NASA-CR-167769

THE **BOEING** COMPANY

CODE IDENT. NO. 81205

THIS DOCUMENT IS:

CONTROLLED BY 2-3751

ALL REVISIONS TO THIS DOCUMENT SHALL BE APPROVED BY THE ABOVE ORGANIZATION PRIOR TO RELEASE.

PREPARED UNDER ☒ CONTRACT NO. NAS9-16445

☐ IR&D

☐ OTHER

DOCUMENT NO. D180-27215-1 MODEL

TITLE DEVELOPMENT OF PRELIMINARY DESIGN CONCEPT FOR A MULTIFUNCTION DISPLAY AND CONTROL SYSTEM FOR THE ORBITER CREW STATION

TASK 4 (DESIGN CONCEPT RECOMMENDATION)

ORIGINAL RELEASE DATE

ISSUE NO. TO

ADDITIONAL LIMITATIONS IMPOSED ON THIS DOCUMENT WILL BE FOUND ON A SEPARATE LIMITATIONS PAGE

PREPARED BY R. J. Spiger/R. J. Farrell/G. A. Holcomb

SUPERVISED BY M. H. Tonkin 10-14-82

APPROVED BY R. A. Collins 10-14-82

(NASA-CR-167769) DEVELOPMENT OF PRELIMINARY DESIGN CONCEPT FOR A MULTIFUNCTION DISPLAY AND CONTROL SYSTEM FOR THE ORBITER CREW STATION. TASK 4: DESIGN CONCEPT RECOMMENDATION (Boeing Co., Seattle, Wash.) G3/18 N83-13152 Unclas 02028

ABSTRACT

Application of multifunction display and control systems to the NASA Orbiter spacecraft offers the potential for reducing crew workload and improving the presentation of system status and operational data to the crew. In this report, a design concept is presented for the application of a multifunction display and control system (MFDCS) to the Orbital Maneuvering System and Electrical Power Distribution and Control System on the Orbiter spacecraft. The MFDCS would provide the capability for automation of procedures, fault prioritization and software reconfiguration of the MFDCS data base. The MFDCS would operate as a stand-alone processor to minimize the impact on the current Orbiter software. Supervisory crew command of all current functions would be retained through the use of several operating modes in the system. This report describes both the design concept and the processes followed in defining the concept.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

1.0 INTRODUCTION

This report describes the recommended design concept developed during performance of NASA contract NAS9-16445, "Development of Preliminary Design Concept for Multifunction Display and Control System for Orbiter Crew Station."

1.1 PURPOSE

The purpose of this report is to summarize the work carried out in Task 1 (Survey of Existing Technology), Task 2 (Application of Technology) and Task 3 (Concept Analysis) and to describe a recommended design concept for a Multifunction Display and Control System (MFDCS) for the Orbiter. The design concept presented as part of Task 4 (Design Concept Recommendation) is based on the results of the previous three tasks.

1.2 SCOPE

The design concept recommended in this report is the result of considerations of hardware, software and human engineering related to the development of an MFDCS to the Orbiter spacecraft. System examples are specifically directed towards and illustrated by the Orbital Maneuvering System (OMS) and the Electrical Power Distribution and Control System (EPDCS). However, the design concept was developed to represent a potential application to a larger number of Orbiter systems. The greatest potential of the MFDCS can be realized through application to the Orbiter display and control system in general, however, in keeping with the study goals of minimizing the effect of the proposed design recommendation on Orbiter hardware and software, the recommended design can operate with minimal interface to the current system.

1.3 DESIGN CONCEPT RECOMMENDATION PROCESS

Results of testing and feasibility studies conducted during Task 3 indicated a preferred set of hardware/software choices as well as an access schema fulfilling the major design goals of the MFDCS. These included provisions for checklist and procedure integration into the MFDCS, automation of the procedures and checklists and presentation of system status at a number of levels of detail. Hardware and software considerations were directed toward provision of adequate display parameters such as size, resolution and luminance and provision of a software operating system which would provide minimal host computer (General Purpose Computer (GPC)) impact and a high degree of flexibility for varying the degree of automation and the logic tree and legends associated with the multifunction keyboards and displays. A considerable degree of automation was found to be necessary in order to minimize the number of required crew inputs. In addition to the functional aspects of the system, the hardware choices were also analyzed for compatibility with the goals of minimizing the weight, power and cooling requirements of the system.

The results of Task 3 were combined with the comments and discussion of the Task 3 review to arrive at the final design concept recommendation. This effort includes specific choices of potential hardware to implement the design and a description of a possible packaging format for use in an Orbiter simulator.

1.4 SUMMARY

The study has been conducted as a series of four consecutive tasks. During the first task (Survey of Technology) the current and projected future status of multifunction display and control technology was assessed with respect to both hardware and human engineering (reference 1-1). Areas of important changes were discussed. These included the introduction of color CRT's for aviation instrumentation displays and the growing development of flat panel displays such as dot matrix arrays using LED's, liquid crystal displays (LCD), vacuum flourescence (VF), plasma, and thin film electroluminescence (TFEL). Another rapidly changing area was that of processing and memory where increasing processor speed and greatly increased chip component densities in both processor and memories permit a high degree of storage and intelligence in a small scale display and control system. Developments in control devices were also surveyed. Prominent among these were multifunction programmable legend switches, touch panel overlays and voice recognition and entry systems. All these developments were reviewed with respect to the constraints of operation in the Orbiter environment and the goals of the study.

Human engineering factors associated with multifunction display and control systems were reviewed with emphasis being given to the development process for the access schema which is associated with each system. Current systems in use and under development were surveyed and some of the design processes followed were illustrated.

The second task (Application of Technology) considered the application of multifunction display and control technology to the Orbiter OMS and EPDCS as particular system examples (reference 1-2). This included a discussion of the study goals, a functional analysis of the OMS and EPDCS, assessment of human factors and hardware requirements imposed by the Orbiter mission and the development of several design concepts applicable as MFDCS designs. The functional analysis provided a detailed analysis of the operation of the OMS system, a listing of OMS control functions and formulation of a preliminary access schema for the OMS and EPDCS. A number of possible applications of the display and control hardware technology to the Orbiter systems were considered. Concepts developed ranged from a multifunction keyboard as both a display and control device to the use of a multifunction keyboard, a flat panel checklist display and a color CRT for the display of graphic system diagrams. The latter concept was suggested for further development. The initial access schema included provision for both manual operation of all the EPDCS and OMS control functions as well as incorporation of checklists.

Task 3 (Concept Analysis) was directed towards the analysis and feasibility testing of implementations of the design concept selected in Task 2. Included in the analysis was a more complete functional analysis of the EPDCS, the development of an access schema offering automation of checklists and procedures and presentation of the analysis and feasibility testing results (reference 1-3).

Functional analysis of the EPDCS and discussions with NASA-JSC personnel indicated a major potential problem with the time constraints in handling malfunction procedures. This is particularly true during ascent where the available time from main engine cut-off until execution of the first OMS burn is limited to 2 minutes if orbit is to be achieved. The EPDCS procedures associated with malfunctions typically involve components in a number of Orbiter systems.

Automation of crew procedures and checklists was included in the access schema to improve the operating speed of the MFDCS. Both automatic and semi-automatic modes were included while retaining a manual mode capability for accessing the complete current set of Orbiter control functions.

Analysis and feasibility testing was conducted to correlate the requirements and options for implementation of the system with respect to hardware, software and human engineering considerations. Results of the analysis and testing included determinations of display size, resolution and color, character size and font style, hardware/software operating speed, display power requirements for different display types, and interfacing between the components of the MFDCS.

The results of Task 4 (Design Concept Recommendation) are included in this report. The results of Tasks 1 through 3 are summarized in greater detail in Section 2. The logical structure and access schema of the recommended MFDCS design are described in Section 3. Four major operating modes are implemented in the design. These are: 1) Normal Operation, in which the activation of procedures may be carried out automatically or semi-automatically, 2) System Status, in which the various systems under MFDCS control are monitored for indications of malfunction, 3) Individual Switch and Control Function Access, in which the current set of switches and control functions may be accessed, and 4) Caution and Warning Handling, in which heirarchially ordered malfunctions or warnings are presented with suggested procedures for crew action. The access schema offers a high degree of flexibility in crew responses while improving potential operating speed and preserving crew command supervision. A specific example of MFDCS operation and some optional system provisions are also included in Section 3.

Section 4 describes the recommended approach for MFDCS hardware and software. Basically the hardware uses a 16 bit control microprocessor and a multibus structure to link the display and I/O modules of the system. Three displays are included. These are: 1) a multifunction keyboard made up of 28 programmable legend switches, 2) a flat panel medium resolution display for checklist and procedure presentation, and 3) a high resolution stroke/raster color CRT display for the presentation of system schematic diagrams and procedure menus. The displays include dedicated microprocessors to improve operating speed and MFDCS modularity. The system software is divided into two major portions. The first is the background operating system which is independent of the specific data base used for a given mission. The operating system handles communication between the Orbiter General Purpose Computers (GPC) and the MFDCS modules, MFDCS initialization and command processing between modules. The second major software portion is the data base which includes the logical structure for accessing the procedures and control functions and the stored legends and display formats. The data bases can be specifically tailored for particular missions and loaded into the system as required. Also included in Section 4 is a discussion of future options, associated with MFDCS hardware choices, and a subsection on system flexibility.

Section 5 discusses some additional considerations pertinent to the MFDCS. These include redundancy and reliability, automation and mission scenarios. In Section 6 some of the aspects of the further development process for the MFDCS and study conclusions are presented. References are included in Section 7.

2.0 STUDY TASK RESULTS AND CONCLUSIONS

The results and conclusions of the preceding study tasks are described briefly in the following subsections. These results and conclusions form the basis for the design recommendations made in this report.

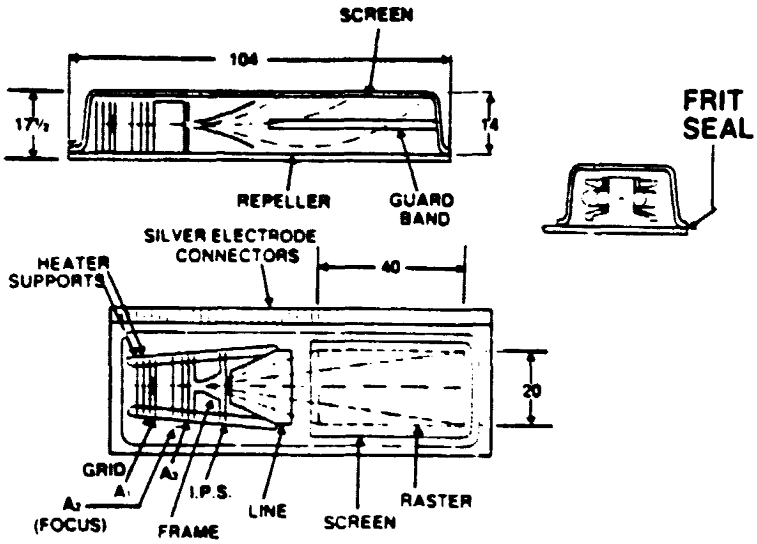
2.1 TASK 1 (SURVEY OF TECHNOLOGY)

During Task 1 efforts were directed towards understanding the present Orbiter system and towards a survey of the present and projected future status of multifunction display and control technology. The OMS and EPDCS were selected as the particular two separate Orbiter systems for detailed application of MFDCS concepts, although the concepts developed are applicable to the Orbiter systems in general. Literature provided by NASA-JSC and discussions with NASA personnel provided the majority of the detailed background on the Orbiter configuration and operation. The literature consisted primarily of training manuals and cockpit layout drawings available to the Orbiter crew. Added to this was an opportunity to inspect the Orbiter simulators and discuss the control panel configurations. The survey of applicable multifunction display and control technology was based on the background provided by this information.

2.1.1 HARDWARE AND SOFTWARE

The hardware applicable to an Orbiter MFDCS was surveyed through a combination of literature searches, vendor contacts and discussions with industrial and Government personnel involved in display and control research and development. One of the principal areas surveyed was that of displays. Included were both CRT displays and flat panel displays. A number of CRT varieties were considered. Among them were monochrome stroke writer and raster, beam penetration color and shadow mask color tubes. Several new types of tubes were just coming onto the market or were being developed. An example of a new configuration was represented by a monochrome flat CRT being developed by Sinclair in Great Britain. A schematic diagram of this tube is shown in Figure 2.1-1. The electron gun is located at the side of the tube as opposed

ORIGINAL PAGE IS
OF POOR QUALITY



(ARBITRARY UNITS)

	MAGNETIC	ELECTROSTATIC	SINCLAIR TUBE
VOLUME	2	2.5	1
DEFLECTION POWER	10	4	1
PARTS COUNT	2	3	1
GLASSWARE	COMPLEX	COMPLEX	SIMPLE
BRIGHTNESS	1	1	3
RESOLUTION	1	1	1
SCALING LAW	ADVERSE	ADVERSE	FAVOURABLE

COMPARISON OF SINCLAIR TUBE WITH CONVENTIONAL ELECTROSTATIC AND MAGNETIC TUBES

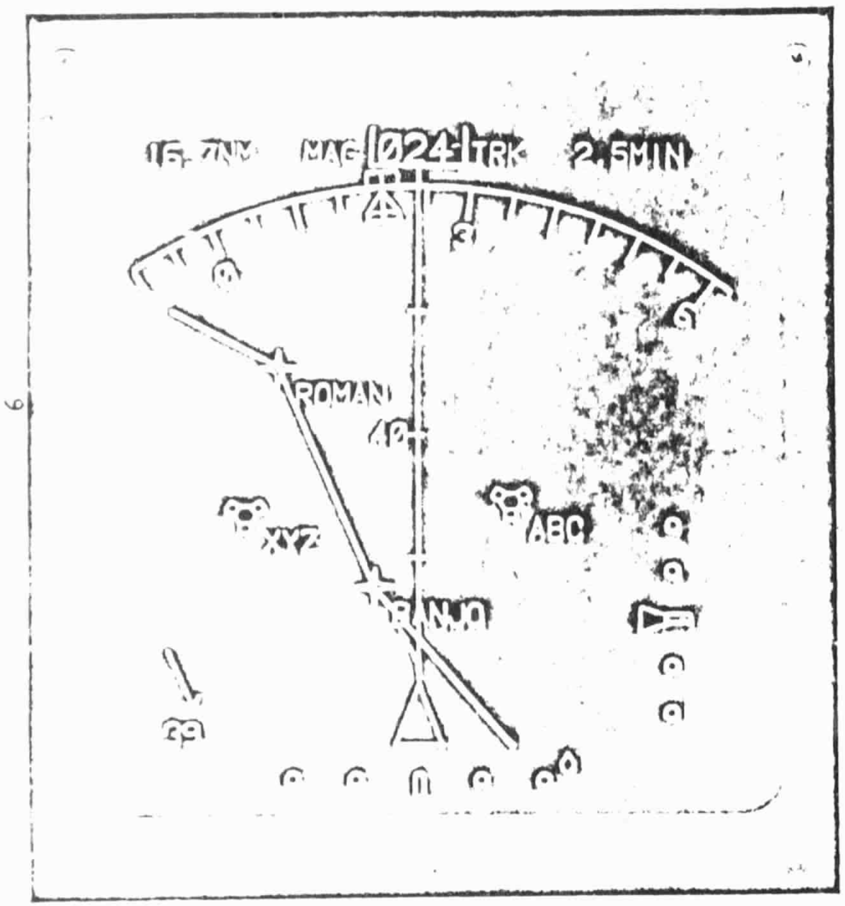
Figure 2.1-1: SINCLAIR 2-INCH FLAT CRT

to the normal rear location. This configuration offers savings in volume and power when scaled up to larger sizes. Another recent development was the application of shadow mask color CRT's to flight cockpit use in commercial aircraft. These tubes, marketed by Collins, Sperry & Smith Industries use a high brightness shadow mask tube driven in both a stroke writer and raster scan mode to present navigation diagrams, aircraft attitude and systems status and display of radar information. An example of the type of display presented is shown in Figure 2.1-2. Vector and symbology information is portrayed in a stroke written mode, while the raster is used for producing color fill areas. This type of display permits a wide range of parameter formats to be displayed with the same hardware. A major current application is in the new Boeing 757-767 aircraft.

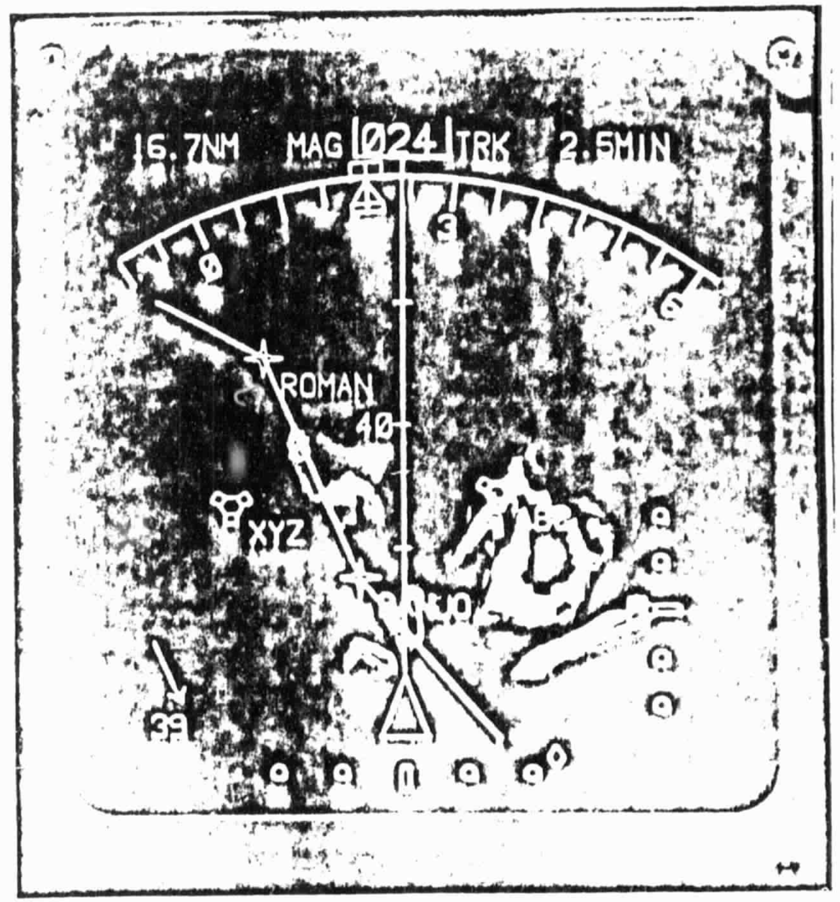
Flat panel displays were found to be under development or available on the market in a number of different forms. Those applicable to present or near future (3-5 years) Orbiter applications were LED, LCD, VF, TFEL and plasma panels. Potential advantages offered relative to CRT displays were seen as lower power requirements, lower volume, more graceful degradation characteristics and longer life. Disadvantages included a lack of color capability, limited type and size options, low resolution and relatively small size. One panel currently available is the Sharp TFEL panel shown in Figure 2.1-3. This unit provides a black on yellow display capable of alphanumeric or graphics portrayed on a 9 x 12.5 cm, 240 x 320 pixel array. A summary of both the CRT and flat panel displays was compiled. Figure 2.1-4 shows a summary of relative parameters for the various display types.

Control devices were another area surveyed in Task 1. Emphasis was placed on newer devices relevant to multifunction applications. Touch panels, multifunction switches and voice recognition and entry systems were the primary items considered. Touch panels were available using a number of sensing techniques (e.g., resistive, capacitive, infrared) and were adaptable to a variety of display types and sizes. They were coming into increased use in a wide variety of applications. Figure 2.1-5 shows an installation on a CRT used in flight test work. One disadvantage was the ease of accidental activation.

Electronic Horizontal Situation Indicator (EHSI)



Map Mode



Map Mode With Weather

Figure 2.1-2: Electronic Horizontal Situation Indicator

Figure 2.1-3: SHARP TFEL PANEL DISPLAYS

OF P

Display	Luminous Efficiency (Lumens/Watt)	Resolution Range (lines/cm (lines/inch)	Color Capability	Gray Scale Levels	Dot Matrix Array Size (H X W)	Display Area H X V	Maximum Voltage Required	Lifetime (hours)
CRT Monochrome	10	26 - 43 (65 - 110)	Monochrome	256	2000 X 2000	75cm diagonal	12 - 18keV	2,000 - 10,000
(Beam Penetration)	4	26 - 43 (65 - 110)	Red - Green	256	2000 X 2000	48cm diagonal	10 - 20keV	2,000 - 10,000
(Shadow Mask)	3	32 (80)	Red - Green - Blue	256	1024 X 1280	75cm diagonal	10 - 25keV	> 15,000
LED	0.1	13 - 51 (32 - 128)	Red - Green	8	256 X 320	10 X 12.5cm	10V	> 11,5[illegible]
LCD	Passive	12 - 20 (30- 50)	Black, Blue, Green, Yellow red (Single)	8	280 X 360	15 X 19cm	3 - 20V	> 50,000
EL	1 - 8	28 (70)	Yellow - Orange (Single)	16	240 X 320	9 X 12cm	100 - 200V	> 50,000
Plasma	.3 - 3	12 - 24 (30 - 60)	Orange, Green (Single)	2	1024 X 1029	1m X 1m	100 - 200V	> 20,000
VF	4 - 9	20 (50)	Blue - Green (Single)	16	128 X 128	7.7 X 7.7cm	30 - 90V	> 30,000

Figure 2.1-4: DISPLAY PARAMETER COMPARISON

Figure 2.1-5: FLUKE INFOTOUCH DISPLAY

Multifunction switches currently coming into availability use a flat panel array to present a programmable legend. Supply was limited to a few prototype units with production in limited quantities projected for late 1982. These units offer a modular design capable of a variety of locations in the cockpit and a positive tactile feedback to the operator. One unit, produced by MicroSwitch, displays either alphanumeric or graphic symbols or a 16 x 35 dot matrix LED array. Switch size is approximately 2.5 x 3.8 cm.

Processing and memory capabilities were also surveyed. The primary development in processing and solid state memory was the continuing trend toward smaller size and higher speed. Sixteen bit microprocessors operating at speeds of 10 MHz or more were seen for an increasing number of applications. Memory chips are becoming available with greatly increased densities at low cost. The introduction of the 64K RAM chips and low costs ($5-10) associated with these chips make large memory arrays possible at relatively small cost and volume. The introduction of 256K RAM chips will increase this trend even further. Larger scale mass storage memories in the form of hard disks are coming into use on aircraft. One example was a sealed disk unit made by Sperry for recording flight data on commercial airliners. A very large read-only storage capability is now available using video discs. These units are coming into use for storage of maintenance data and cartographic information as well as pictorial scenes.

In general, a large amount of technology was found to be currently available for application to multifunction display and control systems. An increasing choice in all categories can be expected in the next few years. Several multifunction control and display systems have been developed using this technology. An example is the Boeing Universal Display and Control System (UDACS) which is being produced for the retrofit of P3 antisubmarine patrol aircraft for the Royal New Zealand Air Force.

2.1.2 HUMAN ENGINEERING

Principles for the design of an access schema for a multifunction display and control system were investigated as part of MFDCS technology. A primary requirement for any of the design techniques is a functional analysis and understanding of the operating modes of the system. These data form the basis from which the logical structure of the access schema is defined. Consideration must be given to control importance, frequency of use, and interaction with other systems in determining the number of levels through which the operator must go before reaching the desired function. Several methods for developing the access schema were assessed. Most involve an iterative procedure in which an access schema is devised, tested and modified as a result of the test data. This procedure is continued until a satisfactory access schema is defined. A diagrammed example of this process is shown in Figure 2.1-6.

2.2 TASK 2 (APPLICATION OF TECHNOLOGY)

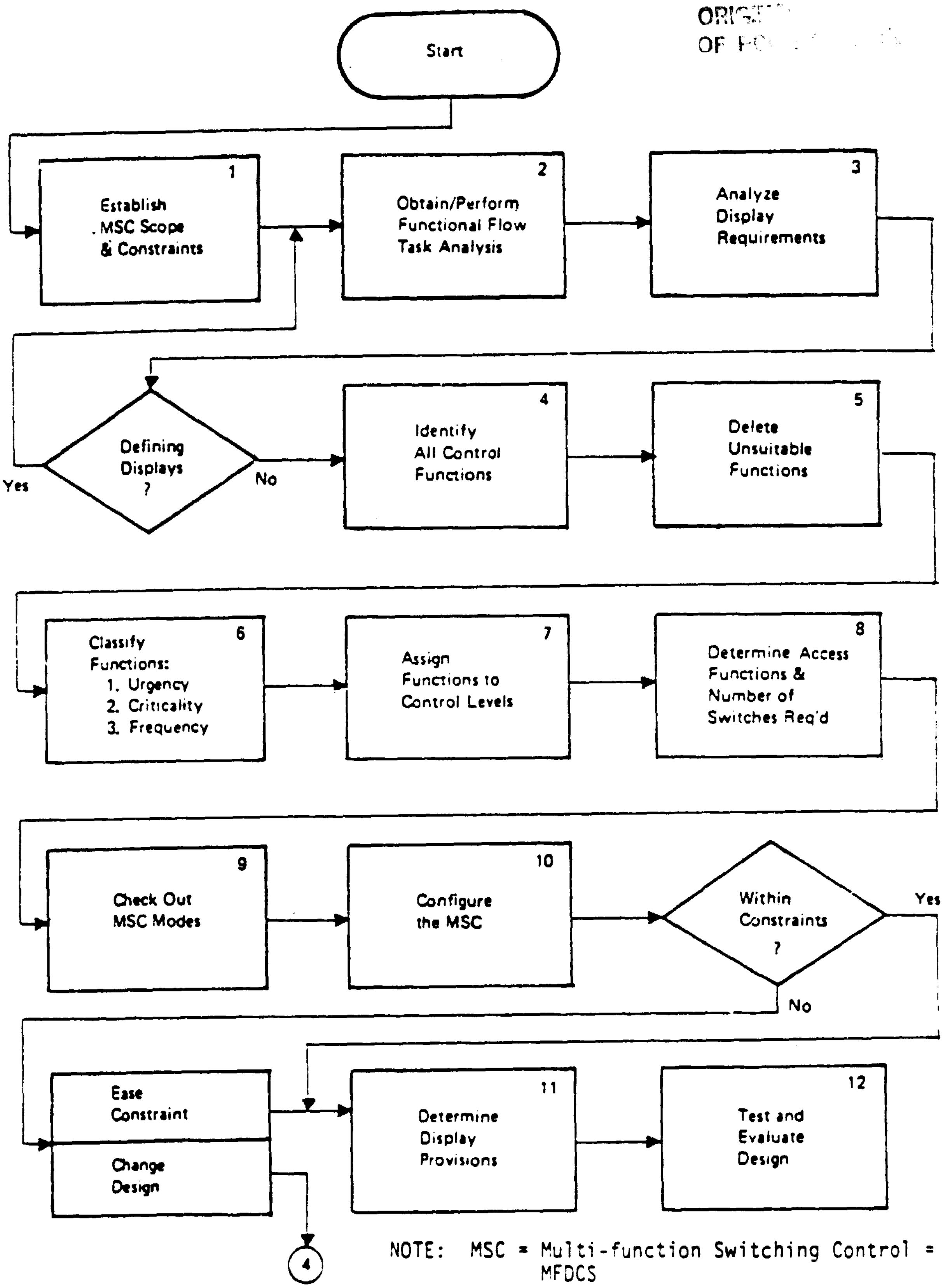
During work on Task 2, two basic efforts were undertaken. The first was a functional analysis of the OMS and EPDCS controls and procedures. The second was the combination of the available multifunction display and control technology with the design constraints pertinent to the Orbiter and the goals of the study to generate alternate MFDCS design concepts.

2.2.1 FUNCTIONAL ANALYSIS

An essential part of the design of a MFDCS is a complete compilation of the system controls and functions. Particularly important in the case of the Orbiter is the handling of malfunction procedures which can often become time-critical during the ascent and reentry phases of the mission. During Task 2, the greatest effort was applied to the analysis of the OMS and its associated procedures. To accomplish the analysis, the available literature was studied in detail and conversations concerning actual operation were held with NASA-JSC personnel.

The OMS is used to place the Space Shuttle into final orbit after the external tanks (ET) are dropped off; to change the orbit characteristics, and finally to reduce the Orbiter's velocity in order to return to earth after a mission. It is also used if a mission abort is necessary requiring return to the launch site during the ascent phase. In this case, the propellant is dumped. Four subsystems were found to be the major OMS components. These are: the Engine Control where thrust is produced; the

ORIG...
OF PO...



NOTE: MSC = Multi-function Switching Control = MFDCS

Figure 2.1-6: *Block Diagram Summary of MSC Design Procedure*

Bipropellant Control where system valving admits propellant to the engine ignition chamber; the Thrust Vector Control (TVC), which points the thrust in the desired direction, and the Propellant Thermal Control, which prevents propellants from freezing in the lines. Operation of each of the subsystems was studied and the interactions of the switches, controls, sensors and GPC's was considered and discussed in terms of actual mission operation. Malfunction procedures were examined and possible methods for including them in the MFDCS access schema were formulated.

A similar process was begun during Task 2 for the EPDCS. The EPDCS distributes Orbiter electrical power from the three fuel cells to the various Orbiter systems using a variety of buses. Incorporated in the EPDCS is the capability to monitor the system through gauge readings, talkbacks and CRT displays as well as the capability to tie main buses together for greater system redundancy.

The three fuel cells each supply power to a Main Bus and an Essential Bus. From a Main Distribution Assembly, each Main Bus provides power to Power Control Assemblies and Panel Buses. The Power Control Assembly supplies power to the Load Control Assemblies, Motor Control Assemblies, AC Bus Generation and Distribution Assembly and Control Buses. An important feature of the EPDCS is the fact that the control of this system does not depend on routing of information and commands through the GPC's. As a result, the MFDCS must be able to drive the relays, etc., associated with the present controls. In addition, the MFDCS must be able to receive and display system status information from the GPC data buses and/or from the EPDCS gauges and meters.

A majority of the requirements for possible crew interaction with the EPDCS were found to be concerned with various possible malfunctions which might occur (e.g., fuel cell failure). In the event of a failure, a number of systems may be impacted depending on the nature of the failure. This could result in a large enough number of caution and warning alerts to obscure the basic problem to the operator. Thus, a necessary feature of the MFDCS was the capability of prioritizing conditions and displaying to the operator the appropriate anomalies to correct first.

One of the results of the functional analysis was the compilation of a table of OMS and EPDCS controls and functions. These are listed at the end of this report in Appendix A.

2.2.2 ALTERNATE DESIGN DEVELOPMENT

The development of the alternate design concepts required the combination of the study goals and constraints with the features of the available multifunction display and control technology to arrive at a prospective design. Some of the factors considered are listed below. These factors were combined with hardware options from Task 1 to arrive at several design concepts.

2.2.2.1 LOCALIZATION OF SYSTEM-SPECIFIC DISPLAYS AND CONTROLS

Present controls are spread over several different flight deck locations. The MFDCS should collect these various displays and controls into one integrated panel or panels, capabl of handling both the OMS and EPDCS.

2.2.2.2 INTEGRATION OF CHECKLISTS, MALFUNCTION AND TROUBLESHOOTING PROCEDURES

Present checklists and malfunction procedures are carried as cue cards or as paper copy in which the appropriate procedures can be looked up. The MFDCS should incorporate these lists into the MFDCS displays.

2.2.2.3 SYSTEM AUTOMATION

The present display and control system presents available data to the operator upon request. The MFDCS should also include the capability to make intelligent decisions about which data the operator needs to see. Thus, in the event of an alarm, the alarm indication might be accompanied by the appropriate data to diagnose the problem.

2.2.2.4 CREW SUPERVISORY COMMAND CONTROL

At present, the Orbiter crew retains control over almost all the accessible controls. The implementation of automation within the MFDCS must provide the option of equivalently complete crew command control.

2.2.2.5 INTERFACE COMPATIBILITY

To be applied to the present Orbiter simulators or vehicles, the MFDCS must interface as closely as possible with the current electrical and mechanical interface and with the available Orbiter panel and depth provisions.

2.2.2.6 MINIMAL SOFTWARE IMPACT

The Orbiter software requires a long lead time and considerable analysis for modifications to be made. The MFDCS should require a minimum impact on the existing software to interface with the General Purpose Computers (GPC's). Thus, the MFDCS unit should be essentially self-contained with respect to software and should "look" like the original arrays of switches and controls to the GPC's.

2.2.2.7 MINIMIZATION OF WEIGHT, POWER AND COOLING

Reduction of vehicle weight for Orbiter flights increases the useful payload. Weight reduction can be accomplished through reduction of equipment weight or a reduction of the capacity of the support required for power and cooling. The MFDCS design should thus attempt to minimize the required weight, power and cooling through the overall system design and the hardware choices.

2.2.3 ALTERNATE DESIGN CONCEPTS

Alternate design concepts arrived at ranged over several levels of complexity for presenting necessary information to the operator. In all cases, it was found necessary to design the MFDCS as an essentially stand-alone system with the simulation of current control commands to the GPC's duplicated as nearly as possible in the interface. This served to minimize the impact on existing hardware and on the software changes necessary to the GPC's. The design concept access schema was developed in preliminary form to handle checklists and provide access to all the current control functions of the OMS and EPDCS. Figure 2.2-1 shows a typical multifunction keyboard layout and an associated logic tree example developed as part of the initial access schema.

Display and control designs considered included multifunction keyboards combined with a small scratchpad display, a larger tabular display, a high resolution graphics display and both the tabular and graphics display. The various options considered are illustrated in Figure 2.2-2. Both the OMS and EPDCS were judged to benefit from the inclusion of both a medium resolution tabular display and a higher resolution graphics display for presenting system status to the crew member. The tabular display was considered primarily as a means of displaying and processing checklists and procedures. The definition of hardware to be used was done during Task 3.

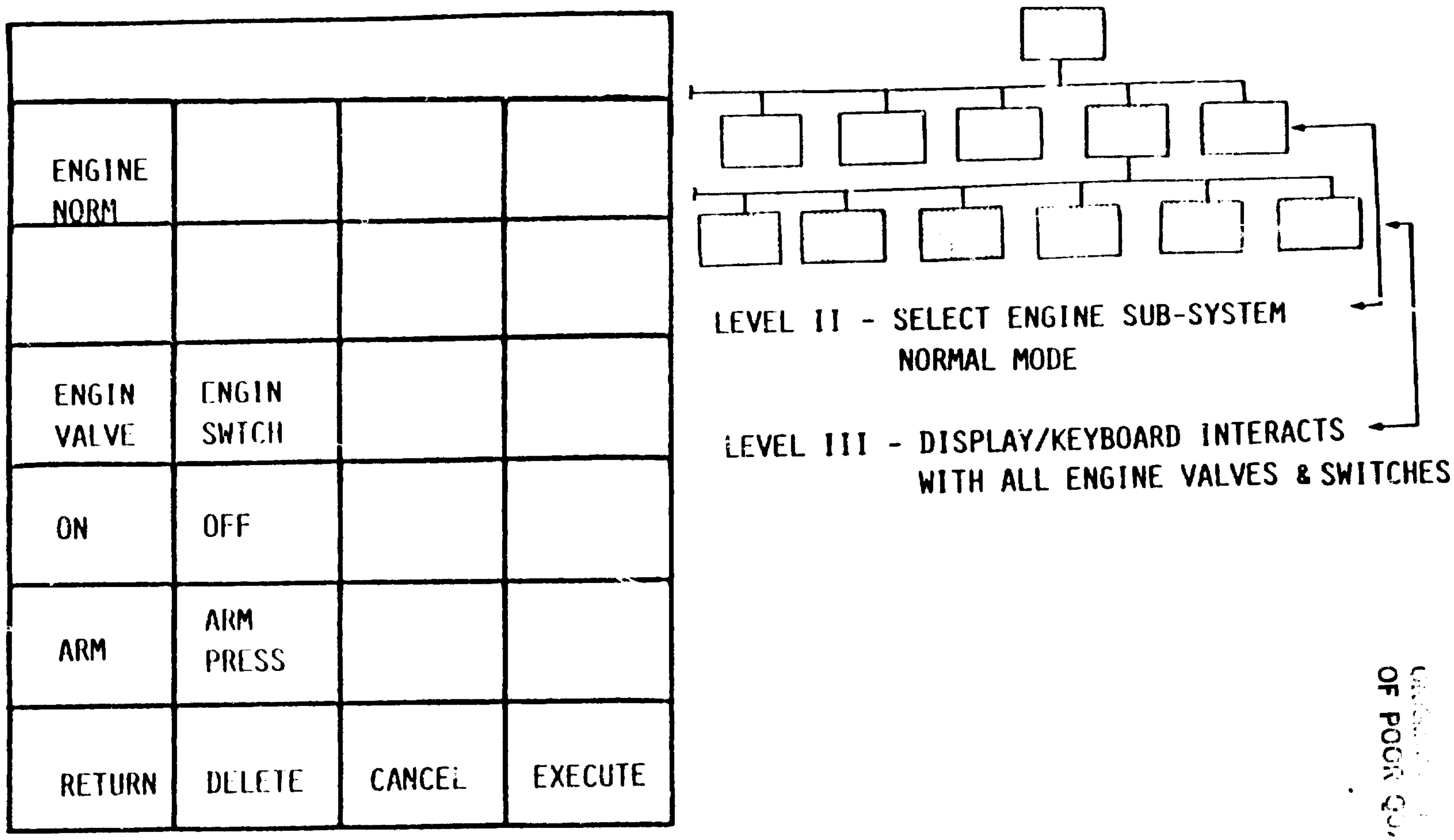
The design concept selected for further development was seen as fulfilling the goals of reducing flight deck clutter through the use of the multifunction keyboard and of integrating the display of system status into a localized interactive station.

2.3 TASK 3 (CONCEPT ANALYSIS)

The major subtasks of Task 3 were the definition of alternate hardware implementations of the preferred design concept, the analysis and feasibility testing of these hardware options with respect to the study goals and constraints and the development of a more complete MFDCS access scheme.

2.3.1 ALTERNATE DESIGN DEFINITIONS

Various hardware options were considered for implementation of the preferred design concept. The design options for processing and the interfacing to the keyboard host and the various displays were based on the general architecture shown in Figure 2.3-1



(NOT TO SCALE)

Figure 2.2-1 MrDCS Concept - OMS System
Level III

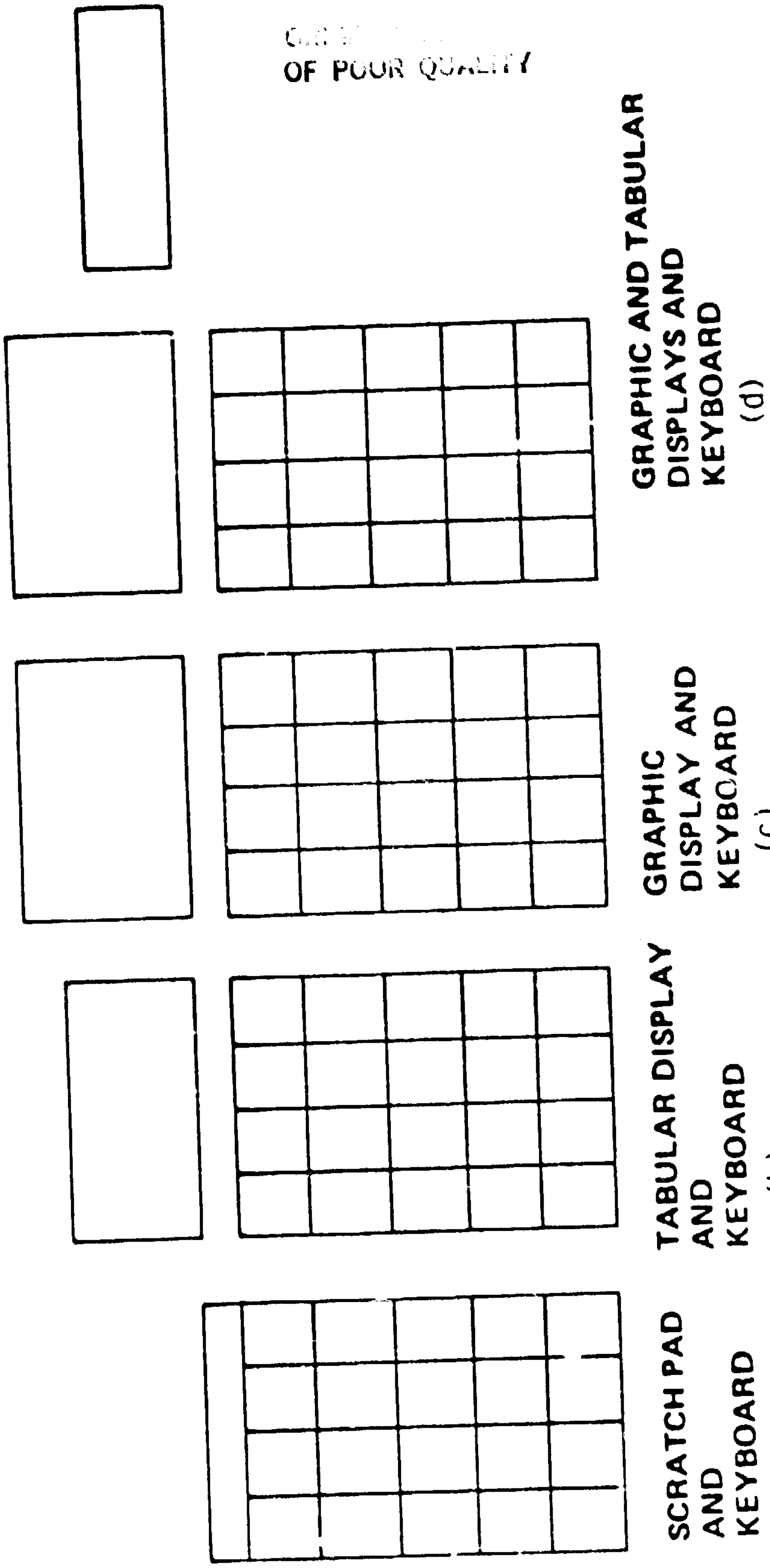


Figure 2.2-2: MFDCS Capabilities Heirarchy

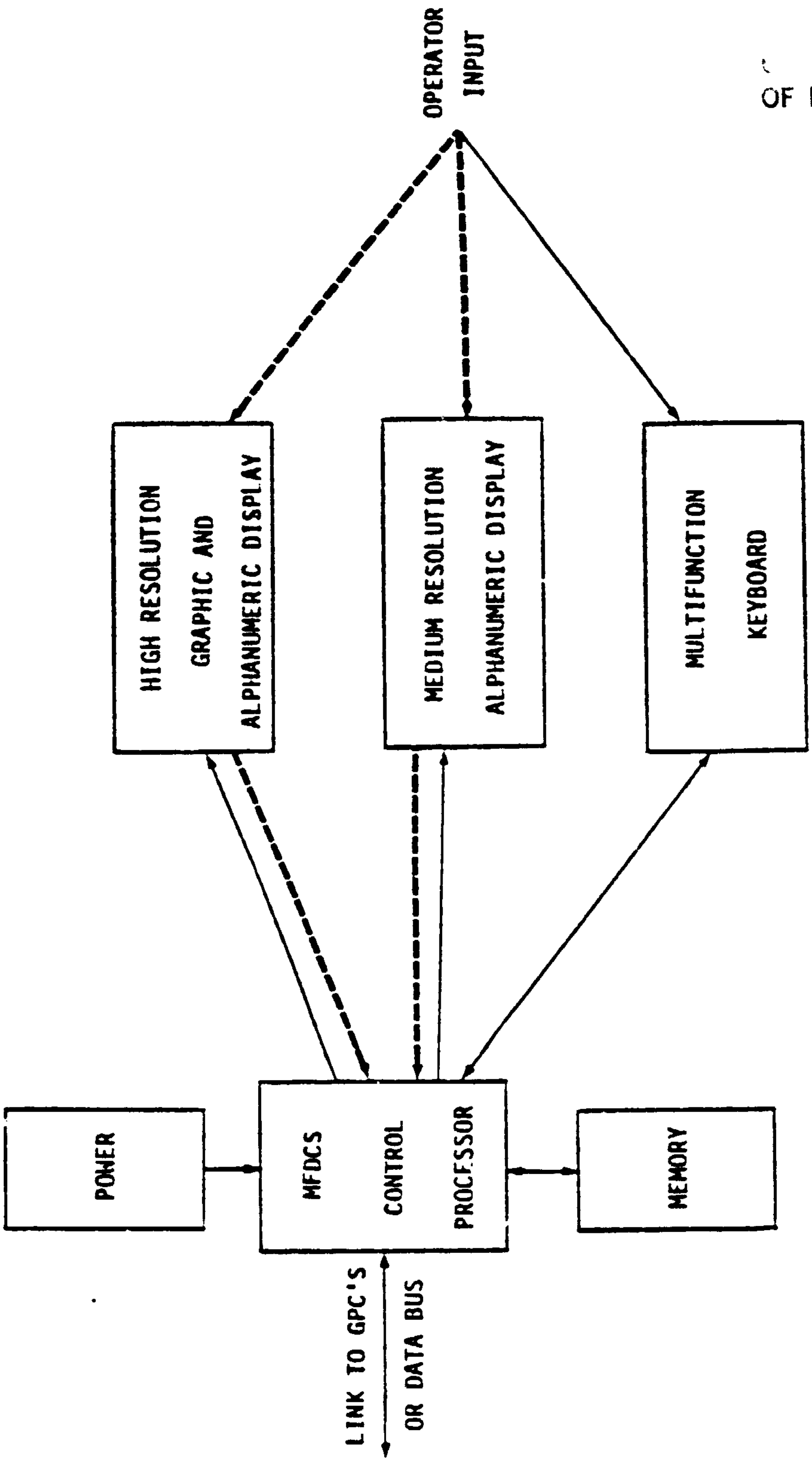


FIGURE 2.3-1 MFDCS BASIC ARCHITECTURE

where the dashed lines indicate optional interaction paths. Display options considered CRT and flat panel devices for use in the various displays. In the general design considered, the processor interacts with the GPC's via a communication link which provides the MFDCS processor with data and caution and warning alerts and permits the MFDCS to transmit command messages which simulate the interfaces previously used by the OMS and EPDCS switches. A high resolution display (~32 lines/cm) provides the capability for the display of schematic diagrams representing configuration and status of Orbiter systems. The medium resolution display (25-30 lines/cm) is used for the display of checklists, procedures and limited instrumentation or trend data. The multifunction keyboard provides the operator input mechanism for issuing commands to the GPC's and for manipulating the MFDCS displays.

Hardware options were defined for the GPC-MFDCS interface, the MFDCS processing architecture, processor-keyboard/display interface, and the MFDCS displays. Analyses and feasibility testing were conducted on these options.

2.3.2 ANALYSIS AND FEASIBILITY TESTING

Analyses were performed to evaluate hardware requirements and options. A number of potential options were limited by the currently available hardware.

2.3.2.1 DISPLAYS

Both monochrome and color CRT's were considered for the high resolution display. Figure 2.3-2 was taken from the set of diagrams developed for the access schema and used to evaluate display options. Display resolution requirements were defined by constructing the diagram of Figure 2.3-2 in a variety of pixel resolutions from 128 to 768 pixels on a side, using a raster CRT graphic generator. An example is shown in Figure 2.3-3. Analysis of characters and line separation indicated a need for a minimum of 512 line resolution. The difficulties in attaining high brightness with a raster tube indicated a requirement for stroke writing capability. Consideration of the display clarity to operators using the experience associated with color use and choices in the Boeing 757-767 cockpit and judgments of the proposed Orbiter displays led to

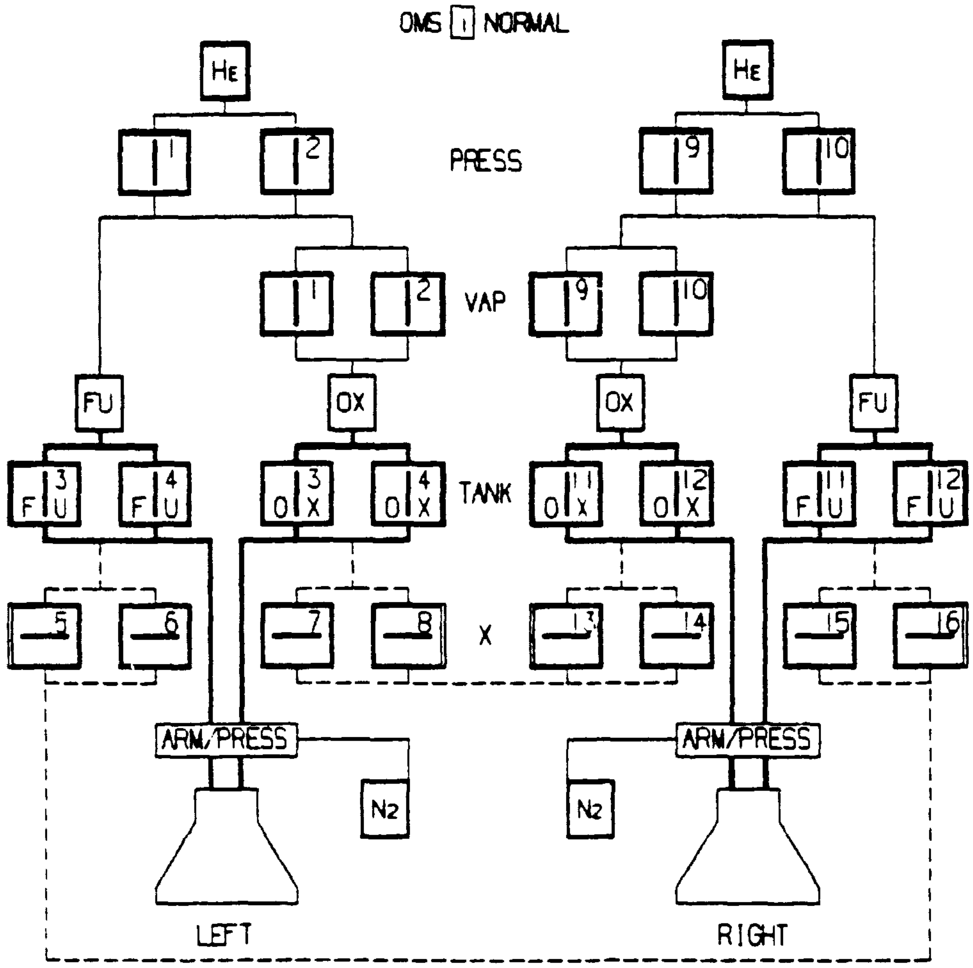


Figure 2.3-2: OMS VALVE STATUS DISPLAY - NORMAL

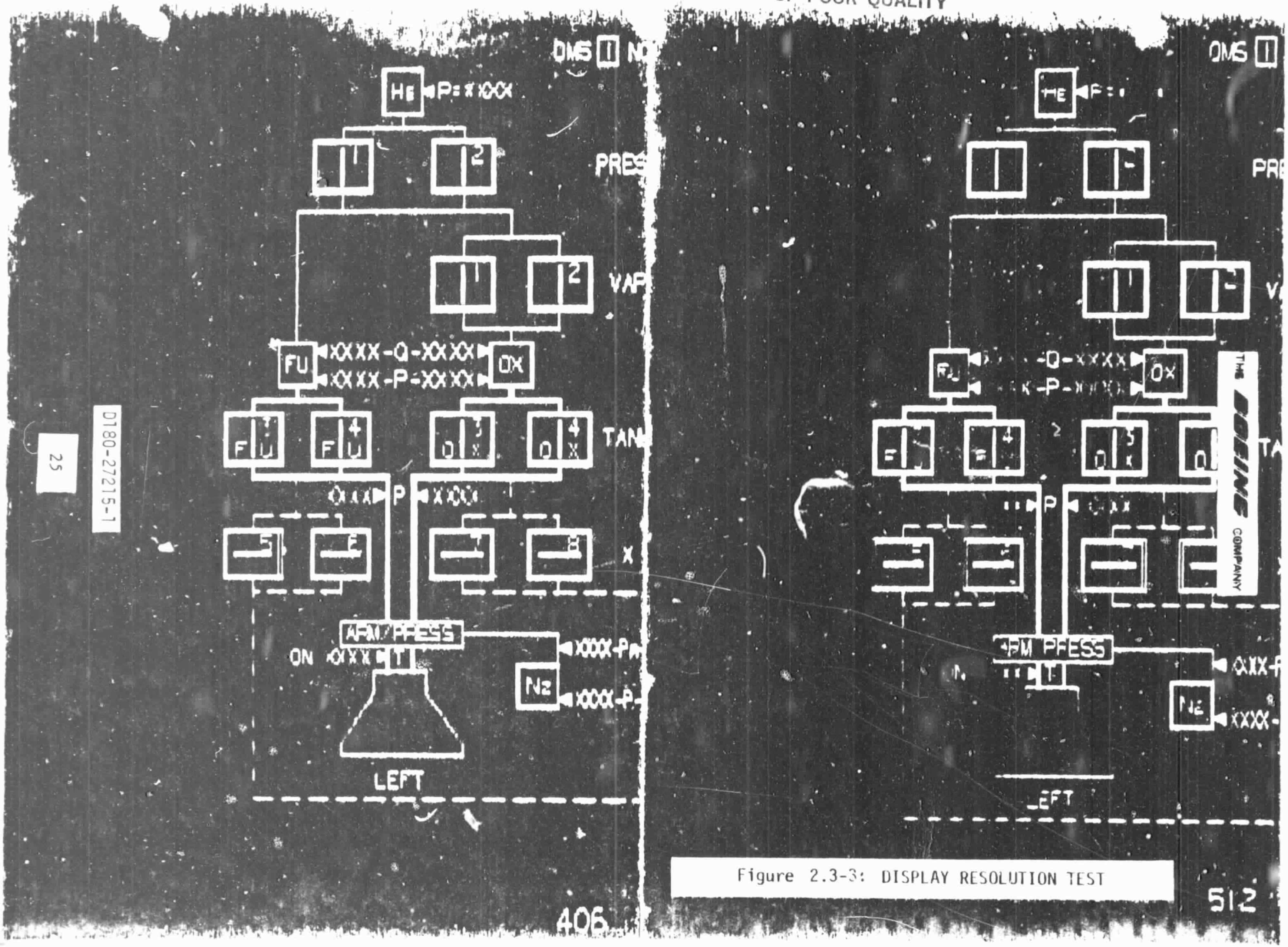


Figure 2.3-3: DISPLAY RESOLUTION TEST

the decision to suggest a color stroke-raster CRT as the high resolution display choice. This choice is discussed in greater detail in Section 4. The tabular display and multifunction keyboard display choices were analyzed with respect to size, power consumption and availability. Choices with sufficient luminance were determined to be LCD and LED displays. An analysis of required character sizes for adequate legibility and of font styles for flat panel dot matrix displays was conducted. These results defined the display sizes chosen in Section 4 and the font style shown in Figure 2.3-4. The font was chosen to minimize confusion due to row or line failure and to reduce power consumption.

2.3.2.2 CONTROL DEVICES

The basic control device choices for the MFDCS were multifunction switches, bezel editing switches and touch panel overlays. Bezel edit switches were found to present problems because of the number of lines of tabular data needed and the rather coarse resolution capability of the bezel edit switches. Touch overlay panels were analyzed and found to have a high susceptibility to accidental activation in the low gravity Orbiter environment. Multifunction programmable, legend switches offered a positive tactile feedback, the required brightness range and a LED dot matrix array as the display. These switches are discussed in greater detail in Section 4.

2.3.2.3 PROCESSING

A first step in analysis of the processor requirements was the decision on how the system was to be partitioned given the desired display complement. A desirable criterion was that the various display components be modifiable as time progressed without affecting the whole system. In addition, an estimate of the processing time required to maintain the refreshing of LED multifunction switches, a medium resolution checklist display and a high resolution graphics display showed that a single processor would be too heavily loaded to provide rapid response times. A goal of <0.2 seconds was set for the update of the keyboard displays. Similarly the desired update time for the checklist display was set somewhat higher at <0.8 seconds. Update time for the high resolution displays was permitted greater latitude with a time on the

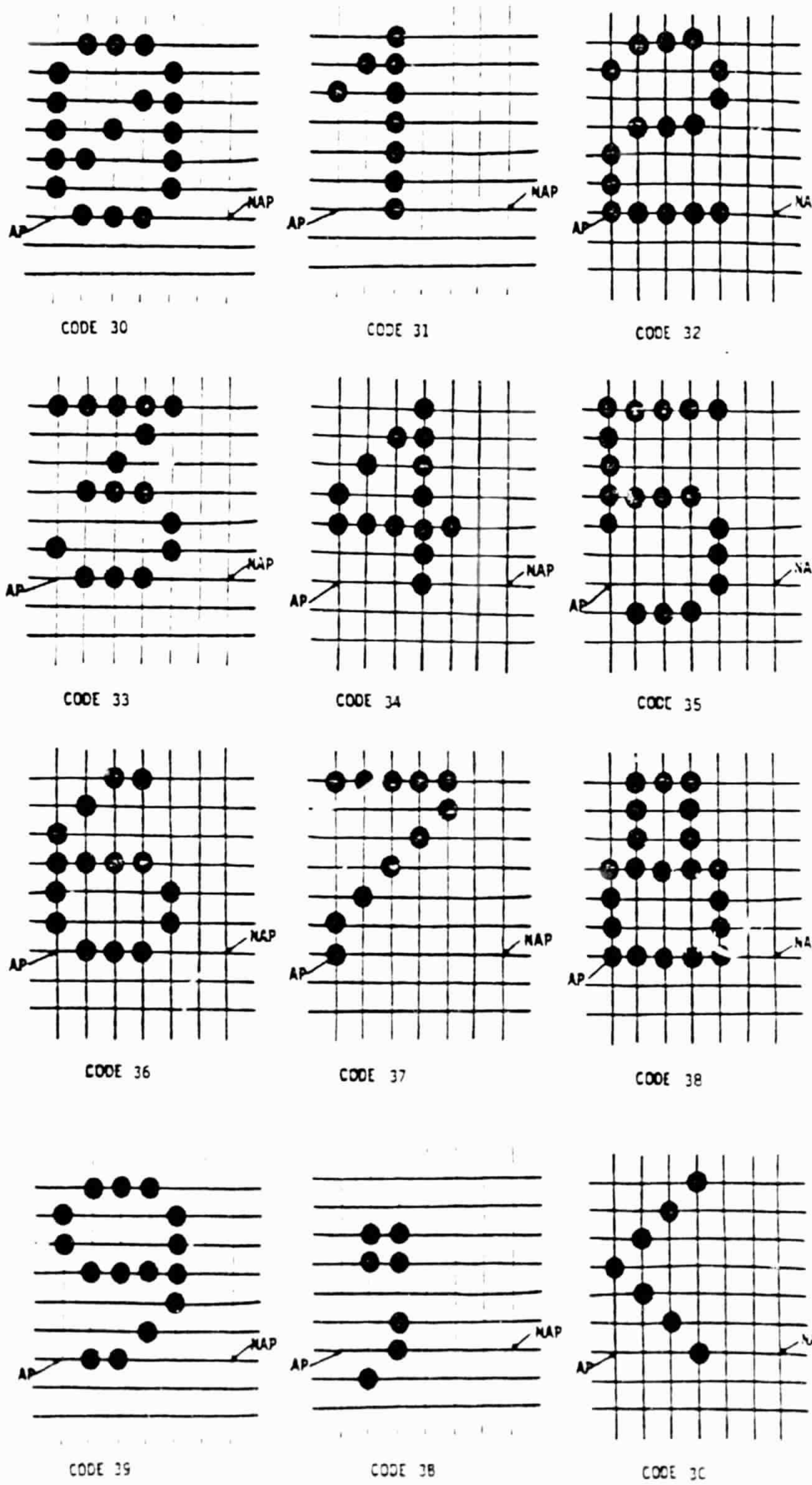


Figure 2.3-4: CHARACTER AND SYMBOL FORMATS

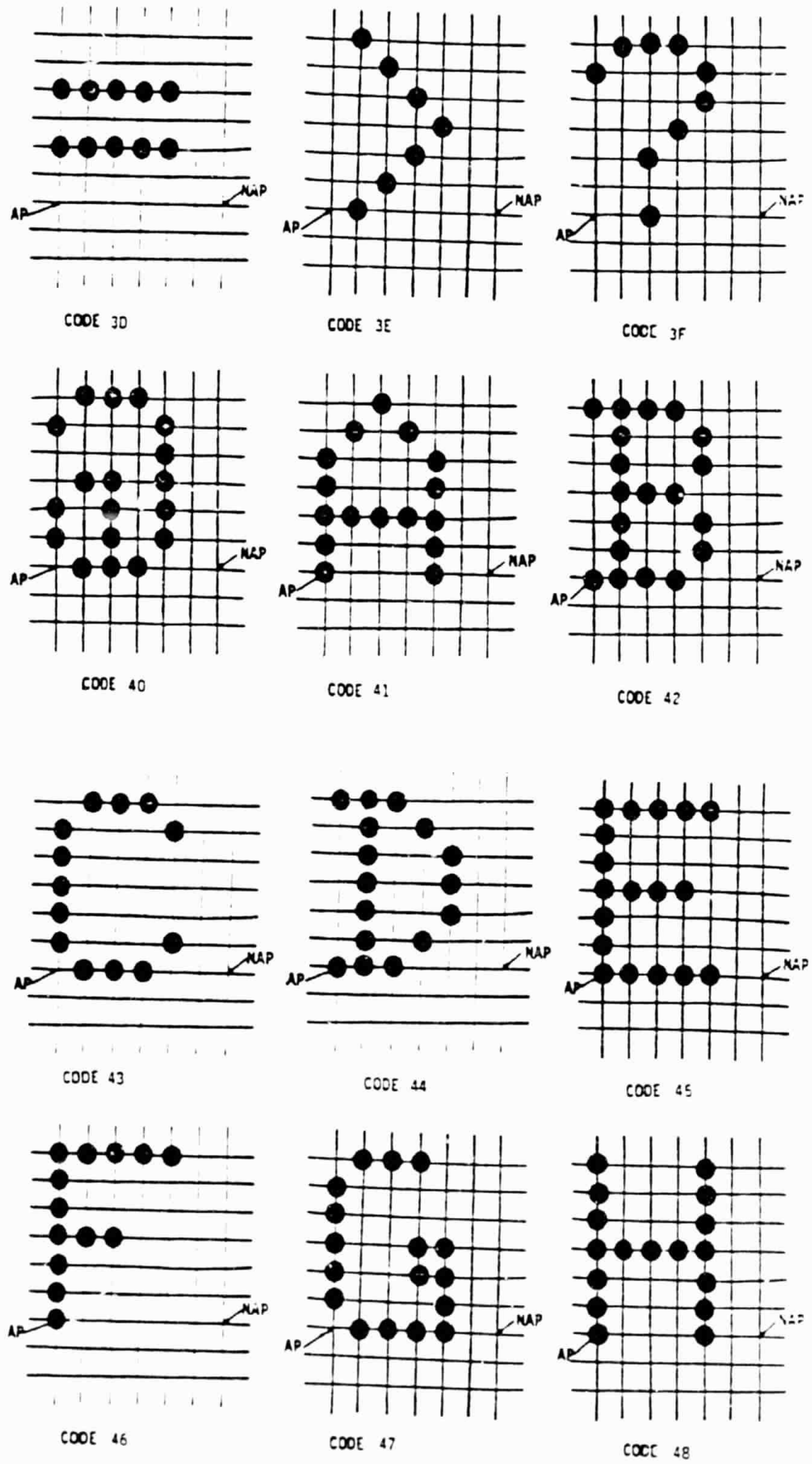


Figure 2.3-4: CHARACTER AND SYMBOL FORMATS (CONTINUED)

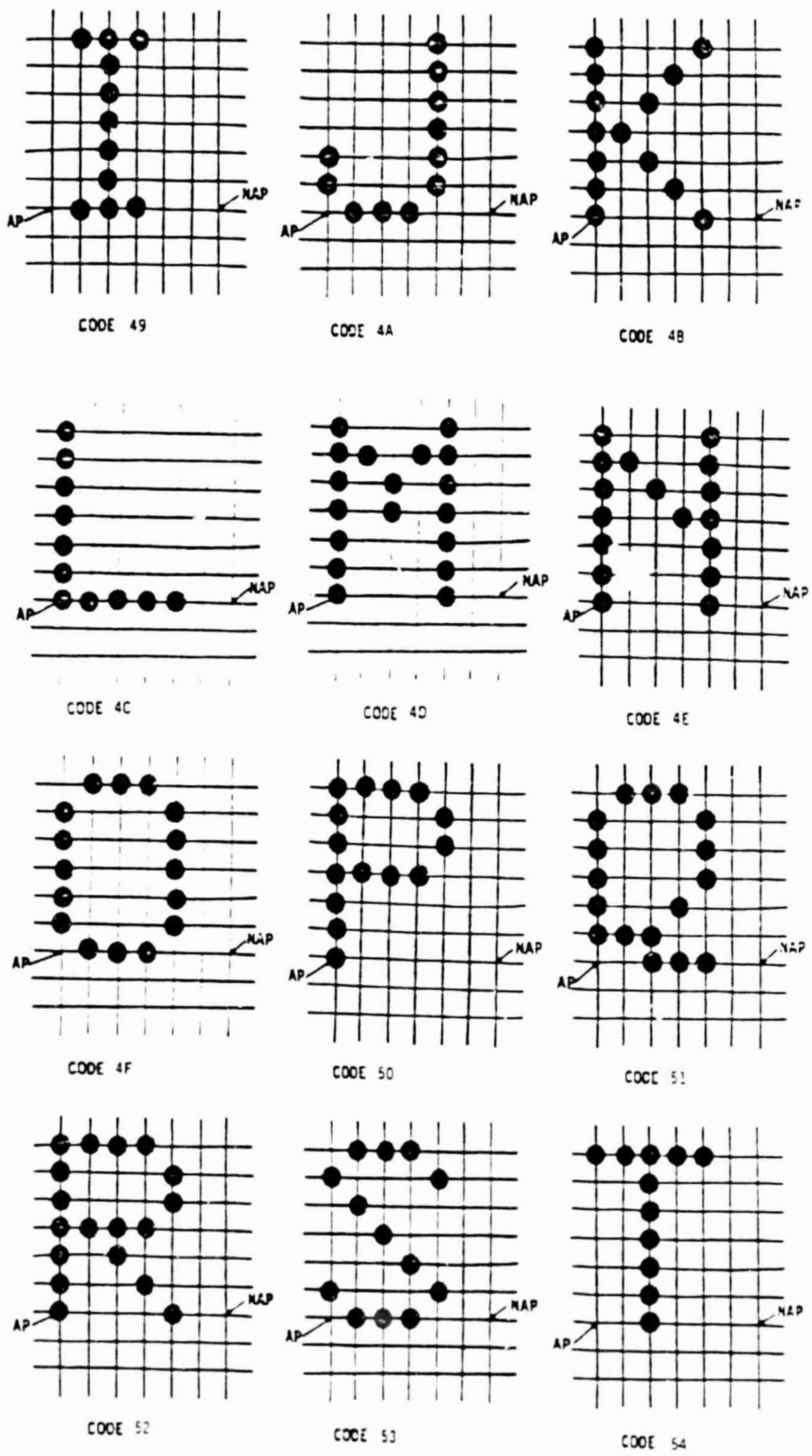


Figure 2.3-4: CHARACTER AND SYMBOL FORMATS (CONTINUED)

ORIGINAL PAGE IS
OF POOR QUALITY

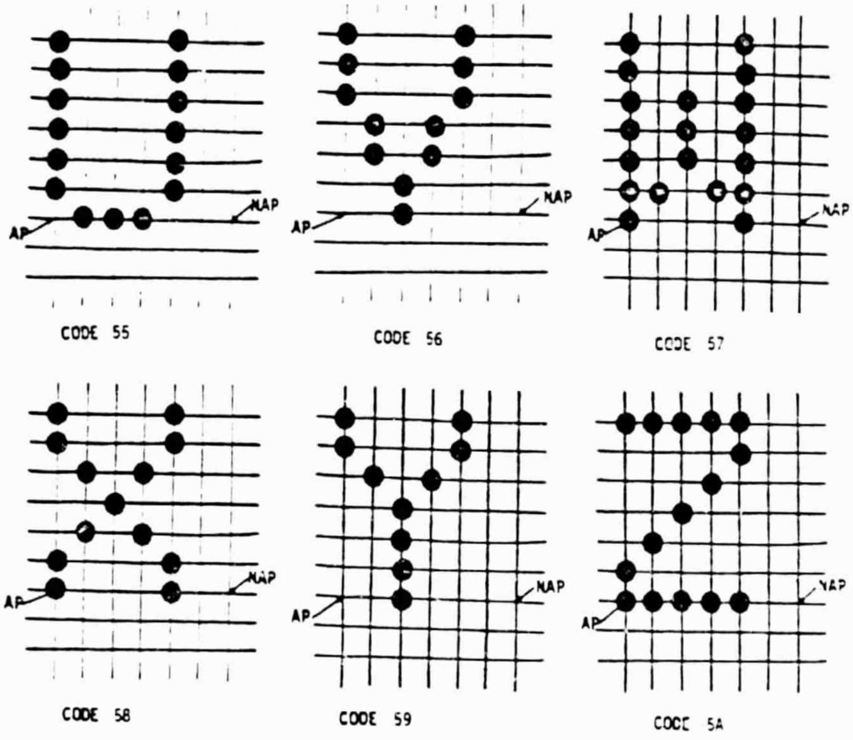


Figure 2.3-4: CHARACTER AND SYMBOL FORMATS (CONTINUED)

order of 1 second being deemed satisfactory. The update rate for dynamic subsegments of the high resolution display however, was targeted at <0.2 seconds as in the case of the keyboard update.

To permit higher speed operation, the MFDCS processing was divided into several subsegments. The central controller processor handles the storage and distribution of commands and legends to the keyboard and checklist display. In addition, the central controller handles the communications with the host computer (GPC). The large number of checklists and procedures to be displayed on the medium resolution display requires a considerable amount of memory. For this reason, the medium resolution display was assigned its own processor and memory.

The graphic display will in general, require its own memory and processor for the storage of images and dynamic modification of the display. Commands from the controller will define the image and/or the subsegment modification to be made. Examples of displays selected from the OMS and EPDCS indicate that the majority of the image will remain static. The arrangement of the processing architecture described above is indicated in Figure 2.3-5.

An analysis of the processing speed and memory required for the controller processor was conducted using two different processors to represent 8 bit (Intel 8085) and 16 bit (Intel 8086) microprocessors respectively. The general analysis was part of another Boeing keyboard development program, but the OMS and EPDCS were used as examples for the results quoted in this report. The analysis makes the assumption of a serial RS 422 interface to each set of four switches and a serial line to the medium resolution display. The analysis showed that for the assumed instruction mix and the interfaces chosen, the update rate for multifunction switches would be limited by transmission time for up to 20 switches for the 8085 and up to 40 switches for the 8086. Above this number of switches the throughput of the processor becomes the limiting factor as shown in Figure 2.3-6. Two cases were considered. The first was the time for pure alphanumerics and the second was the required update time for graphic displays on the switches.

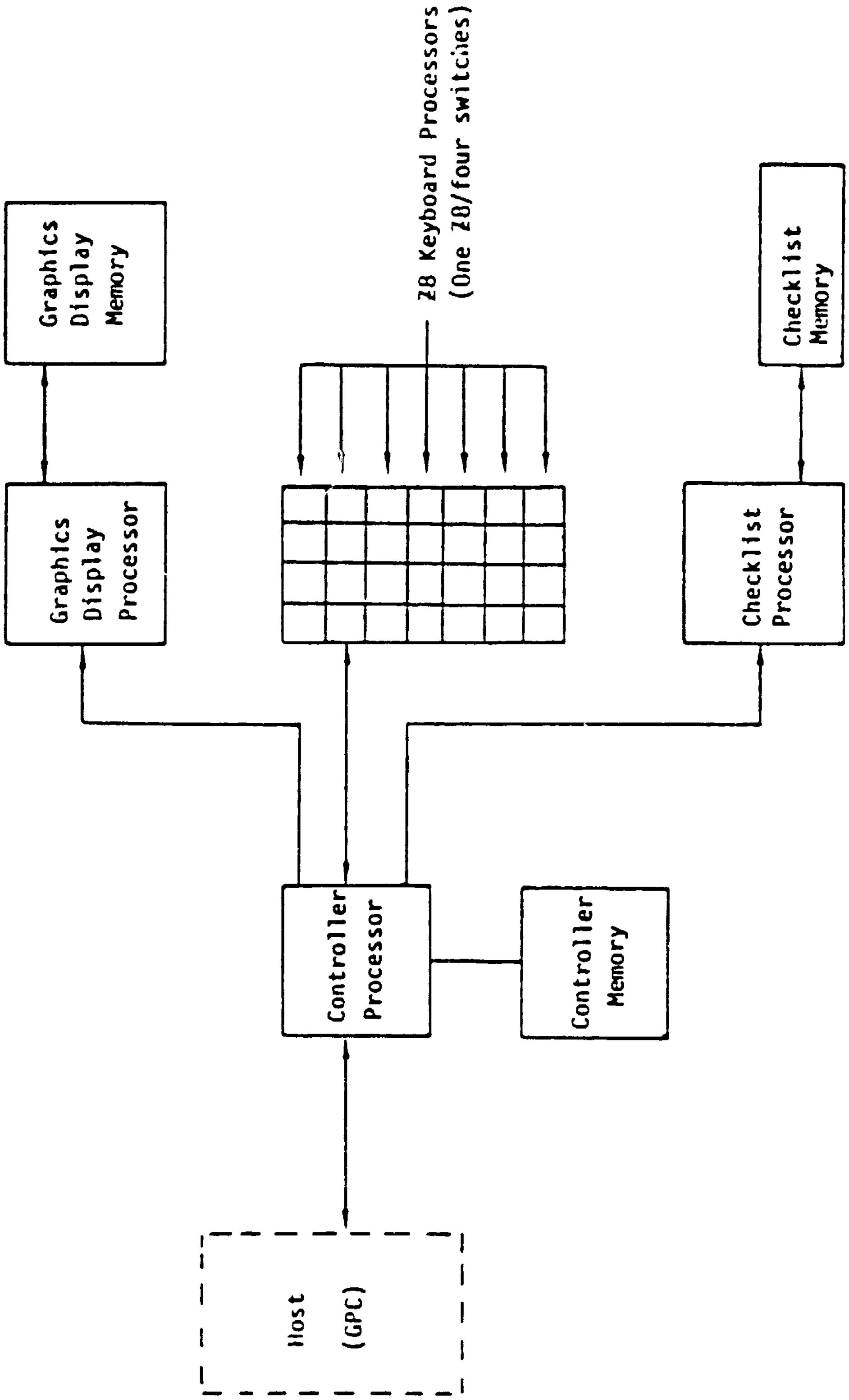


Figure 2.3-5: MFDCS PROCESSING ARCHITECTURE

ORIGINAL PAGE IS
OF POOR QUALITY

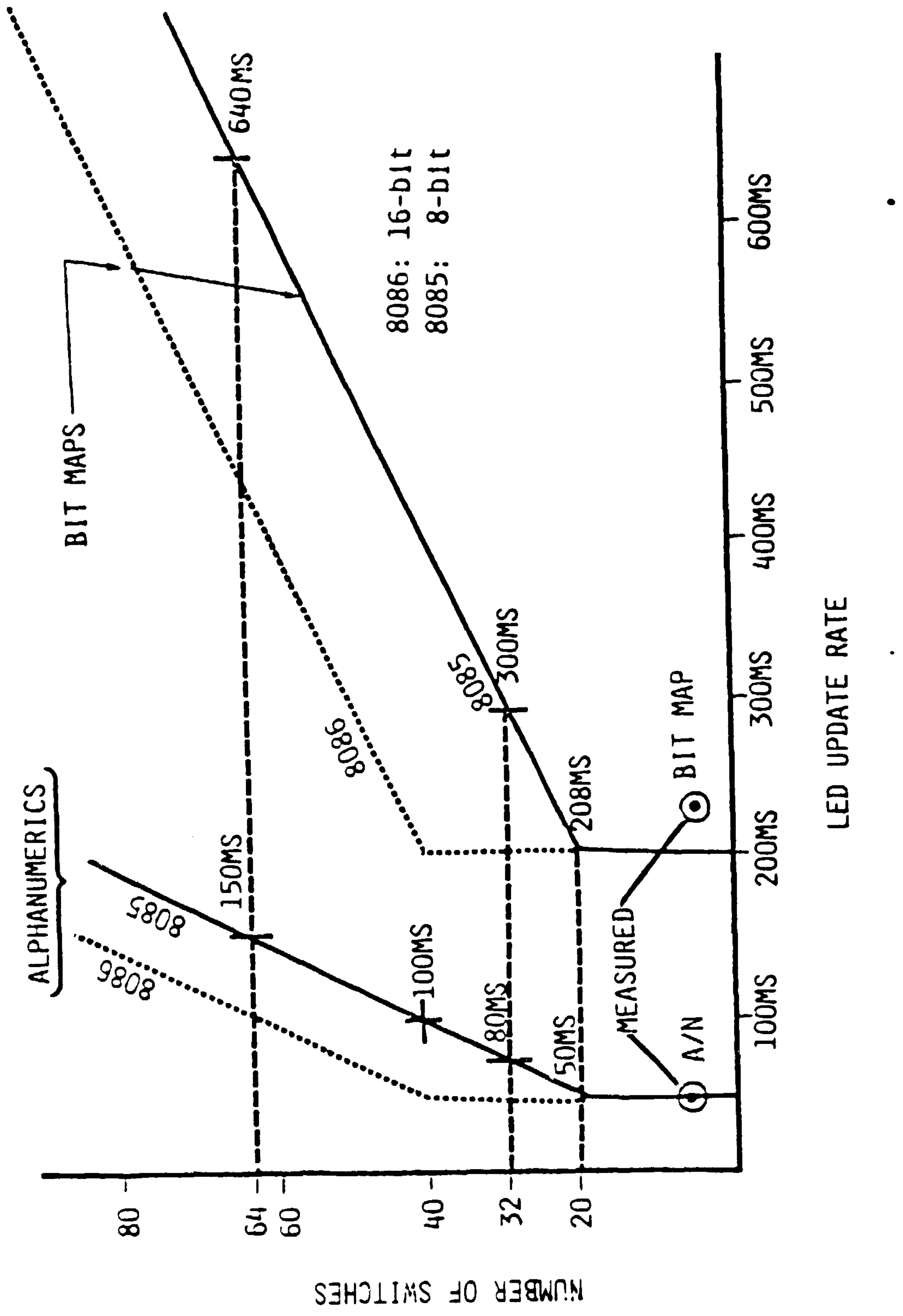


Figure 2.3-6: LED MFK UPDATE VS NUMBER OF SWITCHES

These results were tested using a 8085 controller and a set of four switches as examples of the keyboard. Using the set of four and an data base designed for these four switches, the update time was measured. These results were actually found to be valid for up to 28, as opposed to the estimated 20, switches and an update time of 52ms for alphanumeric displays was obtained. For pattern map displays the estimated time to update the keyboard is longer and was measured at 250ms. Most keyboards will use a mix of symbols and alphanumerics and the total mix update time should be <0.2 seconds. The measured points are shown as circles on Figure 2.3-6.

A limited test of a TFEL medium resolution panel was conducted using both a graphic and an alphanumeric display. The results showed an update time of 608ms for alphanumeric data and 250ms for a graphic display. This test employed a shared bus structure and would result in slower update times than those for a dedicated processor. This relation for the various interface/options is shown in Figure 2.3-7.

A good example of a high resolution color display suitable for inclusion in the MFDCS was not available. Tests were conducted on the update rate of a small color video display. The results showed that an update rate for dynamic symbol modification of <0.2 seconds was achievable. In general, an update time of >30 frames/second is achievable for high resolution stroke or raster graphic generation systems.

The same set of four switches was used to test the operation of the data base structure. The data base format was structured in the same way a larger keyboard array would be handled. Each page of legends stored in the controller memory contained the command, if any, to the GPC, the vectors to legends to be displayed on the keyboard and commands to the medium and high resolution displays. Also included was the vector to the previous legend page. The 8085 controller was found to perform satisfactorily, displaying the appropriate legends in the correct logical sequence and transmitting the correct commands to the host. The test is described in Section 4. A 64k byte memory was found to be adequate for the controller data base storage and operating system.

ORIGINAL PAGE IS
OF POOR QUALITY

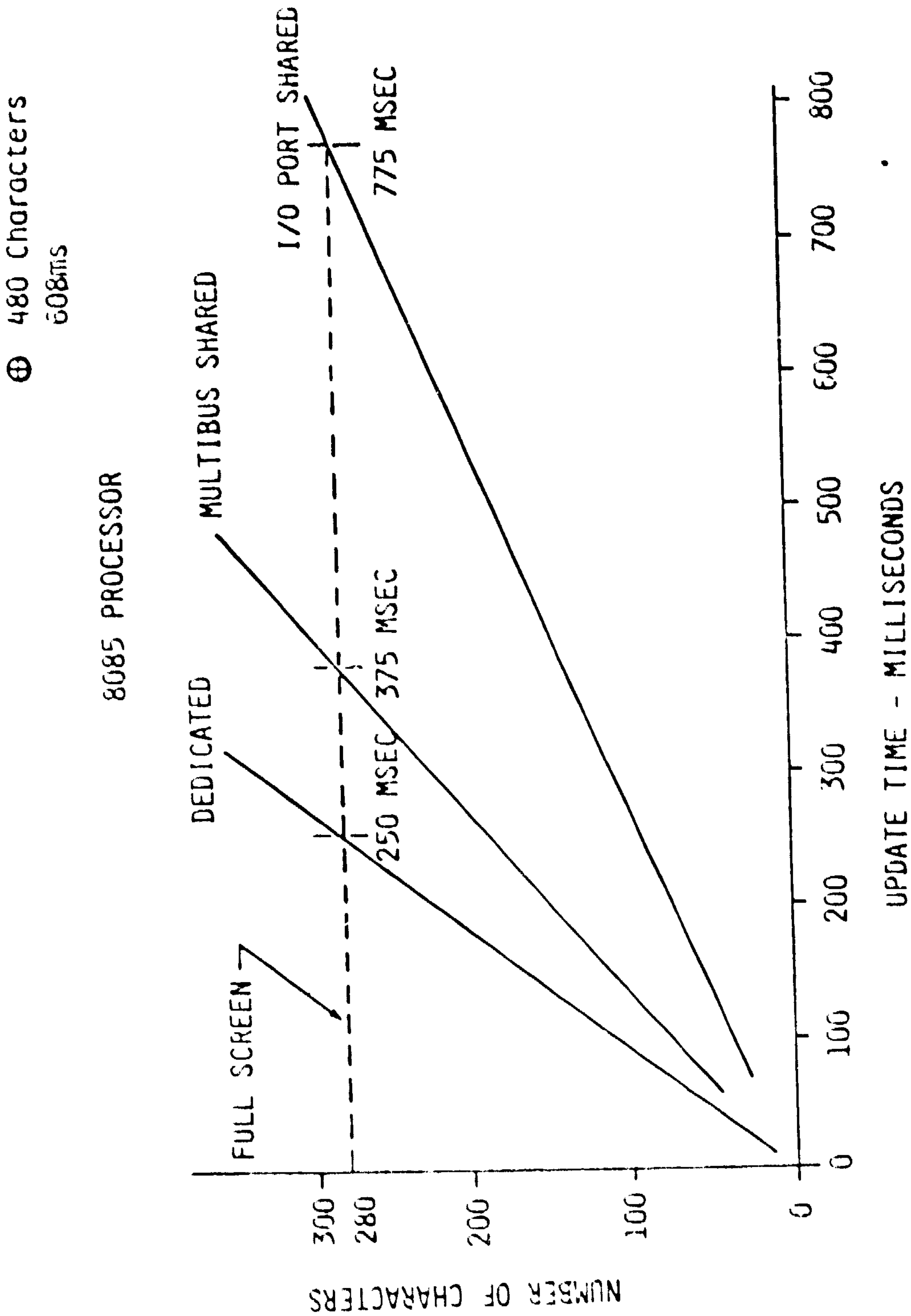


Figure 2.3-7: TFEL ALPHANUMERIC DISPLAY UPDATE RATE

2.3.2.4 INTERFACE ANALYSIS

The interfaces between the host and controller and between the controller and displays were analyzed to determine the type of data transfer to be used. Parallel and serial data line were investigated. The host (GPC)-controller interface will be defined by the access available to the data bus or GPC on the orbiter. The controller tested was designed to operate with an RS-232 interface with the intent of interfacing in a modular fashion to permit changes to the interface routines without changing the basic operating system.

The interfacing to the keyboard multifunction switches was investigated and an RS 422 serial line was selected to interface to each unit of four switches. A parallel line interface was found to be unnecessary with respect to required data transfer speed and required a larger number of wires between controller and keyboard. The RS 422 serial line was chosen over the RS 232 because it required a single 5 volt supply and provided a better driving capability for remote operation of the keyboard relative to the controller. An operating speed of 19.2kb was selected.

2.3.3 ACCESS SCHEMA DEVELOPMENT

Discussions of the preliminary access schema developed in Task 2 coupled with the further functional analysis of the EPDCS indicated a need for greater automation of procedures and checklists if the operation of the MFDCS was not to become cumbersome. The access schema developed was the end result of a number of different trials at developing a technique for reducing the number of keyboard formats required and minimizing returns to the keyboard top level. The access schema developed in Task 3 is basically the one recommended in Task 4. A discussion in Section 3 describes the details of operation.

3.0 MFDCS ACCESS SCHEMA

The access schema developed for the MFDCS performs the functions indicated as goals for the system. These include incorporation of checklists and procedures, localization of controls, automated handling of checklists, procedures and malfunctions and retention of supervisory crew command and control. The access schema also provides an interactive graphic representation of system status for use by the crew.

3.1 MODES OF OPERATION

The MFDCS is designed to operate in four modes. These modes are illustrated in Figure 3.1-1. Interconnecting lines on the diagram indicate the linkage between these four modes.

3.1.1 SYSTEM STATUS MODE

The top level of the access schema is the System Status mode in which the operator has access to all the MFDCS systems. This mode covers normal or malfunction procedure operation of the systems and presents the crew with an overall display of system status and the keyboard entry options to access the individual systems such as the OMS or EPDCS. At operator option, the high resolution graphics display presents a block diagram of systems under MFDCS control. The keyboard display for this level is illustrated in Figure 3.1-2. Occurrence of a caution and warning alert at this level will indicate the system(s) requiring operator attention on the high resolution display by a block color change and an anomaly message display at the bottom of the screen.

3.1.2 NORMAL OPERATION MODE

If no caution and warnings are present, the system may be operated in the normal mode. In this mode, a system (such as OMS) is selected from the top level keyboard. This selection brings up a menu of normal operations for that system on the high resolution display and provides the operator with a keyboard display to select the procedure desired (see Figure 3.1-3). The operator enters the procedure selection

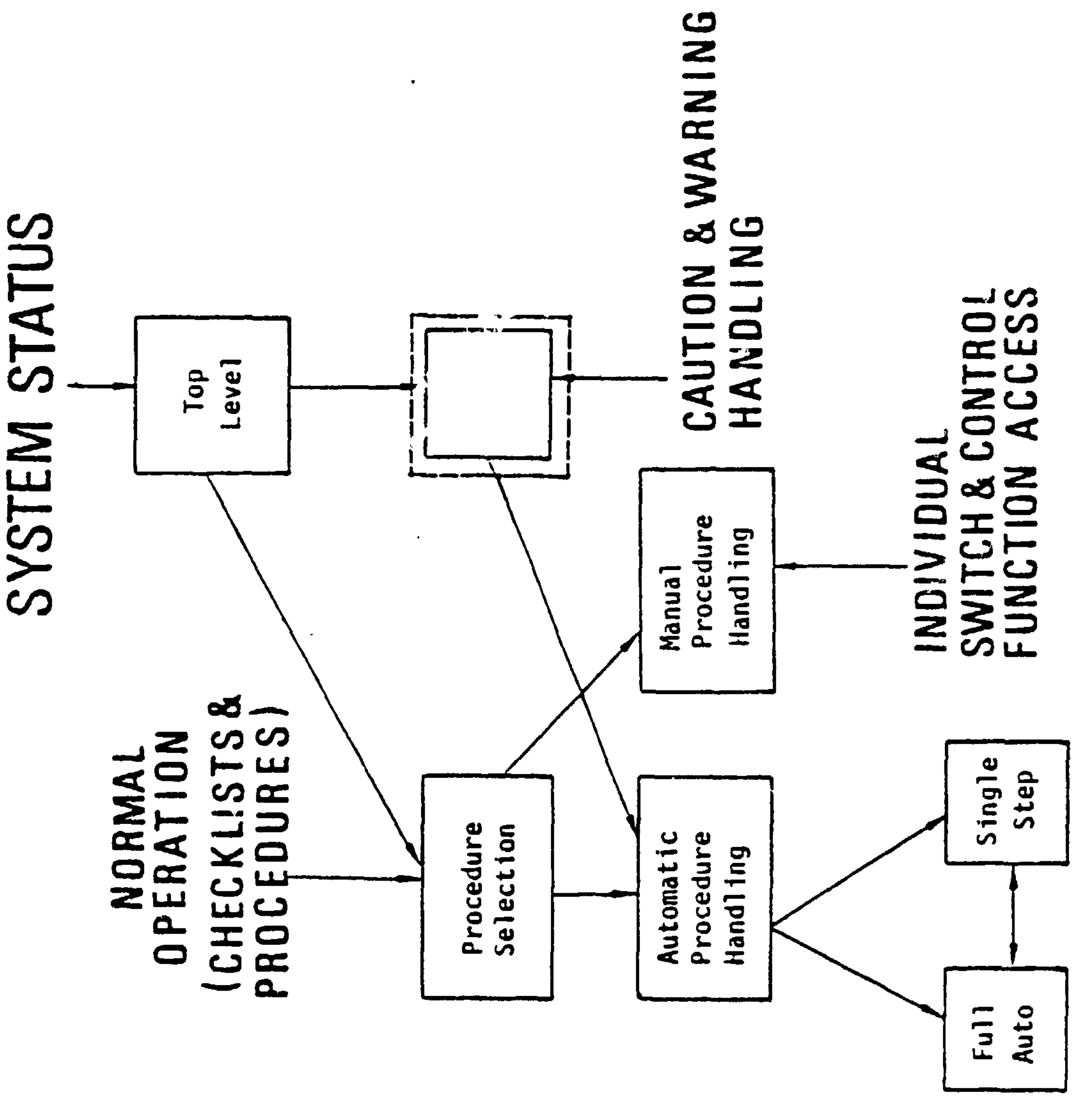


Figure 3.1-1: MFDCS OPERATING STRUCTURE

TOP LEVEL SUB-SYSTEM SELECTION KEYBOARD
(NON-INTERACTIVE)

OMS	EPDCS	SYST 3	SYST 4
SYST 5	SYST 6	SYST 7	SYST 8
SYST 9	SYST 10	SYST 11	SYST 12

(NOT TO SCALE)

Figure 3.1-2 MFDCS SUB-SYSTEM SELECTION KEYBOARD

OMS - MENU SELECTION KEYBOARD
(NON-INTERACTIVE)

OMS			
1	2	3	
4	5	6	
7	8	9	
	0		
AUTO KEYBD		MANUAL KEYBD	
		BACK	

(NOT TO SCALE)

Figure 3.1-3: OMS - MENU SELECTION KEYBOARD number from the menu and indicates whether an automatic option or single function (manual) access is desired. At this point the procedure appears on the checklist display and in the automatic option the keyboard shown in Figure 3.1-4 would appear. Activation of the Auto Mode Key followed by the EXEC key will cycle through the whole procedure automatically. A single step mode is available at any time through the STEP AUTO key. CANCEL eliminates an action before execution. A basic ground rule in the system is the requirement for activation of the EXEC key for all command functions which change the system configuration. BACK returns the operator to the previous page. Here too, the operator has the option of performing all or part of the procedure and, if performing all, of doing so in an automatic or semi-automatic mode. The choices between automatic, semi-automatic or partial procedure implementation preserve the command supervision capability of the crew while providing the capability for automation during conditions of heavy workload.

3.1.3 CAUTION AND WARNING HANDLING MODE

Fault detection, alerts and warnings are handled by the Caution and Warning Handling mode. Incoming fault messages are prioritized in terms of probable system impact and displayed to the operator. The operator may then select which, if any, of the faults he wishes to deal with. Selection of a fault to deal with also provides the operator with a suggested procedure, if available, for dealing with the problem.

If a caution and warning (C&W) signal occurs, the problem will be displayed at the bottom of the CRT and/or scratchpad display together with a suggested procedure. In the normal mode the operator simply backs up to the top level using the BACK key and from there accesses the C&W procedure suggested. In the event that a C&W of overriding importance occurs, the keyboard can exhibit a forced display requiring operator acceptance or acknowledgement of the C&W. Acknowledgement will remove the forced display. Acceptance will take the operator directly to the C&W mode, eliminating the need to back up to the top and then access from there. Once in the C&W mode, the operator will be presented with a hierarchical list of procedures accompanying the prioritized C&W messages. Selection of a procedure leads to the automatic procedure handling area of the normal operation mode.

OMS/EPDCS KEYBOARD-AUTOMATIC MODE
(INTERACTIVE WITH CHECKLIST AND/OR SCHEMATIC DISPLAY)

OMS			
CHECK ✓	SKIP ×	↑	
		↓	DISPL OFF/ON
			TAB OFF/ON
AUTO MODE	MANUAL MODE		
	CANCEL	BACK	EXEC

(NOT TO SCALE)

Figure 3.1-4: OMS/EPDCS - AUTOMATIC KEYBOARD

During the performance of any procedure in which the checklist is displayed on the flat panel display, the software will display a check beside each step performed or previously performed.

3.1.4 INDIVIDUAL SWITCH CONTROL AND FUNCTION ACCESS MODE

This mode of operation is similar to the system currently available on the Orbiter in that it provides access to the individual switch and control functions within the system. In addition, this phase includes the most detailed displays of the subsystems within the OMS and EPDCS. Althougn very comprehensive, this mode is more time consuming to operate within than are the other modes. As a result, it is envisioned primarily for use in a diagnostic or trouble-shooting mode during periods when the crew has more time to work on problem solutions. This mode is accessed through the manual keyboard. If the MANUAL KEYBD option is selected then the operator must address each valve or control using the manual keyboard (Figure 3.1-5), the checklist display procedure, and the status indication on the schematic display. At this point, he is in the Individual Switch and Control Function Access Mode.

3.2 EXAMPLE OF OPERATIONS

In order to better understand operations and function of the MFDCS, the following detailed description of its application to the Orbital Maneuvering System (OMS) is contained below.

As previously described in the Access Schema, the top level keyboard contains access keys to all of the applicable subsystems as shown in Figure 3.1-2. The display associated with this keyboard, which is an extension of the C&W system, shows the system state, i.e., whether any element of that subsystem is in either a normal or out-of-limit state.

Once alerted to a non-normal condition or for any other reason, the operator can examine that subsystem in more detail by depressing the subsystem key, in this case, the OMS key.

OMS - MANUAL KEYBOARD
(INTERACTIVE)

FU	OX	VPR ISOL	ENG SWTCH
1	2	3	ARM
4	5	6	ARM PRESS
7	8	9	KIT
GPC	0		THERM
LEFT	RIGHT	ON OPEN	OFF CLOSE
DISPL FARAM	CANCEL	BACK	EXEC

(NOT TO SCALE)

Figure 3.1-5: **.OMS - MANUAL KEYBOARD**

Depressing the OMS key brings up a menu of system conditions, checklists and schematics from which the operator can select. The OMS menu is shown in Figure 3.2-1 and each item on the menu is numbered. The operator can then select the desired schematic/checklist by keying in the number shown on the menu. Execution of this selection is accomplished by selection of the MANUAL KEYBD or AUTO KEYBD (see fig. 3.2-2).

For example, if the operator desires menu item #1 and wishes to converse with the system manually he would key as follows:

1 ⟶ MANUAL KEYBOARD

Result:
CRT - OMS #1 schematic interactive display (fig. 2.3-2)
Flat Panel - echo of keyboard entry
Keyboard - manual (fig. 3.2-3)

However, if an automatic L-R X feed is desired, the operator would key as follows:

3 ⟶ AUTO KEYBOARD

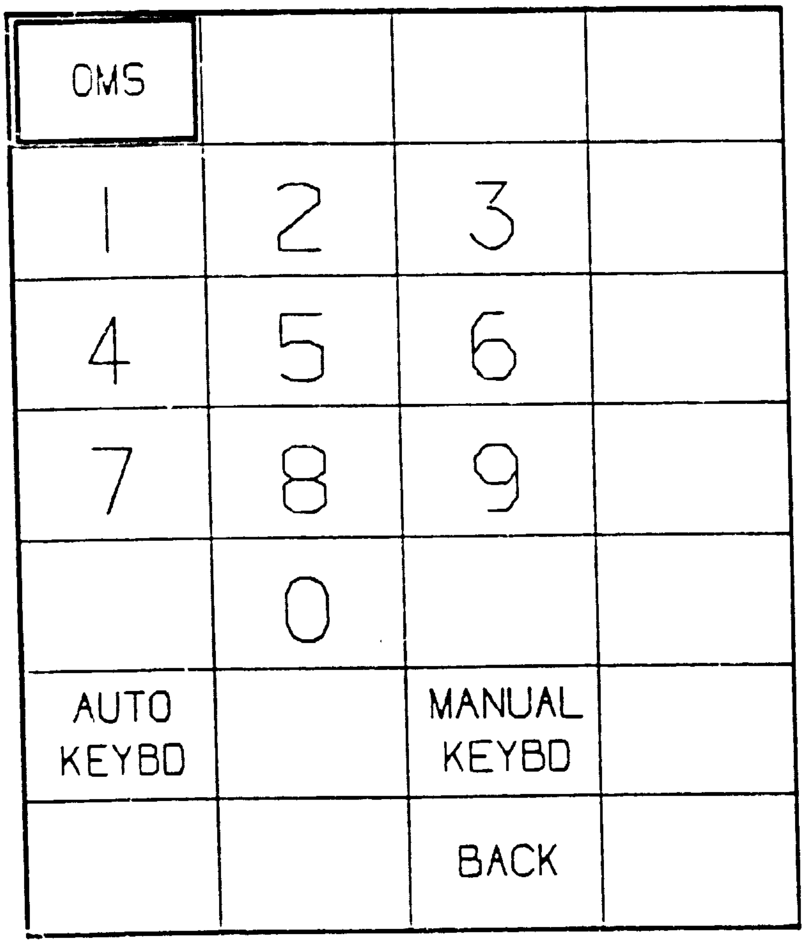
Result:
CRT - L-R X feed valve configuration schematic (fig. 3.2-4)
Flat Panel - L-R X feed checklist (fig. 3.2-5)
Keyboard - Auto (fig. 3.2-6)

The pictoral transition from normal to X feed configuration schematics is shown in Figures 3.2-7 thru 3.2-14.

1. SYSTEM STATUS - ENGINE AND PROPELLANT
2. LEFT ENG. LOST - NORMAL FEED
3. LEFT ENG. LOST - L-R X FEED
4. LEFT ENG. LOST - MIXED FEED - L OX R FU
5. LEFT ENG. LOST - MIXED FEED - R OX L FU
6. RIGHT ENG. LOST - NORMAL FEED
7. RIGHT ENG. LOST - R-L X FEED
8. RIGHT ENG. LOST - MIXED FEED - L OX R FU
9. RIGHT ENG. LOST - MIXED FEED - R OX L FU
10. FU and OX TANK PRESSURE HIGH
11. N_2 TANK PRESSURE LOW
12. N_2 REG. PRESS HIGH
13. N_2 REG. PRESS LOW
14. Ne TANK PRESS LOW
15. PC LOW (DURING BURN)
16. TEMPERATURE LOW (DURING BURN)
17. OMS SECURE

Figure 3.2-1 OMS MENU

OMS - MENU SELECTION KEYBOARD
(NON-INTERACTIVE)



(NOT TO SCALE)

Figure 3.2-2 OMS - MENU SELECTION KEYBOARD

The number of digits in the menu selection is of no consequence since the software selection loop is closed by the keyboard selection key which serves as an "execute" function.

Once the operator decides to operate in the automatic mode by requesting the AUTO KEYBD, he has a further option of performing the checklist in the fully AUTO mode or STEP AUTO mode by pressing the appropriate key on the automatic keyboard (fig. 3.2-6).

In the AUTO mode all steps contained in the checklist are rapidly performed sequentially, each change being reflected in the interactive schematic displayed on the CRT.

In the STEP AUTO mode all steps are also automatically performed, except that each successive step will not be performed until the operator either CHECK or SKIPs the preceeding steps.

The MANUAL keyboard as noted in Figure 3.2-3 allows the operator to change the status of any valve or switch in the system by individual commands. Each valve or switch may be addressed by keyboard alphanumerics as shown on the schematic. Commands are executed by pressing the EXEC key.

Example: Left engine switch on

ENG SWITCH → LEFT → ON → EXEC

OMS - MANUAL KEYBOARD

(INTERACTIVE)

FU	OX	VPR ISOL	ENG SWTCH
1	2	3	ARM
4	5	6	ARM PRESS
7	8	9	KIT
GPC	0		THERM
LEFT	RIGHT	ON OPEN	OFF CLOSE
DISPL PARAM	CANCEL	BACK	EXEC

(NOT TO SCALE)

Figure 3.2-3 OMS - MANUAL KEYBOARD

DISPLAY COLOR CODING

Valve Open - SOLID GREEN	Potential Flow Path - SOLID GREEN
Valve Closed - WHITE	Blocked Flow Path - BROKEN WHITE
System Parameters - MAGENTA (Normal)	System Parameters - YELLOW or ORANGE (Out of Limits)
Engine Enabled - GREEN	Engine Off - YELLOW or ORANGE
Engine Burn - RED	

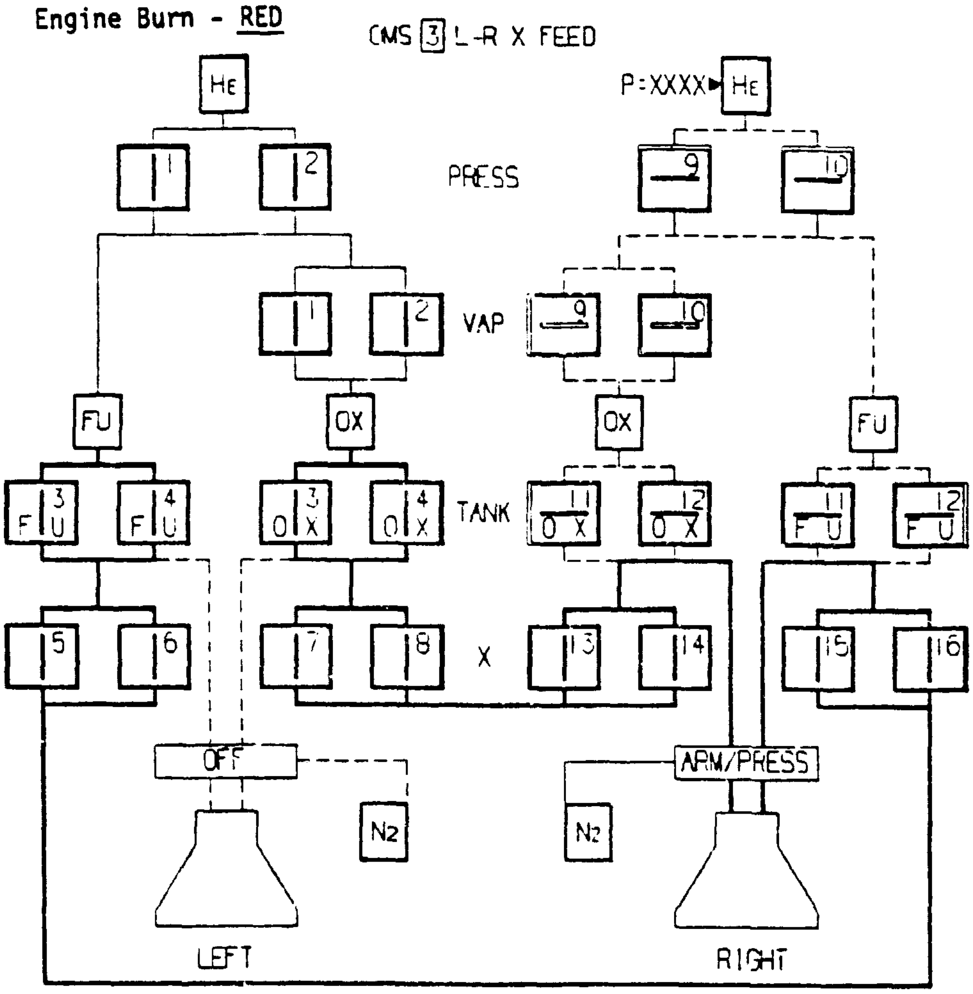


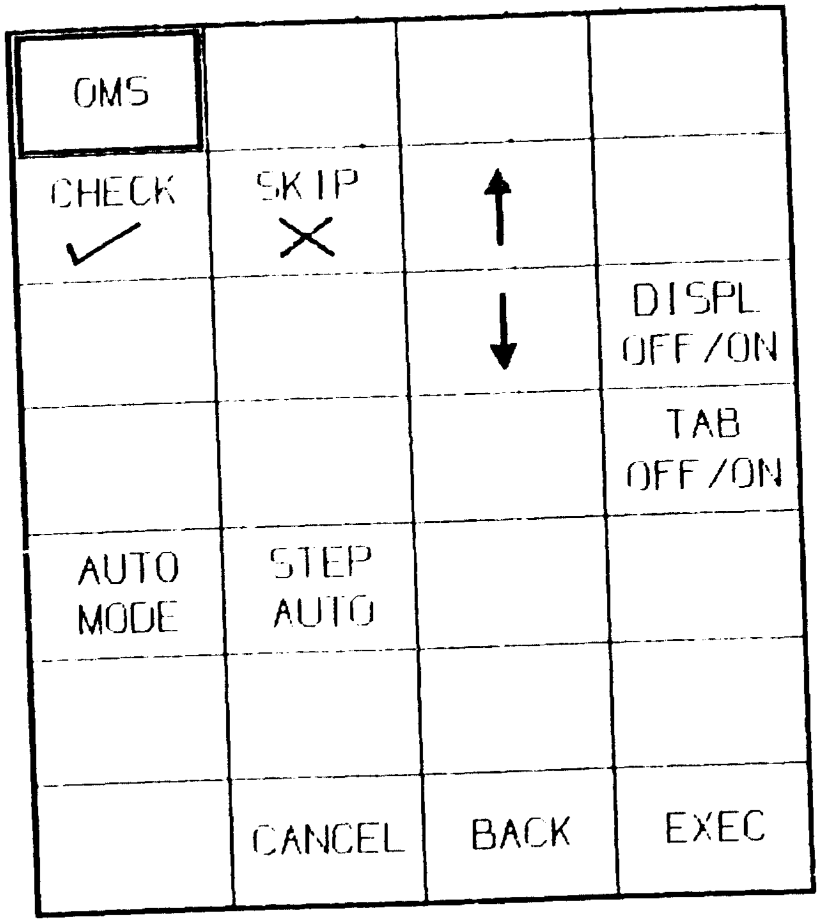
Figure 3.2-4 OMS VALVE STATUS DISPLAY FOR L-R XFEED. VALVES MAY BE MANUALLY CONFIGURED FROM MANUAL KEYBOARD OR AUTOMATICALLY CONFIGURED USING AUTO KEYBOARD.

OMS $\boxed{2}$ L PRPLT TO R ENG

1. LEFT ENG VLV SWITCH - OFF
2. VLV 1 & 2 - OPEN (L HE PRESS/VAP)
3. VLV 3 & 4 - OPEN (L TANK ISOL)
4. VLV 5 & 6 - OPEN (L FU X FEED)
5. VLV 15 & 16 - OPEN (R FU X FEED)
6. VLV 7 & 8 - OPEN (L OX X FEED)
7. VLV 13 & 14 - OPEN (R OX X FEED)
8. VLV 11 & 12 - CL (R HE TANK ISOL)
9. VLV 9 & 10 - CL (R HE PRESS/VAP)

Figure 3.2-5 OMS L-R X FEED CHECKLIST

OMS/EPDCS KEYBOARD-AUTOMATIC MODE
(INTERACTIVE WITH CHECKLIST AND/OR SCHEMATIC DISPLAY)



(NOT TO SCALE)

Figure 3.2-6 OMS/EPDCS KEYBOARD-AUTOMATIC MODE

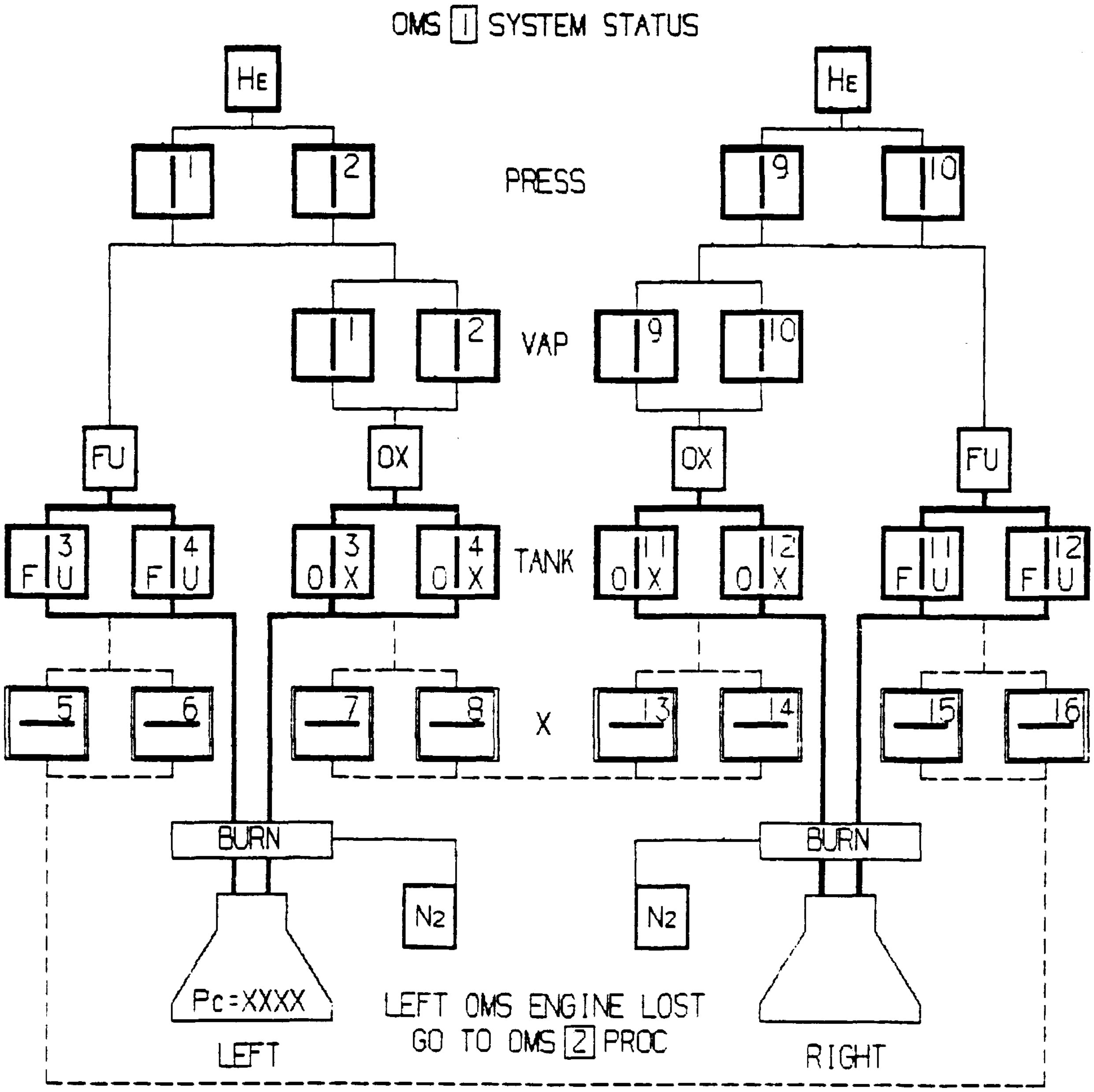


Figure 3.2-7 DISPLAY SHOWING ANOMOLY MESSAGE "LEFT ENGINE LOST", START L-R X FEED CHECK LIST

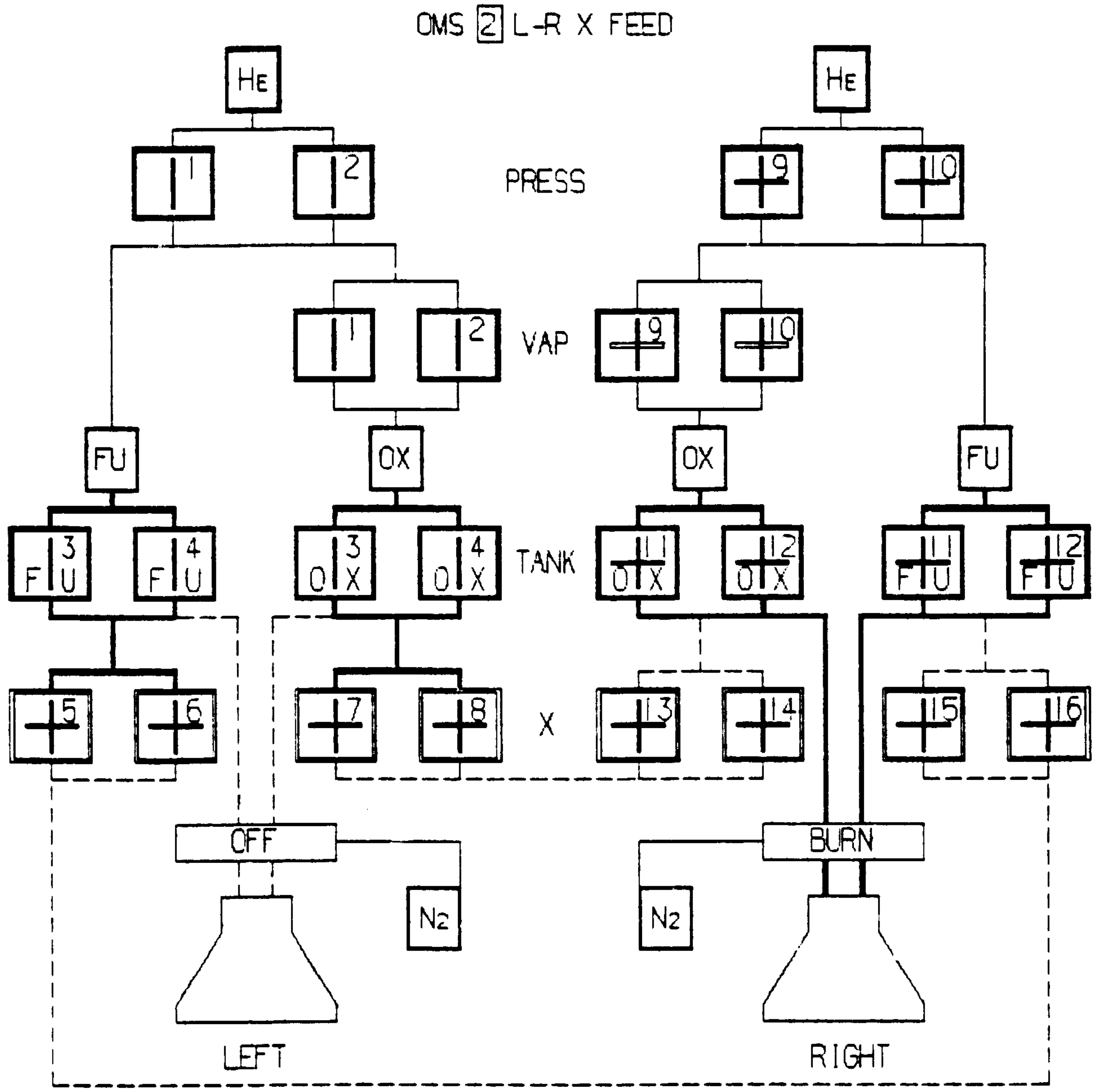


Figure 3.2-8 DISPLAY SHOWING VALVE CHANGES NEEDED TO ACHIEVE L-R X FEED

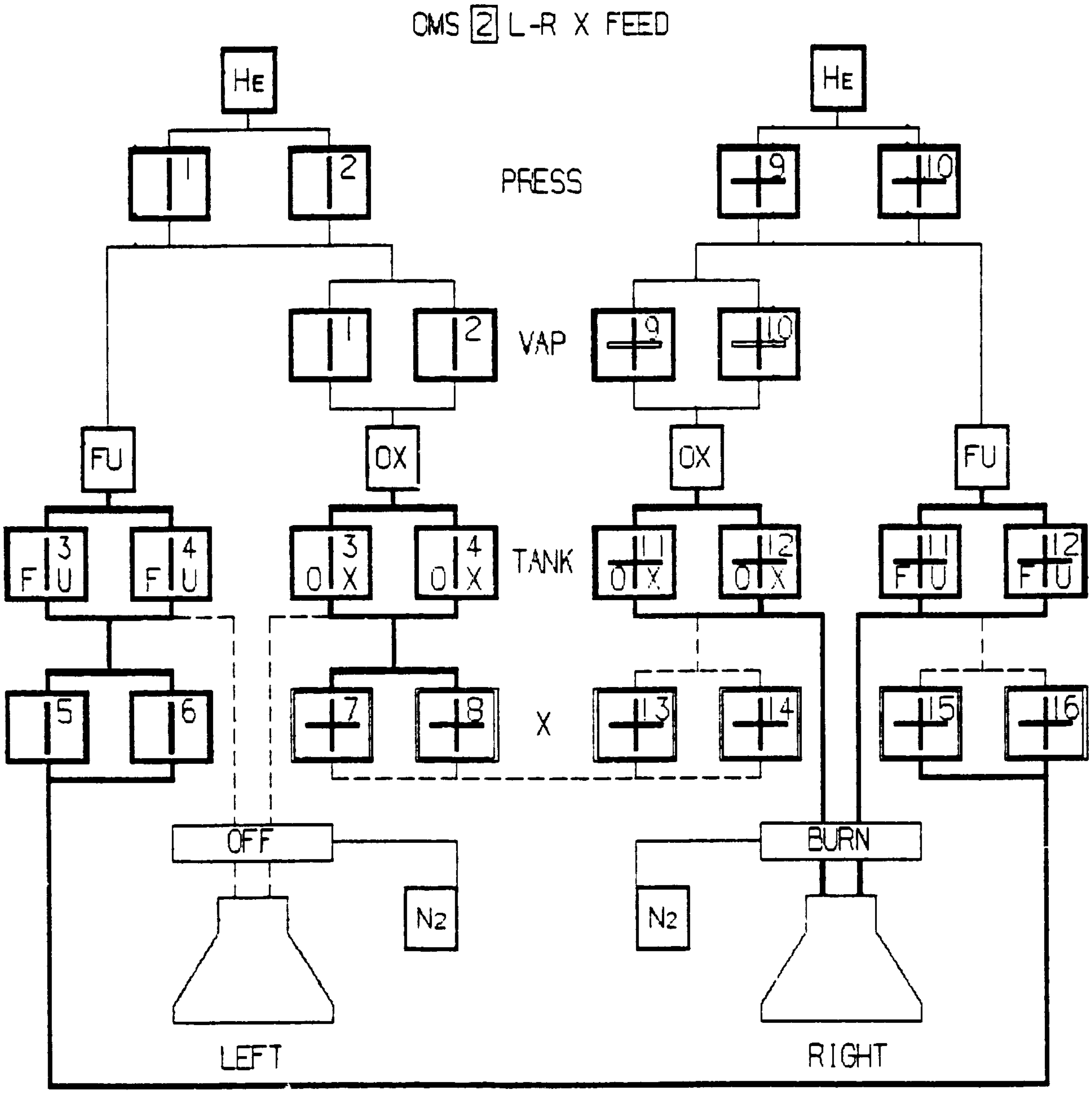


Figure 3.2-9 OPEN VALVES 5 and 6

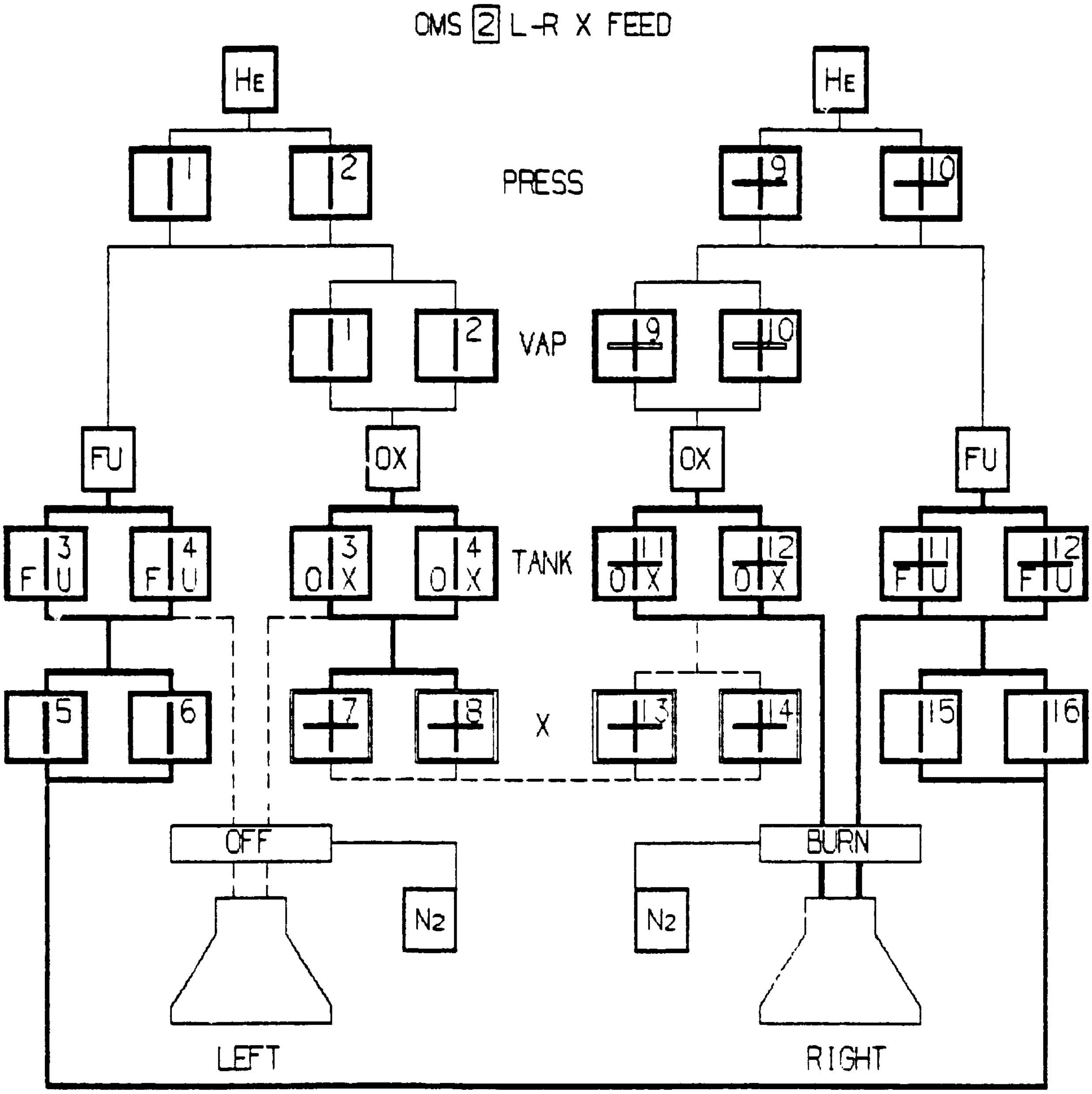


Figure 3.2-10 OPEN VALVES 15 and 16

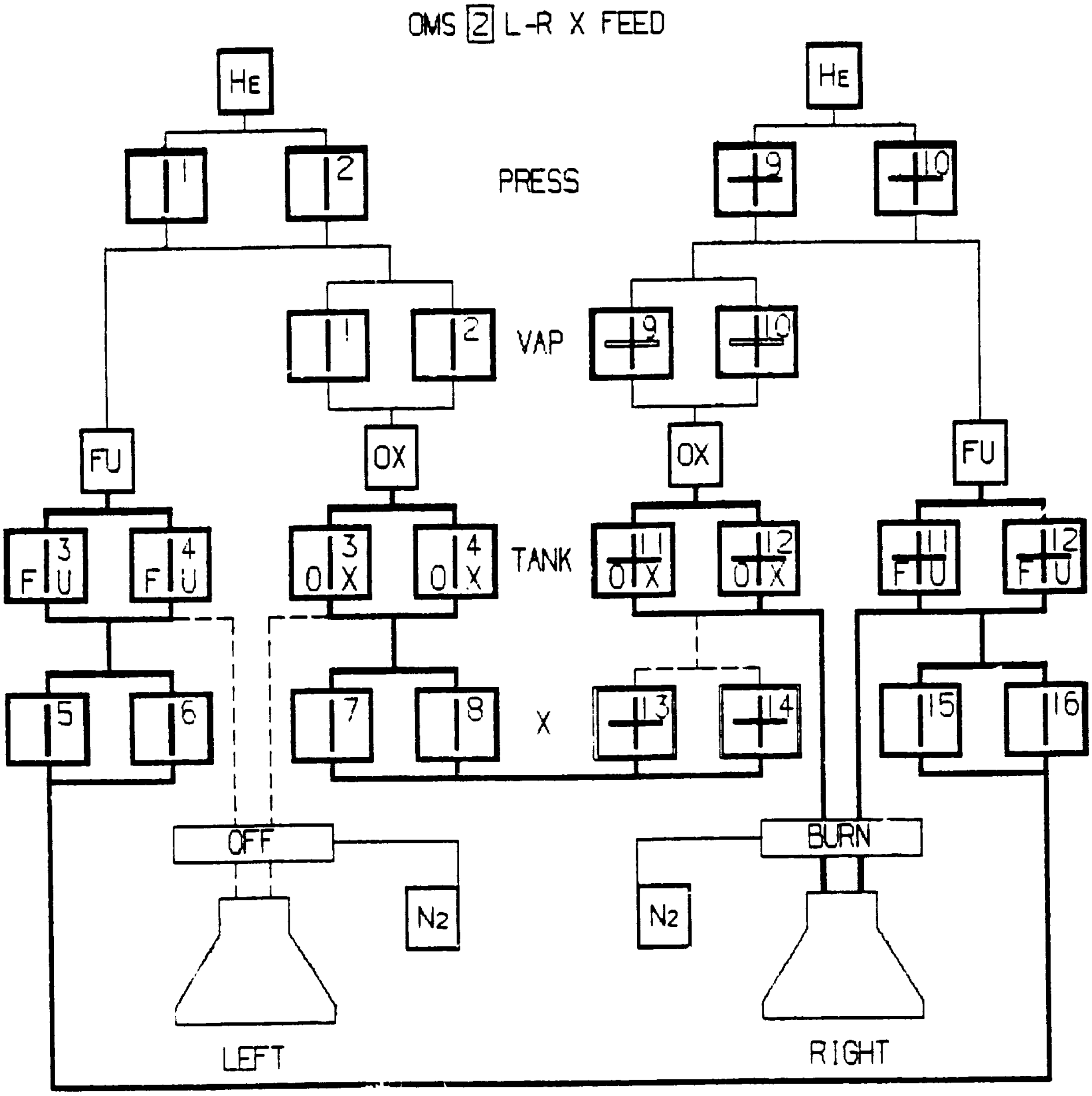


Figure 3.2-11 OPEN VALVE 7 and 8

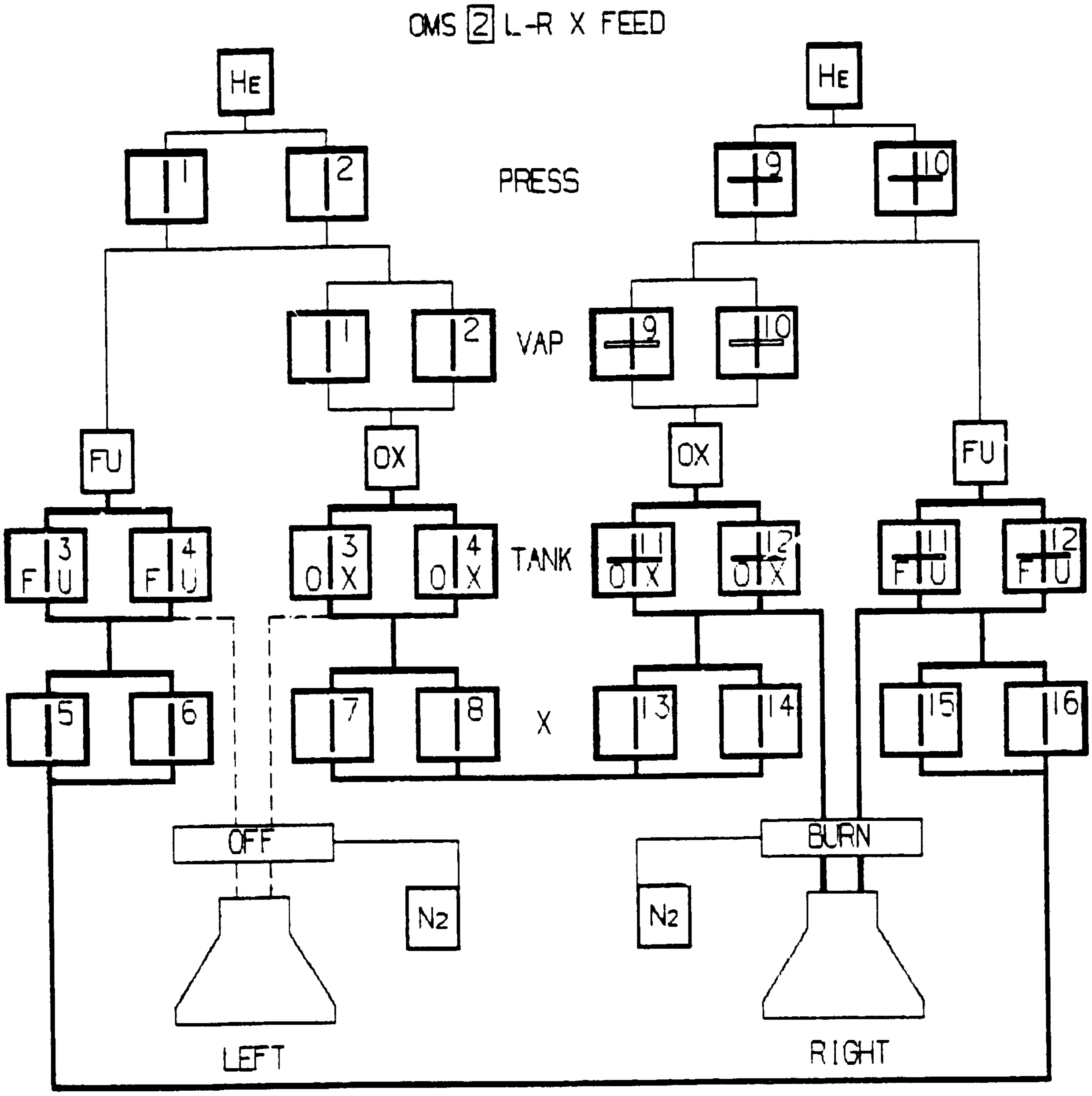


Figure 3.2-12 OPEN VALVES 13 and 14

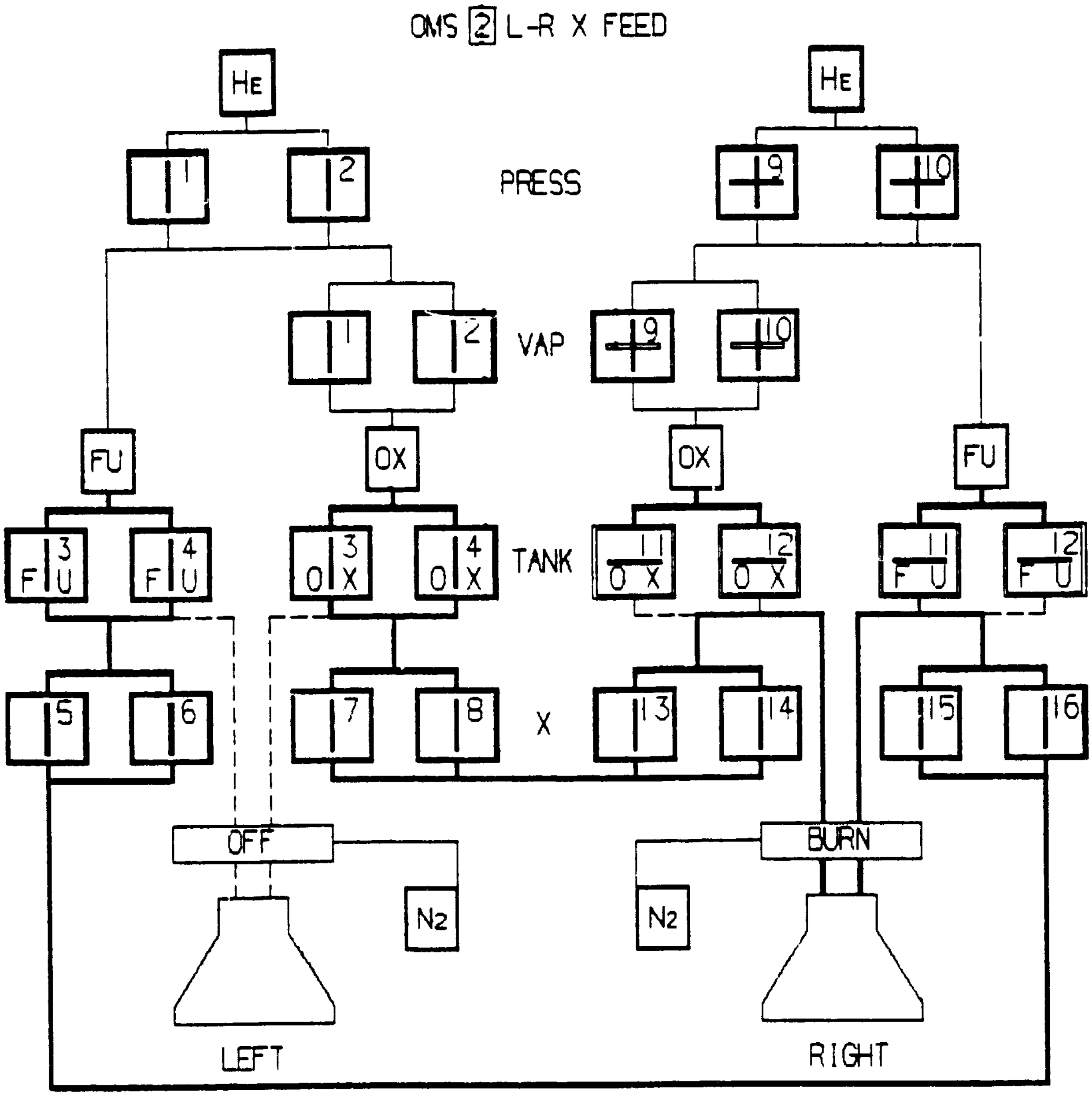


Figure 3.2-13 CLOSE VALVES 11 and 12

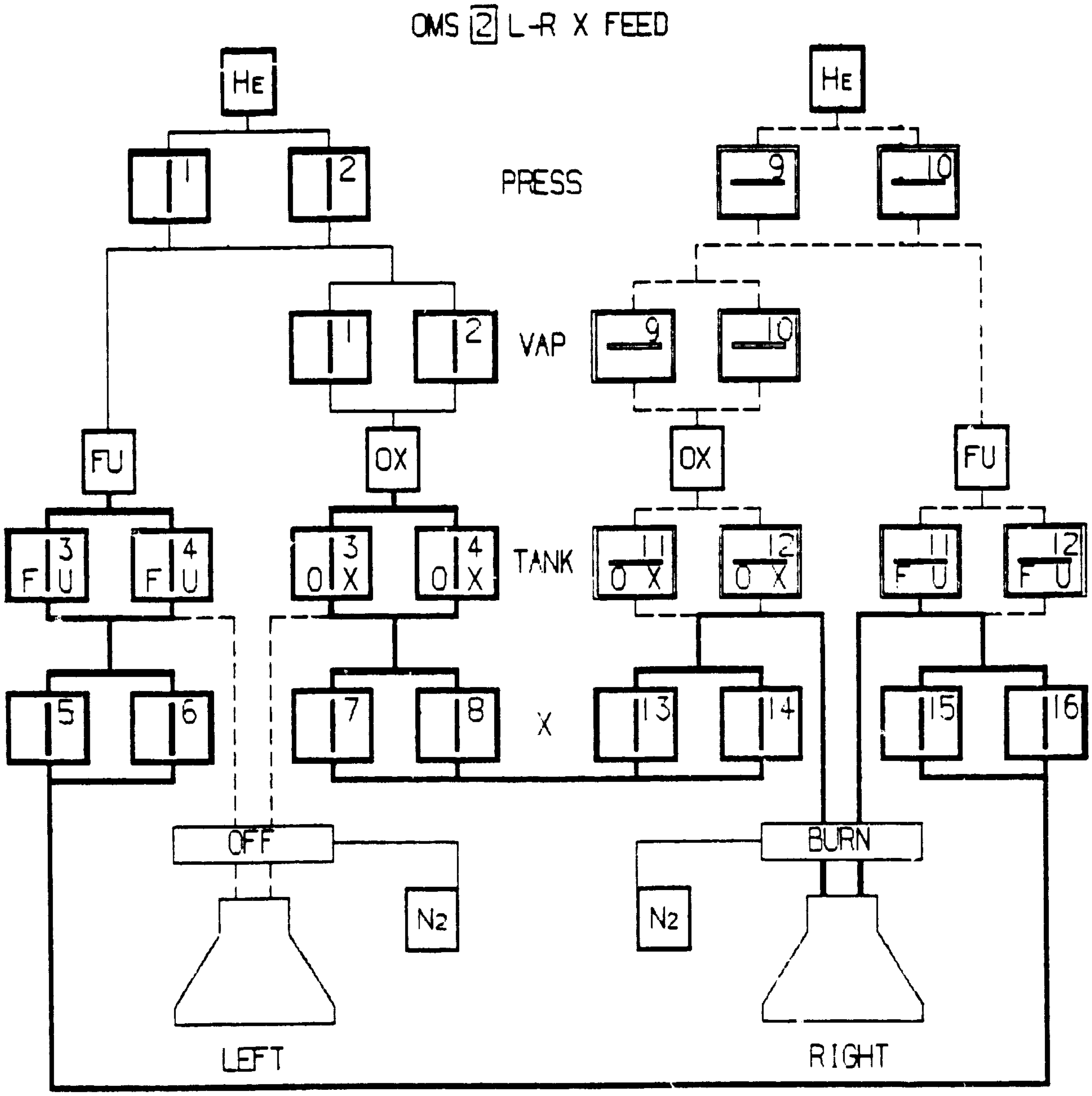


Figure 3.2-14 CLOSE VALVES 9 and 10 - CHECK LIST COMPLETED

4.0 HARDWARE/SOFTWARE SELECTION

The selection of hardware and software described in this section is designed to implement a design specifically addressing the OMS and EPDCS and located primarily in the R1 panel of the Orbiter flight deck. This configuration satisfies the constraints of minimizing the impact on the current Orbiter hardware and software. It should be noted, however, that the software, and to a large extent the hardware, are applicable to a larger number of systems and to relocation of the system to another portion of the Orbiter flight deck. This section includes a discussion of the considerations pertinent to a wider application of the MFDCS. In addition, some of the future options with respect to hardware choices are addressed.

4.1 PRESENT TIME FRAME

This section describes the hardware and software design of the MFDCS and a complement of hardware currently available to implement the design. Rapidly advancing technology in several areas of the MFDCS design has dictated a modular design to permit updating of the hardware as a function of time.

4.1.1 HARDWARE DESIGN

The hardware design for the MFDCS is based on a bus structure through which the various hardware modules of the system are linked to the MFDCS processor. The general configuration is shown in Figure 4.1-1. The hardware design is directed towards construction of a crew station mockup with consideration given to future flight application.

4.1.1.1 MFDCS PROCESSOR AND BUS STRUCTURE

Processing speed and system response time were considered in Task 3 and testing with an 8-bit processor showed a sufficient speed for anticipated MFDCS requirements. At this time, 16-bit microprocessors are coming into increasing use in display and control systems. The 16-bit units offer several advantages including higher speed, greater memory handling capacity and a more powerful and flexible set of instructions and registers. For these reasons, the future data handling and expansion options of the

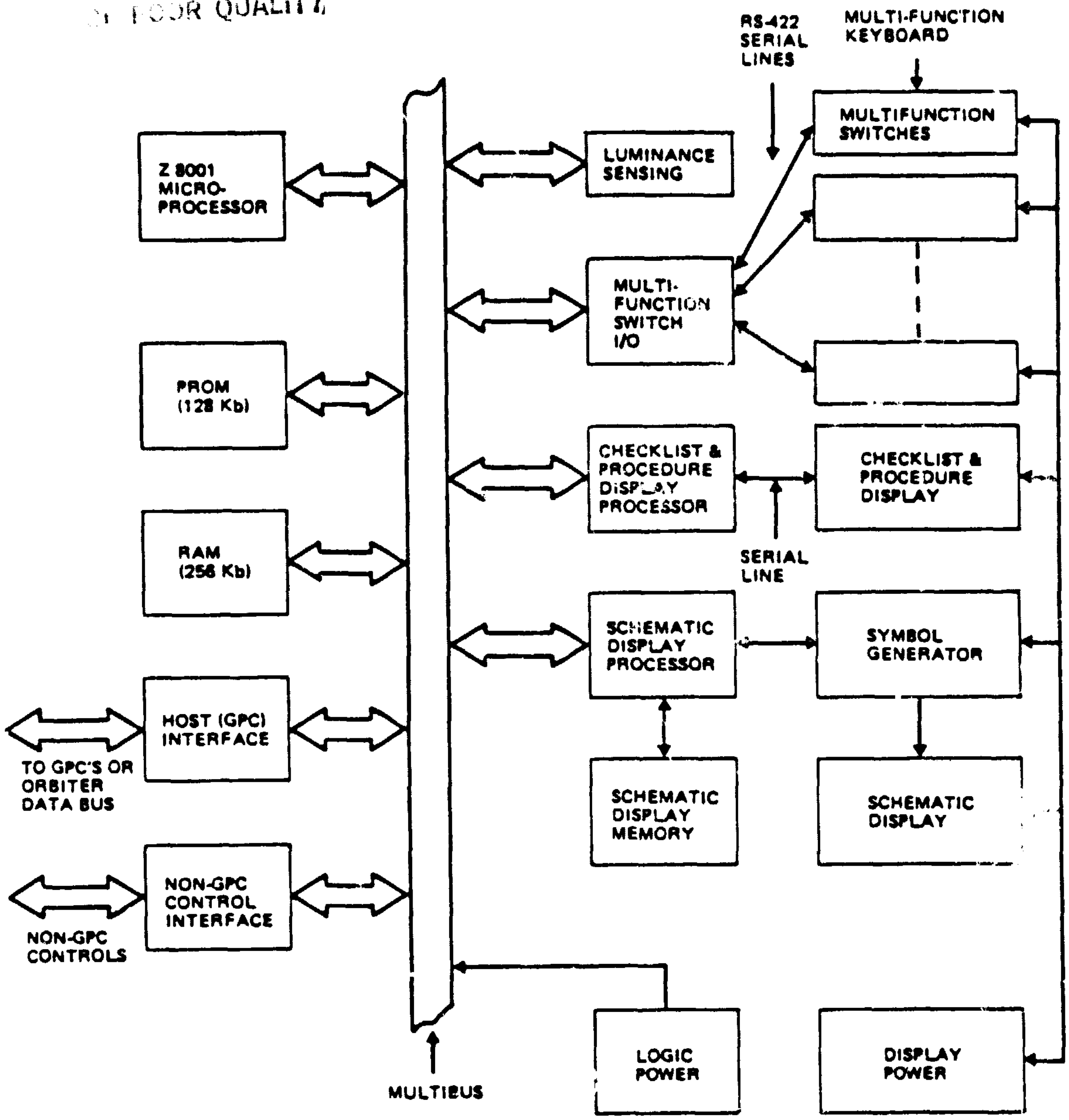


Figure 4.1-1: *MFDCS Hardware Schematic*

MFDCS would be best served by choosing a 16-bit microprocessor at this time. The combination of a Z8001 microprocessor and an Intel Multibus bus structure was chosen for the MFDCS design. The Z8001 offers the advantage of military standard qualification for future flight implementation of the system as well as the features described above. The Multibus bus structure was chosen to take advantage of the large number of standard modules configured for this bus. Use of standard commercial boards during the development of a MFDCS allows rapid reconfiguration of the system without going through a large amount of circuit redesign.

4.1.1.2 MEMORY

Memory requirements for the MFDCS will be ultimately determined by the number of procedures and checklists incorporated in the system data base. A basic system for simulation use as shown in Figure 4.1-1 would include 128Kb of PROM and 256Kb of RAM. The PROM is used to store the operating system and a nominal system data base. The RAM memory stores the operating data base, thus allowing an alternate data base to be downloaded from the host computer or from another computer containing the new data base. These size estimates are based on a limited example of the OMS and EPDCS data base as implemented on a Boeing demonstration unit having 32Kb of PROM and 64Kb of RAM. An estimate was made of the number of pages required for legends, and displays and the memory required per page for the OMS and EPDCS data base. This estimate resulted in a memory requirement of 59K bytes including the operating system. The recommended memory will provide a comfortable margin for growth or multiple data bases.

The Z8001 and the multibus configuration permit memory expansion up to a total of 8Mb in 64Kb blocks. The required amount of memory can thus be added to the system depending on the data base complexity.

4.1.1.3 HOST INTERFACE

The host interface will be defined by the requirements of the control commands to be sent to the GPC's. The purpose of the host interface is to produce signals which will duplicate the signals originally generated by the switches and controls which are incorporated into the MFDCS. The objective is the minimization of impact on the host software presently in place. For the work done in this study, the exact nature of the interface has not been specified. The multibus configuration however is adaptable to a wide variety of interfaces ranging from the RS-232 link commonly used to the military 1553 bus.

4.1.1.4 NON-GPC CONTROL INTERFACE

While many of the OMS controls are routed through the GPC's and are handled by the host interface, a number of the switches and controls are directly connected to the actuator or function they control. A particularly common example is the use of circuit breakers in the EPDCS. The operation of these controls or switches by the MFDCS requires an interface to drive such items as relays and power controllers in response to commands from the MFDCS. Operation of circuit breakers will require the replacement of the manual breakers by remotely controlled breakers. Precise definition of this interface will depend on the drive requirements of the non-GPC controls, switches and circuit breakers.

4.1.1.5 MULTIFUNCTION SWITCHES

Multifunction switches with fully programmable legends are currently quite limited in availability. The inclusion of tactile feedback as part of the switch and the need for avoiding inadvertent activation eliminates the touch panel overlay switch array from consideration. At the present time, the switch most closely matching the requirements for luminance, tactile feedback and color are multifunction switches constructed by MicroSwitch and currently being produced in limited prototype quantities. Figure 4.1-2 shows a schematic diagram of the switch. Each Programmable Pushbutton Switch (PPS) contains a display composed of a 16 x 35 x-y dot matrix array of green LED's. Resolution of the display is 16 lines/cm (40 lines/inch) and typical power requirements are 1.3 watts/switch. Figure 4.1-3 shows an array of four switches with a variety of legends displayed. The dot matrix array is fully programmable and normally displays up to two rows of six alphanumeric chararacters in a 5 x 7 font. Alternatively, any graphic symbol within the limits of the 16 x 35 diode array can be displayed. The tactile feedback force curve for the switches is shown in Figure 4.1-4. Each switch contains its own drive electronics for the LED display. Groups of up to four switches are interfaced to a logic refresh and control

ORIGINAL PAGE IS
OF POOR QUALITY

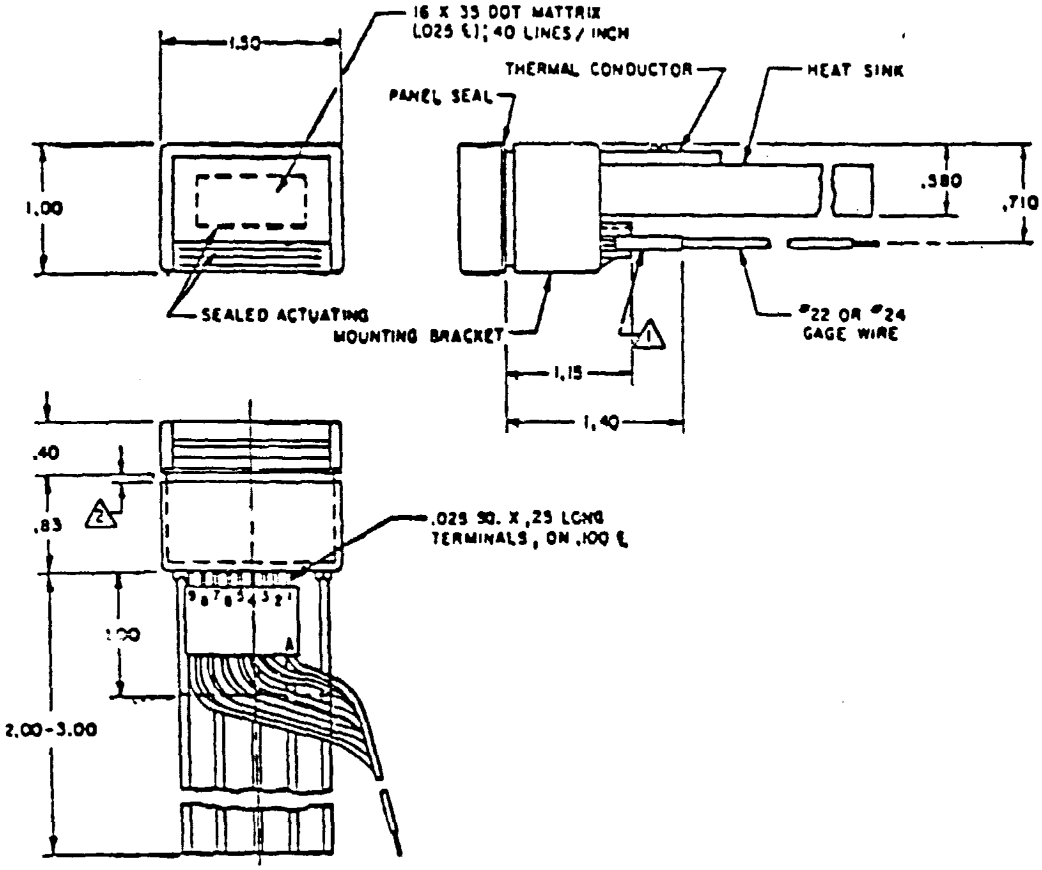


Figure 4.1-2: PPS Mechanical Schematic Diagram

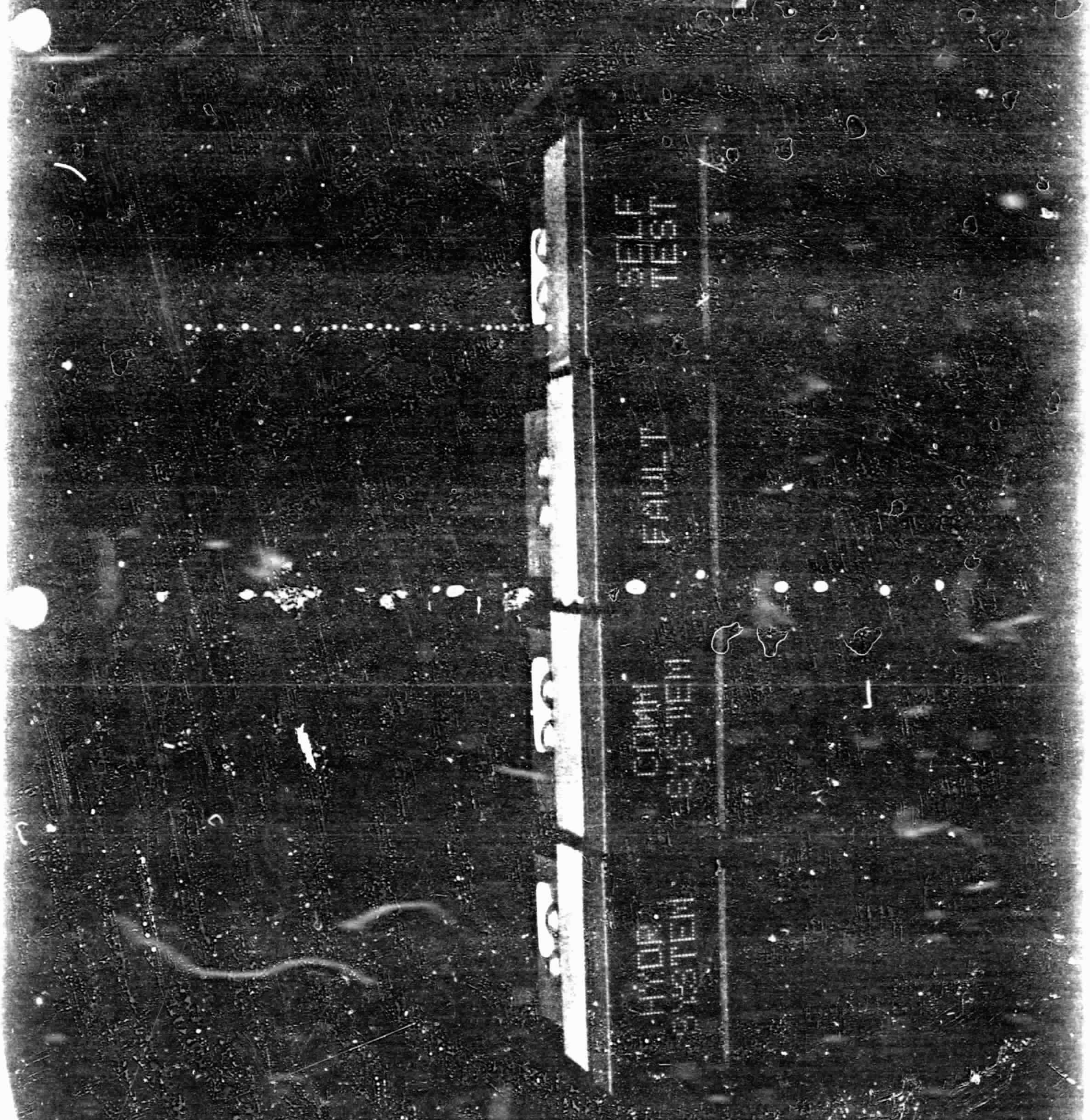


Figure 4.1-3: LED Multifunction Switch Displays

ORIGINAL PAGE IS OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

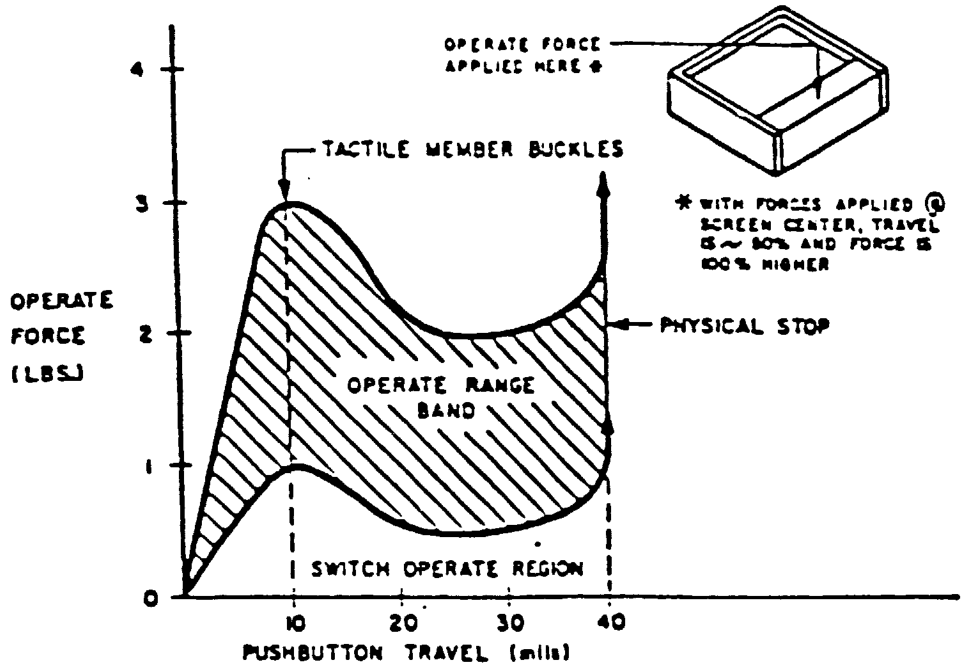


Figure 4.1-4: SWITCH TACTILE FEEL FORCE CURVE (EXPECTED RANGE)

(LRCU) board which includes the switch refresh memories and a Z8 microprocessor to interface the switches to a controlling microprocessor. Commands for display update are passed to the Z8 microprocessor by an RS-422 line which provides a long line driving capability, noise rejection, and a single 5 volt voltage requirement for the switches and LRCU.

To form the multifunction keyboard used in the MFDCS, an array of 28 switches arranged in seven rows of four will be used. All switches will be controlled by the Z8001 MFDCS controller which formats all commands and messages sent to the keyboard for display and receives indications of switch activation from the Z8 microprocessors.

4.1.1.6 MULTIFUNCTION SWITCH I/O

The I/O to the multifunction switches consists of a standard serial RS-232 port (for each set of four switches) modified to drive the RS-422 line. The output ports and Z8's operate at programmable baud rates up to 19.2 kb/sec. The multifunction keyboard will require seven of these serial RS-422 I/O ports. Current design response speeds are achieved at the 19.2kb rate.

4.1.1.7 CHECKLIST AND PROCEDURE DISPLAY

In Task 3, a savings in power and space requirements were indicated by using a flat panel display medium for presenting checklists and procedures to the operator. Medium size flat panel displays with character capacities of 200 to 500 on the screen have been introduced to the market in a variety of forms. These include LED, liquid crystal display (LCD), vacuum flourescent and thin film electro luminescent (TFEL) displays. Figure 4.1-5 shows the relative power level of several display forms. Currently available TFEL and vacuum flourescent panels do not have sufficient brightness to satisfy the Orbiter luminance requirements in a 10^4fc ambient light environment. The available options then become the LCD and LED panels.

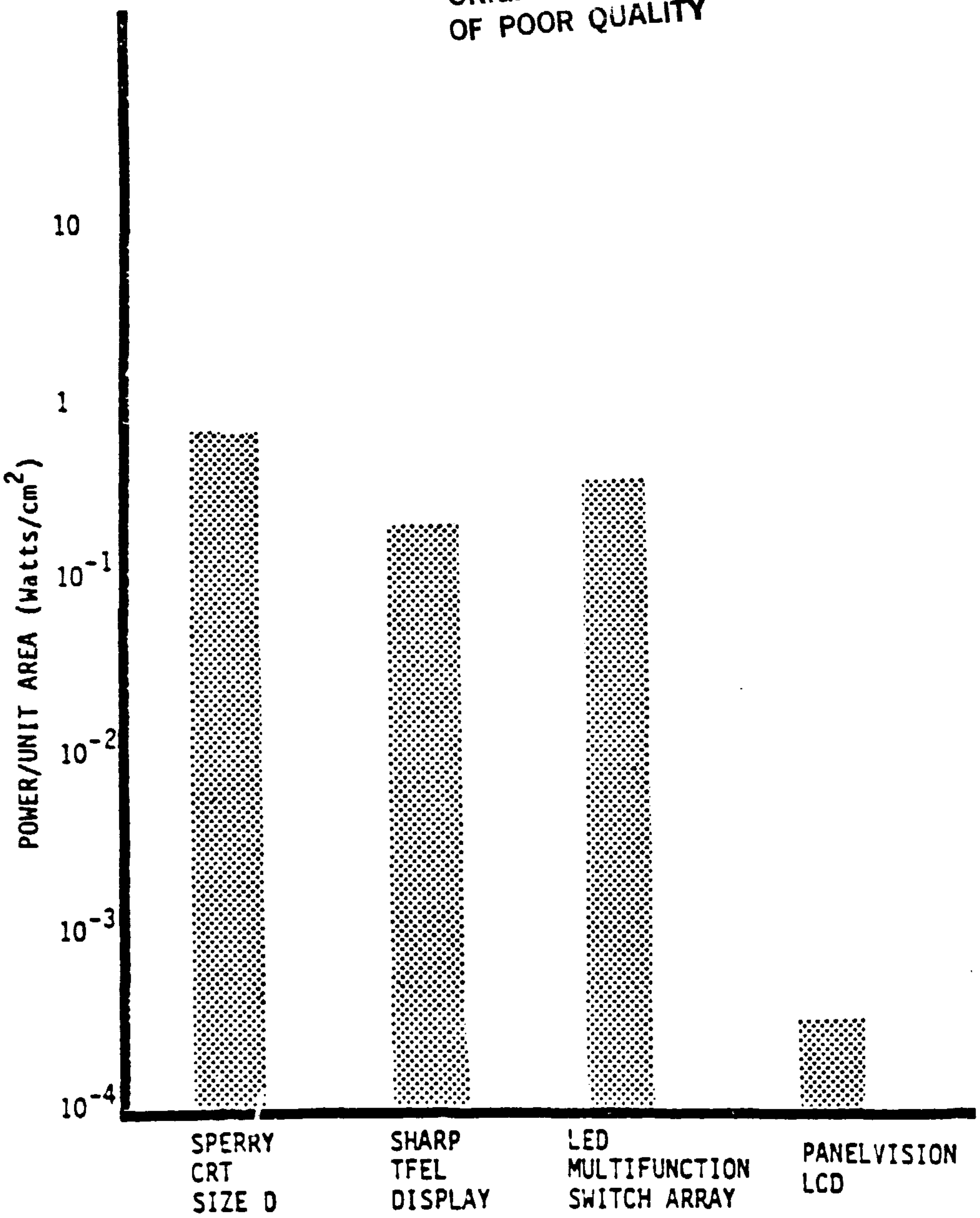


Figure 4.1-5: POWER/UNIT AREA FOR VARIOUS DISPLAY FORMS

LCD panels are under development by a number of manufacturers in the size range needed for the Orbiter MFDCS. These include 3M, Panelvision and General Electric. Of these sources, Panelvision expects to market prototype displays in the fall of 1982. The Panelvision technology incorporates thin film transistors on the LCD display in order to avoid the multiplexing problems usually associated with a high number of lines in the display. The 3M and GE panels accomplish the same thing with a phase change in the LCD material and the use of a varistor array respectively. Either of these panels would also represent a good choice if available. Back or edge lighting would be used to provide adequate contrast at low luminance levels.

An alternative to the use of the LCD panel which provides sufficient display luminance is the LED array. Litton of Canada is currently producing green LED displays in a 2.5 x 7.5 cm dot matrix format with a resolution of 24 lines/cm for use in the F-16. These units are qualified with respect to military standards and provide a 2:1 contrast ratio at 10^4 fc ambient illumination. The units are made up of 2.5 x 2.5 cm modules and the basic module can be used to build a larger array. A 7.4 x 10 cm array would be satisfactory for the checklist display. The major drawbacks to the LED arrays are high power consumption and relatively high cost.

4.1.1.8 CHECKLIST AND PROCEDURE DISPLAY PROCESSOR

The analysis of the checklist and procedure display carried out in Task 3 indicated that sufficient response speed could be achieved through use of either a dedicated processor or through shared use of the MFDCS control processor. For this application, the modularity of the system would be improved by using a dedicated display processor to handle the checklist and procedure displays. The processor choice will depend on the availability of the flat panel displays and on whether a processor is already incorporated into the display panel. The processor will interface to the MFDCS multibus.

4.1.1.9 SCHEMATIC DISPLAY

Requirements for the schematic display were defined in the study of resolution, color and character size conducted under Task 3. Consideration of the displays necessary for the OMS and EPDCS indicate the need for a hybrid stroke/raster color CRT display. A survey of potential applicable displays indicates a color display being developed by Sperry as a suitable unit. This display provides both raster (256 lines) and stroke display capability. The Sperry Size D unit provides an 18 x 18 cm viewing area in a 20 x 20 cm package. Spot size in the stroke writing mode is 0.025 cm and a writing speed of 63,500 cm/sec provides the capability to portray the most complex of the OMS and EPDCS displays. These CRT displays operate at 40 frames/sec. to avoid perceived flicker. Stroke writing is done during the vertical retrace of the raster scan. The Sperry displays are built to provide sufficient brightness for operation in a 10^4 fc ambient light environment and to withstand the vibration environment of commercial jet aircraft. A parallel program is developing a line of color CRT displays for use in tactical military aircraft. The CRT display is driven by a programmable symbol generator. The symbol generator can be programmed with respect to both symbology and color and provides an interface to the dedicated processor handling the schematic display.

4.1.1.10 SCHEMATIC DISPLAY PROCESSOR AND MEMORY

Generation and modification of the displays associated with the MFDCS controlled subsystems can require a considerable amount of processing capacity and memory depending on the number of systems controlled and number of different displays used. To offload the MFDCS control processor and memory, the schematic memory size and processor chosen will depend on the number of stored displays required. A number of processors are available as single board computers to interface to the MFDCS Multibus and both 8- or 16-bit microprocessor could be used. At this time a Z80 microprocessor with 64Kb of memory, would store a moderate number of displays. The displays would be stored largely in vector format rather than on a pixel by pixel basis. In this way, only the end points, colors, character string locations and color fill regions need to be specified in display storage. The symbol generator then uses this information to generate the display. In a similar fashion, the modifications to the stored displays based on system status or MFDCS control actions require the storage of only the change to the display rather than a complete display regeneration.

4.1.1.11 LUMINANCE SENSING

Luminance sensing is provided to permit automatic control of the display luminance under conditions of varying illumination. The output of a photodiode sensor is digitized and processed by the MFDCS software to define the luminance level commands sent to the displays. Figure 4.1-6 shows the luminance control curve to which the display luminance will be controlled. In this figure L_{DS} is the background luminance of the display with the pixels off and ΔLp is the perceived luminance where ΔLp is defined by $\Delta Lp = Ls - L_{DS}$. Ls is the measured on-pixel luminance. Figure 4.1-6 is taken in large part from Reference 4-1. Also incorporated into the luminance control is a manual potentiometer to permit the operator to override the automatic control for optional display brightness.

4.1.2 SOFTWARE DESIGN

The software design divides the software into two major sections. The first is the Operating System which controls the background operation of the MFDCS and is independent of the data base. The data base (or bases) forms the second major software segment and is specific to a particular application or mission. By dividing the software in this way, the operating system need not be changed to adapt the MFDCS to different uses.

4.1.2.1 OPERATING SYSTEM SOFTWARE

The executive system software is stored in the MFDCS controller PROM and controls a number of software modules as shown in Figure 4.1-7. Upon power-up the MFK Controller performs a system initialization. The initialization includes the following areas:

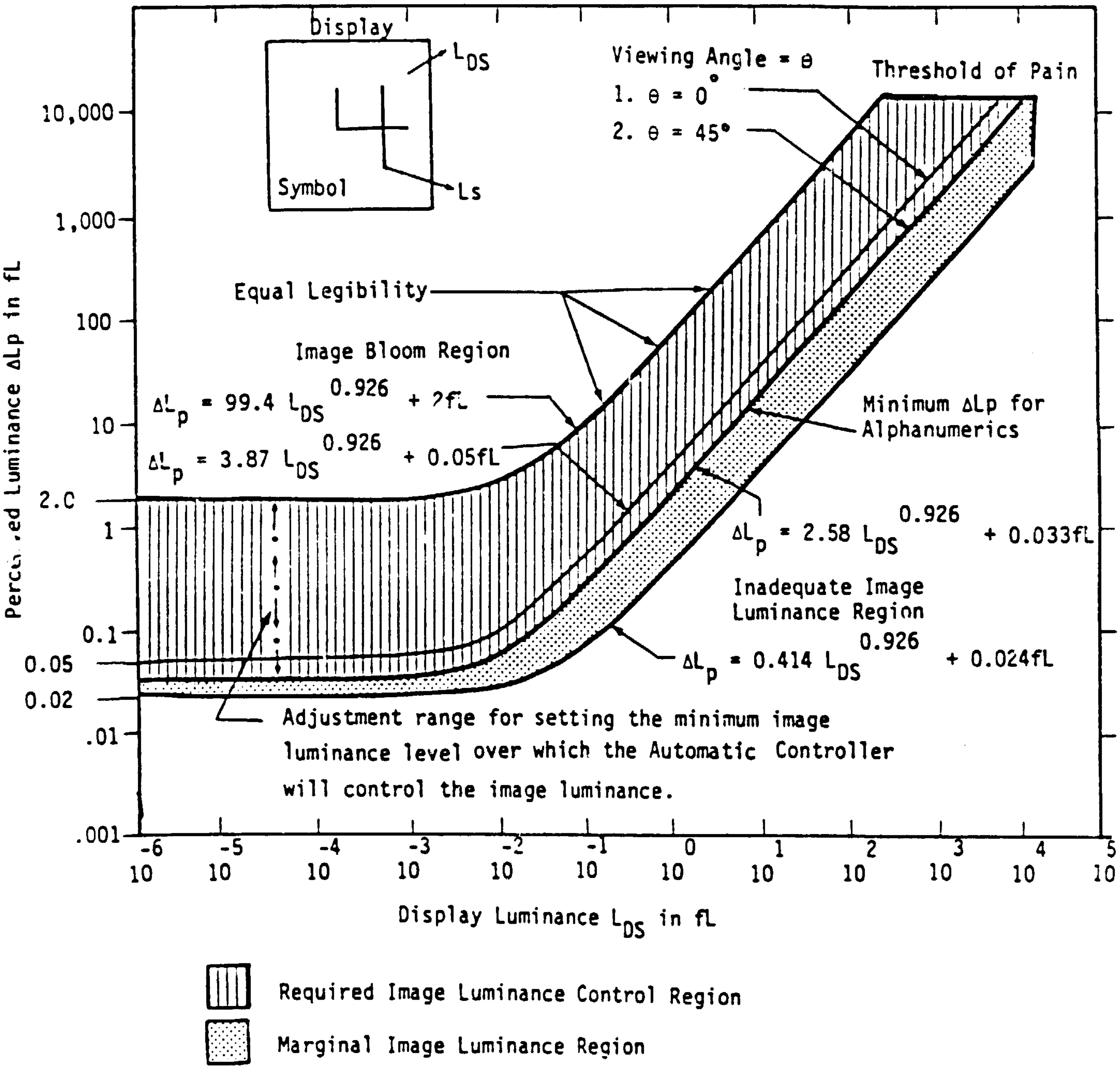
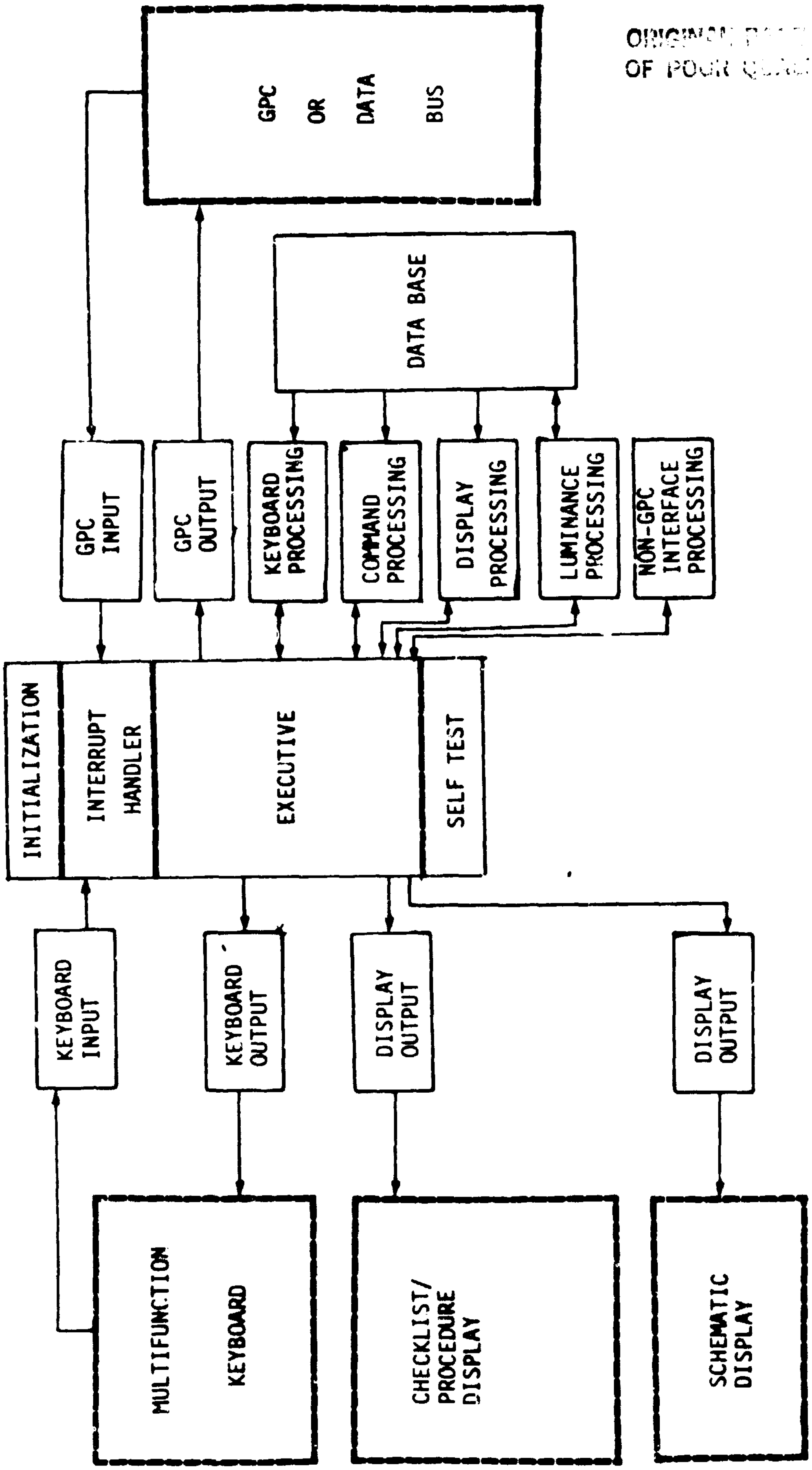


Figure 4.1-6: PERCEIVED LUMINANCE CONTROL REQUIREMENTS



4.1-7: MFDCS SOFTWARE BLOCK DIAGRAM

1) Interrupt structure
2) Baud rate timer
3) Each serial and parallel port
4) All system flags
5) All sytem buffers

Program control is passed to the system executive following initialization. The executive is responsible for sequencing through the system control modules. A particular control module is called by the executive if its control flag is set. This enables the controller to be event driven and thus respond in a real-time manner. In addition, all inputs and outputs are interrupt driven to ensure that no data or commands are lost.

Each control module is concerned with a specific operation within the MFK operating system. The basic set of control modules includes the following:

Initialization
Page Update
Keyboard Legend Processing
Display Processing
Command Processing
Keyboard Input/output
GPC Input/output
Non-GPC Interface Processing
Display Output
Luminance Processing
Self-test

The page update module interrogates each memory page that is called by the system for certain information. However, it must first decide what the next page is and then fetch that page. The module then updates the system information and queues the required control modules. For example, when called, it will look to see if the page contains any display information, if so, it notifies display processing which will process the information for display on the scratchpad. Keyboard legend processing updates each legend that the keyboard output routine sends to the keyboard. This operation is always performed each time a switch is depressed by the operator.

Command processing is also called when a switch is depressed. It looks at the current page to see if there are any special commands associated with the specific switch before passing control to the page update module. If a command is found for a switch, command processing queues the appropriate routines to handle the command. Often times this involves both outputs to the scratchpad display and the GPC. Command processing is also responsible for interpreting and executing any commands from the GPC.

Luminance processing is concerned with monitoring the ambient light intensity and correcting the current switch display intensity for any change in the ambient light level.

The keyboard input/output module is responsible for maintaining the communications protocol with the keyboard switches. This is true for the GPC input and output modules as well. The display outputs are basically simple output drivers.

The non-GPC interface processing module is used to interface the MFDCS to the controls which do not pass through the GPC's to activate their control function.

4.1.2.2 DATA BASE SOFTWARE

The data base for the MFDCS is organized as a series of "pages". The pages are logically linked in hierarchical structure with a top level page leading to a number of second level pages. Pages below the top level can be linked to other pages of the same level, to higher level pages or to lower control level pages. The page format is shown in Figure 4.1-8. Words listed on the page have the following functions.

1) Word 1 contains the address of the top level page.

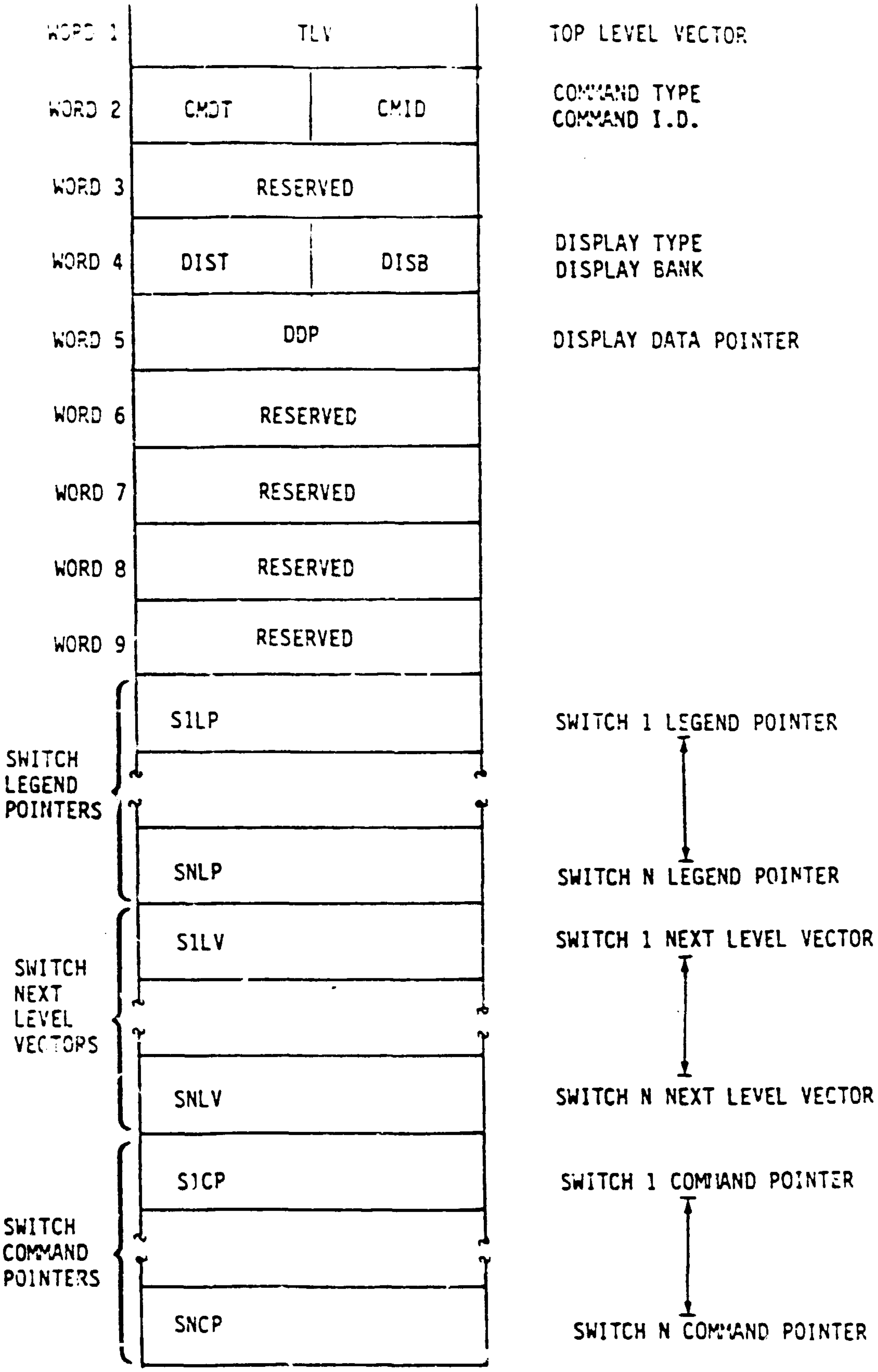


Figure 4.1-8: Data Base Page Structure

2) Word 2 instructs the MFDCS to anticipate a particular type of switch input.

3) Words 4 and 5 provide information to the MFDCS on the display processing and location of display data.

4) Switch legend pointers contains the addresses for the keyboard legends associated with this page.

5) Switch next level vectors contain the addresses, of which, one will be selected to be the next page. The page selected is determined by the keyboard switch being depressed.

6) Switch command pointers contain the addresses of the commands associated with this page. When a switch is depressed, the command selected by the switch number is sent to the host.

This structure provides a standard format for each of the data bases being constructed.

4.1.3 PACKAGING

One of the objectives of the study was to fit the OMS and EPDCS MFDCS into panel space on the simulator currently occupied by those systems. A detailed packaging analysis was not conducted as part of the study, however, the display elements were sized relative to the R1 panel. This panel would be the primary area freed for use by a change to the MFDCS configuration. A layout of the panel is shown schematically on Figure 4.1-9 based on known display package sizes. This location would minimize the electrical and mechanical changes to the remainder of the Orbiter systems since the panel presently contains controls and switches for the EPDCS. Panel area and depth should be sufficient to accept the MFDCS components.

4.2 FUTURE OPTIONS

Several areas of technology are not yet available for application to an Orbiter MFDCS but offer considerable promise in the near future. These anticipated advances are

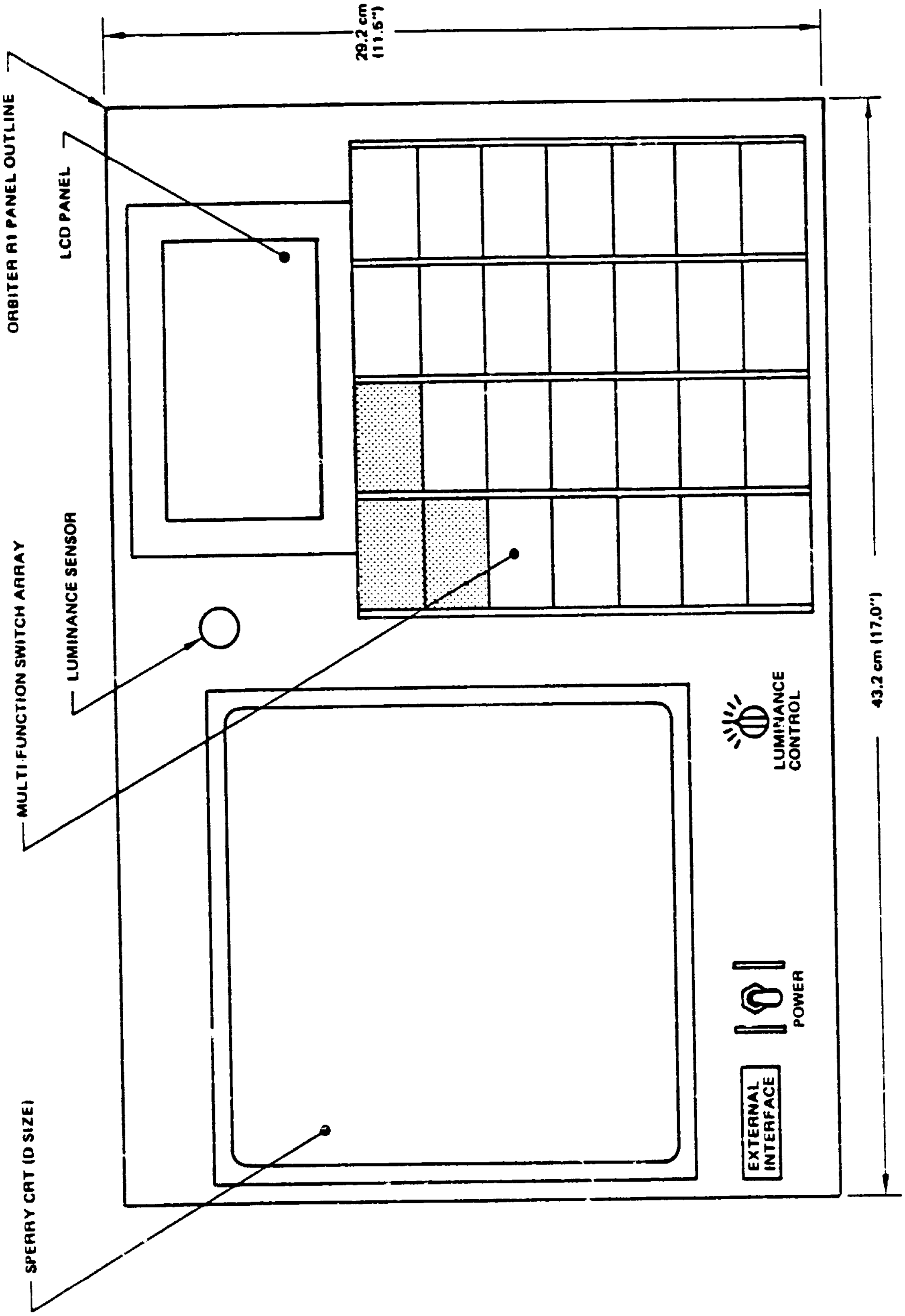


Figure 4.1-9: *MFDCS Packaging Option*

primarily in the area of displays and controls. At the present time liquid crystal displays are being marketed for a variety of small size applications (e.g., watches, calculators and electronic games) with larger panels just starting to enter prototype production. LCD's are quite applicable to multifunction switches and the dichroic and phase change LCD's offer a good viewing angle range at very low power. The Orbiter operates as a "shirt-sleeve" environment for the crew so that the rather slow LCD response at low temperature should not be a problem. By lowering the power requirements, the heat sinking and cooling requirements would be less and the switch packages could be made much smaller. This change in packaging would permit an array of very flat switches to be formed into a multifunction keyboard with resultant savings in volume, weight and power.

Similarly TFEL displays offer the potential for a sunlight readable solid state display which can be produced in volume at relatively low cost. Available resolution in TFEL panels is currently approaching that of CRT's and larger panel sizes are under development through the U.S. Army. A great potential advantage of TFEL panels is the possible construction of a full color flat panel device through the use of multiple phosphor layers with different doping. Development of this type of panel would enable the replacement of CRT's in the Orbiter display complement while saving additional weight and power.

At this time, the goals of reducing Orbiter weight, power and cooling through the use of the MFDCS would require a more complete integration of the MFDCS into the Orbiter systems. In addition, the use of LCD or TFEL multifunction switches wuld be needed to reduce the high power requirements of the LED displays. As a minimal change add-on to the Orbiter, the package descried would add to the current weight, power and cooling required.

4.3 FLEXIBILITY

An important feature of an MFDCS is the capacity to adapt to new missions and/or new hardware configurations. The design presented provides considerable latitude in its ability to handle new data bases and display hardware. Changes in the data base are not restricted to redefinitions of switch legends, display redefinitions of switch legends, display formats or checklist and procedure contents. The MFDCS system can be reconfigured to control a completely different set of systems or to access the systems controlled through a completely different logic tree format. These features result from the separation between the background software operating system and the data base for the functions being displayed and controlled.

Changes in the hardware configuration of the MFDCS are made easier by the modular structure of the operating system. For example, a change from an LED multifunction switch to a liquid crystal or thin film electoluminescent switch would not require changes in the remainder of the system with the exception of the power supply voltage and current changes pertinent to the new display. If the matrix size on the switch were changed, the changed display format will be accounted for by a change in the data base only. Changes in the number of the switches would require a change in the number of output ports addressed by the data base, however, this change would involve only the addition or deletion of input/output modules to the basic MFDCS bus structure and the addition or deletion of the appropriate I/O software. Similarly, a modification of one of the other displays would require only a change in the display, power supplies and the display's dedicated processing.

These features in the MFDCS design also extend to memory additions necessary for changes in data base complexity. Memory can be added in 64K banks.

By configuring the MFDCS in the modular fashion described, the system can adapt to both changes in display technology and to changes in the mission procedures or mission hardware.

5.0 ADDITIONAL MFDCS CONSIDERATIONS

Several other areas, not directly involved in the present MFDCS design should be considered with respect to application of the MFDCS to the Orbiter. These areas include redundancy and reliability, automation and mission scenarios.

5.1 RELIABILITY AND REDUNDANCY

The recommended MFDCS concept provides several features that enhance reliability and support an extremely high fault tolerance level for flight critical applications. A MFDCS is, by definition, multipurpose and hence, assuming that several MFDCS's are incorporated into the Orbiter flight deck, functions usually performed on one MFDCS can be transferred to another if the first one fails. In some cases this may require backup display and control-label formats so that more than the usual number of functions can be combined into a single MFDCS.

A second factor that contributes to high reliability is the organization of the MFDCS into several display and control modules. By designing the entire Orbiter flight deck around a small number of unique types of modules such as these, several of each type will be present. If any display or control module fails, the system can be reconfigured so that information display or control actions assigned to that module are moved to a similar module in another area. Alternatively, if sufficient time is available, the failed module can be manually replaced by an identical unit from a lower priority area.

The reconfiguration in response to failed display/control modules can be partially automated. Built-in-tests (BIT) and built-in-test-equipment (BITE) can be used to detect failures and recommend particular reconfiguration schemes in response to particular failures and, upon operator concurrence, to automatically implement the reconfiguration. BIT and BITE can detect most but not all failures, so operator testing capability must be retained. In particular, the system must be designed so that potentially critical failures are immediately obvious to the operator. Control devices should provide feedback that the control has been moved, for example by tactile feedback, and that a signal from the control has reached the computer. The latter feedback might be in the form of a change in the visual display. Similarly, critical displays must not fail in a mode in which they appear to be functioning normally even though new information required by the operator is not being displayed.

5.2 AUTOMATION

Automation in the Orbiter can be of considerable assistance in reducing crew workload, however, the experience base for deciding what functions should be automated is still quite limited. Thus, any automation program should include a high degree of flexibility with respect to changes in the functions automated and the level of automation implemented. The MFDCS provides this flexibility by incorporating automatic, semi-automatic or manual means of control. The automatic mode allows the system to accomplish an adequate level of crew support while permitting crew initiative and variation from predetermined procedures. The ability to use a variety of data bases offers a considerable range of increase or decrease in automation level.

A number of automation designs are beginning to appear, however, they are usually specified in terms of the automation of one system. Boeing, for example, is currently working on the automated control of commercial and military aircraft electrical power systems. This effort includes features such as automatic load shedding and remote automated control of circuit breakers. Other examples of automation are automatic landing systems and navigation systems. The MFDCS can serve as a flexible test-bed for the investigation of automation in the various Orbiter systems. With a variety of data bases and mission scenarios, the implications of automation at varying levels of function control and under varying degrees of operator stress can be tested.

5.3 MISSION SCENARIOS

Adequate testing of the MFDCS will depend on developing mission scenarios which test its capabilities under all phases of Orbiter operation. This development will require close cooperation between personnel programming the MFDCS and the Orbiter crews. Data base development for the MFDCS can be a very time consuming and error-prone process if this sort of a liaison is not established. Experience in the development of demonstrations and tests for the MFDCS design has shown the necessity for close and continuous cooperation between these groups if high efficiency is to be obtained from the MFDCS.

6.0 MFDCS DEVELOPMENT PROCESS

Further development of the MFDCS and use in a simulator involve a number of considerations. These include potential alternate uses for the system, the definition of the data base to be used in the system, the time frame over which the development program is to take place and the necessity for testing prior to incorporation of the system into the Orbiter simulator.

6.1 POTENTIAL ALTERNATE USES

The MFDCS design permits operation with a variety of data bases and is therefore applicable to a number of potential uses. Two obvious potential space applications are in the area of Orbiter payload management and as part of a work station associated with a manned space platform. The use of an MFDCS in Orbiter payload management offers the option of implementing an operational system without impacting as many other Orbiter systems. In addition, the payload variety could supply the opportunity to exercise the system for a wider range of potential requirements.

Space platform development is an area where some form of MFDCS will be needed to minimize the hardware required for system monitoring. The MFDCS is designed to provide the capability for varying degrees of system automation and could act as a valuable tool in deciding the degree of automation necessary or desirable in a manned platform environment.

6.2 DATA BASE DEFINITION

A major factor in the MFDCS development will be in the definition of the data base associated with the system. The use of automated systems is just coming into widespread use and the Orbiter is still quite limited in total flight test time. This is particularly true for the landing and takeoff phases of operation. The questions of what procedures to automate and what functions require the most rapid access will need to be resolved using simulation testing and a great deal of discussion between the users and the personnel developing software for the system.

6.3 DEVELOPMENT TIME FRAME

The time frame over which the MFDCS will be developed determines to a significant extent, the options available in the development process. A short term plan to install an MFDCS in one of the Orbiter simulators within the next year will require rapid acquisition of the closest hardware available to flight qualified equipment and a rapid build-up of software programming liaison with designated users of the system. Development will also be constrained by the current usage of the simulation facilities. On the other hand, a longer development period could include a phase in which a preliminary engineering model is built using commercial equipment and a flexible format for design and packaging. This mode would permit use of the system for a variety of uses in addition to the Orbiter flight deck application.

6.4 PRE-SIMULATION TESTING

The principal costs in the MFDCS development will include the areas of flight qualification of components, integration with the present Orbiter systems and development of the software data base. As multifunction display and control technology advances, more flight qualified components will become available at reasonable cost. Similarly, if the software can be developed independently of the Orbiter simulators and tested for satisfactory operation of the access schema before integration begins, the tie-up of simulation time and hence expense can be reduced. Both funding considerations and time frame options indicate a development process in which the design is tested before an actual package destined for use in the present simulators is constructed.

7.0 REFERENCES

1-1: Spiger, R.J. and R.J. Farrell, "Survey of Multifunction Display and Control Technology", Boeing Technical Document D180-26864-1, 1982.

1-2: Spiger, R.J., R.J. Farrell and G.A. Holcomb, "Application of Multifunction Display and Control Technology", Boeing Technical Document D180-26988-1, 1982.

1-3: Spiger, R.J., R.J. Farrell and G.A. Holcomb, "Development of Preliminary Design Concept for Multifunction Display and Control System for Orbiter Crew Station, Task 3 (Concept Analysis), Boeing Technical Document D180-27106-1, 1982.

4-1: "Advanced E/O Keyboard Application Evaluation", Solicitation Number F33615-80-R-3608, United States Air Force, 1980.

APPENDIX A

ORBITER SYSTEM FUNCTIONS

TABLE A-1

OMS DISPLAY/CONTROL FUNCTIONS

SWITCHES	FUNCTION	DESTINATION	DISPLAY
	ENGINE CONTROL		
________	(L) N2 TK P #1	GAUGE	GAUGE
________	(L) N2 TK P #2	GPC-MCC	GNC SYS SUMM 2
________	(R) N2 TK P #1	GAUGE	GAUGE
________	(R) N2 TK P #2	GPC-MCC	GNC SYS SUMM 2
(L) OFF, ARM, ARM/PRESS	(L) N2 PRESS VLV POSITION	GPC-MCC	GNC SYS SUMM 2
(R) OFF, ARM, ARM/PRESS	(R) N2 PRESS VLV POSITION	GPC-MCC	GNC SYS SUMM 2
(L) ENG VLV SWITCH (014)	(L) SWITCH POS	GPC-MCC	________
(R) ENG VLV SWITCH (016)	(R) SWITCH POS	GPC-MCC	________
(GPC)	(L) BALL VLV POS %	GPC-MCC	GNC SYS SUMM 2
(GPC)	(R) BALL VLV POS %	GPC-MCC	GNC SYS SUMM 2

TABLE A-1 (CONTINUED) SHEET 2

SWITCHES	FUNCTION	DESTINATION	DISPLAY
________	(L) N2 TK REG PRESS	GPC-MCC	GNC SYS SUMM 2
________	(R) N2 TK REG PRESS	GPC-MCC	GNC SYS SUMM 2
________	(L) FU INJ TEMP	GPC-MCC	GNC SYS SUMM 2 PASS PRPLT THERMAL
________	(R) FU INJ TEMP	GPC-MCC	GNC SYS SUMM 2 PASS PRPLT THERMAL
________	(L) CHAMB PRESS	GPC-MCC GAUGE	GAUGE
________	(R) CHAMB PRESS	GPC-MCC GAUGE	GAUGE
________	(L) FU IN PRESS	GPC-MCC	GNC SYS SUMM 2
________	(R) FU IN PRESS	GPC-MCC	GNC SYS SUMM 2
________	(L) OX IN PRESS	GPC-MCC	GNC SYS SUMM 2
________	(R) OX IN PRESS	GPC-MCC	GNC SYS SUMM 2

TABLE A-1 (CONTINUED) SHEET 3

SWITCHES	FUNCTION	DESTINATION	DISPLAY
	BIPROPELLANT CONTROL		
(L) TK ISOL FU A	OPEN/CLOSE STATUS	GPC	OPEN/CLOSE DISPARITY
(L) TK ISOL OX A			PANEL 08
(L) TK ISOL FU B	OPEN/CLOSE STATUS	GPC	OPEN/CLOSE DISPARITY
(L) TK ISOL OX B			PANEL 08
(L) X FEED FU A	OPEN/CLOSE STATUS	GPC	OPEN/CLOSE DISPARITY
(L) X FEED OX A			PANEL 08
(L) X FEED FU B	OPEN/CLOSE STATUS	GPC	OPEN/CLOSE DISPARITY
(L) X FEED OX B			PANEL 08
(K) TK ISOL FU A	OPEN/CLOSE STATUS	GPC	OPEN/CLOSE DISPARITY
(K) TK ISOL OX A			PANEL 08
(K) TK ISOL FU B	OPEN/CLOSE STATUS	GPC	OPEN/CLOSE DISPARITY
(K) TK ISOL OX B			PANEL 08
(R) TK ISOL FU A	OPEN/CLOSE STATUS	GPC	OPEN/CLOSE DISPARITY

C-2

TABLE A-1 (CONTINUED) SHEET 4

SWITCHES	FUNCTION	DESTINATION	DISPLAY
(R) TK ISOL OX A			PANEL 08
(R) TK ISOL FU B	OPEN/CLOSE STATUS	GPC	OPEN/CLOSE DISPARITY
(R) TK ISOL OX B			PANEL 08
(R) X FEED FU A	OPEN/CLOSE STATUS	GPC	OPEN/CLOSE DISPARITY
(R) X FEED OX A			PANEL 08
(R) X FEED FU B	OPEN/CLOSE STATUS	GPC	OPEN/CLOSE DISPARITY
(R) X FEED OX B			PANEL 08
(L) PRESS/VAPOR ISOL A	OPEN/CLOSE STATUS	GPC	ALERT (FDI BURN CHECK)
(L) PRESS/VAPOR ISOL B	OPEN/CLOSE STATUS	GPC	ALERT (FDI BURN CHECK)
(R) PRESS/VAPOR ISOL A	OPEN/CLOSE STATUS	GPC	ALERT (FDE BURN CHECK)
(R) PRESS/VAPOR ISOL B	OPEN/CLOSE STATUS	GPC	ALERT (FDI BURN CHECK)
(K) PRESS/VAPOR ISOL A	OPEN/CLOSE STATUS	GPC	ALERT (FDI BURN CHECK)
(K) PRESS/VAPOR ISOL B	OPEN/CLOSE STATUS	GPC	ALERT (FDI BURN CHECK)

TABLE A-1 (CONTINUED) SHEET 5

SWITCHES	FUNCTION	DESTINATION	DISPLAY
———	(L) OX TK PRESS	GPC MCC	METER (P03) GMC SYS SUMM 2
———	(R) OX TK PRESS	GPC MCC	METER GNC SYS SUMM 2
———	(L) FU TK PRESS	GPC MCC	METER GNC SYS SUMM 2
———	(R) FU TK PRESS	GPC MCC	METER GNC SYS SUMM 2
———	(K) OX TK PRESS	GPC MCC	METER GNC SYS SUMM 2
———	(K) FU TK PRESS	GPC MCC	METER GNC SYS SUMM 2
———	HE TK PRESS	PANEL F7	METER (F7)
———	HE TK PRESS	GPC MCC	GNC SYS SUMM 2
ROTARY SWITCH	(L) FU QTY	PANEL 03	METER
ROTARY SWITCH	(R) FU QTY	PANEL 03	METER

TABLE A-1 (CONTINUED) SHEET 6

SWITCHES	FUNCTION	DESTINATION	DISPLAY
ROTARY SWITCH	(K) FU QTY	PANEL 03	METER
ROTARY SWITCH	(L) OXID QTY	PANEL 03	METER
ROTARY SWITCH	(R) OXID QTY	PANEL 03	METER
ROTARY SWITCH	(K) OXID QTY	PANEL 03	METER
	THERMAL CONTROL		
(L) POD HTR A			
(L) POD HTR B			
(R) POD HTR A	TEMPERATURES LIMIT SENSED	GPC MCC	ANNUNCIATORS BFS SM OPS THERMAL PRLT THERMAL
(R) POD HTR B			
(K) HTR A			
XFEED HTR A			
XFEED HTR B			

TABLE A-1 (CONTINUED) SHEET 7

SWITCHES	FUNCTION	DESTINATION	DISPLAY
	THRUST VECTOR CONTROL		
	CURRENT GIMBAL PITCH AND YAW ANGLES LEFT AND RIGHT	GPC MCC	XXXX MNVR YYYY
KEYBOARD/CRT	LOAD GIMBAL PITCH AND YAW ANGLES LEFT AND RIGHT	GPC MCC	XXXX MNVR YYYY
KEYBOARD/CRT	PRIM AND SECOND DRIVE	GPC MCC	XXXX MNVR YYYY
KEYBOARD/CRT	GIMBAL CHECK	GPC	XXXX MNVR YYYY

TABLE A-2

EPDCS DISPLAY/CONTROL FUNCTIONS

SWITCH	C/B	LOC	FUNCTION	DISPLAY
		MAIN BOS & TIE		
FC/MN BUS A	--	R1	ON/OFF	CONTR STATUS R1
MN BUS TIE A	--	R1	ON/OFF	CONTR STATUS R1
--	MNA CONTR	013	ESS 1 BC	--
FC/MN BUS B	--	R1	ON/OFF	CONTR STATUS R1
MN/BUS TIE	--	R1	ON/OFF	CONTR STATUS R1
--	MN B CONTR	013	ESS 2 CA	--
FC/MN BUS C	--	R1	ON/OFF	CONTR STATUS R1
MN/BUS TIE C	--	R1	ON/OFF	CONTR STATUS R1
--	MN C CONTR	013	ESS 3 AB	--
--	--	CRT	FC/MN VOLTS/AMPS	SM OPS 2 ELECTRICAL

TABLE A-2 (SHEET 2)

EPDCS DISPLAY/CONTROL FUNCTIONS

SWITCH	C/B	LOC	FUNCTION	DISPLAY
		MAIN BUS & TIE		
--	--	CRT	FC/MN VOLTS/AMPS TOTAL AMPS	SM OPS 2 SM SYS SUMM 1
--	--	CRT	FC/MN VOLTS/AMPS TOTAL AMPS	BFS SM SYS SUMM 1
		ESS BUS		
MN B/C	--	R1	ON/OFF	--
FC 1	--	R1	ON/OFF	--
MN C/A	--	R1	ON/OFF	--
FC 2	--	R1	ON/OFF	--
MN A/B	--	R1	ON/OFF	--
FC 3	--	R1	ON/OFF	--

TABLE A-2 (SHEET 3)

EPDCS DISPLAY/CONTROL FUNCTIONS

SWITCH	C/B	LOC	FUNCTION	DISPLAY
		CONTROL BUSES		
MN A	--	R1	RESET RPC	--
MN B	--	R1	RESET RPC	--
MN C	--	R1	RESET RPC	--
--	--	CRT	CNTRL BUS	SM OPS 2 ELECT VOLTS
--	--	CRT	CNTRL BUS	SM OPS 2 SYS SUMM 1 VOLTS
--	--	CRT	CNTRL BUS	BFS SM SYS SUMM 1 VOLTS
		AC POWER		
AC BUS SNSR -1	--	R1	NOW/OFF/AUTO TRIP	--
INV/AC BUS -1	--	R1	ON/OFF	STATUS R1
INV PWR -1	--	R1	ON/OFF	STATUS R1

TABLE A-2 (SHEET 4)

EPDCS DISPLAY/CONTROL FUNCTIONS

SWITCH	C/B	LOC	FUNCTION	DISPLAY
		AC POWER		
--	AC 1 SNSR	013	ESS 1 BC	--
--	AC CONTR 10A	R1	ESS 1 BC	--
--	AC CONTR 10B	R1	ESS 1 BC	--
--	AC CONTR 10C	R1	ESS 1 BC	--
AC BUS SNSR -2	--	R1	MON/OFF/AUTO TRIP	--
INV/AC BUS -2	--	R1	ON/OFF	STATUS R1
INV PWR -2	--	R1	ON/OFF	STATUS R1
--	AC 2	013	ESS 2 CA	--
--	AC CONTR 20A	R1	ESS 2 CA	--
--	AC CONTR 20B	R1	ESS 2 CA	--
--	AC CONTR 203	R1	ESS 2 CA	--
AC BUS SNSR -3	--	R1	MON/OFF/AUTO TRIP	--

TABLE A-2 (SHEET 5)

EPDCS DISPLAY/CONTROL FUNCTIONS

SWITCH	C/B	LOC	FUNCTION	DISPLAY
AC POWER				
INV/AC BUS -3	--	R1	ON/OFF	STATUS R1
INV PWR -3	--	R1	ON/OFF	STATUS R1
--	AC 3 SNSR	013	ESS 3AB	--
--	AC 3 CONTR 30A	R1	ESS 3AB	--
--	AC 3 CONTR 30B	R1	ESS 3AB	--
--	AC 3 CONTR 30C	R1	ESS 3AB	--
--	--	CRT	AC VOLTS/AMPS	SM OPS 2 ELECTRIC
--	--	CRT	AC VOLTS/AMPS	SM OPS 2 SYS SUMM 1
FORWARD MOTOR CONTROL				
MCA LOGIC - A #1	--	MA73C	ON/OFF	--
--	MCA PWR AC1 - 30 FWD 1	MA73C	AC10A - 0C	--

TABLE A-2 (SHEET 6)

EPDCS DISPLAY/CONTROL FUNCTIONS

SWITCH	C/B	LOC	FUNCTION	DISPLAY
		FORWARD MOTOR CONTROL		
--	FWD RCS 1 VLV 0A	MA73C	AC10A	--
--	FWD RCS 1 VLV 0B	MA73C	AC 1 0B	--
--	FWD RCS 1 VLV 0C	MA73C	AC 1 0B	--
MCA LOGIC -B #2	--	MA73C	ON/OFF	--
--	MCA PWR AC1-30 FWD 2	MA73C	AC 2 0A - 0C	--
--	FWD RCS 2 VLV 0A	MA73C	AC20A	--
--	FWD RCS 2 VLV 0B	MA73C	AC20B	--
--	FWD RCS 2 VLV 0C	MA73C	AC20C	--

TABLE A-2 (SHEET 7)

EPDCS DISPLAY/CONTROL FUNCTIONS

SWITCH	C/B	LOC	FUNCTION	DISPLAY
		FORWARD MOTOR CONTROL		
MCA LOGIC -C #3	--	MA73C	ON/OFF	--
--	FWD RCS 3 VLV 0A	MA73C	AC30A	--
--	FWD RCS 3 VLV 0B	MA73C	AC30B	--
--	FWD RCS 3 VLV 0C	MA73C	AC30C	--
--	MCA PWR AC1 - 30 FWD 3	MA73C	AC30A - OC	--
		MID MOTOR CONTROL		
MN A/MID 1 LOGIC	--	MA73C	ON/OFF	--
MN B/MID 1 LOGIC	--	MA73C	ON/OFF	--
--	MID 1 PWR AC1 30	MA73C	AC 1	--

TABLE A-2 (SHEET 8)

EPDCS DISPLAY/CONTROL FUNCTIONS

SWITCH	C/B	LOC	FUNCTION	DISPLAY
		MID MOTOR CONTROL (Cont'd)		
--	MID 1 PWR AC2 30	MA73C	AC 2	--
MN B/MID 2 LOGIC	--	MA73C	ON/OFF	--
MN C/MID 2 LOGIC	--	MA73C	ON/OFF	--
--	MID 2 PWR AC2 30	MA73C	AC 2	--
--	MID 2 PWR AC3 30	MA73C	AC 3	--
MN A/MID 3 LOGIC	--	MA73C	ON/OFF	--
MN B/MID 3 LOGIC	--	MA73C	ON/OFF	--
--	MID 3 PWR AC1 30	MA73C	AC 1	--
--	MID 3 PWR AC 2 30	MA73C	AC 2	--
MN B/MID 4 LOGIC	--	MA73C	ON/OFF	--

TABLE A-2 (SHEET 9)

EPDCS DI: LAY/CONTROL FUNCTIONS

SWITCH	C/B	LOC	FUNCTION	DISPLAY
		MID MOTOR CONTROL (Cont'd)		
MN C/MID ^ LOGIC	--	MA73C	ON/OFF	--
--	MID 4 DWR AC 2 30	MA73C	AC 2	--
--	MID 4 DWR AC 3 30	MA73C	AC 3	--
		AFT MOTOR CONTROL		
MNA/AFT 1 LOGIC	--	MA73C	ON/OFF	--
AFT POP VLV LOGIC GP 1/3	--	MA73C	ON/OFF	--
AFT POD VLV LOGIC GP 1/2	--	MA73C	ON/OFF	--
--	AFT 1 PWR AC1 30	MA73C	AC 1	--
--	AFT 1 -A POD VLV GP 1	MA73C	AC 1 0A	--

TABLE A-2 (SHEET 10)

EPDCS DISPLAY/CONTROL FUNCTIONS

SWITCH	C/B	LOC	FUNCTION	DISPLAY
		AFT MOTOR CONTROL (Cont'd)		
--	AFT 1 0 B POD VLV GP 1	MA73C	AC1 0B	--
--	AFT 1 0 C POD VLV GP 1	MA73C	AC1 0C	--
MNB/AFT 2 LOGIC	--	MA73C	ON/OFF	--
AFT 2 POD VLV LOGIC GP 1/3	--	MA73C	ON/OFF	--
AFT 2 POD VLV LOGIC GP 1/2	--	MA73C	ON/OFF	--
--	AFT 2 PWR AC2 30	MA73C	AC 2	--
--	AFT 2 0A POD VLV GP 1	MA73C	AC 2 0A	--
--	AFT 2 0B POD VLV GP1	MA73C	AC 2 0B	--

TABLE A-2 (SHEET 11)

EPDCS DISPLAY/CONTROL FUNCTIONS

SWITCH	C/B	LOC	FUNCTION	DISPLAY
		AFT MOTOR CONTROL (Cont'd)		
--	AFT 2 0C POD VLV GP 1	MA73C	AC 2 0C	--
MNC/AFT 3 LOGIC	--	MA73C	ON/OFF	--
AFT 3 POD VLV LOGIC GP 1/3	--	MA73C	ON/OFF	--
AFT 3 POD VLV LOGIC GP 1/2	--	MA73C	ON/OFF	--
--	AFT 3 PWR AC 30	MA73C	AC 3 0A-0C	--
--	AFT 30A POD VLV GP1	MA73C	AC 3 0A	--
--	AFT 30B POD VLV GP1	MA73C	AC 3 0B	--
--	AFT 30C POD VLV GP1	MA73C	AC 3 0C	--

TABLE A-2 (SHEET 12)

EPDCS DISPLAY/CONTROL FUNCTIONS

SWITCH	C/B	LOC	FUNCTION	DISPLAY
		PAYLOAD/CABIN		
PR1/FC3	--	RS	ON/OFF	STATUS R1
FC/MN BUS	--	R1	ON/OFF	STATUS R1
PR1/MN C	--	R1	ON/OFF	STATUS R1
PR1/MN B	--	R1	ON/OFF	STATUS R1
AUX	--	R1	ON/OFF	--
AFT/MN C	--	R1	ON/OFF	--
AFT/MN B	--	R1	ON/OFF	--
CABIN	--	R1	MN A/OFF/MNB	--
--	--	CRT	AFTB-C/DC AMPS	SM OPS 2 ELECTRIC

TABLE A-2 (SHEET 13)

EPDCS DISPLAY/CONTROL FUNCTIONS

SWITCH	C/B	LOC	FUNCTION	DISPLAY
		MISC		
ROTARY-9 POS	--	F9	AC VOLTS	METER
ROTARY-9 POS	--	F9	DC VOLTS DC AMPS/SIG STR	METER METER
AC 1 OMS KIT VLV LOGIV	--	MA73C	ON/OFF	--
--	AC1 OMS KIT 0A	MA73C	--	--
--	AC1 OMS KIT 0B	MA73C	--	--
--	AC1 OMS KIT 0C	MA73C	--	--
--	AC2 OMS KIT 0A	MA73C	--	--
--	AC2 OMS KIT 0C	MA73C	--	--
--	OMS KIT 0C	MA73C	--	--

THE **BOEING** COMPANY

ACTIVE SHEET RECORD

SHEET NO.	REV LTR	ADDED SHEETS				SHEET NO.	REV LTR	ADDED SHEETS			
		SHEET NO.	REV LTR	SHEET NO.	REV LTR			SHEET NO.	REV LTR	SHEET NO.	REV LTR
i						40					
ii						41					
iii						42					
iv						43					
v						44					
vi						45					
1						46					
2						47					
3						48					
4						49					
5						50					
6						51					
7						52					
8						53					
9						54					
10						55					
11						56					
12						57					
13						58					
14						59					
15						60					
16						61					
17						62					
18						63					
19						64					
20						65					
21						66					
22						67					
23						68					
24						69					
25						70					
26						71					
27						72					
28						72					
29						73					
30						74					
31						75					
32						76					
33						77					
34						78					
35						79					
36						80					
37						81					
38						82					
39						83					

ACTIVE SHEET RECORD

SHEET NO.	REV LTR	ADDED SHEETS: SHEET NO.	REV LTR	ADDED SHEETS: SHEET NO.	REV LTR	SHEET NO.	REV LTR	ADDED SHEETS: SHEET NO.	REV LTR	ADDED SHEETS: SHEET NO.	REV LTR
84											
85											
86											
87											
88											
89											
90											
91											
92											
93											
94											
95											
96											
97											
98											
99											
100											
101											
102											
103											
104											
105											
106											
107											
108											
109											
110											