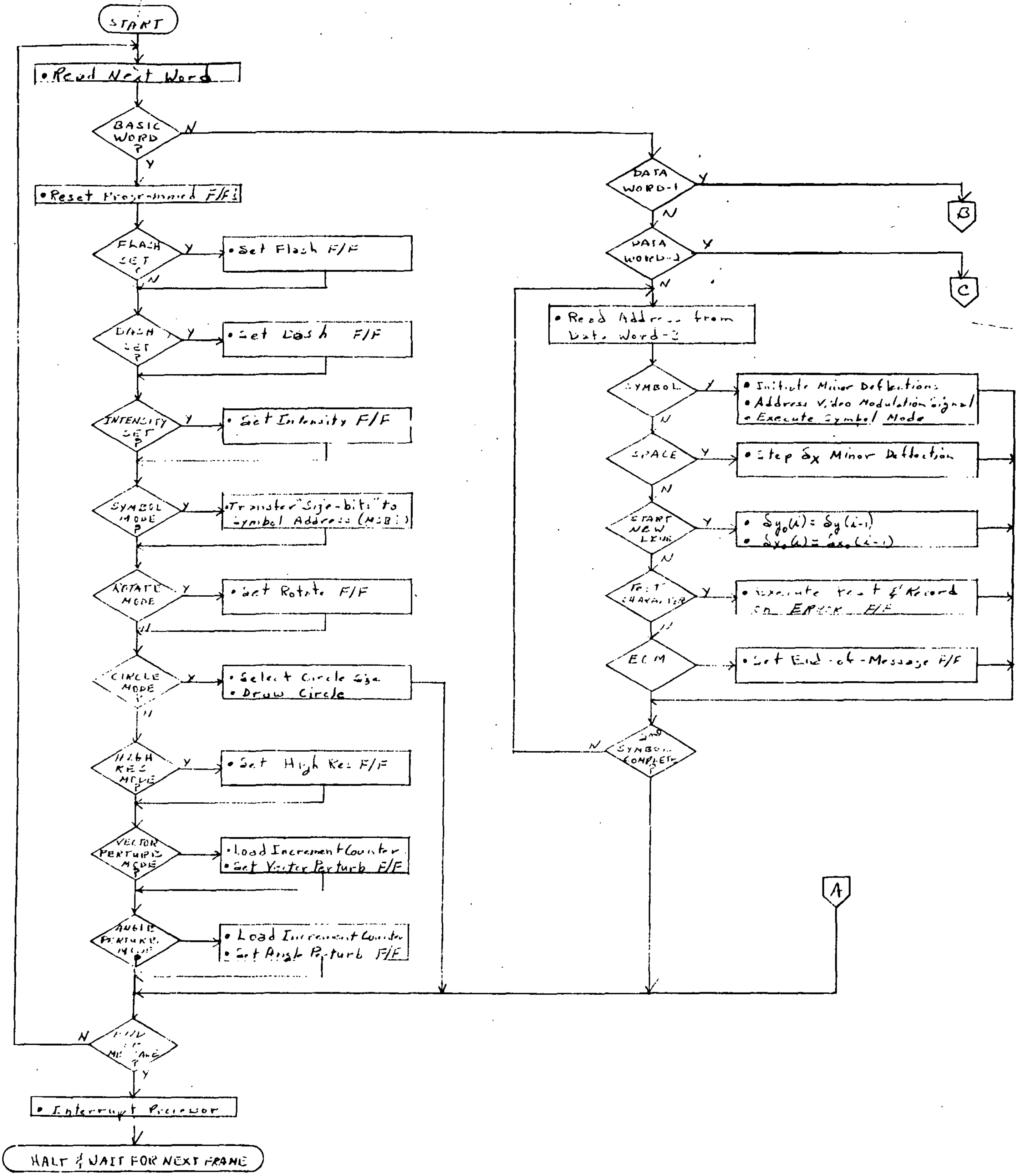


FIGURE 5-20. BASIC AND DATA WORD-3 MICROPROGRAM INSTRUCTION FLOW

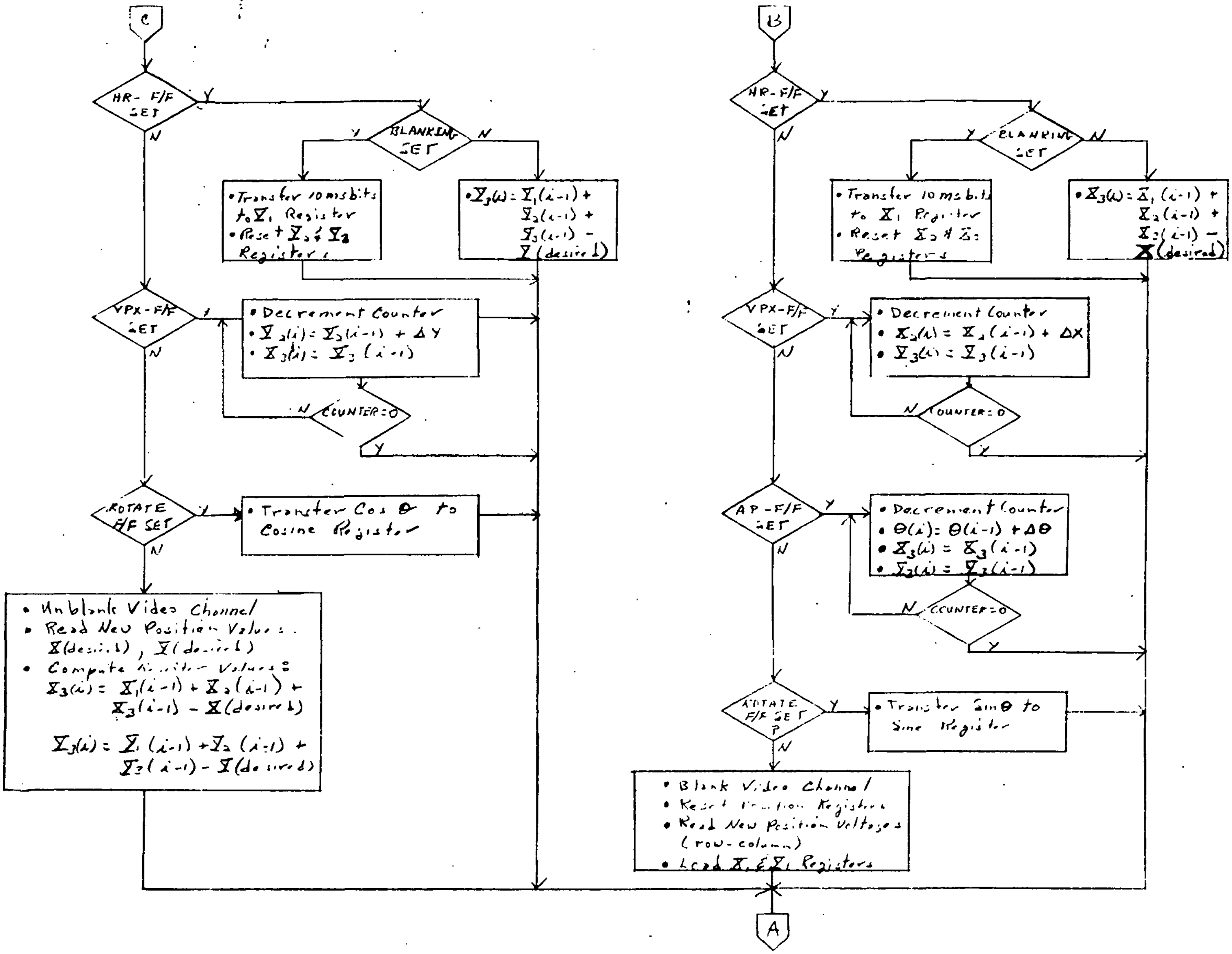


FIGURE 5-21. DATA WORDS 3 & 4 MICROPROGRAM INSTRUCTION FLOW

B7 →		0	0	0	0	1	1	1	1
B6 →		0	0	1	1	0	0	1	1
B5 →		0	1	0	1	0	1	0	1
B B B B 4 3 2 1	Column → Row ↓	0	1	2	3	4	5	6	7
0 0 0 0	0	*SPA	A	Q					
0 0 0 1	1	*SNL	B	R					
0 0 1 0	2	*EOM	C	S					
0 0 1 1	3		D	T					
0 1 0 0	4		E	U					
0 1 0 1	5		F	V			*BT4		
0 1 1 0	6		G	W					
0 1 1 1	7		H	X					
1 0 0 0	8		I	Y					
1 0 0 1	9		J	Z					
1 0 1 0	10		K	*BT3					
1 0 1 1	11		L						
1 1 0 0	12		M						
1 1 0 1	13		N						
1 1 1 0	14		O						
1 1 1 1	15		P						

*Control Words: SPA - Skip Space

SNL - Start New Line

EOM - End-of-Message

FIGURE 5-22 - TYPICAL ADDRESSABLE SYMBOLS

5.3.4 Memory Storage and Speed Estimates

Most of the quick-look effort in this area was concentrated on evaluating the effect of using 16-bit display control words over that of the 32-bit words.

To make a meaningful evaluation between the two word lengths, formats were selected from the various groupings described earlier and coded using both word lengths. These data were then tabulated and compared to show whether any improvement would be made in storage requirements using a 16-bit word organization over that of 32-bits. The results indicated an improvement anywhere from 2 to 25 percent, Table 5-8. The variation in percentage is primarily attributed to writing single characters using a 32-bit word rather than a 16-bit word, e.g., Format 979.

To estimate the impact on mass memory, the percentage improvement per group was multiplied by the number of formats in that group and then weighted by the complexity factor. This computation showed an estimated reduction of 35,100 32-bit words or approximately 12 percent improvement.

Such an improvement is worthy of further consideration, recognizing that the failure dictate and the 100 percent design allowance boosts this to a requirement of 212,000 32-bit words. On the other hand, such ramifications as increased programming required for the 16-bit word approach must be considered, i.e., the number of display control instructions is doubled. Additionally, either software or hardware is required to pack and unpack the 32-bit I/O (data bus) data. More addresses may have to accompany each of the formats due to the increased number of instructions. All of these represent trade areas that would be required in selecting between concepts A and B.

FORMAT NUMBER	DOT MATRI (16-bit Wo ds)	RANDOM STROKE (32-bit Words)	16:32 IMPROVEMENT (%)**	FORMATS PER GROUP	WEIGHTING FACTOR	MASS MEMORY REDUCTIONS (32-bit Words)
131	*2,130	*1,236	14	180	.6	18.5K
304	690	410	16	-	-	-
***405	730	420	13	130	.6	8.3K
507	630	320	2	-	-	-
721	550	310	11	22	.8	.6K
979	510	340	25	121	.8	8.2K

* Includes 30 events with no differentiation between static and dynamic

** Rounded off

*** Selected worst cases for this group (204, 405, 507 of same group)

Total Reduction Shown = 35,600 32-bit words

TABLE 5-8 - STORAGE IMPROVEMENT WITH WORD LENGTH

6.0 DMS IMPACT AND PROBLEM IDENTIFICATION

6.1 INTRODUCTION

The following section summarizes the impacts of the alternate control/display design concepts upon the DMS configuration and describes problems identified during the analysis. Problem areas identified include tradeoffs yet to be performed, as well as design, development, and operational usage problems.

6.2 DMS IMPACTS

The most significant impact on the DMS is upon the mass memory. To estimate the magnitude of this impact, the Phase B Space Shuttle DMS mass memory requirement shown in Table 6-1 was compared with an adjusted Phase B DMS requirement derived by substituting the display/control concept requirements for equivalent portions of the Phase B DMS estimates. The calculation was made in the following manner. The total Phase B DMS mass memory requirements were reduced by subtracting the following integrated control/display elements:

(a) Display Format Control Tables (2,000 words)
(b) Display Format Skeletons (29,800 words)
(c) Keyboard Input Control Tables (2,800 words)
(d) ID&C Programs (3,781 words)

This yielded an adjusted mass memory requirement (without controls and displays) of 140,000 32-bit words. To this adjusted requirement was added the estimated mass memory requirement for the control/display concept under study (Figure 5-15), reduced by the estimated 12 percent to be gained by using 16-bit control words; i.e., 266,000 equivalent 32-bit words. The total, or approximately 400K words, represents the DMS requirements with the least demanding of the two control/display alternates.

If the estimated requirements are further adjusted by a 100 percent design allowance, the requirements are approximately 400K words and 800K words for the Phase B DMS requirement and the Concept B requirement, respectively. Since this estimate is for one of a triply redundant memory system, when the requirements are adjusted for failure provisions, the total mass memory requirement is 1,200K and 2,400K for the two systems, respectively. The impact, then, is that the control/display concept, at a minimum, effectively doubles the DMS mass memory requirement. These data are summarized in Table 6-2.

Table 6-2. Comparison between Phase B DMS Mass Memory Requirements and Concept B Mass Memory Requirements

	DMS w/o C/D Memory	C/D Memory Reqt	DMS + C/D Memory	DMS + 100% Design Allowance	DMS with Triple Redundancy
Phase B Design	140K	37K	177K	≅ 400K	≅ 1,200K
Concept B Design	140K	266K	400K	≅ 800K	≅ 2,400K

Table 6-1. Baseline DMS - Estimated Mass Storage Requirements

TABLES	32-BIT WORDS
MISSION PHASE PROFILE	8,000
SYSTEM STATUS TABLE	1,750
TASK CONTROL	1,600
PROGRAM CONTROL	2,560
MISSION PHASE CORE MAP	2,400
MISSION PHASE DRUM MAP	600
CONTROL ACTION TABLES	6,000
TEST POINT MONITORING LIMITS	5,144
DIAGNOSTIC ANALYSIS DATA	2,400
SYSTEM RECONFIGURATION TABLES	728
DCM RECONFIGURATION	744
DISPLAY FORMAT CONTROL TABLES	2,000
DISPLAY FORMAT SKELETONS	29,800
KEYBOARD INPUT CONTROL TABLES	2,800
PROGRAMS	
EXECUTIVE	2,880
COFI	3,468
ID&C	3,781
SUBSYSTEM SOFTWARE	2,100
GUIDANCE, NAVIGATION & CONTROL	18,300
COFI DIAGNOSTICS	30,000
RECORDING	
STORAGE	50,000
TOTAL MASS STORAGE	177,055

The second significant impact on DMS design resulting from the display/control design concept is the necessity to provide a direct access channel to the display processors. This necessity arises from the choice of local processing rather than central processing for the control/display subsystem. If format data were transmitted over normal data bus channels, either an undesirable increase in format retrieval time would result or the DMS would have to be redesigned to allow more time on the data bus and/or to provide greater memory capacity in the ACT.

The selection of local processing reduces central processor requirements such as size, timing (or duty cycle), instruction repertoire, and I/O (or data) rates. The requirements imposed on the central processor using Concept B are less than those imposed by the Phase B control and display design approach. The Phase B central processor design was considered to include provisions for (a) the measurement data required by the formats, (b) the routines for executing system commands initiated from the keyboard, and (c) the basic I/O structure.

Both preliminary design concepts A and B kept within the data bus data rates specified by the baseline DMS configuration, given as follows:

(a) Processor-to-display:

124 32-bit data words @ 25 times/second

(b) Display-to-processor:

31 32-bit data words @ 25 times/second

Based on the assumptions made during the study, no other major impacts on the selected baseline DMS configuration were found resulting from the preliminary designs. It should be noted, however, that elimination of the stored checklist formats would decrease by half the anticipated impact of the display/control design upon DMS mass memory requirements and would lessen software requirements by at least 40 percent.

6.3 PROBLEM IDENTIFICATION

No catastrophic problems were revealed by the preliminary designs. However, several areas which require further study and evaluating, but which were beyond the scope of this study, did arise. These problems are discussed below.

6.3.1 Stroke vs Dot Matrix Techniques

While the analysis revealed that both the stroke and the dot matrix techniques are feasible techniques for the generation of the formats developed during the study, further tradeoffs are required before selection of one technique over the other. These tradeoffs include consideration of relative versatility (the dot matrix technique is much more restrictive to data format composition), power requirements, software requirements (complexity and magnitude) and cost (together with related reliability and simplicity of design factors).

6.3.2 Direct Access Channel

A tradeoff is required between the provision of a direct access channel between the display processor and mass memory and the provision of more time availability on the data bus and/or an increased ACT memory capacity. This assumes that increased access time to successive display formats is undesirable, from the operator's standpoint, an assumption for which supporting data are not yet available.

6.3.3 Software Programming

The large number of formats estimated for the Space Shuttle system presents a potential problem in software development. Consider 500 transient programs being operated on by one resident program. Furthermore, consider that the 500 programs were coded by 500 different programmers. What is the probability that all or any of the 500 programs can be operated on successfully by the resident program? In essence, this reasoning leads to a need for a "hard core" standardization, or even better, a compiler language for aiding in the programming of formats. Without the aid of either of these, the feasibility of the control/display concept becomes marginal due to the economics of programming, checkout, and software verification.

The standardization or compiler referred to must be designed to:

(a) Permit ease of coding by the programmer(s)
(b) Provide for separation of static and dynamic data
(c) Compact the dynamic data in a manner readily accessible for updating by the resident program.

To specify a compiler and a "user's" manual in accordance with these design requirements is beyond the scope of this study. However, certain recommendations can be made for further study and development.

First, it is recommended that the following preliminary design procedures be used to develop the standards:

(a) Categorize all update data required by the formats and analyze for commonality; e.g., 2-state discretes, 3-state discretes, analog bar charts, analog tape dials, analog magnitude, etc.

(b) Allocate these data to specific (addressable) locations in the dynamic memory.

(c) Develop specific routines for testing the presence of the data and for updating these locations whenever present.

(d) Categorize historical data, i.e., crew last-commanded component states stored in the historical matrix, in terms of 2-state commands, 3-state commands, etc.

(e) Develop specific routines for updating the corresponding symbols and for accounting for ambiguities between formats (a command displayed on more than one format).

(f) Develop universal (all 500) method for storing and interpreting the queuing and table lookup data with the formats.

After developing the resident routines, format storage should be organized in a compatible manner. It should be noted that a 5 to 10 percent reserve for variations in basic standards could be required. The basic formulation suggested for the storage media should correspond to that described in the preliminary design.

To recap, the resident routines for updating dynamic memory should be developed and a standard format storage medium, compatible with those routines, should be structured. With this in mind, a compiler language could be developed for the generation of formats which would be compatible with the resident program.

A procedure could be used for compilation, either the "brute force" method (draw it on paper, punch cards, compile, check listings, etc.) or an on-line CRT terminal. The latter would reduce turnaround time and would give the programmer a quick look at the format on the display. A better recommendation, however, would be the use of a dedicated format generator. To accomplish this, one of several available graphic display generators could be integrated with the compiler in the generator processor. In this manner, the programmer could, off-line, input the data in the form that it would actually appear on the display. Furthermore, he would have the capability to make immediate changes and to separate both static and dynamic data. Upon completion of a satisfactory format, the programmer would then simply request the compilation (or translation) into the language used for storage in mass memory.

To test this approach, Format 510 was generated on the Information Displays Incorporated (IDI) IDIIOM display generator. The result, drawn by graphic plotter, is shown in Figure 6-1. It was found that the entire format could be drawn in less than an hour, less time than required to make the original pencilled drawing. Coding into a format compatible with the XDS 9300 computer was automatic.

6.3.4 Operational Utilization

Several problems arose concerning the operational utility of the control/display concept under investigation. Of greatest impact on the overall DMS design was the decision to store and display operational checklists. Timeline analyses showed that within the assumed available time and operational procedures, both stored and printed checklist approaches were feasible. The use of printed checklists greatly increases the amount of "flipping" between formats required to complete most operational procedures, but it cuts in half the increase in DMS mass memory required to utilize the control/display concept. No data are available to determine the amount of savings in lowered error rates, lower operator fatigue and reduced training which may be gained by the use of stored checklists - data which must be gained through controlled simulation experiments.

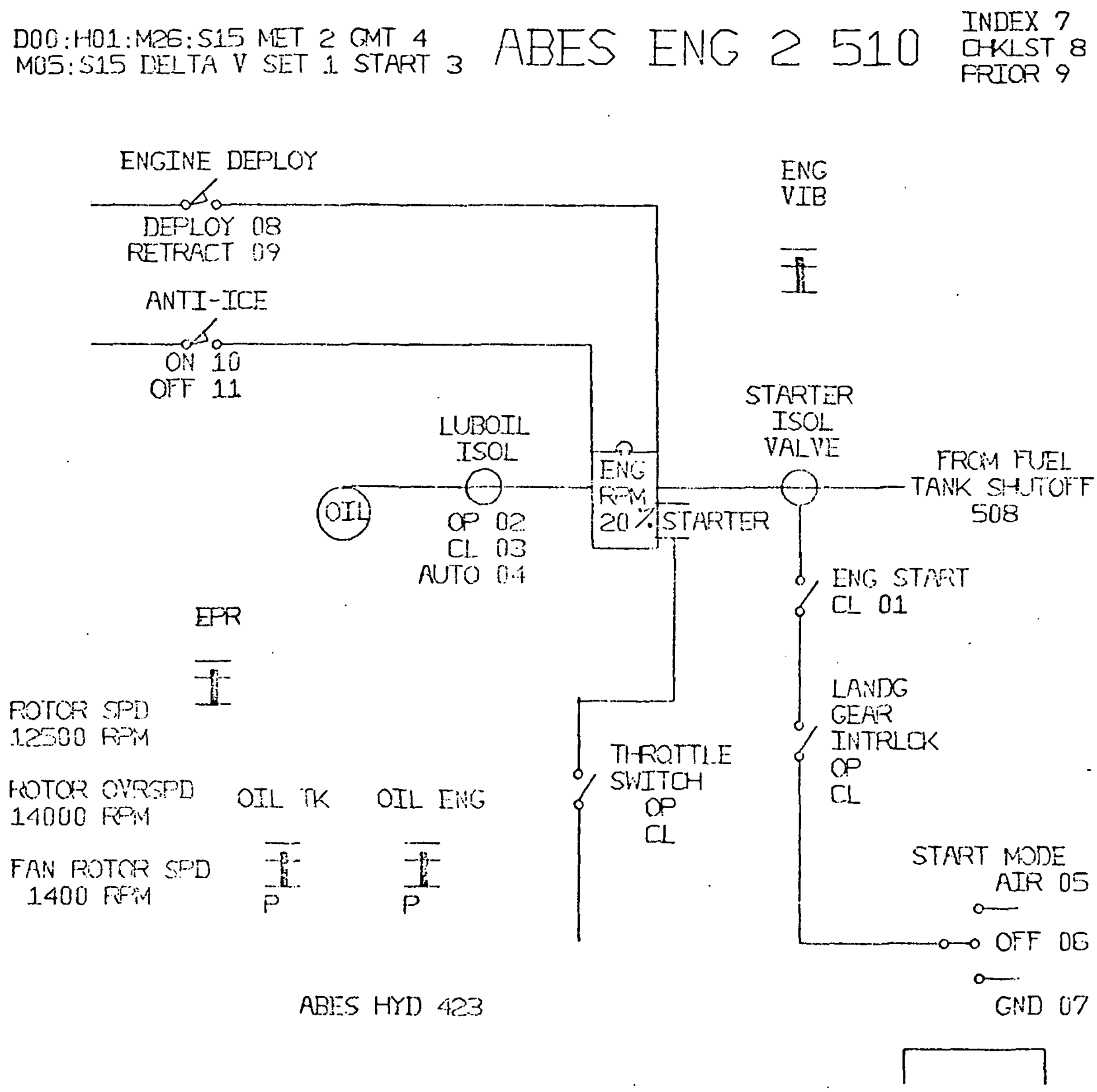


Figure 6-1. Display Format Developed on IDI Display Generator

During the development of the sample formats, a number of decisions were made based on expert judgments concerning such factors as maximum permissible format density, symbol size and shape, organization of data, etc. Within the context of the study, it is believed that the decisions made were in keeping with shuttle operational requirements and good human engineering standards; however, there is a strong need for systematic experimental verification of the integrated effect of the assumptions and for the development of a data base built around this type of display approach to facilitate its use in the future.

Of course, no data are available concerning the acceptability of this approach to trained pilots/astronauts previously trained on systems utilizing dedicated controls and instrumentation.

All of the above considerations indicate a need for man-in-the-loop simulation of the control/display concept to permit realistic further evaluation and development of the concept.

7.0 APPLICATION OF CONTROL AND DISPLAY CONCEPT TO THE NORTH AMERICAN ROCKWELL - SPACE DIVISION (NR-SD) PROPOSAL SHUTTLE CONFIGURATION

This section describes a limited supplemental study performed after completion of the main study (Sections 1 through 6) and directed toward examination of the application of the control and display concept to the NR-SD shuttle configuration proposed in response to NASA space shuttle program request for proposal No. 9-BC421-67-2-40P. This NR-SD configuration is referred to in this report as NR-SD baseline.

7.1 OBJECTIVE

This supplemental study objective is to examine application of the control and display concept to the NR-SD baseline by defining a mechanization approach, impacts and problem areas.

7.2 WORK ACCOMPLISHED

The supplemental study was performed in five phases: (1) Review of mission and vehicle characteristics, (2) select representative subsystems for evaluation and define requirements for the selected subsystems, (3) define a mechanization approach, (4) preliminary design considerations of key major items of the CRT control and display system, and (5) assessment of impact of applying concept to the vehicle.

7.3 BASELINE MISSION AND CONFIGURATION

This section presents the results of the review of the baseline mission and vehicle characteristics, the selection of subsystems for evaluation, and describes the selected subsystems.

7.3.1 Mission and Vehicle Configuration

Missions 1, 2 and 3 described in section 1.2.0 of NASA Space Shuttle Program Request for Proposal No. 9-BC421-67-2-40P were reviewed against the baseline mission defined for the control and display concept study and described in section 3.2 of this report. The functions and tasks required by the baseline mission were found to encompass those required for Missions 1, 2 and 3. Therefore, the baseline mission was adopted for the supplemental study.

The orbiter vehicle described in NR-SD shuttle proposal 5D-72-SH-50-3, volume III, is used as the baseline configuration for the supplemental study. Diagrams of the principal subsystems are provided in Appendix E.

The NR-SD system was reviewed for the purpose of selecting two subsystems to investigate application of the control and display concept. The two subsystems were selected as representative of the range of conditions to be encountered in the total vehicle since study resources did not provide for defining specific concept application for every subsystem. Selection criteria included expected magnitude of change of adapting to the concept and a representative range of data handling and redundancy conditions. The Guidance Navigation and Control (GN&C) subsystem is characterized by largely digital data handling and processing, a significant crew interface through a multifunction CRT subsystem, and critical redundancy requirements. The electrical power distribution and control subsystem (EPDC) is almost entirely analog, uses largely dedicated controls and displays with only a small interface to the multifunction CRT subsystem, and has a relatively large number of end effectors (remote controlled circuit breakers and power contactors) to control. The other subsystems appeared to fall within the range of conditions represented by the GN&C and EPDC; hence, these two subsystems were selected for investigation of application of the control and display concept. The Data Processing and Software subsystem (DPS) role in data handling and control and display functions involves the DPS as a primary study area. The baseline configuration for these subsystems and comparison to Phase B are described below. The baseline descriptions are condensed from the NR-SD shuttle proposal SD-72-SH-50-3, which is used as the basic data source.

7.3.2 Data Processing and Software Subsystem

Application of the control and display concept involves examination and possible change to the data processing and software subsystem which is central to a significant part of the vehicle data handling. The following description of the baseline data processing and software subsystem is therefore provided.

The data processing and software subsystem provides the on-board digital computation required to support the vehicle subsystems. The system configuration proposed by NR-SD shown in Figure 7-1 uses two computer types, the GN&C computer and the modular display electronics (MDE) in several combinations to satisfy functional and redundancy requirements.

Key features of the data processing and software subsystem configuration are:

- Computation tasks are grouped and allocated for separation of high development activity and isolation of high traffic data from flight critical functions.
- Display, keyboard and non-GN&C computation functions mechanized in a single type, small computer augmented by tape mass memory.
- No direct exchange of data between computers performing redundant functions (multiple cross switching but no cross strapping), low data rate and non-interrupt transfer of data, memory protection.

The hardware elements which comprise the data processing and software subsystem include the on-board computers, the mass memories, and the adapting input-output elements. A summary of the important design features is in Table 7-1. Primary GN&C functions are mechanized in a high-speed, 64,000-word main memory, general purpose computer.

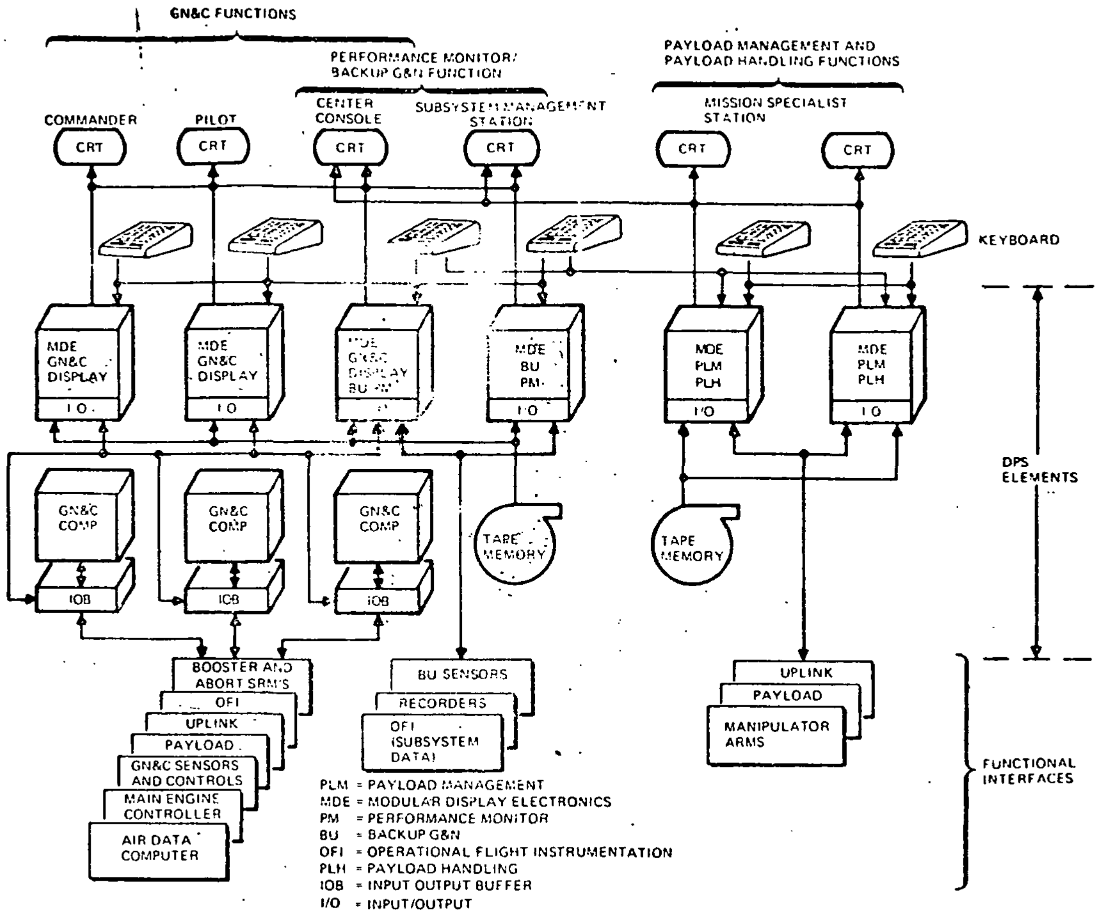


Figure 7-1. Data Processing and Software Subsystem

Table 7-1. Hardware Design Features

Features	Benefits
Computer interface	
Direct memory access input/output	Concurrent CPU and input/output operation.
Modular input/output interface	80% standard, 20% custom, modular design allows use of off-the-shelf equipment in other subsystems.
PCM decommutation channel (MDE)	On-board decommutation capability for operational flight instrumentation and payload serial data channel (256 Kb/s, maximum), permits on-board performance monitoring.
Computer features	
Off-the-shelf subassemblies	Uses existing subassemblies from military production programs plus MSI/LSI devices from same programs for new subassembly. Allows use of existing hardware for early lab test and software development
Memory and register protection/preservation	Retains current register data and protects memory contents in the event of anomalies in input power.
Floating point hardware	Reduces software preparation and verification costs. Software savings exceed hardware cost increase.
Display processor, symbol generator and refresh (MDE)	Combined electronics for display and computation reduces development costs.
Phase locked internal clocks (GN&C) to Master Timing Unit	Simplest way to avoid relative string drift and accumulated time inaccuracies.
Growth provisions	
Speed greater than 300 kops	128 kops required, reserve > 100%.
Main Memory--64K 32 bit words (GN&C)	30,300 words required, reserve > 100%.
--8K 32 bit words (MDE)	5400 words required, 50% reserve plus mass memory.
Input/Output--channels	100% growth possible within existing LRU by adding required logic hardware.
--3.2 M bit/sec channel (GN&C)	Provisions for future mass memory without design modification.
Mass Memory--Tape 256 K words 40 K bit/sec transfer rate (MDE)	Allows smaller main memory; low transfer rate compatible with available tape equipment.

LSI - large scale integrated
MSI - medium scale integrated

Technical evaluation of the remaining computer functions shows that they are not time critical, can be broken into small segments for processing, and are not all required simultaneously. Therefore, these functions are distributed among several small identical processors with mass memory for program reload.

The payload data processing requirement of 10,000 32-bit words is satisfied by the use of a modular display electronics unit with an equivalent of 8000 32-bit words in the main memory and the tape mass memory.

The input/output (I/O) interface between the computers and the other vehicle subsystems is implemented using a modular design concept to provide the flexibility to accommodate changing requirements and permit early computer design. The modular display electronics I/O, computing, and display subassemblies are combined into a single unit, which permits a simple design and is feasible because the identified I/O channel requirements are primarily multiplexed, serial digital. The I/O to the GN&C computers is significantly more complex and subject to change; therefore, these functions have been grouped into a separate unit identified as the GN&C I/O buffer. The I/O buffer provides the functions of signal conversion, multiplexing, and transfer of data to and from the computer memory. The transfer functions are accomplished by using a direct memory access channel which operates independently of the CPU, except for initialization.

The on-board software design approach is intended to provide a single design (baseline) program that can accommodate all shuttle missions. The flight software structure uses self-contained program modules, all intermodule communication being through mutually accessible, common data pools. This concept provides isolation of changes in order to control error propagation, management change control at the unit level, and elimination of intermodule interference in order to simplify program verification. Control and scheduling of the individual modules are provided by the executive program, the structure of which is identical for all programs and is based on internal timer interrupt, fixed time slice, tabular look-up mode of operation devoid of external interrupts. This type of executive structure simplifies the verification process by providing a repeatable program pattern at fixed intervals whenever the intervals are predetermined during the program design phase.

Table 7-2 illustrates the assignment of programs and requirements to the functionally dedicated GN&C computers and MDE's and identifies the memory size, speed estimates, and capabilities.

A brief comparison with the Phase B data processing and software subsystem demonstrates the two different methods of solving the processing problem. The Phase B approach utilizes a centralized multiprocessor configuration rather than dedicated. In this configuration the central processor is interconnected and interfaced with the on-board elements through a five-channel data bus subsystem and acquisition, control and test (ACT) units, respectively. A simplified block diagram illustrating the Phase B approach is provided in Figure 7-2.

Table 7-2. Program Functional Requirements & Memory Estimates

GN&C Function	Size and (Speed) GN&C	Size and (Speed) MDE
Executive Data pool, subroutines, input/out, sequencing, scheduling, tables	3950 (13.8)	350 (0.5)
System status Redundancy management, GN&C, system performance monitor, ground checkout	2200 (25.5)	
Flight crew displays GN&C system status, procedures	450 (0.4)	3600 (5.6)
Navigation State vector, attitude reference	5850 (2.1)	
Guidance Steering commands, engine control, abort	7500 (39.5)	
Targeting	4200 (19.3)	
Flight control TVC, RCS, digital outer loop, boost blending	2950 (20.1)	
Program services Uplink, PCM, preflight, system align and calibration, interfaces (booster, payload, main engine controller, GSE interface)	2700 (5.0)	
Unmanned orbiter Sequencing, calculation for autonomous flight	500 (2.5)	
Program loader		100
Peak memory loading	30300 (128.2)	4050 (6.1)
Machine capability main memory	65536 (380.0)	8192 (296.0)
Tape memory		256 K

PM and Backup GN&C MDE's Function	Size and (Speed) PM	Size and (Speed) BU GN&C
Executive Subroutines, input/output, data pool, tables	400 (0.5)	400 (5.0)
System status Non-GN&C system performance monitor, annunciator lights, self-check	900 (20.0)	
Crew station displays Input/output conversions, formats, tables, display services, time share GN&C, PM, and backup GN&C	3900 (5.6)	
Backup GN&C Steer to displays, get-home guidance and navigation		2950 (33.1)
Program loader Tape memory load on crew request	150	150
Peak memory loading	5350 (26.1)	3500 (38.1)
Machine capability main memory	8192 (296.0)	
Tape memory	256 K	

PLM and PLH MDE's Function	Size and (Speed) PLM	Size and (Speed) PLH
Executive Subroutines, input/output, data pool, tables	900 (2.5)	900 (2.5)
System status Performance monitor, analog, discrete, serial limit checks	*2000	1400
Crew displays Input/output conversions, formats, tables, display services	500 (5.6)	500 (5.6)
Payload checkout Minimal on-board checkout, no experiment processing	*2000 (3.0)	
PLH control program Closed-loop control of attitude, rate, and position		1000 (36.3)
PLH constraint tables Deployment and retrieval trajectories, payload dependent tables		1000
Program loader Tape memory load on request	150	150
Peak memory loading	3550 (13.1)	4950 (44.9)
Machine capability main memory	8192 (296.0)	
Tape memory	256 K	

Note: Sizing is in terms of equivalent 32-bit words. Most GN&C computer instructions are 16 bits.
MDE computers are all 16 bits. Floating point data are 32 or 48 bits and other data are 16 or 32 bits. Speed in KADS.
MDE—modular display electronics PLM—payload management PM—performance monitor PLH—payload handling

*Mutually exclusive, tape memory load

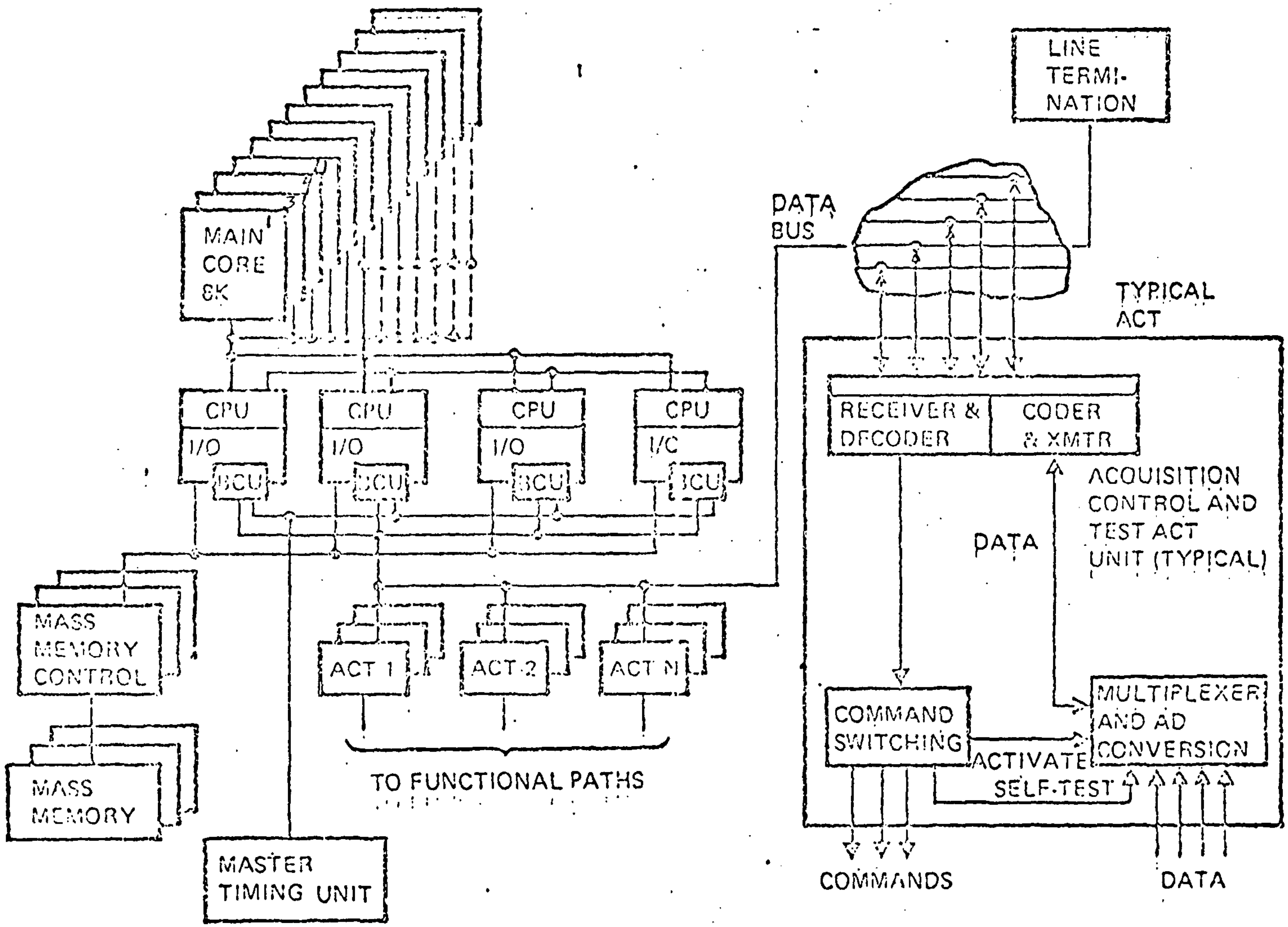


Figure 7-2. Phase B Central Computer System

7.3.3 GN&C Subsystem

The Guidance, Navigation and Control subsystem is one of the several on-board dedicated subsystems. Briefly, the selected baseline GN&C subsystem provides the capability for both automatic and/or manual control over the entire mission.

The GN&C subsystem is divided into three groups of equipments: the primary GN&C, the backup GN&C and the Aerodynamic Stability Augmentation Subsystem (ASAS). A simplified diagram depicting the overall mechanization, as proposed by NR-SD, is presented in Figure 7-3. Additionally, the various modes of operation are given in Table 7-3.

In accordance with SD, the primary GN&C equipments provide: (1) automatic and manual control capability for all of the flight phases except for docking, which is manual only; (2) guidance commands for the control loops; (3) steering displays for the crew; and (4) inertial navigation updated by star and horizon sensors for autonomous orbital flight and by RF navigation aids for rendezvous, approach, and landing.

The primary subsystem provides for both automatic (command) and manual (control stick steering) modes (Table 7-3). The flight control loops used with the main engine and orbital maneuver subsystem, thrust vector controls, and the reaction control system are closed through the GN&C computers. Aerosurface control is provided by the GN&C computers and the ASAS.

The basic aerodynamic stability of the orbiter is augmented by using the ASAS. The ASAS is a conventional type employing body-mounted rate gyros and accelerometers. Gain scheduling is provided by a digital air data computer and deployable probes. Side stick rotation controllers, rudder pedals and trim control allow for manual control.

The backup GN&C subsystem provides a safe return capability from all flight phases. These equipments are separate from the primary subsystem and use dedicated sensors and electronics. Backup flight control is manual; rotation controller and rudder pedal inputs are used. Steering information is displayed on the cockpit CRT's (MDE's).

It is interesting to note the difference between this baseline GN&C subsystem and the integrated concept (Phase B study). A fundamental difference is the means for data flow. In the case of the integrated concept all of the avionics subsystems are interfaced with and controlled by a central computer complex via a common data bus. As such, this allows a simple non-redundant display subsystem complete access to all of the data within, as well as control over, the entire avionics system.

The baseline approach, on the other hand, divides the various avionics functions into equipment groupings wherein the equipments in each group are interconnected through conventional dedicated cabling practices. For this reason, the dedicated system uses a larger number of controls and displays. However, in order to meet the failure criteria (fail-op, fail-safe) overlapping of functions is permitted within certain of the display subsystems and, in particular, the MDE's. Of further importance, due to the redundancy

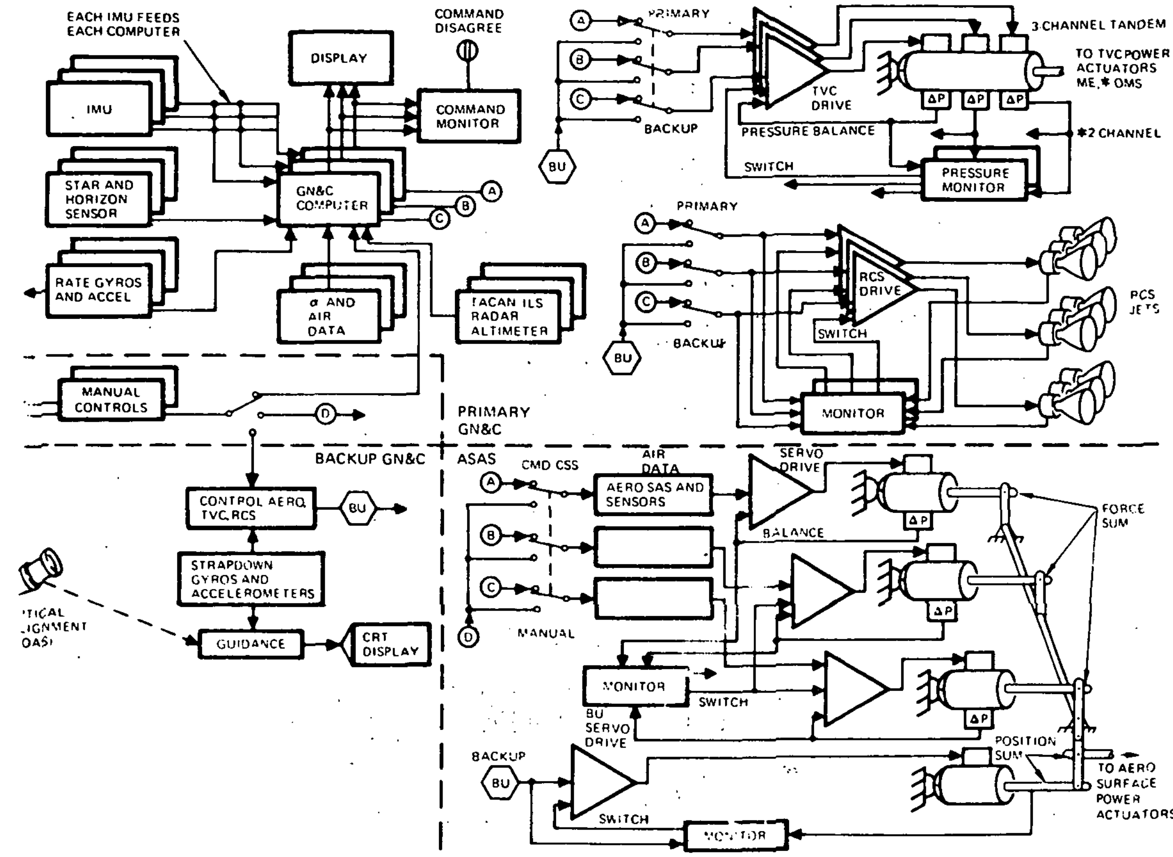


Figure 7-3. Mechanization of GN&C

Table 7-3. Control Modes

Mode	Flight Phase	Characteristic
Command	• Boost/insertion (TVC) Orbital (OMS TVC,RCS), Entry, Aero, Landing	• Crew initiates guidance and control modes and monitors—control automatic through GN&C computer
Control stick steering	• Orbital (OMS TVC or RCS), Entry, Aero, Landing	• Manual control and guidance displays through GN&C computer • Rate command, attitude hold, and RCS minimum impulse; RCS translation—acceleration command
Manual	• Aerodynamic	• Manual control through ASAS Rate command and damp
Manual (backup)	• Boost/insertion (TVC) Orbital (OMS TVC or RCS), Entry, Aero, Landing	• Backup sensors and computer; Rate command and damp • Direct RCS jet

criteria, is the operational configuration. The integrated system uses multiple independent subsystems interconnected to a quad redundant central processor via five independent multiple data bus channels. In this manner fault detection is achieved by voting on the data and weighing results at the various terminals, performing independent parallel processing, and maintaining the central processor in overall control. In the case of the baseline subsystems, the GN&C, in particular, operates as three independent strings with cross strapping of signals at the force servos and jet drivers, as well as the IMU outputs at the processors for initialization and fault detection. Fault detection of the processors themselves is done by BITE; otherwise, the subsystems themselves are left to detect any faults generated by the processors; e.g., note the servo and reaction jet inputs A, B, and C shown in Figure 7-2.

Further differences between the two approaches include the following:

1. An analog aerodisplay subsystem as well as CRT's is included in the baseline approach.

2. A completely independent backup subsystem is used by the baseline approach.

3. The use of horizon sensors, TACAN, and ILS over that of the multilateration system used in the Phase B.

7.3.4 Electrical Power Distribution and Control Subsystem

The electrical power distribution and control subsystem (EPDC) provides distribution, control, and conversion of all electrical power, and, in conjunction with the electrical power subsystem, assures power characteristics compatible with all orbiter, tank, and SRM requirements. EPDC also provides sequencing functions and interconnecting wiring for all subsystems.

Figure 7-4 depicts the proposed NR-SD orbiter EPDC bus control/distribution scheme and its interface with power sources and loads.

The subsystem is characterized by 28 volts nominal dc buses and 115/200 volts, 400 Hz, nominal main and inverter ac buses. Three redundant buses operate simultaneously; each is isolated to avoid complex paralleling controls and to confine power transients to a single redundant string. The essential control buses supply sequencer logic power and loads required to initialize main bus pcwer from a power-off state. Salient features of the EPDC and the candidate hardware types are shown in Table 7-4.

Comparison to the Phase B EPDC (Figure 7-5) shows similarity of power sources and bus structure. The difference of significance to this study is the interface with the remote controlled circuit breakers (RCCB) and the remote power controllers (RPC). Phase B provides control to these elements from the central data bus of the data control and management subsystem (DCM) via acquisition control and test units (ACT) whereas the NR-SD baseline typically provides dedicated wire and cockpit switch control of these elements.

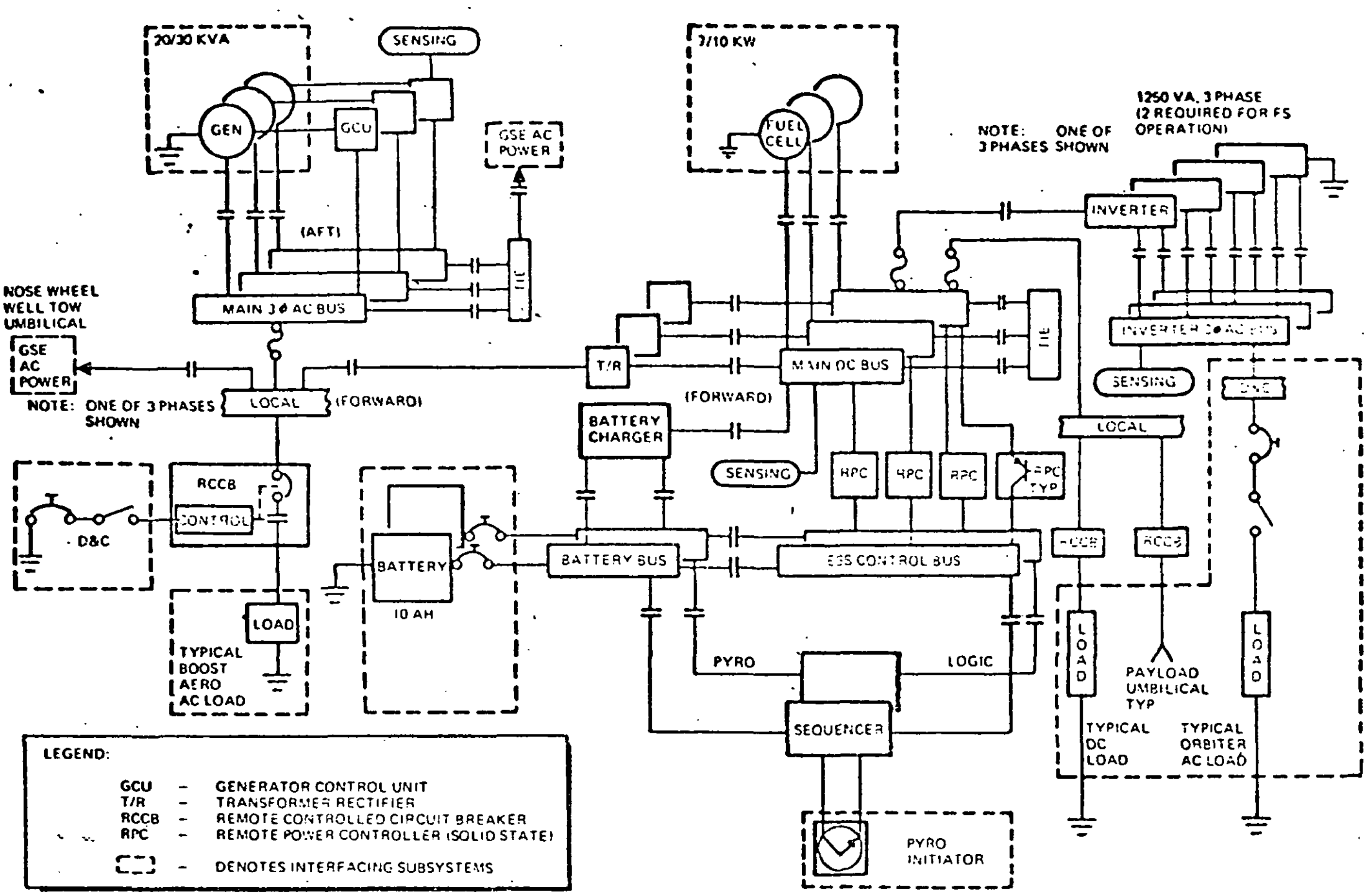


Figure 7-4. Electrical Power Distribution and Control Schematic

Table 7-4. EPDC Features

Feature	Selected Approach	Equipment/Components
Power types		
DC	24-30 v at load	Fuel cells, 150-amp transformer-rectifier, 10 amp-hr batteries, battery charger
Aero, boost and entry ac	115/200-v, 400-Hz generator (MIL-STD-704A)	Generators, generator control unit
Orbit ac	115/200-v, 400 Hz central inverter system (CSM limits)	CSM 1250-va 3-phase inverters (refurbish-reuse)
GSE	115/200-v, 400-Hz (MIL-STD-704A)	Ac power umbilicals
Bus redundancy	Three redundant	Magnetic latch, hermetic sealed power contactors
Redundancy management	Isolated (ac nonsynchronized—isolation maintained from source through load) Bus transfer after source failure Redundant loads powered from redundant buses	Magnetic latch, hermetic sealed power contactors
Load control	Hardwired electromechanical	Magnetic latch, hermetically sealed RCCB's RPC's, high-reliability relays
Power current return	Structure, multipoint ground (single-point ground for signal circuits)	
Sequencing	Conventional logic—with voting inputs and basic timing from GN&C computer	Relays and solid-state logic
Circuit sensing Main ac	Over-under voltage Over-under frequency Overload	Generator control unit
Dc	Undervoltage, overload	Solid-state sensors
Inverter	Over-under voltage, overload	Solid-state sensors
Fault	Inverse time-current interruption Current limited, timed interruption	RCCB's, thermal circuit breakers, fuses MIL-Spec solid-state RPC's

[ ] Denotes non-avionics equipment; RCCB—Remote control circuit breakers; RPC—remote power controllers

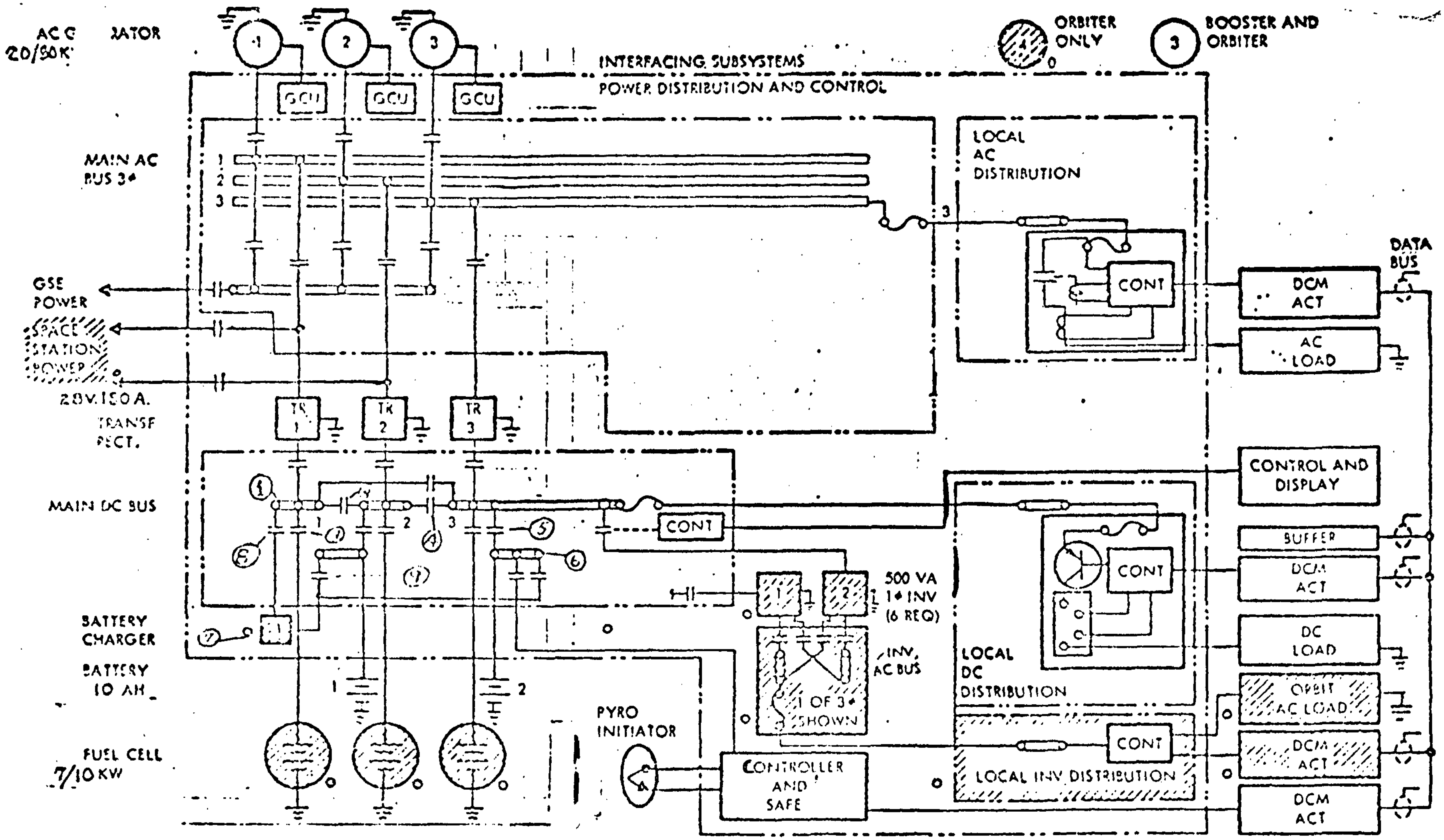


Figure 7-5. Phase B EPDC

3

7.4 APPROACH TO INCORPORATE CONTROL AND DISPLAY CONCEPT

This section describes (1) the changes to the Phase B CRT formats to apply the control and display concept to the baseline system and (2) the system changes in the DPS, GN&C, and EPDC subsystems to accommodate the concept.

The crew function allocations, crew stations, number of keyboards and CRT's, and display of flight path monitoring by dedicated mechanical instruments are retained from the NR-SD baseline system.

7.4.1 CRT Formats

The control and display formats defined for the Phase B GN&C and EPDC and described in section 3.0 were reviewed to determine applicability to the shuttle baseline subsystems described in sections 7.3.2 through 7.3.4.

The GN&C functions handled through the Phase B CRT formats (section 3.7.4) group into the principal areas of vehicle management, GN&C subsystem management (mode, power and redundancy), checkout, caution and warning, checklist, and index. Examining these functions in terms of the NR-SD baseline system, the principal impact due to the difference between Phase B configuration and the NR-SD proposal baseline is in the vehicle management and checkout areas. The baseline provides for dedicated mechanical instruments to perform the ADI and HSI flight path display functions and, hence, does not require formats for primary vehicle flight path control; however, typical formats are required for backup GN&C flight path control. Format deletions and additions are also required to accommodate the deletion of the Phase B precision ranging system (PRS) and the addition of horizon sensor, TACAN, ILS and dedicated GN&C computers. Checkout and caution and warning comprise functions included as performance monitoring in the NR-SD baseline.

In Phase B fault detection and isolation was accomplished by the on-board computer system by appropriate troubleshooting logic routines. In the baseline system, fault detection and isolation is crew accomplished using BITE. This significantly reduces the format requirements for this function.

Review of the design approach of the Phase B formats does not indicate the need for significant change to adapt to the NR-SD baseline system. The two- and three-digit operation codes, symbology and data content per format (Table 3-3) are applicable and, in general, the formats require only re-drafting to conform to the NR-SD baseline configuration. Table 7-5 is an estimate of the GN&C format impact of the baseline.

Table 7-5. GN&C Format Comparison

	Phase B	NR-SD Baseline
Index	1	1
Subsystem Management	12	14
Vehicle Management	15	15
Checkout/Performance Monitoring	7	4
Caution and Warning	7	9
Total Formats	42	43

The EPDC functions handled through the Phase B CRT formats group into the areas of subsystem management, checkout, caution and warning, checklist and index. Review of the Phase B formats indicate, with minor exceptions, adequacy as designed due to the very close similarity between the NR-SD Phase B and NR-SD baseline EPDC subsystems. The greatest change would be adapting checkout formats to performance monitoring.

Storage in mass memory of timeline format and the checklists required for flight operations is a feature of the application of the control and display concept to the Phase B shuttle vehicle. Both of these features are retained in the application of the concept to the NR-SD baseline vehicle. Format requirements for checklists and timelines are considered nominally equivalent for both configurations.

7.4.2 Subsystem Changes

7.4.2.1 Data Processing and Software

The baseline data processing and software arrangement, illustrated in Figure 7-1, requires certain changes in order to conform with the display and control concept under study. The purpose here is to identify and define the need for these changes.

The first significant change is the addition of three subsystem management (SM) computers and supporting equipments: three input/output buffer units; two additional mass memory tape units; and a multitude of command decoders. These added equipments and their rearrangement are presented in Figure 7-6.

The addition of these equipments and ultimate rearrangement of functions is based on the system reliability criteria for fail-operational, fail-safe. The application of these requirements comes about as a result of the concept under study which dictates the replacement of hardwired cockpit switches and controls with keyboard inputs and an interactive CRT display-to-operator interface. That is, the functions performed under computer control at the subsystem management station become critical and therefore must meet the system reliability goals. This implies a minimum of triple redundancy; i.e., three independent means of performing subsystem management functions. The choice of adding three additional computers over that of integrating into the MDE's is based on the conflict of dedication. That is, only one MDE could be dedicated to GN&C without having to perform other functions. Thus, with the addition of SM computers, a rearrangement of functional allocations is also in order.

The first logical rearrangement of functions (and thereby changes in software), other than performance monitoring, involves the GN&C backup computations. These, along with those for performance monitoring, are removed from the MDE processors and placed in the SM computers. The function of performance monitoring is integrated with the added requirement for command and control or in essence combined to effect the display formats described earlier in this report. The SM program (software) functions and corresponding memory size and speed estimates are given in Table 7-6.

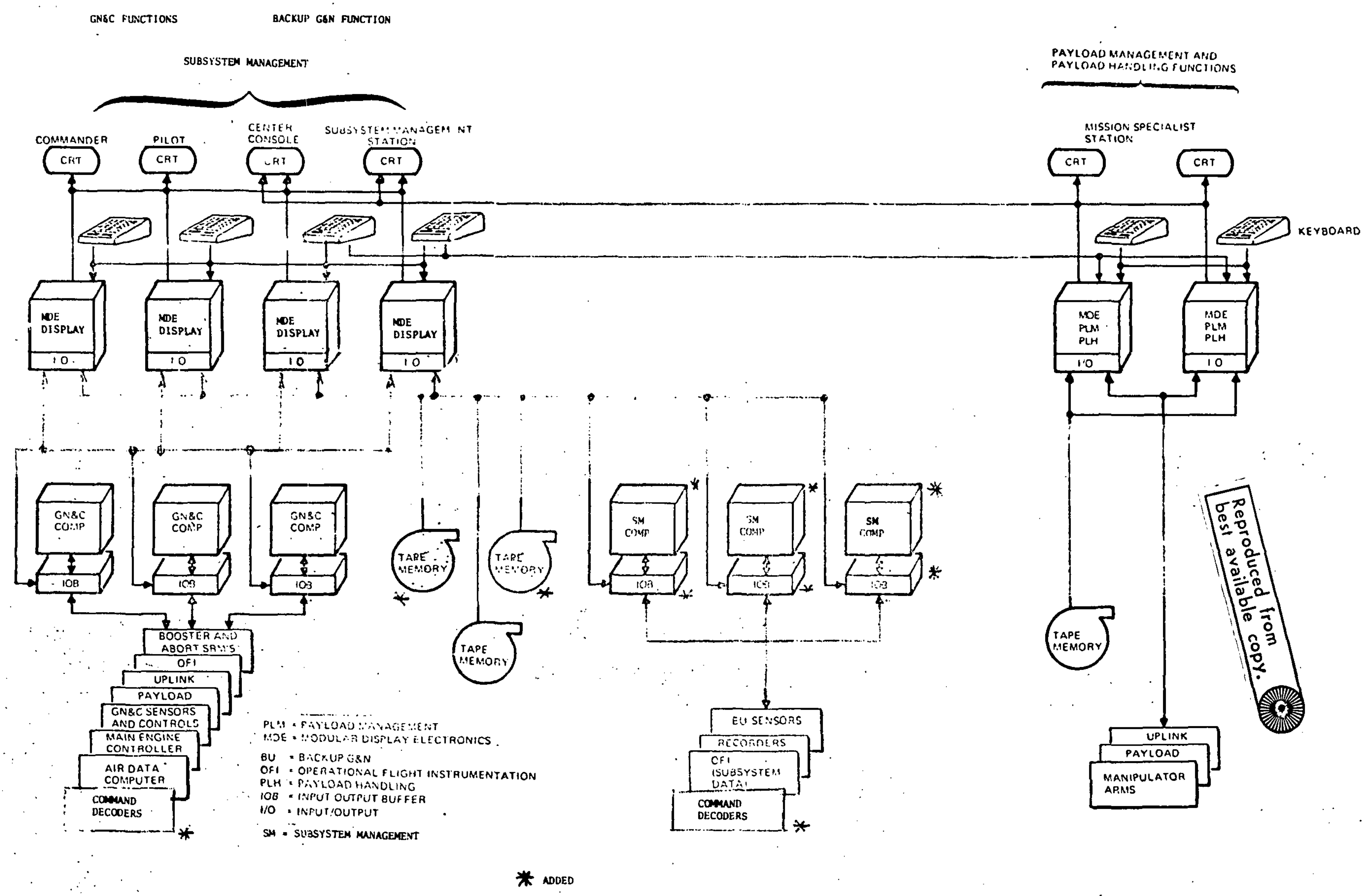


Figure 7-6. Data Processing and Software Rearrangement

Table 7-6. SM Computer Program Functional Requirements and Memory Estimates

FUNCTION	SIZE & (SPEED)
Executive Utility Routines, Input/ Output, Tables, Data Pool Scheduling	900
Crew Displays Execute Input Commands, Read Requested Meas Data Tables	750
Performance Monitoring, Limit/Status Chk, Fault Annunciation	2,400
Command Execution Routines	1,500
Measurement Routines	2,000
Backup GN&C Steer to displays, get-home guidance and navigation	2,950 (33.1)
Program Loader Tape Memory Load on Crew Request	150
Peak Memory Loading	10,650
Memory Size	16,384
Speed KADS Size 32-bit Words	50% Reserve

One of the obvious advantages in the rearrangement is the resulting commonality generated between the four MDE's studied. That is, the MDE's are configured to have identical hardware including their I/O's. Furthermore, since the only function performed by the MDE's is that of display processing, identical software is used at all four stations (commander, pilot, center console, and subsystem management station). The functions performed and memory and speed estimates are given in Table 7-7. The functions performed are listed in the form given for the baseline. A further functional breakdown of the memory estimates and a comparison with Phase B is given in Table 7-8.

Relative to the rearrangement described, it is assumed (without further study) that the MDE's servicing the mission specialist station have identical hardware and software between them. Furthermore, it is assumed that their functional and memory requirements are the same as baseline.

The only relationship between the MDE's servicing GN&C and SM functions and the MDE's serving the payload functions is the ability to act as repeaters. This capability assumes no dependency of software and is for convenience only.

The mass memories are triplicated for the same reliability reasons as the SM computers. The tape units are under control of the MDE's. Each unit will store all of the formats and all of the supporting software. Fault detection of erroneous data is performed by the requesting computer by voting on the input data.

7.4.2.2 GN&C

This section describes the changes to the baseline Guidance, Navigation and Control subsystem necessary for the implementation of the control and display concept under study. All of the changes are in conformance with the rearrangement described in 7.4.2.1. In addition, the requirements for any supporting software will be mentioned.

Before describing the various changes to the GN&C subsystem, the added requirements imposed by the format for the display and control concept are highlighted.

One of the purposes of this concept is to allow the operator(s) the capability to command and control the subsystems' functions through a keyboard/CRT interface thereby significantly reducing the number of required cockpit switches. All of this involves interaction between the operator(s) and the display subsystem. To provide this capability, the formats are designed to display (1) the status or condition of the subsystem, unit, sub-unit, subassembly, device, etc., under command; (2) any supporting measurement data; and (3) the last command issued to the device. Furthermore, the display subsystem in combination with the GN&C subsystem must be capable of accepting keyboard inputs in conformance with the various formats and translating these into the required commands. All of these are to be integrated with the baseline GN&C subsystem. The need for a bi-directional data link between the GN&C computers and the MDE's (modular display subsystem) is first emphasized.

Table 7-7. SM & GN&C MDE Program Functional Requirements & Memory Estimates

SM, BACKUP GN&C AND GN&C			
FUNCTION	SIZE AND (SPEED)		
	SM	BU GN&C	GN&C
Executive Subroutines, input/output, data pool, tables	400	400	400
Crew station displays Input/output conversions, formats, tables, display services, time share GN&C, PMC and backup GN&C	4,650 (6.0)	4,650 (6.0)	4,650 (6.0)
Program loader Tape memory load on crew request	150	150	150
Peak Memory Loading	5,200	5,200	5,200
Main Memory Size	8,192		

(Memory in 32-bit word equivalents
Speed in KADS)

Table 7-8. MDE - Estimated Processor Storage Sizing

FUNCTION	Ø B CONCEPT	NR-SD BASELINE MODIFIED
EXEC	400R	400R
KYBD	700R 800T	500R 300T
UPDATE	600R 100T	500R 50T
I/O	600R 100T	1500R 50T
SELF-TEST	300R	200R
UTILITY	600R	600R
TABLES	1000R	- (MOVES TO COMPUTER GROUP)
REFRESH BUFFERS	1500Y	500X
MASS MEMORY CONTROL	-	500R 100T
EST. PEAK LOADING	6700	5200

R: resident

T: transient

Memory in 32-bit word equivalents

This need is based on the reliability assurance that the appropriate computer subsystem receives the desired input keyboard command. To accommodate this, all GN&C input commands are required to be boot-strapped through the computer performing the command execution and to be verified on the display by the User prior to execution. Some additional supporting software for this function will be required in the GN&C computers.

Other software to be added is the supporting software defined as the measurement and command execution routines. The measurement routines involve the added instructions peculiar to the format on display necessary to read and convert the status of the command device and any supporting data. The command execution routines deal with those instructions added for the purpose of translating and outputting the input keyboard command into a format acceptable by the device (command decoders).

The last significant software additions involve the routines and storage for displaying and memorizing the last command issued by the operator to the device. This involves the addition of a two-dimensional matrix used for the purpose of recording the state of all of the last commands. Some additional overhead is also required with each format in order to keep track of redundancies between checklists and subsystem formats.

The memory and speed estimates for the additional software described are reflected in Table 7-9. A comparison of these estimates to those for the baseline, Table 7-2, shows that the added requirements use up approximately two percent more memory and 4.5 percent more speed.

The one last ingredient which has been implicitly mentioned is the command decoders out at the sub-unit or sensor level and its interface with the GN&C processor IOB. The command decoders are considered digital and/or discrete in nature and serially interfaced with the processor through the IOB. Furthermore, it is assumed that these devices are configured to operate with the 3-string technique described by NR-SD. In essence, each of the sub-units operating within a GN&C string is provided an independent command decoder interfaced with the computer peculiar to that string.

7.4.2.3 EPDC

Application of the control and display concept to the EPDC is basically replacing dedicated switches and wires to controlled items, typically remote controlled circuit breakers and remote power controllers, with command signals from the data processing and software subsystem (DPS) keyboards through the MDE's, SM computers and command decoders. The revisions to the data processing and software subsystem to implement the required DPS capability is described in Section 7.4.2.1 and consists of the addition of functions between MDE's and SM computers and resultant software changes. The number and deployment of the command decoders are largely a function of the requirements of each serviced subsystem. Connection of the command decoders into the EPDC is the principal EPDC area of change to accommodate the EPDC to the control and display concept. (The data required from the EPDC for display are already collected and available via the operational flight instrumentation and are adequate to apply the control and display

Table 7-9. GN&C Program Functional Requirements & Memory Estimates

GN&C	
Function	**Size and (Speed)**
Executive Data pool, subroutines input/out, sequencing, scheduling, tables	3950 (13.8)
System status Redundancy management GN&C, system performance monitor, ground checkout	2600 (27.0)
Flight crew displays GN&C system status, procedures	900 (0.8)
Navigation State vector, attitude reference	5850 (2.1)
Guidance Steering commands, engine control, abort	7500 (39.5)
Targeting	4200 (19.3)
Flight control TVC, RCS, digital outer loop, boost blending	2950 (20.1)
PROgram services Uplink, PCM, pre-flight system align & calibration, interfaces (booster, payload, main engine controller, GSE interface)	2700 (5.0)
Unmanned orbiter Sequencing, calculation for autonomous flight	500 (2.5)
Command Execution Routines	300 (6.1)
Measurement Routines	150 (2.0)
Peak Memory Loading	31,600
Main Memory Size	65,536

Speed in KADS 100% Reserve
Size in 32-bit word equivalents

concept to the EPDC.) The command decoders to support the EPDC are accordingly estimated below.

The NR-SD hardware utilization list for the baseline configuration identifies 19 power distribution and control units with control elements planned per Table 7-10. Wherever possible, command decoders units are associated on a one-to-one basis with subsystem functional loops. On this basis, review of the power distribution design including redundancies indicates approximately half of the distribution units require two command decoder units. This then results in a requirement of 28 command decoders with a requirement for each command decoder to handle an average of approximately 8 and a maximum of up to 12 controlled circuits.

7.5 PRELIMINARY DESIGN CONSIDERATIONS

Preliminary design considerations of the hardware added to incorporate the control and display concept are described in this section. This hardware is low risk current state-of-the-art. Off-the-shelf units could be identified for all items except the command decoders and the Input Output Buffer which would be tailored to the application.

7.5.1 MDE/CRT

A preliminary organization and design of the MDE and CRT configuration and its interface with the keyboards, tape units, and GN&C and SM computers were devised. A simplified block diagram depicting a typical MDE/CRT and its interface is presented in Figure 7-7.

The MDE processor is designed to interface and operate simultaneously (in real time) with

1. one of four input keyboards
2. three mass memory units
3. three GN&C input/output buffer units
4. three, one at a time, SM input/output voting units.

The MDE interface is performed through the use of a direct memory access channel. In addition, the MDE can be considered internally interfaced through this same channel with the MDE Refresh Controller. A provision of 2,048 32-bit words is made for the I/O memory. This includes an estimate of 512 words for the static and dynamic refresh buffers; 320 words per GN&C (total of 960 words since these operate in 3 string); 160 words for the system management computer; 384 words for transient routines, read from mass memory; and 32 words for input commands and control.

With few exceptions the design of the MDE/CRT is considered identical with that described for the second alternate of the Phase B concept (Section 5.3). The processor is designed to provide and update the refresh memory buffers as well as performing the functions of a general purpose computer. The function generators are designed to accommodate the symbol, vector, circle, vector and angle perturbation, and rotation modes. The CRT electronics are designed to operate using the dot matrix technique for symbol

Table 7-10. NR-SD Baseline EPDC Control Element Summary

		Control Elements	
		Per Box	Total
Main DC Dist Boxes (3)	3 Contactors 2 RPC 2 Relays	7	21
Main AC Dist Boxes (3)	3 Contactors 27 RCCB	30	90
Inverter AC Dist Boxes (3)	3 Contactors	3	9
Local Pwr Dist Box (6)	15 RCCB	15	90
Fwd Avionics AC Dist Box (1)	1 Contactor 5 RCCB	6	6
Local AC Dist Box (3)	1 Contactor 5 RCCB	6	18
			234

Circuits to be controlled by command decoders in EPDC.

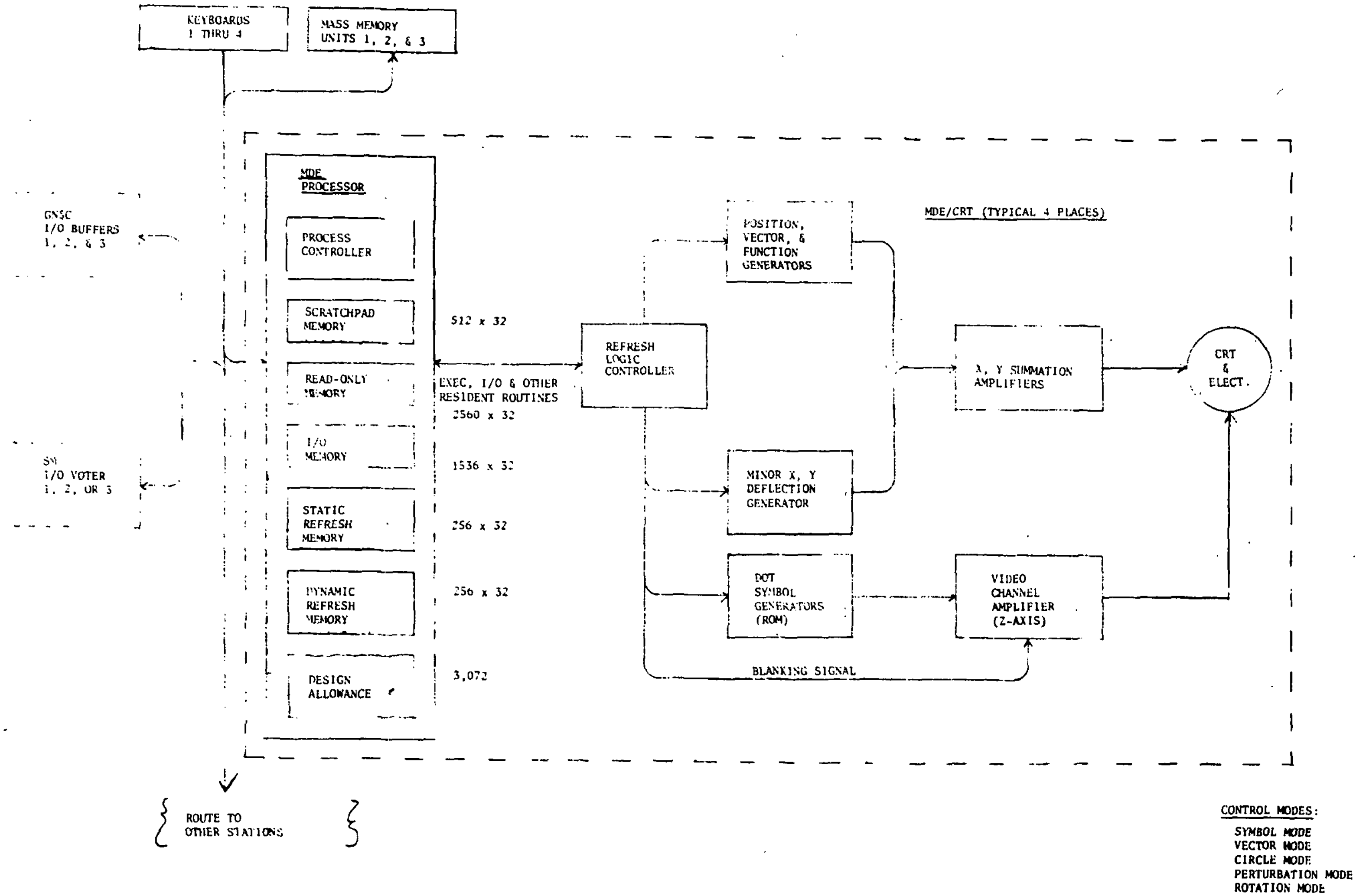


FIGURE 7-7. MDE/CRT - SIMPLIFIED BLOCK DIAGRAM

writing and the electromagnetic detection method for vector writing. Refer to Section 5.2.2 for further details.

The exceptions in the design are attributed mainly to the differences in the input/output section of the processors. That is, in the Phase B concept the processor was required to interface with a data bus rather than three GN&C computers and the SM computers; three keyboards rather than one; and three refresh logic controllers rather than one (implying up to three CRT's rather than one). A preliminary analysis indicates that the data rates are reduced by approximately 50K words per second. This assumes an update rate of up to 20 times per second and a refresh rate of 50 times per second. The memory requirements are basically the same in that the reduction in refresh storage is replaced by the increase due to the input block sizes from the GN&C computers. That is, since all programs are resident in these computers, a complete measurement list is taken on each update and transferred to the MDE where sorting and/or voting is performed per the requested format. Note, this imposes some additional software on the MDE's and thereby some additional memory requirement. These additions, however, are not critical to the design.

In summary, the MDE/CRT design is well within the state-of-the-art and is considered less stringent than the designs specified for Alternates A and B given for the Phase B concept.

7.5.2 Command Decoders

The command decoders are designed to interface the GN&C and SM computer outputs with the command and control switching devices at the subsystem level.

The command decoders are designed to accept serial bit-by-bit inputs consisting of an 8-bit word: 4 bits for address, one bit for control, two bits for data, and one bit for parity. Normally, the 4-bit address is used to select one of 16 possible 2-state logical switching drivers; however, in the event the control bit is set, the adjacent least significant driver is also selected and both set in accordance to the two bits used for data. The latter is used to control 3-state switches (e.g., auto, off, or on); otherwise, the address is unique and only one drive is set (2-state).

Built-In Test Equipment consisting of monitoring the outputs of the switch drivers is made available to the controlling computer. A preliminary block diagram of a typical command decoder is presented in Figure 7-8.

7.5.3 SM Computers

The subsystem management computers are designed to perform all of the logical decisions and arithmetic computations necessary to the functions of performance monitoring, backup GN&C, and command and control, the latter being in conformance with the concept under study.

The SM computer is considered to consist of a processor unit and an input/output buffer unit. The processing unit is a general-purpose digital

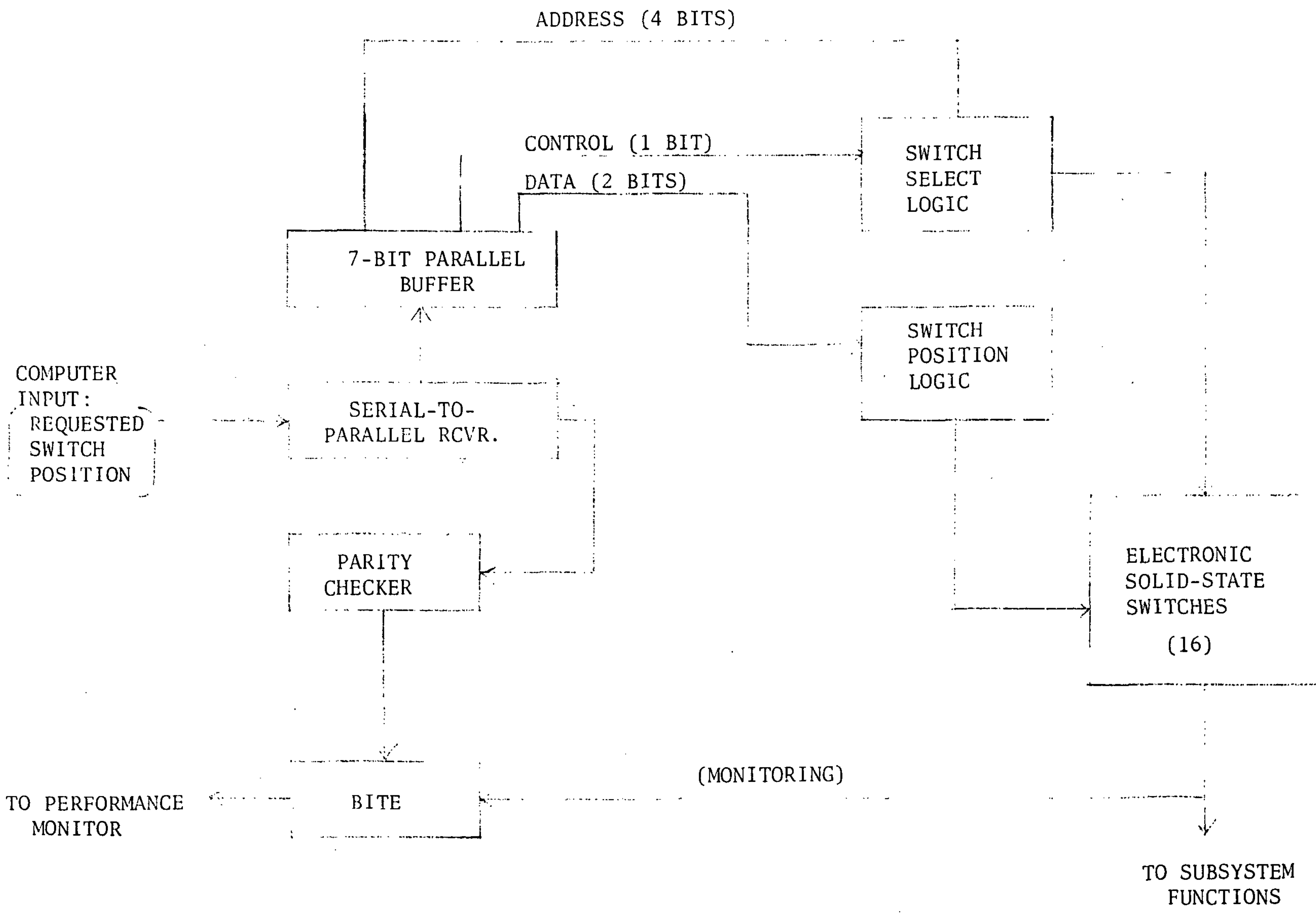


Figure 7-8. Simplified Command Decoder Block Diagram

computer and is identical to those used by the modular display electronics. The unit is basically a 16-bit parallel machine capable of performing single and double precision arithmetic. The basic characteristics of the processor are the same as those described in Section 5.0, Table 5-4, "Basic Processor Characteristics," with the following exceptions. The memory capacity is increased from 8K to 16K and the processor unit by itself is considered as having an I/O consisting only of a parallel direct memory access channel.

The input/output buffer (IOB) unit serves as the interface between the processing unit and all of the other subsystems involved. In this capacity the IOB performs the function of signal conditioning and converting and that of fault detection by voting on the output signals. The input section of the IOB unit consists of three independent input signal converters and conditioners, each interfaced through a multiplexer with one of the three SM processor units. The processing units (under software control) operate on the same input data (assuming no errors or faults) and provide an output to each of the three voters. The voters then weigh the data and under normal conditions output the master computer data. The first non-compare, if not master, results in C&W annunciation; if the master is at fault, output is enabled from non-master and the master is disabled. For second non-compares, all results are held and operator uses BITE to select good computer. A simplified block diagram illustrating the signal flow through the SM computer complex is given in Figure 7-9.

7.5.4 Mass Memory Storage

The number of tape units required for the mass memory storage media and the estimated storage capacity are increased over that given for the baseline. The increase referred to here deals only with the MDE's associated with the GN&C and subsystem management functions and not with the payload handling and management.

The number of tape units referred to is increased from one to three in order to conform with the reliability criteria fail-operational, fail-safe. This requirement is a dictate of having to store the many various command and control formats necessary to the implementation of the concept. The added units referred to here are shown in Figure 7-6.

The increase in the estimated storage capacity over that of the baseline is simply due to the added number of formats required for the concept under study. The formats estimated for use here, and thereby influencing the mass memory size, were derived from those used for the Phase B concept. The results of the estimate are presented in Table 7-11 and demonstrate the need for a capacity of 408,000 words per unit including a 50 percent design margin.

7.6 SUMMARY AND CONCLUSIONS

Application of the control and display concept to the NR-SD baseline requires the addition of major items of hardware and software. Three subsystem management computers, two tape decks and a large quantity (estimated as 230) of command decoders are required to achieve the desired capability

Figure 7-9. SM Computer Complex

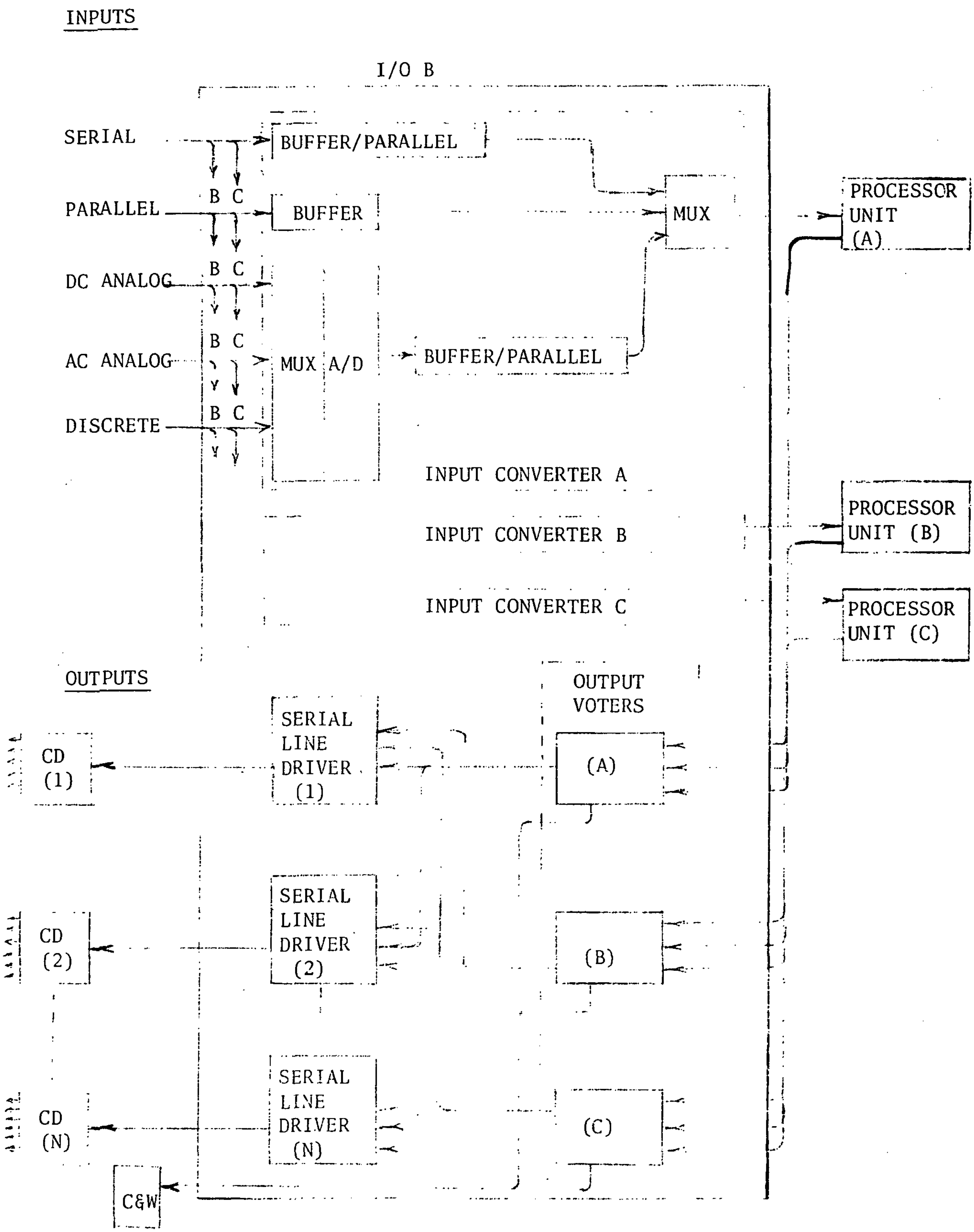


Table 7-11. Mass Memory Storage Estimate

	NO. OF FORMATS		*STORAGE REQMT.
	Ø B	NR-SD Baseline	Modified
Checklist	180	180	163,000
Subsystem Management	130	132	59,000
Technical Management	22	12	8,000
Checkout Formats	61	Ø	Ø
Caution & Warning	60	60	19,000
Timelines	22	22	6,000
Indices	24	24	4,000
			259,000
Baseline estimated rqmts. (GN&C MDE + BU GN&C + PM) ≈			13,000
		Total Est. =	272,000
		50% Margin =	136,000
		Total Reqmt.	408,000

*Sized for 32-bit words.

with a reliability commensurate with vehicle requirements. Software is required for the added computers as is augmentation of the GN&C computer software. Also, a significant increase in system engineering integration effort is required for command decoder integration into the controlled subsystems.

Alternate mechanizations examined to simplify the approach invariably tended toward a centralized data processing subsystem with data bus as typified by the Phase B designs. However, the approach was considered not admissible under the NASA RFP requirements that lead to the NR-SD baseline.

While application of the control and display concept to the NR-SD baseline is technically feasible, a major problem arguing against application is the significant cost and complexity increase resulting from the additional hardware and software. While a reduction in dedicated switches and wiring is realized, control panel space is not critical in the shuttle.

The control and display concept has considerable merit as a man-machine interface for a centralized digital computer controlled system; however, application of the concept to a system where a control interface with a digital computer is not pre-existent requires hardware and software additions resulting in cost and complexity increases that appear to preclude incorporation of the concept.

The control and display concept does not appear attractive for the NR-SD baseline shuttle vehicle.

8.0 SOURCE DOCUMENTS

In accordance with Section 4.5 of the contract statement of work, the following listing of source documents utilized during the contract period of performance is provided.

1. Development of Space Shuttle Vehicle Crew Workload Criteria for Systems Monitoring - Appendices A thru F. Sperry Rand Corporation 1971, for Marshall Space Flight Center

    A. Mission Porfile and events summary charts
    B. Subsystem operating descriptions
    C. Crew operating requirements
    D. Validating experiments
    E. Off-nominal and emergency cases
    F. Subsystems simplification and comparative flight workloads

2. Development of Space Shuttle Vehicle Crew Workload Criteria for Systems Monitoring - Appendix G. Sperry Rand Corporation, 1971, for Marshall Space Flight Center

    A. Booster/Orbiter per function workloads (scan freq., dwell time, deviation)
        (1) Two-man
            (a) Normal
            (b) Off-nominal
            (c) Emergency
        (2) One-man crew
            (a) Normal
            (b) Off-nominal
            (c) Emergency

3. Development of Space Shuttle Vehicle Crew Workload Criteria for Systems Monitoring - Appendix H. Sperry Rand Corporation, 1971, for Marshall Space Flight Center

    A. Orbiter per function workloads (scan freq., dwell time, deviation)
        (1) Two-man
            (a) Normal
            (b) Off-nominal
            (c) Emergency
        (2) One-man crew
            (a) Normal
            (b) Off-nominal
            (c) Emergency

4. Development of Space Shuttle Vehicle Crew Workload Criteria for Systems Monitoring - Appendix I. Sperry Rand Corporation, 1971, for Marshall Space Flight Center

    A. Booster/Orbiter Total Workloads (Pilot, Copilot)

5. Development of Space Shuttle Vehicle Crew Workload Criteria for Systems Monitoring - Appendix J. Sperry Rand Corporation, 1971, for Marshall Space Flight Center

    A. Orbiter total workloads (Pilot, Copilot)

6. Avionics Subsystem. Grumman-Boeing, Phase B Final Report, no date.

   A. Overview
   B. Guidance and Navigation
   C. Flight Control
   D. Data Management
   E. Instrumentation
   F. Telecommunications and Air Traffic Control
   G. Displays and Controls
   H. Avionics Subsystem Design

7. AVIONICS, Displays and Controls. McDonnell-Douglas , E0395, Phase B Final Report, June 1971

   A. Summary
   B. Requirements
   C. Subsystem Description and Rationale
   D. Subsystem Implementation Studies
   E. Built-in Test
   F. Ground Support Equipment (GSE)

8. Avionics Subsystem Group. North American Rockwell Space Division, SD 71-114-2(2), Phase B Final Report, no date

   A. Avionics Trade Study Summary
   B. Guidance, Navigation and Control (GN & C)
   C. Data and Control Management
   D. Displays and Controls
   E. Communications
   F. Instrumentation
   G. Power Subsystem Group

9. Avionics Requirements Documentation. TRW Internal Letter, January 1971

   A. Introduction (contains eriticality of functions)
   B. Avionic System Requirements
   C. Guidance and Navigation Subsystem Requirements
   D. Communications and Navaids Subsystem Requirements
   E. Data Management Subsystem

10. Functional and Performance Requirements Specification - Space Shuttle Avionics System. NASA Manned Spacedraft Center MSC-04075 REV., July 1971

   A. Guidelines, Constraints and Common Requirements
   B. Data Management Subsystem Requirements
   C. Guidance, Navigation and Control (GN&C) Subsystem Requirements
   D. Communication and Tracking Subsystem
   E. Avionics Displays and Controls Subsystem
   F. Power Distribution and Control (PDC) Subsystem
   G. Electronic/Electrical Ground Support Systems Requirements

11. Integrated Displays and Controls Trade Study. North American Rockwell Space Division, Internal Letter SSP-IE-71-053. (CS-2.3.2.4 - 15048)

A. Introduction
B. Study Approach
C. Conclusions and Recommendations
D. Integration Concept and Hardware Approach
E. Briefing Charts
F. Study Plan and Control Sheets
G. Supporting Data
   (1) Appendix A - Selection Criteria and Display - Control Synthesis
   (2) Appendix B - A/N Display Trade-Off Study
   (3) Appendix C - Flight Station Integration
   (4) Appendix D - Caution and Warning Subsystem

12. Configuration and Sequencing Control Study. North American Rockwell Space Division, Internal Letter SSP-IE-71-021, March 1971. (CS-2.3.2.1 - 15021)

A. Introduction
B. Definitions
C. Study Approach
D. Conclusions
E. Redundancy Management
F. Local Automation Hardware
G. Backup Data
H. Crew Workload Analysis (Briefing Charts)
I. Cost
J. Study Plan and Trade Study Control Sheets

13. Control Display Unit DLU-B Functional Specification. Collins, no date

A. CDU I/O Function - Diagnostic IPL Sequence
B. CDU I/O Function - Preflight NAV Test
C. Control/Display Unit: Route Definition/Initialization
D. Control/Display Unit: Capability During the Navigate Mode
E. Control/Display Capability During an In-Flight FDSU Access and Flight Plan Assembly

14. Space Shuttle Avionics Subsystems - Associate Contractor For Electronics Statement of Work, April 1971. NASA.

A. Purpose and Scope
B. Program Description
C. Technical Description
D. Program Management
E. Support Requirements
F. Systems Reliability and Quality Assurance
G. Appendix A - Space/Shuttle Orbiter/Booster Performance Measurement Specification

15. Space Shuttle, Crew Station Review No. 2. North American Rockwell Space Division. Report SW 1-13, 2 April 1971.

16. Space Shuttle Request for Proposal. NASA. No. 9-BC421-67-2-40P, March 1972.

17. Space Shuttle Technical Proposal, Vol. III. North American Rockwell Space Division. Report SD 72-SH-50-3, May 1972.

18. Apollo Operations Handbook, Command and Service Modules J-Series Missions, CSM 112 through 114, Vol. 2 Operational Procedures, 25 March 1971.

19. Apollo 13 Guidance and Navigation Summary, AC Electronics Division of General Motors Corporation.

20. Operations Plan for Phase C/D Volume II Orbiter, SD 71-103-2, 25 June 1971.