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THE **BOEING** COMPANY

NASA-CR-167583

CODE IDENT. NO. 81205

NUMBER D180-26988-1

TITLE: APPLICATION OF MULTI-FUNCTION DISPLAY AND CONTROL TECHNOLOGY

ORIGINAL RELEASE DATE_____. FOR THE RELEASE DATE OF SUBSE-QUENT REVISIONS, SEE THE REVISIONS SHEET. FOR LIMITATIC IMPOSED ON THE DISTRIBUTION AND USE OF INFORMATION CON-TAINED IN THIS DOCUMENT, SEE THE LIMITATIONS SHEET.

MODEL__________	PREPARED UNDER:
ISSUE NO.__________	☒ CONTRACT NO. NAS9-16445
ISSUE TO__________	☐ IR&D
	☐ OTHER

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

SUPERVISED BY M.H. Tonkin
M. H. Tonkin

APPROVED BY__________

APPROVED BY Richard A Collins 3/19
R. A. Collins

(NASA-CR-167583) APPLICATION OF MULTI-FUNCTION DISPLAY AND CONTROL TECHNOLOGY Progress Report (Boeing Co., Seattle, Wash.) 71 p HC A04/MF A01 CSCL 22B
N82-21246
Unclas
G3/16 09502

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ABSTRACT

The NASA Orbiter spacecraft incorporates a complex array of systems, displays and controls. The incorporation of discrete dedicated controls into a multi-function display and control system (MFDCS) offers the potential for savings in weight, power, panel space and crew training time. In this report, technology identified as applicable to a MFDCS is applied to the Orbiter Orbital Maneuvering System (OMS) and the Electrical Power Distribution and Control System (EPDCS) to derive concepts for a MFDCS design. Several concepts of varying degrees of performance and complexity are discussed and a suggested concept for further development is presented in greater detail. Both the hardware and software aspects and the human factors considerations of the designs are included.

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1.0 INTRODUCTION

This report describes the procedures followed and results obtained by Boeing in performing Task 2 (Application of Technology) for NASA contract NAS9-16445, "Development of Preliminary Design Concept for Multi-function Display and Control System for Orbiter Crew Station".

1.1 PURPOSE

The purpose of this report is to describe the design criteria used, the designs developed and the rationale for suggesting a design concept for further consideration. The designs arrived at are based on the technology surveyed and described in the Task 1 (Survey of Existing Technology) report.

1.2 SCOPE

Designs developed in this report include consideration of applicable hardware and the human factors research and technology necessary to integrate the hardware into an efficient MFDCS for the OMS and EPDCS. While the designs developed are applied to the OMS and EPDCS, the concepts involved in the designs are, in general, applicable to a wider range of Orbiter systems. From a hardware point of view both current hardware and developing technology are considered.

1.3 TECHNOLOGY APPLICATION PROCESS

The design of a MFDCS for the OMS, EPDCS or other Orbiter system involves several areas of concern. One of these areas is the set of design constraints defined in both the

Statement of Work and by the nature of the Orbiter operation and construction. Operational constraints and hence MFSCS capability requirements will vary considerably during different phases of an Orbiter mission.

Hardware represents another area of concern. Within some hardware categories the pace of development is relatively rapid and the newer developments offer considerable promise for savings in weight, power and space. To permit the future consideration of these developments for inclusion in the MFDCS system the design concepts will be developed in this task in a general way without defining the precise pieces of hardware to be used. Hardware definition will be considered in greater detail in Task 3 (Analysis of Design Concepts).

The final major area of concern involves the human factors aspects of the MFDCS design. Here the hardware and software involved in the system must be combined with operator constraints, system functional requirements, time constraints and workload and reliability considerations to arrive at a MFDCS providing maximum usefullness to a variety of operations.

1.4 MULTI-FUNCTION DISPLAY AND CONTROL SYSTEM DEFINITION

Given the functional and predefined constraints on the MFDCS design for the OMS and EPDCS the definition of the design concepts can be broken down into the two major areas of hardware and human factors definition.

1.4.1 Hardware Definition

The available hardware for application to a MFDCS has been discussed in the Task 1 report. From the functional requirements and predefined constraints on the system, a set of hardware requirements will be developed. In general, the difference between design concept hardware choices will not be a matter of exclusivity between the various design concepts. The design concepts will represent a heirarchy of increasingly versatile control options for the operators with a commensurate required increase in the hardware capabilities. At the same time consideration will be given to future incorporation of new technology into the MFDCS.

1.4.2 Human Factors

One of the major human factor advantages of the MFDCS concept, as applied to the complexity of the Space Shuttle, is the reduction of flight deck clutter due to over 1700 existing dedicated switches. The more complex the system, the more that can be gained by a MFDCS.

Each switch action requires the operator to first locate the switch; then reach it and finally activate it. It is physically impossible to layout a workplace for two operators containing over 1700 dedicated controls which meets minimum human engineering requirements with regards to vision and reach. Using conventional controls, then, the most sophisticated space vehicle in the world is relegated a flight deck design far below the human engineering standards of modern commercial and military air vehicles.

Another major advantage of the MFDCS concept is the potential reduction in operator errors and gain in speed. By keyboard mode select the operator is given only those keys (switches) pertinent to the task at hand. The operator's choice now becomes 1 out of 20 or 30 switches instead of 1 of 1700. Awareness of these and other human factors principles during design trade studies will insure a balanced design emanating from the MFDCS concept development.

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2.0 DEFINITION OF FUNCTIONAL REQUIREMENTS

The functional requirements of the MFDCS for the OMS and EPDCS are of several different types. These requirements include the basic design constraints defined in the contract, design constraints imposed by the nature of the two systems, requirements resulting from the different mission phases, hardware requirements and human engineering requirements. Each of these is discussed below.

2.1 DESIGN CONSTRAINTS

A number of goals and requirements for the MFDCS are specified as ground rules for the design effort. These include the following:

2.1.1 Localization of System-Specific Displays and Controls

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

2.1.2 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.

2.1.3 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.

2.1.4 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.

2.1.5 Interface Compatability

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.

2.1.6 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.

2.1.7 Minimization of Weight, Power, and Cooling

Reduction of vehicle weight for Orbiter flights increases the useful payload. Weight reducation 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 SYSTEM DESCRIPTIONS

The two Orbiter systems under primary consideration are the OMS and EPDCS. Although the detailed design concept is directed towards these particular systems, it should be emphasized that the concepts being developed are equally well applicable to other systems on the Orbiter. In this report, the OMS has been selected as an example to illustrate the design concepts in detail. For this reason, a much more complete description and analysis of the OMS relative to the EPDCS is given. A similarly detailed analysis of the EPDCS will be completed as the detailed design is formulated in Task 3.

2.2.1 Orbital Maneuvering System (OMS)

The OMS System is comprised of four subsystems, i.e., the Engine Control where thrust is produced; the 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.

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 orbit is necessary requiring return to the launch site during the ascent phase. In this case, the propellant is dumped.

These subsystems are discussed in greater detail as related to crew actions as follows and in Section 2.5, Man-Machine Interface.

2.2.1.1 Engine Subsystem (including N_2 Pressurization)

An OMS engine burn is the result of allowing fuel and oxidizer to mix in the thrust chamber. Ignition is hypergolic. The flow of pressurized propellants to the thrust chamber is controlled by two sets of mechanically linked butterfly valves - each set in series.

Each valve is spring loaded in the "closed" position, but can be opened 0-100% by control valves which allow pressurized N_2 to move pistons, which in turn rotate the butterfly valve to some "open" position. Burn characteristics, i.e. fuel/oxidizer mix and burn duration are controlled by the GPC firing sequencer and cannot be controlled by the crew. The crew can manually terminate a burn by switch action.

However, for a software controlled burn to occur, the crew must have enabled the system by the following switch actions:

1) Setting the OMS ENG switch to ARM/PRESS which opens the N_2 ENG P VLV. There is no software control of this valve.

2) OMS ENG VLV switch to "ON"

These switches are normally set by ground personnel at T-30 min. However, the ENG switch is turned "OFF" after injection and is reset by the crew 2 minutes before a burn.

The OMS ENG VLV switch is used as a redundant method of terminating a burn after a massive failure, but normally remains on throughout the entire mission.

The only display associated with these switches is the OP/CL states of the N_2 P VLV shown on the GNC SYS SUMM 2 display. The position of the bipropellant butterfly valve controlled by the GPC is also shown on the same display.

2.2.1.2 Propellant Subsystem

Each OMS pod has a fuel and an oxidizer tank which are pressurized by a common He tank. During normal operations each tank feeds through a parallel pair of tank isolation valves, A and B, into the engine bipropellant valves and then into the engine. The left tank feeds the left engine and the right tank feeds the right engine. In this normal mode the tank isolation valves are always open. Crossfeeding the left tank to the right engine or the right tank to the left engine is possible by opening all the XFEED valves and closing the tank isolation valves on the side receiving propellant.

Interconnecting of OMS propellant to the aft RCS jets is also possible utilizing the OMS XFEED and RCS XFEED valves.

In practice, the crew refers to Pocket Checklist Schematic 7-1 and cue cards for XFEED, or Interconnect mode valve configurations and manually sets switches on Panel 08 to match the OP/CL valve status shown on the cue cards. A barber pole warning display appears on the panel if the fuel or oxidizer valves are not in the same OP/CL state for each pod.

Although the tank isolation and crossfeed valve switches are 3 position, i.e. OPEN, GPC and CLOSED, the GPC position is not normally used. Exception to this is during ascent when the XFEED A valves are CL; the B valves GPC and the aft RCS TK ISOL and XFEED GPC which allows the GPC to dump propellant through the RCS during launch abort.

Also, if a mixed crossfeed deorbit burn should become necessary, the normal valve configuration is changed via a GPC memory read/write procedure. (OMS Cue Card Procedures Rationale, Section 7.8.)

If this should occur, Panel O8 will not reflect the true valve status and a barber pole warning will be displayed indicating disparity between fuel and oxidizer valve state, which has been purposely induced by the software.

The He PRESS/VAP ISOL valve switches have "OPEN", "CLOSE" and "GPC" positions. The "GPC" position is used during nominal burns. The "OPEN" position is used for off-nominal burns. At times when no burn is being performed the "CLOSE" position is used except during ascent when the valves are preset to "GPC" for OMS 1 burn.

2.2.1.3 Propellant Thermal Control Subsystem

Controls for the propellant heaters are presently located on Panel A14 in the aft flight deck. Switches are divided into 3 segments - left pod, right pod and crossfeed, each segment having an "A" and "B" circuits. Each switch can be set to "OFF" or "AUTO". When in the "AUTO" position heating is under thermostat control.

Pod heaters are in the "OFF" position during launch and entry and the crossfeed line heaters "A" and "B" are in "AUTO". On orbit, one of the two circuits of each of the pod segments are in "AUTO". Other than these settings no further operator control of the propellant thermal system is required.

2.2.1.4 Thrust Vector Control (TVC) Subsystem

OMS guidance is the result of a lot of computations in the GPC. As a result of these computations the OMS engines are gimballed by two electromechanical actuators to produce thrust vectors through the c.g. with relation to the x, y and z axes to produce the correct control moments to achieve the desired target.

All displays associated with the OMS TVC is contained in the MNVR CRT display which is used for every OMS burn. Interactions with the TVC through the keyboard/CRT are as follows:

1) Pitch and yaw load trim angles,
2) Primary or secondary gimbal drive mechanism selection, and
3) Gimbal checkout.

2.2.2 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 are concerned with various possible malfunctions which may 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 may result in a large enough number of caution and warning alerts to obscure the basic problem to the operator. Thus, the MFDCS should be capable of prioritizing conditions and displaying to the operator the appropriate anomalies to correct first.

2.3 MISSION IMPLICATIONS

Although the main source of energy to put the Space Shuttle Orbiter into orbit is the solid rocket boosters and the main engines (using propellant from the external tanks), the Orbital Maneuvering System (OMS) is used to place the Orbiter into final orbit. This is because the external tanks are dropped off prior to orbit to prevent them too from going into orbit.

The first OMS burn then is critical in terms of timing, since the Orbiter would fall back to earth if this burn is not precisely conducted. In that case the Orbiter and crew would be forced into a Return To Launch Site (RTLS) abort mode in which the propellant is jettisoned. The OMS 2 burn makes corrections in orbit characteristics only and is not as critical, since the shuttle is already in orbit. Malfunctions in the OMS or EPDCS during the critical ascent flight phase must be recognized and dealt with rapidly to insure mission success and safety. For example a critical malfunction in the EPDCS would require manual actions by the crew and a malfunction of an OMS engine might require reconfiguring the bipropellant valving, all within a critical time frame.

Anomalies occurring during orbital activities are not as critical since the crew has time to diagnose the problems and to institute work around procedures.

However, almost as critical in terms of crew response to anomalies, is the deorbiting and reentry phase. Again, the crew must recognize and respond to the malfunction in a timely manner to insure mission success.

The final design of the MFDCS must be predicated on and be preceded by a functional analysis of critical mission phases assuming critical system failures and recognizing the deleterious effects of stress on human responses and error proneness.

2.4 HARDWARE REQUIREMENTS

Hardware available for the implementation of the Orbiter MFDCS is described in detail in the Task 1 report. The hardware requirements are dependent on the particular systems, logic trees and displays for which the MFDCS is designed. Basic system considerations such as response speed, number of displays, resolution and color capability will determine much of the hardware requirements. Hardware considered for application will include both the currently available technology and developing technology considered to have relatively near term applications and potential advantages for the Orbiter systems. A brief description of some of the relevant hardware capabilities is given in Section 3 of this report.

2.5 MAN-MACHINE INTERFACE - OMS

One of the systems requiring detailed scrutiny within this study, is the Orbital Maneuvering System (OMS). Since this system is used to get into orbit and to get out of orbit, crew errors during anomolous conditions, and occuring during certain critical flight phases, could produce catastrophic results.

This section describes the functions performed on the OMS as these have been identified from NASA-supplied documentation. These functions provide the basis for the preliminary MFDCS implementation described in Section 5.3. Because these functions have been identified and listed here to provide an application structure within which to evaluate the potential usefulness of a MFDCS concepts to the orbiter, they have not undergone extensive review by NASA to ensure validity and they should not be considered an exact definition of the current orbiter configuration.

As currently configured the crew must address and/or monitor ten different gauges or meters, six different control panels, four different CRT display formats, 28 different switches plus TVC keyboard addresses in order to fully exercise control of the OMS. These control/display functions are listed in Table 2.5-1 and are divided into four subsystems:

1. Engine Control
2. Bipropellant Control
3. Thermal Control, and
4. Thrust Vector Control (TVC)

2.5.1 OMS Engine Control

Assuming the N_2 and bipropellant sub-systems are pressurized, two crew actions must have taken place for an OMS burn to occur, i.e.;

1) The N_2 PRESS VLV must be open, and,
2) The ENG VLV switch must be "ON".

There is no dedicated switch which reads "N_2 PRESS VLV OPEN". This function is controlled by the OMS ENG switch which must be in the ARM/PRESS position to enable the control valve; open the N_2 PRESS VLV and enable the N_2 purge valve. The N_2 PRESS VLV position is displayed on the GNC SYS SUMM 2 CRT display but purge status is not. There may be times when a burn capability must be preserved without depleting the H_e reservoir by purging. In this case, the OMS ENG switch must be placed in the ARM position during the preceding burn which inhibits the N_2 purge.

Although the ENG VLV switch must be in the ON position to enable a burn, the crew has not display showing the status of these switches but can observe the position of the switches on Panels 014 and 016.

Man-Machine Interface

The crew should have an integrated burn status display containing information similar to the example shown below:

ENG VLV SWITCH	ENG SWITCH	ENG CONTROL VLV	N_2 PRESS VALVE	N_2 PURGE VALVE
ON	ARM/PRESS	ENABLE	OPEN	ENABLE
ON	ARM	ENABLE	CLOSED	INHIBIT
ON/OFF	OFF	CLOSED	CLOSED	INHIBIT

This display may be tabular or graphic. If a graphic display is used then most of the N_2/FU/OXID pressure and temperature information shown on the GNC SYS SUMM 2 display in tabular form could be displayed on the N_2 subsystems schematic as well as the position of the N_2 PRESS valve and the N_2 purge and ENG control valve enables. During an actual purge the N_2 purge valve should be displayed "open". The position of the ball valves as controlled by the GPC should also be displayed.

The control functions of the OMS ENG and ENG VLV switches should be incorporated on the MFDCS keyboard with display feedback as previously described.

If the valve switches are addressed solely by keyboard commands, the following key function will be required:

ENG VLV SWCH
ENG SWCH
ARM
ARM/PRESS
ON
OFF

2.5.2 Bipropellant Control

Control of fuel and oxidizer to the OMS engines during a burn is accomplished mainly by the crew manually setting switches on Panel 08. These switches in turn control the PRESS/VPR ISOL, TK ISOL, and XFEED valves. The setting of these valves is determined by the mode of operation whether it be normal or anomalous. Anomalous operation may require propellant crossfeed-left-to-right-engine, or crossfeed-right-to-left-engine. In addition, the GPC controls valve configuration for a possible fuel dump during RTLS abort and a possible mixed crossfeed during flight. Interconnect of OMS fuel to the RCS aft system is also possible.

The current configuration (including kit configuration) requires the crew to operate or monitor 17 switches and eight meters on three separate panels, plus a CRT display. Propellant quantity is presently displayed on a multi-function meter on Panel 03.

Current operational practice requires the crew to refer to the OMS schematic shown in Check List sheet 7-1. They then determine which valve should be open, closed or placed under GPC control and manually set the switches on Panel 08. There is A display feedback and a "barberpole" warning on the control panel in case there is a disparity between the OP/CL status of fuel and oxidizer valves. GPC FDI also checks the open status of the PRESS/VAPOR ISOL values prior to a burn and alerts the crew if the valves are closed. There is no discernable display of "actual" valve status when under GPC control. If not under GPC control the crew must also refer to Panel 08 to determine OP/CL valve status, since there is no bipropellant valve status display.

Man-Machine Interface

There are several human factor problems associated with the current method of propellant control. First of all, the crew is dependant on check list schematic 7-1 and cue card information to set valve positions on Panel 08. However, the 7-1 schematic does not correctly show the interlock between FU and OXID valves shown on Panel 08. For example, we cannot open the TK ISOL FU valve without opening the TK ISOL OXID valve since there is a common switch to both valves. If both do not open, a "barberpole" disparity display appears on Panel 08 and the burn is inhibited by the crew. However, there is no discernable display to indicate which valve did not open.

Another problem is that of unknown true valve status. Whereas, we assume the TK ISOL and XFEED "talkback" or Panel 08 is from the valve itself and can be believed, there is no "talkback" from the PRESS/VAPOR ISOL valves. The crew must believe that the PRESS/VAPOR ISOL valve is truely in the position indicated by the switch, and if in the GPC position, that the valve is in the position it should be for that flight mode. The GPC FDI pre-burn check for "OPEN" valve position would be unnecessary if the crew had a display showing true valve status.

Considering the possibility of one engine burn using left-to-right, or right-to-left crossfeed (or even worse, mixed crossfeed), it would seem that the crew would be heavily involved in setting and verifying correct valve configuration at a time when their attention should be devoted to load gimbal trim angles and monitoring TVC effects on the spacecraft.

A subsystem schematic display is a far better way of communicating valve status information to the crew than a tabular display. At a glance, an operator can see the effect of changing any valve position on the total subsystem. From the schematic the operator should know the current, actual valve position and the desired valve position, dependent on the mode selected on the keyboard.

Any disparity between actual and desired position should be flagged and addressable by commands using the MFDCS keyboard. Dialogue between the operator and the system via the graphic display could be:

1) Keyboard commands to valves and switches,

2) Touch panel overlaying the graphic display, or

3) Cursor positioning using pushbuttons or a continuous control such as a trackball or joystick.

OX, FU, and He tank pressure information now displayed on GNC SYS SUMM 2 could be integrated with the graphic systems display. Meter display of tank pressure and quantity could be retained for redundancy.

If the valves are addressed soley by keyboard commands, the following key functions will be required.

TK/ISOL FU-OX
XFEED FU-OX
PRESS/VAP ISOL
LEFT
RIGHT

A

B

OPEN

CLOSE

GPC

If the valves are addressed solely by touch panel or cursor positioning, only the action verb keys OPEN, CLOSE and GPC will be required.

2.5.3 Thermal Control

There are seven heater control switches, i.e., left pod circuits A and B, right pod circuits A and B, crossfeed circuits A and B and kit circuit A. Switches are either OFF or in AUTO. Thermal protection is thermostatically controlled.

Man-Machine Interface

Currently, there are few operator actions associated with the thermal protection subsystem. The operator must set either the A or B pod circuits to AUTO (on orbit only); crossfeed circuits to A and B during all flight phases, and monitor the PRPLT THERMAL and OP52 SM CRT displays for out-of-limit temperatures. Annunciator alerts and MCC backs up the crew in recognizing any out-of-limit conditions. The only action available to the crew is the manual switching to the redundant circuit in case of the primary circuit failure.

If these switches are addressed solely by keyboard command the following key functions will be required.

XFEED

POD

KIT

LEFT

RIGHT

A

B

OFF

ON (AUTO)

2.5.4 Thrust Vector Control (TVC)

Currently there are no independent switches associated with the TVC. Most TVC control is from the GPC and MCC. Operator dialogue with the TVC is now via the existing CRT/keyboard and consists of:

1) Gimbal check request,

2) Load trim angles (pitch and yaw), and,

3) Primary or secondary gimbal drive mechanism selection.

At present, information on OMS engine pitch and yaw gimbal angles is available only in the form of a tabular listing on a CRT display. A dynamic display of pitch and yaw gimbal angles, possibly integrated with other relevant information such as the relationship of the OMS thrust vector to Orbiter center of gravity, would provide a more effective interface with the crew. Such a display could be integrated into the graphic display portion of a MFDCS.

TABLE 2.5-1

OMS DISPLAY/CONTROL FUNCTIONS

SWITCHES	SENSOR	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 2.5-1 (CONTINUED) SHEET 2

SWITCHES	SENSOR	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 2.5-1 (CONTINUED) SHEET 3

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

TABLE 2.5-1 (CONTINUED) SHEET 4

SWITCHES	SENSOR	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 2.5-1 (CONTINUED) SHEET 5

SWITCHES	SENSOR	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 2.5-1 (CONTINUED) SHEET 6

SWITCHES	SENSOR	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	TEMPERATURES LIMIT SENSED	GPC MCC	ANNUNCIATORS BFS SM OPS THERMAL PRLT THERMAL
(L) POD HTR B			
(R) POD HTR A			
(R) POD HTR B			
(K) HTR A			
XFEED HTR A			
XFEED HTR B			

TABLE 2.5-1 (CONTINUED) SHEET 7

SWITCHES	SENSOR	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

3.0 TECHNOLOGY CAPABILITY EVALUATION

The capabilities of the current and projected technologies applicable to MFDCS for the Orbiter have been discussed in the report on Task 1 (Survey of Multifunction Display and Control Technology) (Reference 3-1). In this section, these capabilities will be briefly reviewed with respect to application to the OMS and EPDCS.

3.1 DISPLAY MEDIA

The two basic forms of display media available for the Orbiter MFDCS are the CRT and the flat panel display. The CRT is by far the dominant display form in current display and control systems. Flat panel displays include light emitting diodes (LED), liquid crystal displays (LCD), plasma, electroluminescent panels, vacuum fluorescence and electrochromics.

3.1.1 Resolution

At this time, the only medium available for high resolution displays is the CRT. Recent improvements in the capabilities of shadow mask CRT's have resulted in aircraft qualified tubes which will operate in either a stroke-writer or raster scan mode. Shadow mask tubes are available with resolutions up to 32 lines/cm (80 lines/inch) where the limiting factor is the triad spacing of the mast. Monochrome or beam penetration tubes are limited in resolution by the beam spot size with resolutions up to 43 lines/cm (110 lines/inch) currently available.

Flat panel displays have recently appeared in medium resolution dot matrix array formats in several technologies. In the resolution range of 24-30 lines/cm (60-75 lines/inch), panels are available using LED, LCD, vacuum fluorescence, plasma and thin film electroluminescent (TFEL) technology. Of these technologies, the LED arrays are closest to flight application with a number of units being currently produced for the F-16 program. The rapid recent development of the various flat panel technologies implies a relatively near term capability for these display forms to function as general purpose medium and perhaps high resolution displays.

3.1.2 Color

Multiple color capabilities within a single display are available in both the shadow-mask and beam penetration CRT's. The shadow mask tubes offer a full red-green-blue color capability while the beam penetration tubes are limited to colors ranging from red through yellow to green. Currently, the only flat panel display with multi-color capability is the LED panel. By combining a red and a green diode at each dot matrix position, colors from red to green may be obtained.

TFEL technology offers the potential of increased color capability by using multiple EL layers. This technique would provide medium to high resolution displays with colors in the red to green range. Current forecasts place TFEL color panels several years in the future for preliminary examples.

The question of whether to include color in a MFDCS visual display involves several issues. Color offers potential benefits by providing an additional dimension for encoding information. Color also imposes penalties in terms of display hardware cost, reliability, lower spatial resolution and possible clutter. The MFDCS concepts discussed in this document are not dependent on the use of color but most can benefit from the addition of color.

Thousands of colors can be displayed on a shadow mask CRT but only a few are useful for encoding displayed data. The upper limit on the number of colors that can be used depends on several factors. The limit is much smaller if the observer must identify each color when it is present singly, rather than just distinguishing that two adjacent colors are different. The upper limit is also lower if a wide range of illumination conditions can occur. To cite one specific example, the six or seven colors on the avionics displays used in the new Boeing 757/767 aircraft were selected to be identifiable on a vertical- or horizontal- situation display under display intensity settings and illumination conditions ranging from direct sunlight falling on the display to a light level commensurate to maintaining observer dark adaptation as required for night landings.

Color can be used to encode information redundantly with some other dimension such as a symbol shape or nonredundantly. If the encoding is not redundant the observer must correctly identify the color to obtain the displayed information. If important information is involved, the designer must be certain that nothing will interfere with the display of color nor with the observer's ability to identify each displayed color. Redundant coding is most useful as an aid in locating particular elements or classes of information. For example, all the information on one topic in a large table might be a single color. In this application, the display user could read each item in the table and eventually locate all the items on that topic, but these could be located faster when they are all a single color that differs from the rest of the table.

Excessive use of color, particularly by the introduction of too many different colors, can increase the information density on a display and interfere with the interpretation of the displayed information. Experience in the design of color displays indicates that overuse of color is one of the most common faults that occurs.

3.1.3 Interfacing

Interfacing between CRT displays and computers has been well developed in graphics generation facilities and airborne applications. Numerous video controllers chips and/or boards are available with the variety depending on the resolution and array size desired.

The flat panel displays can, in general, be interfaced to a processor in either a serial or parallel mode. Most of the panels commercially available with driver electronics are designed to accept serial data using an ASCII format. This design reflects the desirability of using many of the flat panel displays as terminal screens.

3.1.4 Physical and Electrical Parameters

A primary physical constraint in the installation of CRT's is their relatively high depth requirements. This may preclude their use in some of the Orbiter panel locations because of conflict with the structure or wiring. The electrical power consumption for a given display area is relatively efficient for a CRT (3-10 lumens/watt) compared to the LED flat panel (0.1 lumens/watt). The other flat panel displays offer improved efficiency comparable to the CRT in a number of cases, (TFEL, vacuum fluorescence, plasma). The liquid crystal and electrochromic displays offer even higher efficiency since they are non-luminous. A flat panel installation in the Orbiter would offer the advantages of long life, low panel depth and lower high voltage requirements.

3.2 DATA HANDLING AND PROCESSING

Much of the capability of a MFDCS depends on the intelligence designed into the processor controlling the keyboard and displays. Similarly the complexity of logic trees and displayable information requires sufficient memory capacity to store the appropriate data.

3.2.1 Processors

Currently available microprocessors include both 8 and 16 bit units with 32 bit microprocessors slated for the near future. The existing microprocessors have been used in a large array of video display and control systems and continue to improve in speed and component density. The primary limitation of current microprocessor technology lies in the rapid generation of complex high resolution displays. Depending on the display complexity, it may be desirable to generate a majority of the complex images off-line and store them for call-up and display by the microprocessor in a MFDCS.

3.2.2 Storage

Most of the storage requirements for an MFDCS can be handled using the present variety of ROM and RAM memory for high speed access and a disc system for the storage of large quantities of data. The capabilities of the new video disc systems show considerable promise for the storage of fixed displays for CRT's or flat panel arrays. A large number of images (~50,000 in 512 line format) can be stored on a single laser video disc. The readout produces no disc wear and the images are not seriously damaged by small scratches or by handling the disc. This type of storage system would be particularly well adapted to the storage of trouble-shooting and maintenance data for the Orbiter. A study is currently under way at Boeing to assess the potential and potential problems associated with video discs and their interface to microprocessor or computer control.

3.3 CONTROLS

Controls applicable to a MFDCS include both conventional controls and the relatively new controls associated with programmable switches and displays.

3.3.1 Conventional Controls

Conventional controls include the available range of dedicated switches in a variety of forms as well as controls such as light pens, trackballs, joy sticks, etc. These devices are well understood and readily available and will be considered, for this report and the concept development, only as a general class of devices. Detailed selection will be considered in Task 3.

3.3.2 Touch Panels

The integration of touch panel overlays and CRT or flat panel displays offers a powerful new technique for man-machine interactions. Touch panels are available using several technologies to indicate the touch position. By programming the touch panel resolution to match the desired interaction features of the overlaid display, the combined system can provide a high degree of adaptability to different displays and desired interactions. Two current problems with the touch panel displays are the possibility of partially obscuring the display with the panel and the relatively light pressure needed to activate the panel. The lack of high pressure requirements eliminates much of the tactile feedback often associated with standard switches. As a result, accidental activation is much more likely. Some indication will be needed to inform the operator that the switch has been activated and a guard mechanism to prohibit accidental activation will be needed.

3.3.3 Discrete Programmable Legend Switches

Discrete switches incorporating a programmable display offer the advantage of a positive tactile feedback and a range of flight deck placement options. On the other hand, unless the switch displays can be made edge-abuttable, the capability of a continuous image is lost. Thus, continuous displays must be accommodated on a separate display. These switches are currently in the development phase and a number of varieties are expected on the market in the next one to two years.

4.0 POTENTIAL DESIGN CONCEPT DEVELOPMENT

In this section, the design concepts considered in the application of MFDCS technology are described. In this description the correlation of the system designs with the OMS and EPDCS, the orbiter mission and the hardware options will be discussed.

4.1 CANDIDATE CONCEPTS

A variety of concepts were considered for the OMS and EPDCS MFDCS. This variety is probably best viewed as a heirarchy of potential systems with increasing levels of capability and resultant hardware and software complexity. Within this heirarchy, there are hardware options which reflect the current state of technological development. In cases where new technology looks promising, two concepts have been proposed; one with currently available equipment and another using what is felt to be a possibly advantageous future technology.

The most basic concept for a MFDCS will provide the capability to perform the present OMS and EPDCS switch functions from a multifunction keyboard (MFK) composed of programmable legend switches. The keyboard will consolidate the various switches of the two systems into a single area in Orbiter Panel R1. Displays and gauges will remain in their current configuration. The keyboard will consist of either a touch panel overlaying a display for keyboard legend presentation or an array of individual switches with programmable legends. Top level switches will allow the operator to select either the OMS or EPDCS and to return to the initial display for system change. The logic tree structure associated with the keyboard will provide access to all the OMS and EPDCS switch functions. The access schema and number of indenture levels involved in performing each function will be defined by the prerequisites for performing the function, the function criticality and the frequency of access for that function relative to the other functions. Capabilities of this system are illustrated in the schematic diagram shown in Figure 4.1-1a.

An important modification to the basic system described above can be made by the addition of a moderate scratchpad and graphic display capability as shown in Figure 4.1-1b. A display with medium resolution (25-30 lines/cm) can be used to display both text material and limited graphics for such purposes as instrument indicators. Such a display would typically be approximately 10 x 12 cm in size. By adding this display, a number of important capabilities may be included in the MFDCS. By the addition of text listing the operator can use the system to display and edit data being entered, receive messages from the host computer, interact with checklists and display procedures to be followed in the event of malfunctions. For example, using the keyboard alone to enter data such as radio frequencies, the feedback to the operator of data being entered depends on operator memory to a large extent. The host may accept or reject the data and the operator can only try again. With a display, the text of the data entry may be inspected before entry to the host computer, thus avoiding errors and improving accuracy in information transfer. The operator not only gets to see what is going to the host, but also can receive a host acknowledgement of the action taken. The capability for medium resolution graphic displays will allow the use of the scratchpad area for display of information such as display of gauges, limited graphic display of system status and the display of graphic caution and warning information. This capability will permit the elimination of some of the low and medium resolution gauges and meters. Given the sizable number of procedures, checklists and options involved in the Orbiter operation, their incorporation into the display formats of the MFDCS will relieve the operator of considerable searching for the appropriate action.

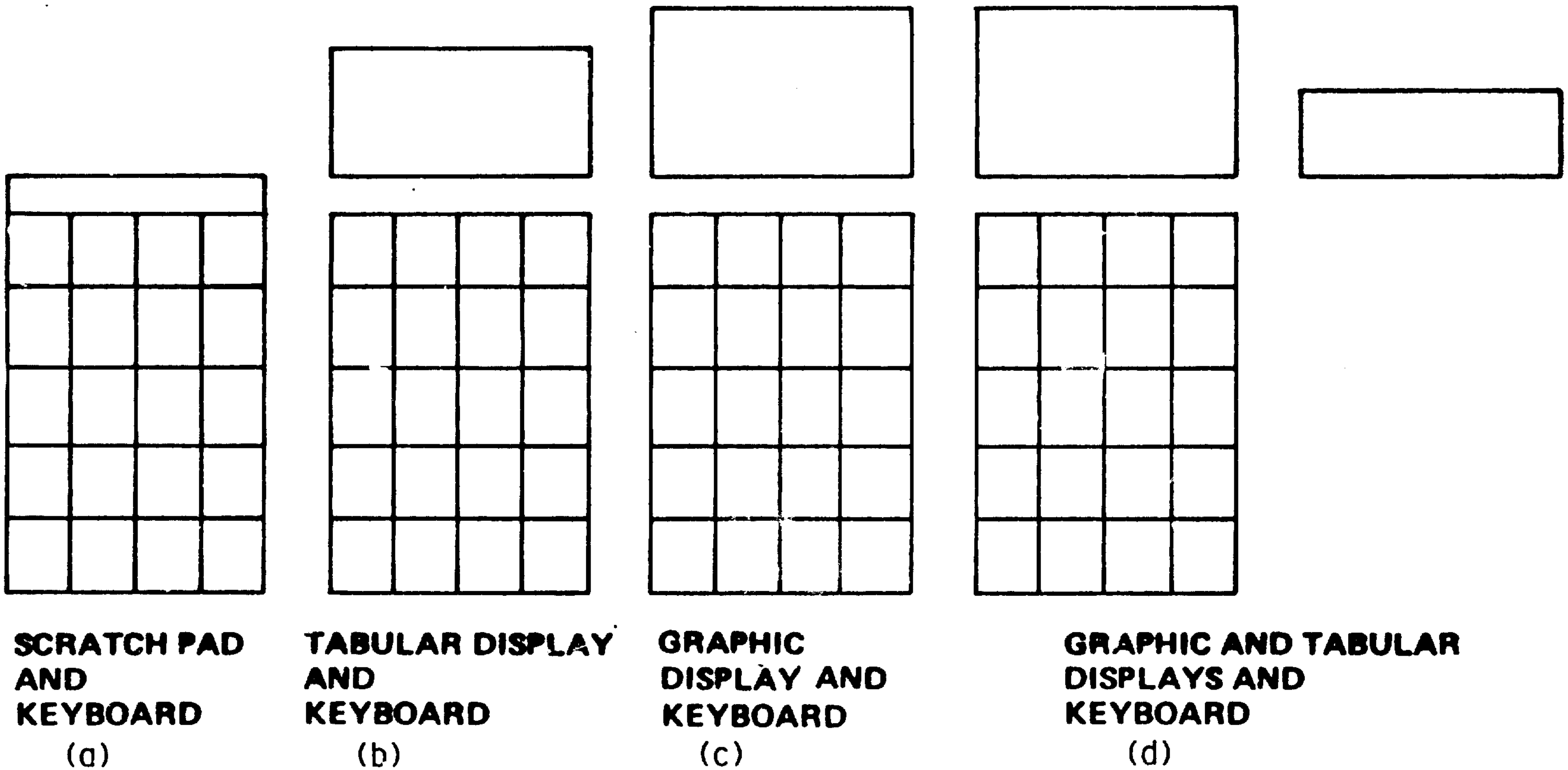

Figure 4.1-1 MFDCS Capabilities Heirarchy

Additional capability for the MFDCS, as shown in Figure 4.1-1c, can be achieved by the addition of a higher resolution display capability, with the possible inclusion of color. A higher resolution display will permit the display of high resolution graphics such as detailed system graphics, text and graphic combinations and tabular data. For example, a display of the OMS system, either in whole or in part, can be displayed with the configuration of the system shown. Errors in system configuration can be identified or the configuration can be computed with a stored configuration and the error status indicated. Changes in status of the system can be made through operation of the keyboard and/or through interaction with the graphics display. Changes in configuration and warnings or alerts can be indicated on such a graphics display through changes of color and/or shape of graphic symbology or by the appearance of text to indicate a particular condition.

The range of possible system capabilities presented in the preceding descriptions offer considerable latitude in complexity, versatility and operator usefullness. The following subsections will describe, in more detail, the application of these MFDCS system concepts to the orbiter systems and mission.

4.2 CORRELATION WITH OMS AND EPDCS

Both the OMS and EPDCS interact with the Orbiter GPC's through the display of system sensor and status information in the CRT display formats. In addition, most of the OMS switching functions are routed through the GPC's for execution at the appropriate sensor or actuator. On the other hand, the EPDCS switches are primarily directly wired to contacts, relays, actuators, etc., and hence do not pass through the GPC's. The basic assumption that the proposed MFDCS will be able to control both systems requires that the MFDCS be capable of driving the hard-wired lines of the EPDCS and of simulating the commands to the GPC's of the OMS switches.

Any of the concepts described in the previous subsection would include this capability.

The capability to include the checklists and malfunction procedures associated with OMS and EPDCS is satisfied with the incorporation of a moderate sized scratchpad display into the system. The assumption is made that the MFDCS will have access to the sensor information going to and command information from the GPC's. With this information the MFDCS software can be designed to interpret the sensor information and display the appropriate malfunction procedure to the operator.

Both the OMS and EPDCS are systems for which a graphic display of system status can be very useful to the operator, particularly in setting up a system for a particular function or troubleshooting system malfunctions. This graphics capability requires the inclusion of a relatively high resolution display in the system.

4.3 CORRELATION WITH ORBITER MISSION

The Orbiter flight is generally most critical in terms of time limitations on crew action during the ascent and reentry phases of the flight. During these times many operations would allow little time for system diagnosis and hence the display needs for the MFDCS will be best satisfied by the capability of displaying low to medium resolution graphics (e.g. gauge readings) and text. In particular, this would permit the display of cue card information, checklists and malfunction procedures as well as limited instrumentation graphics. During the orbital phase of the flight, however, considerably more time may be available to analyze problems, reconfigure systems or perform troubleshooting and/or repairs. This type of operation would benefit from the inclusion of a high resolution display in the MFDCS in the case of both the OMS and EPDCS.

4.4 CORRELATION WITH HARDWARE OPTIONS

Hardware is currently available to implement any of the display and control options mentioned. Displays can be implemented using a variety of CRT's. For example, a keyboard can consist of a CRT with programmable legend areas and a touch panel overlay. Flat panel displays are also available for keyboard construction and the display of text and medium resolution graphics. The requirement for a high resolution display leaves only the option of the CRT at this time. While high resolution flat panel displays are under development, they are still several years away.

5.0 CONCEPT SELECTION

Selection of a preferred design concept for the MFDCS as applied to the OMS and EPDCS is discussed in this section. A MFDCS can be viewed as a collection of displays and controls where a keyboard is a control device. In this sense, a MFDCS can be constructed in modular form to satisfy the system requirements. This concept is shown schematically in Figure 5-1. It should be noted that the modular concept is applicable not only to the OMS and EPDCS, but also to other Orbiter systems. In Section 5.3, a detailed application of the selected design concept to the OMS is given.

5.1 SELECTION CRITERIA

Many of the functional requirements described in Section 2 are satisfied by any of the design concepts. Two basic requirements for the OMS and EPDCS are: 1) the capability to integrate checklists, malfunction procedures and cue cards into the system displays, and 2) the option of displaying high resolution diagrams of the two systems.

These requirements drive the selection of the displays for the MFCDS. The requirements for the keyboard controller in terms of interfacing and processing speed will be determined by the number and complexity of the displays and keyboard legends being used, the interface to the Orbiter GPC's, and the levels of automation desired for the MFDCS. In a similar fashion, the requirements for memory will depend on the final controller program complexity and the amount of stored data to be considered. The selected design concept must also satisfy the human factors requirements associated with the man-machine interface.

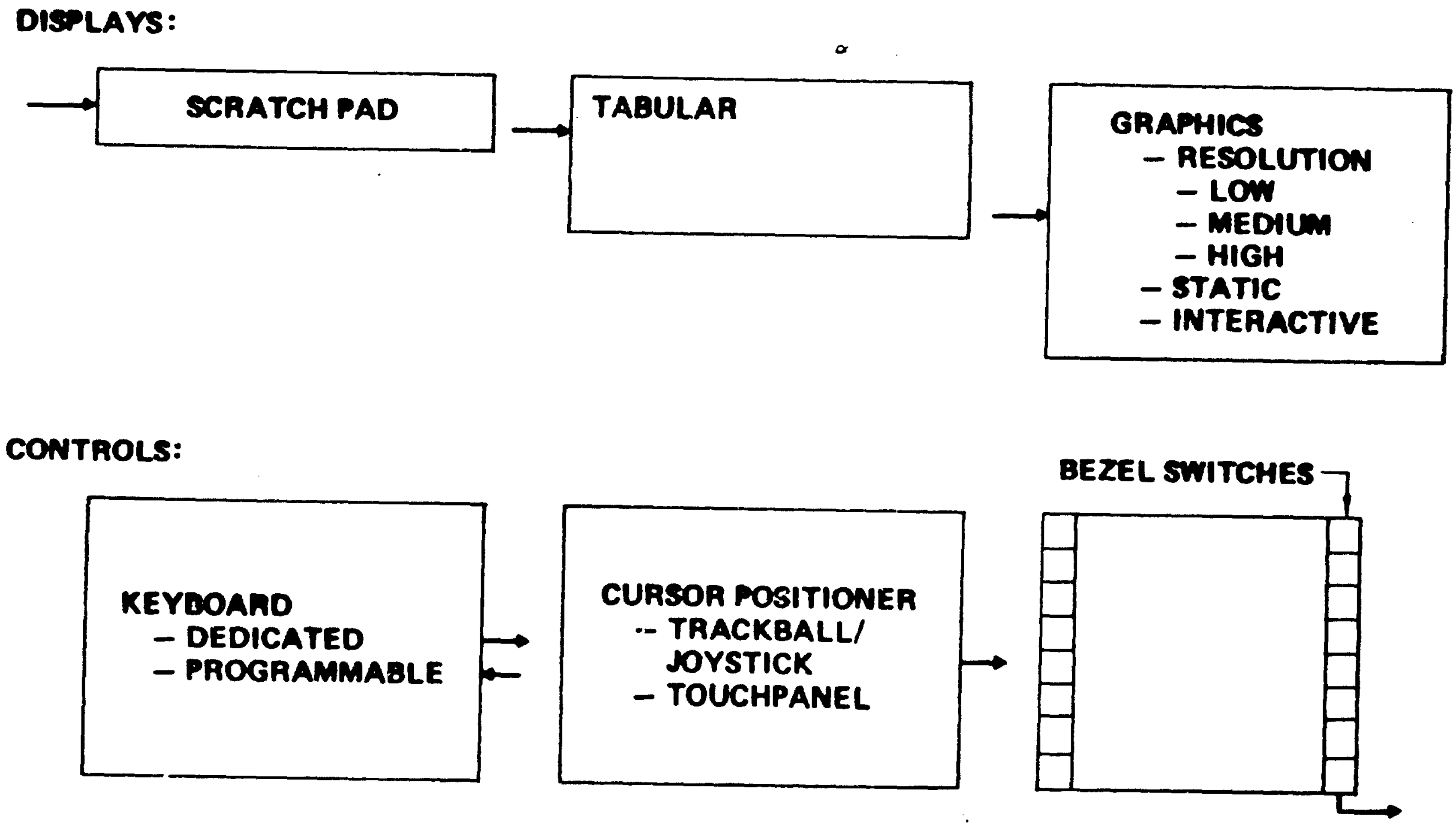

Figure 5-1 Modular Components of a MFDCS

5.2 SELECTED CONCEPT

The recommended MFDCS design concept selected from the various design alternatives consists of a programmable legend keyboard, a scratchpad display capable of multiple line list displays and moderate resolution graphics, a high resolution display with a capability for displaying test and system schematics and a means for operator interaction with the displays.

Software will form a very important part of this concept and will be designed to make the MFDCS a self contained unit as much as possible. The software will provide storage of legends and logic trees associated with the keyboard, an executive program for handling the keyboard and display operation and communications between the GPC's OMS and EPDCS elements. The software will also incorporate storage procedures for checklists and procedures for both normal and anomalous conditions together with the logic structure for analyzing alerts and warnings and determining condition priorities. A major capability of the software will be a logic structure which permits a relatively simple modification of legends, lists, logic trees and displays. This feature will permit changes in checklists, procedures, etc. to be more easily made as a function of mission scenario, equipment changes, or new information.

Storage of legends, lists and logic structure will utilize ROM and RAM memory associated with the MFDCS controller. Storage of complex displays will depend on their number, complexity and the degree of display modification available to the operator. A mass storage device will be necessary for significant numbers of complex displays.

This design concept permits the use of either CRT or flat panel displays where both are available. The attractive potentials of available flat panels and those under development should be included in considerations for future system construction and/or upgrade.

5.3 APPLICATION OF THE MFDCS CONCEPT TO THE OMS

The discussion of man-machine interface considerations in Section 2.5 covers areas where considerable improvements could be made by the application of the MFDCS concept to the OMS. Since the OMS contains more varied crew functions than the EPDCS (as shown in Table 2.5-1), it was chosen for more detailed decomposition to arrive at a preliminary MFDCS configuration.

Because the list of functions in Section 2.5 has not undergone a thorough review by NASA, it should be considered tentative. Since the MFDCS implementation is multi-functional and modular, the list of functions can easily be expanded or modified.

The MFDCS can be thought of as accomplishing three major objectives depending upon the degree of implementation.

- First and foremost, - it relieves flight deck clutter by locating the controls in one place. The multi-function keyboard accomplishes this objective and can be used with existing displays, checklists and cue cards.

- A second and perhaps equally important objective is to provide the crew with an interactive and integrated display of <u>current</u> subsystem status and <u>desired</u> system status, which allows the crew to make changes to the system via the multifunction keyboard. In this sense the graphic display incorporates some of the information now contained on checklists, cue cards and the existing CRT displays and gauges. Of course this information, which is now scattered, is brought together on a series of integrated displays.

- A third level of implementation would be to add a small second tabular display capable of displaying the remaining checklist and cue card information as required by the crew.

Access Schema

Many M/F concepts have suffered in the past from unnecessary access complexity. The key is simplicity. The crew must be able to access any necessary component in the system rapidly and easily with minimal reference to manuals.

In the OMS concept, shown here, the operator chooses the OMS system from an array of system keys (Level I). The remaining keys then change legends and display a menu of subsystems and all possible modes of operation (Level II) (Figures 5.3-1 and 5.3-2).

A selection from that menu again changes the legends and the operator now has all the keys necessary to converse with that subsystem in its desired operational mode (Level III). Figures 5.3-3, 5.3-4, and 5.3-5 show examples of accessing the engine control - normal, propellant control - normal, and thermal control subsystems using a M/F keyboard. Figure 5.3-6 shows an example of an engine control interactive display which can be addressed via the keyboard.

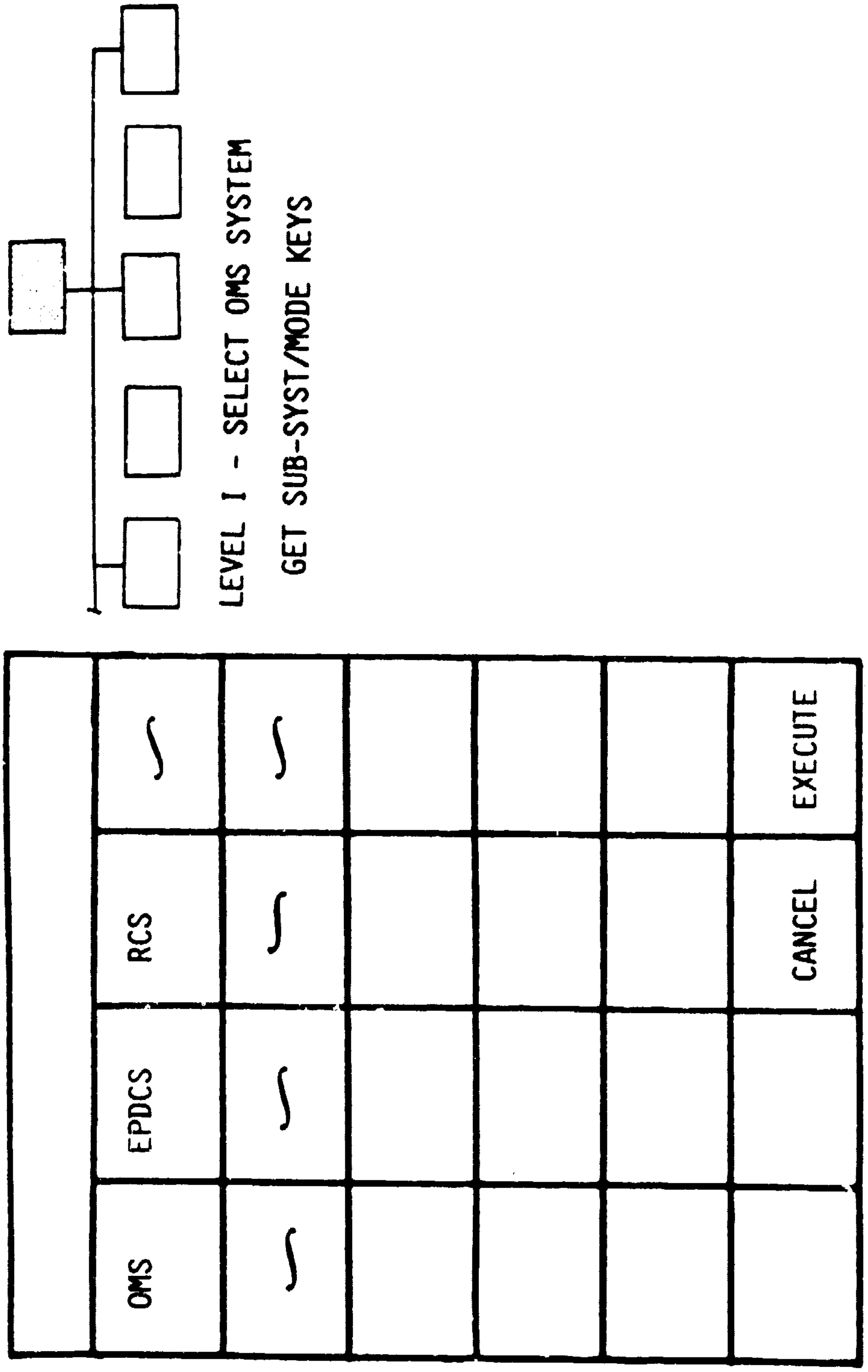

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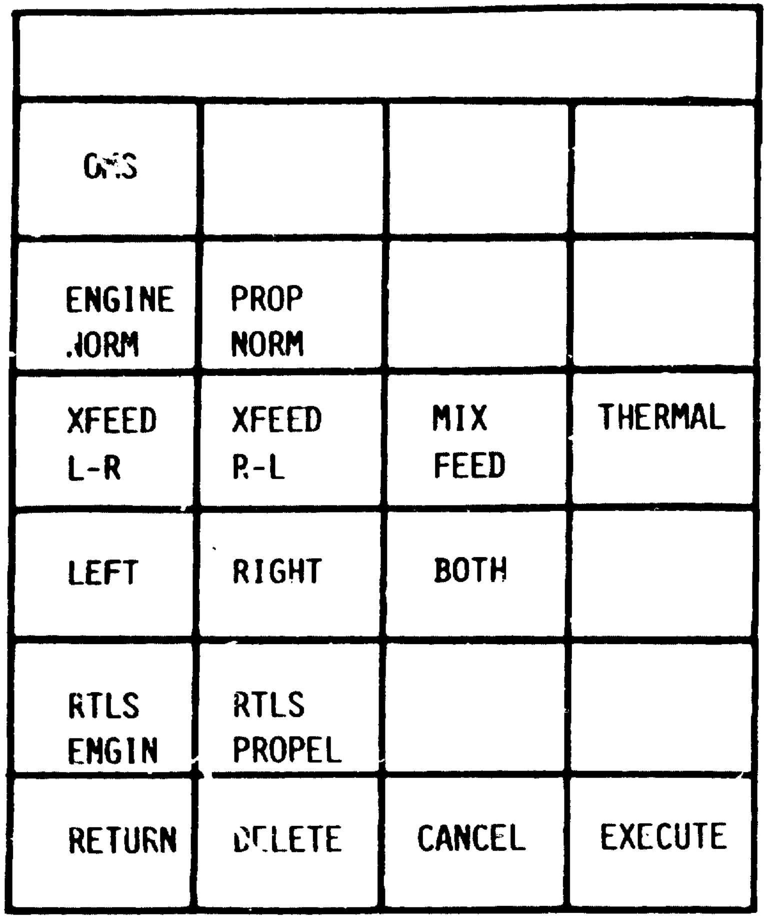
Figure 5.3-1 MFDCS Concept - OMS System
Level I



OMS			
ENGINE NORM	PROP NORM		
XFEED L-R	XFEED R-L	MIX FEED	THERMAL
LEFT	RIGHT	BOTH	
RTLS ENGIN	RTLS PROPEL		
RETURN	DELETE	CANCEL	EXECUTE

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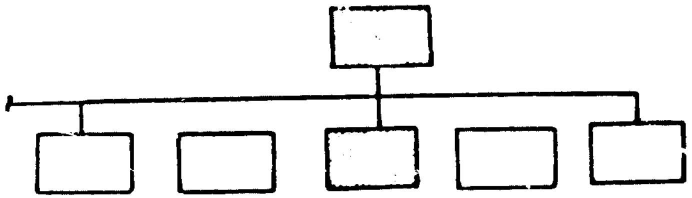
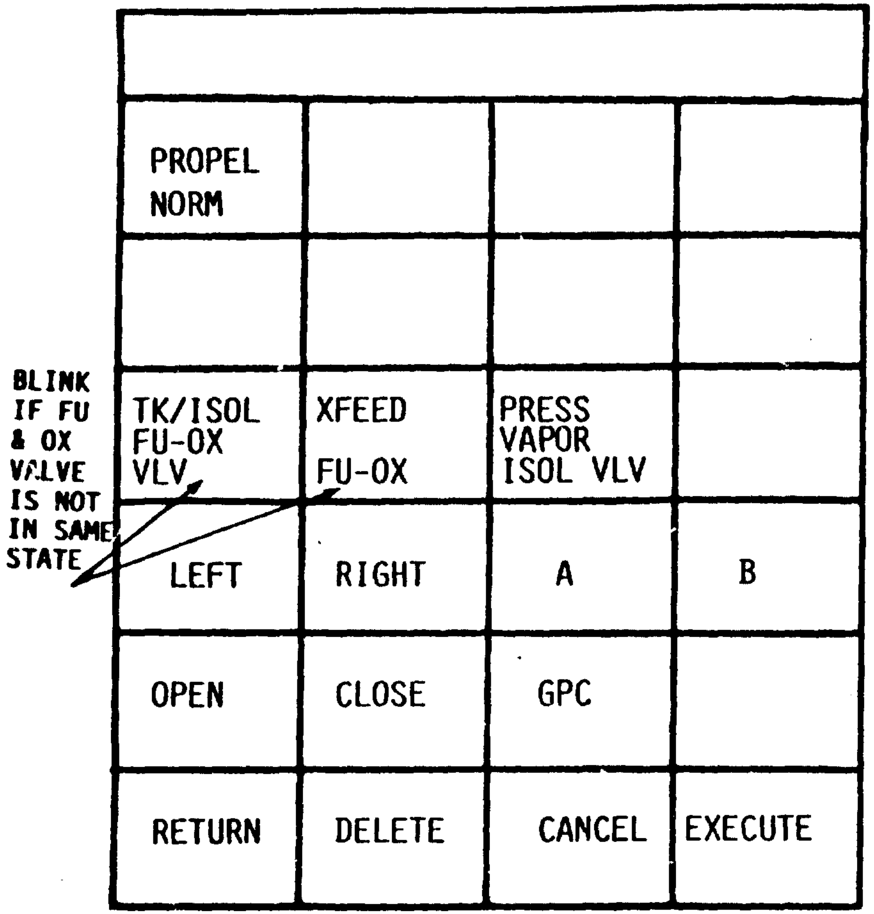


LEVEL II - SELECT PROPELLANT SUB-SYSTEM

NORMAL MODE

Figure 5.3-2 MFDCS Concept - OMS System
Level II



PROPEL NORM			
TK/ISOL FU-OX VLV	XFEED FU-OX	PRESS VAPOR ISOL VLV	
LEFT	RIGHT	A	B
OPEN	CLOSE	GPC	
RETURN	DELETE	CANCEL	EXECUTE

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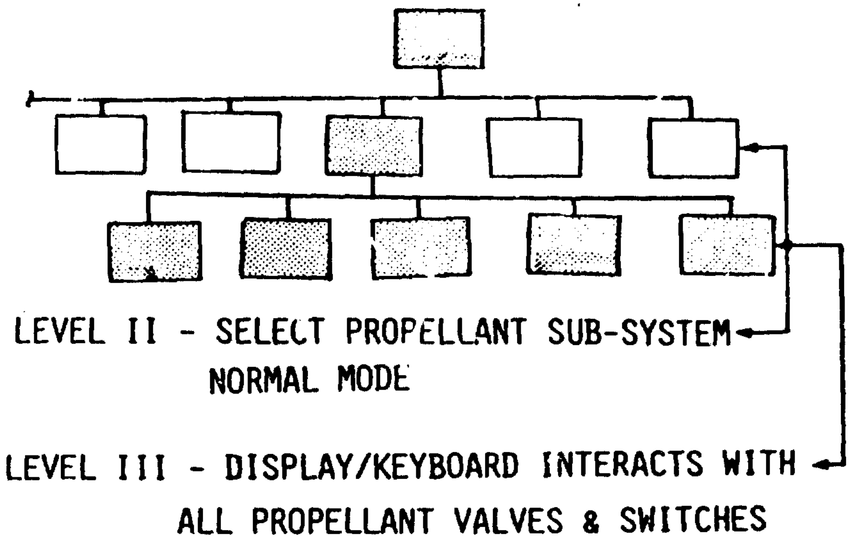
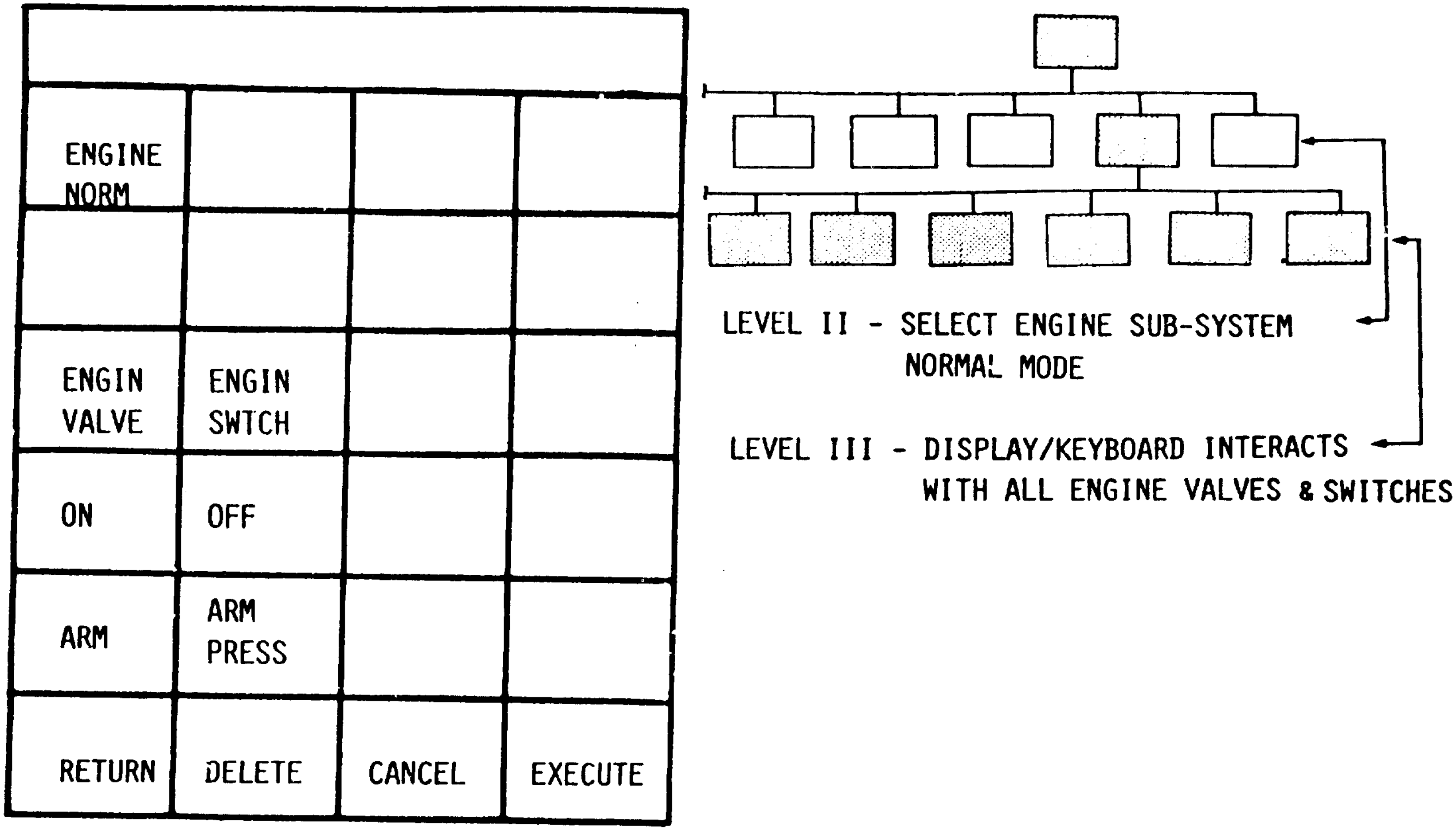


Figure 5.3-3 MFDCS Concept - OMS System
Level III



ENGINE NORM			
ENGIN VALVE	ENGIN SWTCH		
ON	OFF		
ARM	ARM PRESS		
RETURN	DELETE	CANCEL	EXECUTE

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Figure 5.3-4 MFDCS Concept - OMS System
Level III

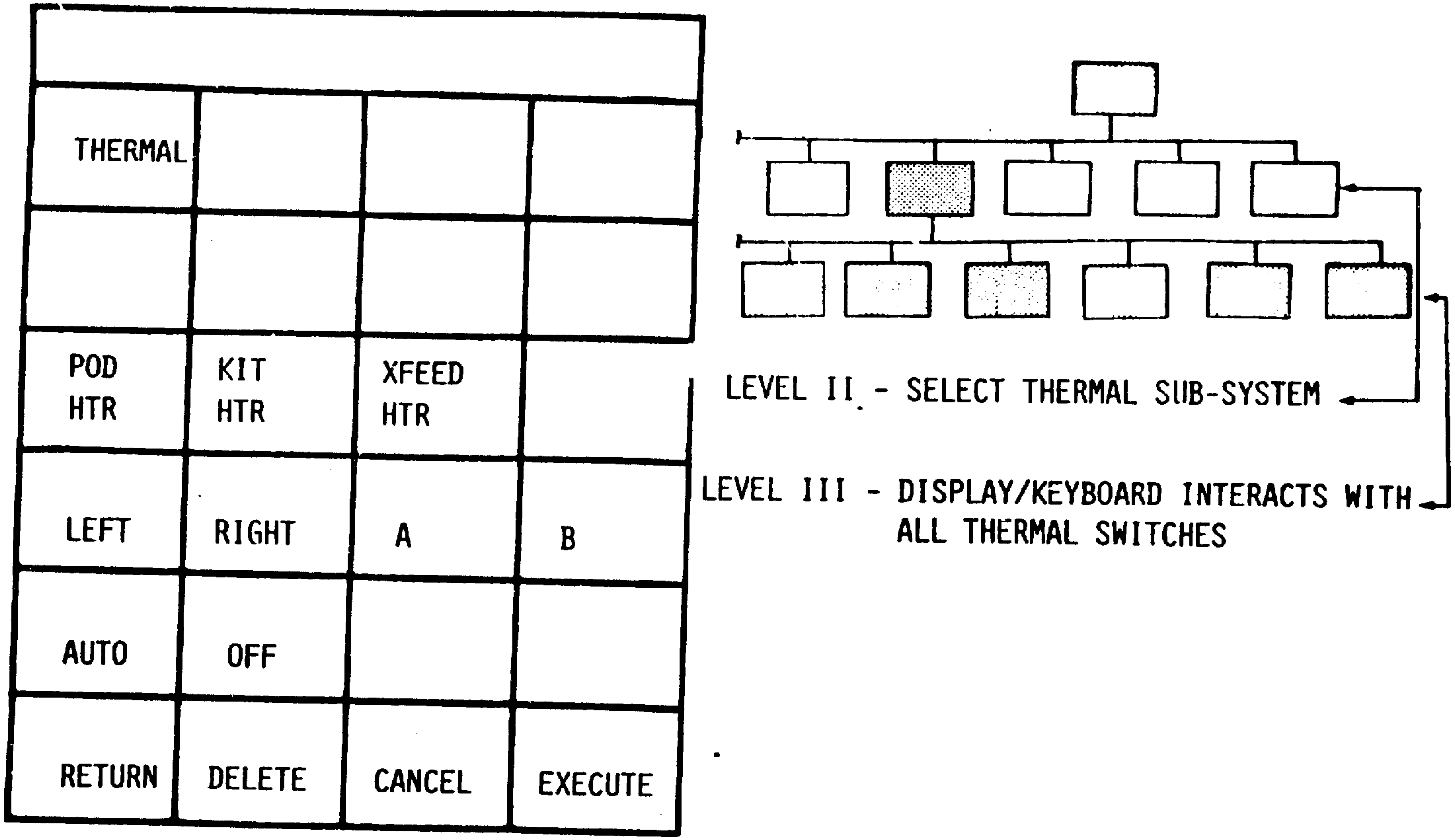

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Figure 5.3-5 MFDCS Concept - OMS System
Level III

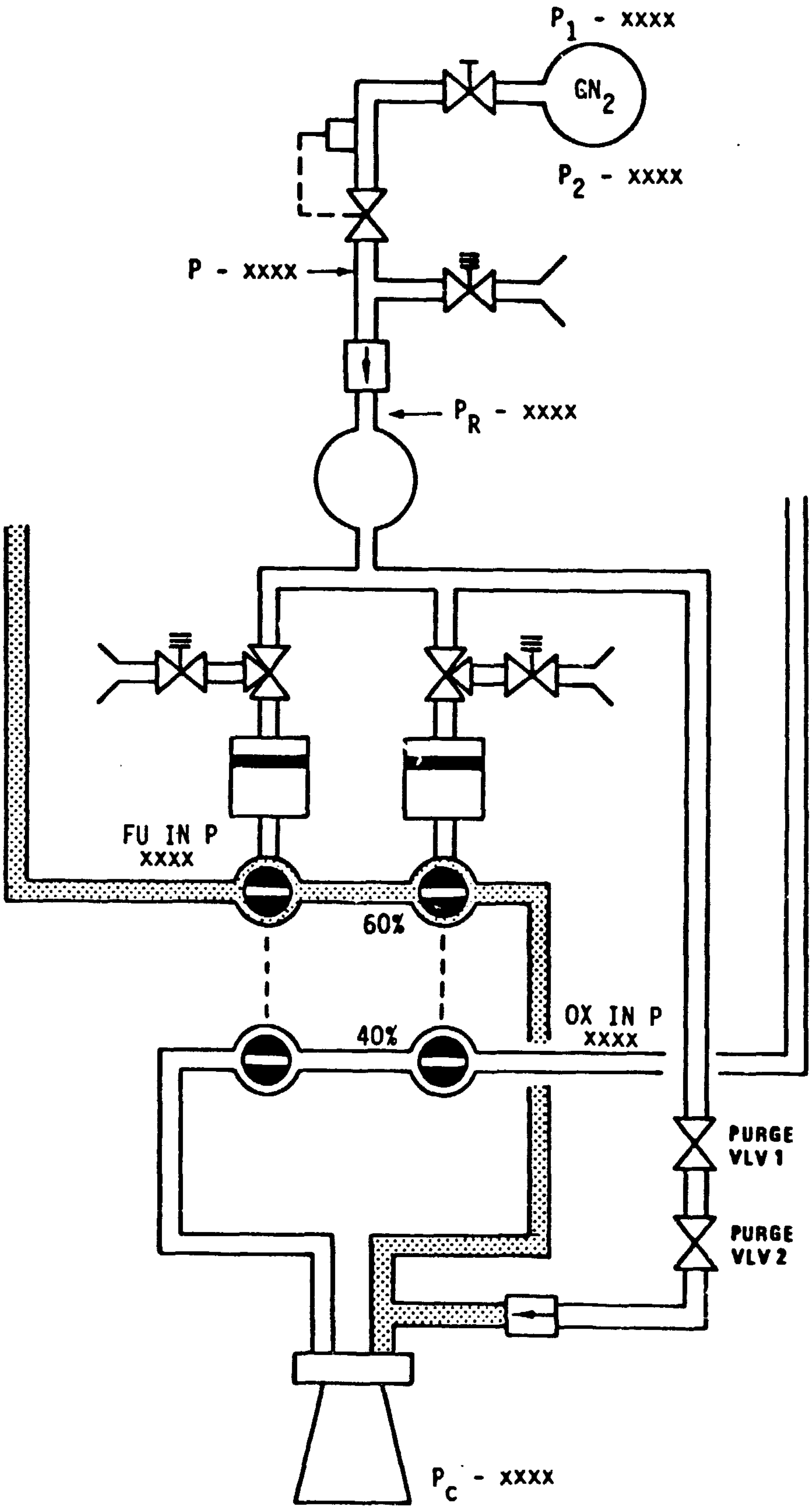

Figure 5.3-6 N_2 & Engine Control Subsystem

6.0 PROGRAM FOR TASK 3

During Task 3 the baseline MFDCS concept selected during Task 2 and described in this report will be subjected to additional analysis and refinement. The emphasis will be on (1) operator interface issues such as the arrangement of functions within the MFDCS access schema, data presentation and entry methods and system syntax, (2) hardware issues such as display size and resolution and display/control arrangement, and (3) data handling issues such as the logical structure of the MFDCS executive and access schema software and the data transfer between a MFDCS and the Orbiter GPC's.

Refinement of the MFDCS concept during Task 3 will involve both analyses and tests of a variety of different parameters and design questions. Most of the tests will involve setting up a portion of an OMS or EPDCS MFDCS in different ways and then comparing these different approaches. In most cases the evaluation will consist of (1) programming or constructing the required MFDCS interfaces, (2) defining a brief but realistic task to be performed using the several MFDCS configurations, (3) training a small number of individuals to perform the task, (4) measuring performance speed and accuracy when appropriate and asking the individuals who used the MFDCS configuration to subjectively evaluate the success of each approach or configuration. Standard experimental control protocols and procedures will be imposed in this process to the maximum extent feasible within the resources available. In other cases, the testing will not involve operators using the simulated MFDCS to perform a task. Instead, images portraying the alternate configurations will be produced and these will be subjectively evaluated by NASA and Boeing personnel.

To the extent possible, testing will utilize the display concept breadboard (DCB) being developed under Task 5. This is a self-contained microprocess-based computer with a graphics display output and a touch panel input configured as shown in Figure 6.0-1. The CRT in the DCB will serve as a terminal during programming. When used to simulate a MFDCS, the CRT will display a set of programmable switch legends, a list of tabular data, a graphics image portraying a portion of the OMS or EPDCS, or a combination of these. By touching the touch panel in the region of a switch legend, the system will respond as if that switch had been pressed. Similarly, the touch panel can be used to position a cursor within a graphics image to designate a particular portion of the image. In situations where this hardware does not have sufficient speed, resolution or other capability to assess a particular design question, display/control hardware and computers in the Boeing Man/Machine Interface Laboratory will be used instead. The display concept breadboard. will be used whenever possible because this approach will make the display formats and operator interface programming used in the testing accessible to NASA.

6.1 GRAPHIC DISPLAY IMAGE CONTENT

As is discussed in Section 4.1, graphic images are desirable in an OMS and EPDCS MFDCS. Figure 5.3-6 illustrates how one of these images might appear. During Task 3, the content requirements for graphic images needed in OMS and EPDCS MFDCS access schema will be identified and a set of sample images designed to portray this information will be developed. Because of the need to place these images on displays with limited resolution, these sets of images will be defined in parallel with the display resolution requirements activity described in Section 6.2.

6.2 DISPLAY RESOLUTION

Within the limitations of the operator's visual system, higher display resolution allows more information to be presented per unit of display area. Because of the large amount

- S-100 Bus Computer, CP/M Operating System
- Sample Programmable Switch

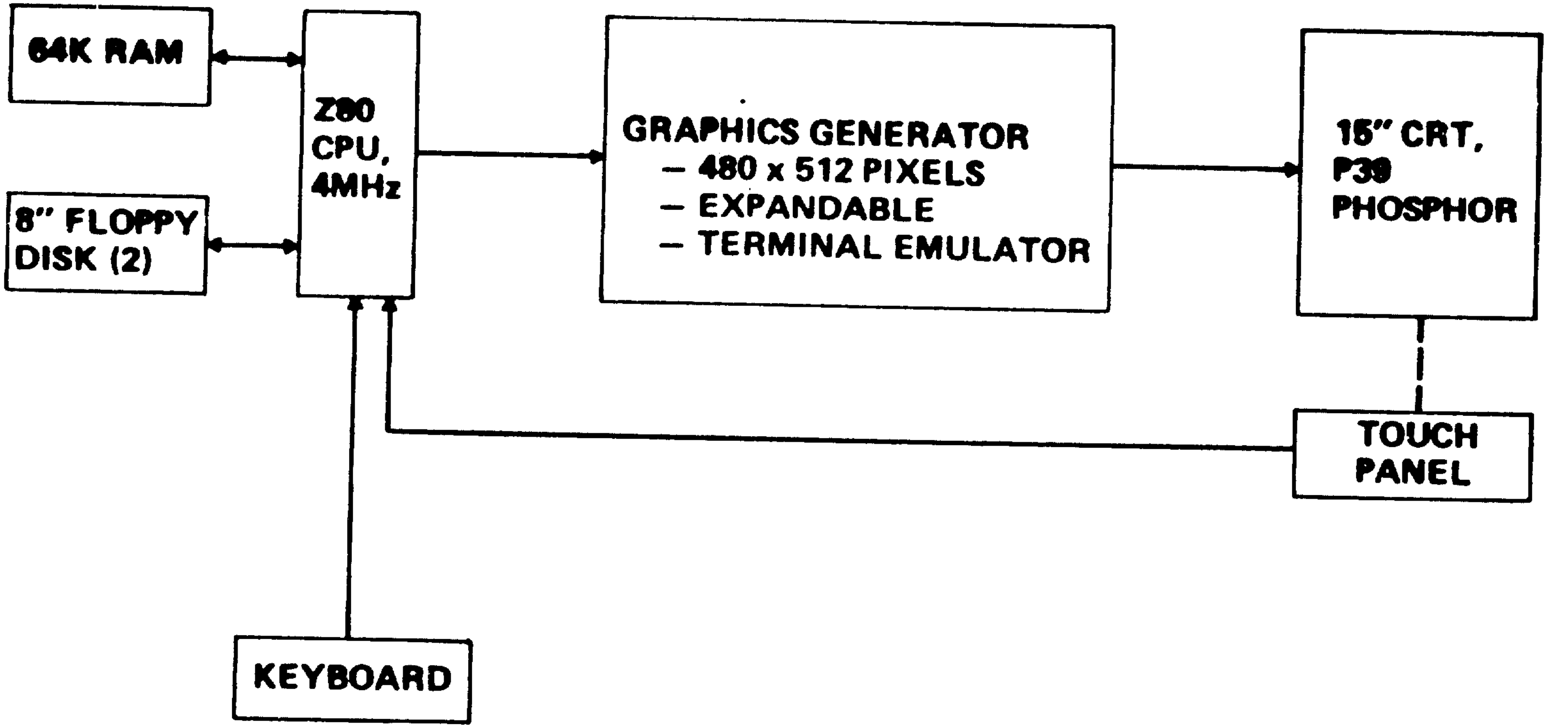

Figure 6.0-1 Planned Display Concept Breadboard (DCB) Configuration

of information in a graphic image that portrays systems as complex as the OMS or EPDCS, display resolution limits will have their greatest impact on the presentation of graphic images rather than text. During Task 3, display resolution requirements will therefore be evaulated primarily in terms of presenting graphic images. The goal of this evaluation effort will be to establish approximate limits on how much graphic material of the type involved in an OMS or EPDCS MFDCS can be presented on a graphic display of a given resolution.

A preparatory step in establishing display resolution requirements is determination of what information must be displayed. For the OMS, this will represent an expansion of man/machine function definition summarized in Section 2.5. A similar function definition will be developed during Task 3 for the EPDCS.

Next, the special symbols that will be included in the displayed graphic images will be identified and the number of displayed picture elements (pixels) required to portray each symbol will be determined. This will involve displaying each symbol at a range of sizes and using a range of height to width ratios. Figure 6.2-1, for example, illustrates the double triangle symbol typically used to represent a valve as this would appear using line-drawing algorithms on a dot matrix display. The size of the triangle increases to the right in this figure and each higher row involves a larger height to width ratio. In the lower left hand corner, for example, the symbol is 3.5 pixels high by 3.5 pixels wide. In the upper right hand corner, the symbol is 34 pixels high and 21 pixels wide. Final selection of a particular symbol size and shape will depend on the specific display used, but a tentative selection based on this figure would probably be near the middle of the second row from the bottom.

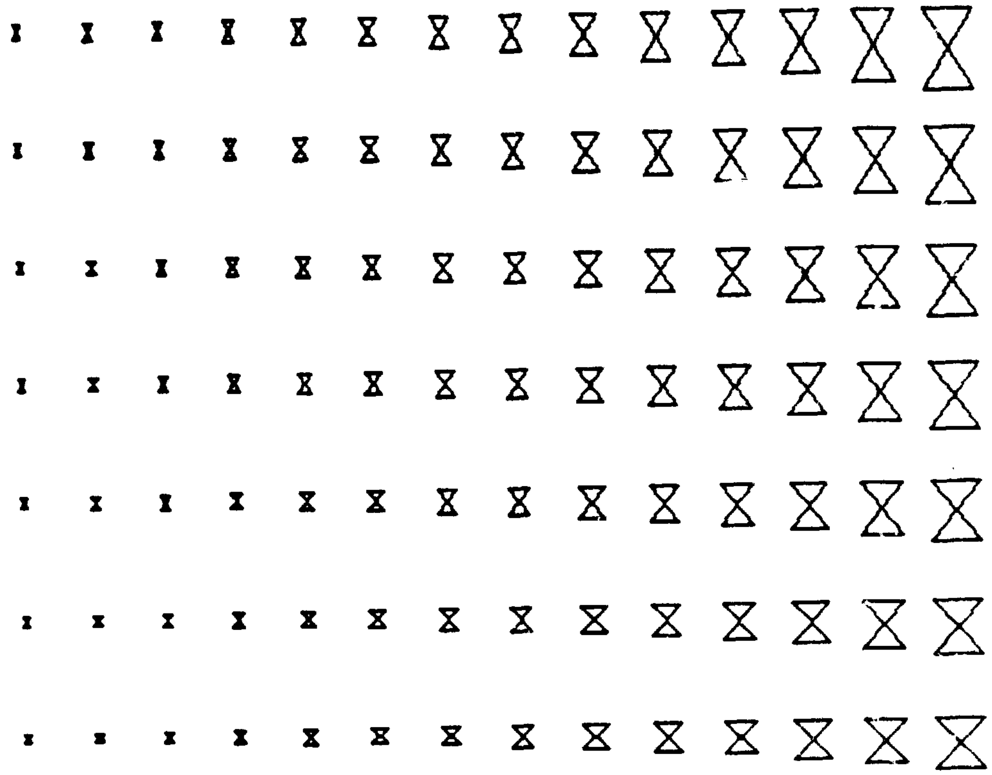

Figure 6.2-1 Example of double-triangle graphics symbol at a range of sizes and height to width ratios on a dot matrix display.

The final part of the evaluation process will involve programming one or more graphics images representing a subset of an OMS or EPDCS MFDCS as these would appear on displays covering a range of resolutions and involving both raster and stroke-drawn symbols. The display concept breadboard (DCB) hardware will provide raster display capability of 480 by 512 pixels, and by using only about a fourth of the display surface, a capability of 256 by 256 pixels. Higher resolution and stroke-drawn graphics images will be prepared using displays in the Boeing Man Machine Interface Laboratory.

6.3 METHOD OF ACCESSING SYSTEM ELEMENTS DISPLAYED GRAPHICALLY

Graphic display of portions of an orbiter OMS or EPDCS is an important part of the recommended MFDCS concept. When using such a MFDCS, the operator will frequently need to interact with some component in the graphic display. These interactions will include changing component status, for example opening a valve, and requesting information not normally displayed such as the temperature or pressure sensed at a particular point in the displayed system. These types of interactions will require some method by which the operator can designate a particular component or location in the system. Several methods of designation can be implemented:

1) The operator uses a keyboard to type the name or code number of the component or sensor location.

2) The operator selects the component or sensor location from a menu on programmable switches or on a display associated with bezel-mounted switches.

3) The operator designates the selected system element by using a trackball or joystick to move a cursor on the graphic display to the desired component or sensor location.

4) A touch panel input device overlays the graphic display and the operator touches the desired component or sensor location.

During Task 3, these methods of designation will be evaluated using sample OMS or EPDCS graphic displays.

6.4 COLOR

There are too many considerations involved to resolve during Task 3 the issue of whether color should be used in an orbiter MFDCS. (Some of these are discussed in Section 3.1.2.) The evaluation of color will therefore involve primarily the preparation of colored versions of some of the graphic displays used for other purposes in Task 3. These will serve to illustrate how color might contribute to such displays and will aid in deciding whether more extensive evaluation of this issue is needed in the future. In addition, the planned display concept breadboard (DCB) hardware can be expanded by NASA to provide a color display capability and can then be used in such an expanded evaluation program.

6.5 ACCESS SCHEMA ALTERNATIVES

The initial portions of a MFDCS access schema for the OMS appears in Section 5.3. During Task 3 this access schema will be developed further and a similar access schema will be developed for the EPDCS. Portions of each of these will then be programmed into the display concept breadboard (DCB) and used to evaluate display/control logic arrangements and system syntax alternatives. Particular concern will be given to issues such as the number of indenture levels required to access any particular function, the grouping of functions into logical groups, the display of prompts and sensor and system status data to aid the operator and the feasibility of checking for errors in operator control actions.

6.6 SYSTEM RESPONSE SPEED

Response speed is an important aspect of any MFDCS design. Several components must be considered. These include, among others (1) the time delay between an operator control action and the system feedback that indicates that the control has been actuated, (2) the time required for the system to process an operator request such as opening a relay or displaying sensor data, and (3) the time required to display a new access scheme page of switch labels or graphics. Although a number of response time recommendations have been published[1], valid limits depend on the operating requirements imposed on the system. Operating requirements are not currently available in published form for the OMS and EPDCS.

Response speed testing during Task 3 will be directed toward establishing requirements for the OMS and EPDCS. Subsets of the OMS and EPDCS display/control interface will be programmable and operators will use these with various time delays present. By using only subsets of each system, the maximum speed available will be higher than if an entire system access schema is resident in the computer, but will still be limited by the

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[1] See, for example, the system response time table by R. B. Miller in Reference 6-1.

simulation hardware available. The method of evaluating different speeds will be limited to judgments of acceptability by observers familiar with the OMS and EPDCS. For validity, these observers should be NASA-supplied astronauts.

6.7 DATA HANDLING

The MFDCS will involve a relatively small amount of data transfer between the GPC's, OMS and EPDCS as part of the basic design. However, the internal transfer of data between the keyboard, display and storage components can be quite high depending on the number of lists and displays to be stored and displayed. A part of Task 3 will thus involve an analysis of the amount of data to be stored and displayed, the transfer rates required to achieve the desired system response time and the potential interface options between MFDCS components and with the Orbiter.

This type of analysis was recently conducted at Boeing for a multifunction keyboard using discrete programmable legend keys and a moderate size TFEL scratchpad display. The result was a definition of system capacity, memory requirements, interfacing and required processing speed.

7.0 REFERENCES

3-1 Spiger, R.J. and Farrell, R.J., Survey of Multifunction Display and Control Technology. Document D180-26864-1, The Boeing Company, Seattle WA, 1982.

6-1 Shneiderman, B. Software Psychology, Winthrop Publishers, Cambridge Massachusetts, 1980.

ACTIVE SHEET RECORD

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