FINAL REPORT
OF THE FIRST PHASE

ADVANCED NAVAL TACTICAL COMMAND AND CONTROL STUDY

Prepared for
The Advanced Warfare Systems Division
Naval Analysis Group
OFFICE OF NAVAL RESEARCH

VOLUME-V
TECHNOLOGY
PART ONE

Prepared by
informatics inc.

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Final Report of the First Phase of the

ADVANCED NAVAL TACTICAL COMMAND AND CONTROL STUDY (U)

VOLUME V - TECHNOLOGY

(Part One)

15 January 1965

Prepared for
Advanced Warfare Systems Division
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ABSTRACT

This volume presents results of a study to identify, analyze, and evaluate information systems technology applicable to future tactical Navy Command and Control Systems. Included is a discussion of electronic data processing systems, memories, input/output devices, displays, computer programming, components and packaging, artificial intelligence, and self-diagnostic systems. These technical areas are analyzed on the basis of current technology and anticipated developments versus requirements of a 1970 era Naval tactical system.

GENERAL PREFACE TO ALL VOLUMES OF THE FINAL REPORT OF THE FIRST PHASE OF ANTACCS

The first phase of the Advanced Naval Tactical Command and Control Study (ANTACCS) is complete. A final report of the first year's work is presented in five volumes of which this is Volume V. This Volume is presented in two parts. Part One consists of Sections 1 through 6. Part Two contains Sections 7 through 10 and Appendices A, B and C. The five volumes are:

Volume 1	Summary Report; a review of the total study to date, summarizing study findings and giving principal conclusions and recommendations. Provides an introduction to all other volumes.
Volume II	General System Requirements; develops for system planners, details of command and control needed to meet the anticipated threat with the anticipated Naval force posture of the 1970-1980 period.
Volume III	Integration; uses system concepts developed in Volume II to give a planning example by analyzing command and control needs of a Task Force Commander, showing how technology (Volume V) and methodology (Volume IV) can be applied to meet his needs.
Volume IV	Methodology; analyzes planning tools for system design and evaluation and interprets their use in planning tactical command and control systems.
Volume V	Technology; collects for system planners basic information on current and projected electronic data processing and display technology of importance to the improvement of tactical command and control.

ANTACCS is a continuing study to assist planners of the Navy's tactical command and control system of 1970-1980. It is sponsored and directed by the Office of Naval Research and is supported by the Bureau of Ships and the U.S. Marine Corps.

The overall program is directed by Mr. Ralph G. Tuttle, the ONR Scientific Officer. The program benefitted from the assistance of a Study Monitor Panel consisting of representatives from:

Bureau of Ships
Bureau of Weapons
Naval Command System Support Activity
Office of the Chief of Naval Operations
Office of Naval Research, and
United States Marine Corps

The first phase of the study was carried out by Booz Allen Applied Research, Inc. and Informatics Inc. from January 1964 through January 1965. Booz Allen Applied Research Inc. prepared Volume II and supplied parts of Volume I. Informatics Inc. prepared Volumes III, IV, and V, and the rest of Volume I.

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Section 1
INTRODUCTION

There will be some kind of system (or systems) performing tactical command and control tasks in the 1970-1980 time period. No assumption is made a priori in this report as to the type of system (or systems) which will be operational. It is necessary throughout this report to refer to the undefined system (or systems). For convenience, and to avoid having to repeat a long descriptive phrase each time reference is made to this generic system, the term ACDS (Advanced Command Data System) is used throughout this report. It is NOT INTENDED that this term be identified with any system (or systems) currently under development.

1.1 SUMMARY

Since the inception of current naval command and control systems (Naval Tactical Data System, Air Tactical Data System), major innovations and improvements have occurred in information processing technology. Many of these innovations now indicate new and more powerful ways of achieving the goals of tactical command and control. The purpose of Volume V, Technology, is to explore these developments and to project their future implications to tactical command and control. These developments are reviewed to see how they may contribute to an increased military usefulness by satisfying future system needs to meet future threats or by increased cost-effectiveness in current or improved future systems. Of necessity, no proprietary information or developments can be presented as part of this technology discussion. To help planners determine the impact of technological advance on current and future tactical data systems, the ANTACC Study provides this exploration of advanced technology. It will serve to help planners relate technological implementation to system needs, to anticipate future capabilities more accurately and to assure that systems will be able to incorporate the best that technology has to offer in the evolutionary development of future naval systems.

The information in this volume was prepared jointly with those of the other volumes of the ANTACC Study, and many of the considerations and analyses in it have been used as a basis for the implementation and technical methodology expounded in Volume IV, Methodology, and in the generation of a system design methodology in Volume III, Integration.

This review of technology represents a broad concensus of experts in industry, research and government laboratories. The material presented was acquired by consultation, library research and independent analyses. As it does attempt to project technology that will be available in the period 1970-1980, it of necessity must take into account many different views and estimates of rate of progress.

This information was gathered in many visits and discussions at various facilities. Throughout the study, guidance was received from the ONR Scientific Officer and the ANTACC Study Monitor Group on which technologies they deemed important and also those which they felt were limiting current system responsiveness. The firm of L.C. Hobbs Associates, which acted as consultants in technology to Informatics Inc., was responsible for preparing Sections 4, 5 and 6 and their associated Appendices A and B. Amdahl Associates prepared Section 7.7.

ANTACC Study technology exploration emphasizes all aspects of Advanced Command Data System information handling and how it may be affected by changing data systems technology. Data systems processing, storage, display and transfer technology are concentrated on. The fusion of components, procedures and software to yield adequate data system aids to tactical command and control is treated in the many system studies undertaken. Indicated system design and evaluation techniques are analyzed and weighed for their applicability, and references to their use in the system planning process are given. Provisions for tying together the many data system processing nodes and various equipments within the nodes are treated in studies of the system design requirements for efficient data transfer. This study, however, does not treat the technology of data communication. Current and programmed communication system capability is considered as part of the technical environment. Communication links and their system design considerations are described primarily in their interface aspects such as buffers, etc.

1.2 THE PLANNER AND TECHNOLOGY

The following areas of data systems technology are investigated because of their importance to the realization of an ACDS:

- Components and packaging
- Memories and their usage
- Input and output devices
- Displays and their usage
- Machine systems organization
- Programming systems
- Advanced usage techniques

Some of the topics listed are dominant component techniques, while others deal primarily with system considerations. Due to the great breadth of the topics, selectivity is exercised to concentrate on those topics that most affect the economy and effectiveness of tactical command and control systems. For example, the increasing interplay of commanders and their staffs with processors and their displays requires much better definition to provide the capabilities missing in current systems supporting tactical command. The efficiency of modifying and providing new programs for new requirements is also deemed important. The assessment of progress in adaptive techniques is also necessary to determine whether substantial reliance can be placed upon them in the ACDS time frame.

The system planner must have at his disposal a full description of all components and techniques upon which he can plan a system of desired capabilities. He must appreciate the impact of specific technologies on the abilities of the system, and the extent to which he must provide necessary capacities to retain these abilities in situations of high stress and degradation due either to equipment or personnel failure or to enemy action. System design should be viable in a range of situations.

In general the way in which the system planner can relate specific techniques to functional system requirements is by checking their contribution to the most cost-effective method of technical implementation. Cost and effectiveness considerations are described in <u>Volume IV - Methodology</u>.

The four major system qualities that must be provided for in an ACDS are:

1) Availability.
2) Survivability.
3) Flexibility.
4) Adaptability.

All too often these qualities grace a system by exhortation rather than by incorporation. The technical specifications must clearly define what is meant by these qualities in a quantitative manner, so that various candidate system configurations and designs can be judged as to the efficacy in their accomplishment.

The system planner must define the way to measure system availability and how the contributions of component and subsystem reliabilities and their maintainability assures system availability. Different models of availability are applicable depending on the ways in which systems must be used. The modularity of a system should allow it to degrade gracefully if one element malfunctions. This modularity should also let the system reconfigure easily to handle a different mix of assignments. Enhanced intercommunication between all modules and subsystems that may be used together, is one of the necessities to insure survivability. With the increasing tendencies to fragment the exercise of control, the ability to shift control effectively in support of command is a pressing need.

Flexibility of the data handling systems of an ACDS is required to incorporate changing requirements for different types of processing as the system evolves and the need for new functions to be incorporated becomes clear. An ACDS has to be able to incorporate efficiently the gamut of processing, from the highly computational type characteristic of threat evaluations and weapon assignment applications to the dominantly data handling type characteristic of intelligence and communication switching applications.

The system planner also reviews his arsenal of technology to insure the system's adaptability to a wide range of physical environments. An ACDS incorporates systems for afloat, undersea, airborne and mobile or transportable ground environments. The adaptability expresses itself further in the extent to which compatibility of interface is readily achievable with other units of own service or sister services, and other combined operating units. The particular needs of different operational environments puts great reliance on the ease of adaptation to different situations. For example, the highly fluid ground combat operations of amphibious assault by the USMC requires that data processing and communications be effected over geographically difficult as well as hostile terrain.

A word on cost and effectiveness reflects its relationship to technology. The straightforward means of reducing costs by less expensive building block use must be complemented by more efficient usage of the system and by lowering the costs of training and personnel levels for operation and maintenance of these systems. Even though individual systems or subsystems become more simple with respect to operation and maintenance, increased needs for additional system capabilities and their resultant overall system complexity will require close attention to the necessary trade-offs and to balancing with manpower skill levels and training. Close monitoring of the innovations in technology is needed so that the benefits of the newer techniques can be incorporated at the earliest feasible time. This time is, of course, dependent on the size of the modification and the optimum schedule for introducing the newer techniques to the forces without creating any decrease of combat readiness.

Much of the technology reviewed and evaluated is found to be applicable to a tactical command data system such as the CTF command node described in Volume III-Integration. In particular, noteworthy developments in advanced input/output and display techniques, component and packaging technology, memories and multiprocessing and multicomputer techniques are found to be very applicable to the ACDS.

1.3 TECHNOLOGY OVERVIEW

1.3.1 General Comments

In introducing many of the concepts and technologies of this volume, a balance had to be struck between the necessity to include instructive material and the necessary emphasis in technology projection. It is understood that though the system planning process is a continuous one, the planners do not necessarily have personal continuity with the process. Therefore many explanatory sections are included which would not have been required for naval planners already learned in the field of information processing technology.

In each of the sections, applications to possible future requirements and illustrative material are presented which relate the areas of technology to the future system capability and to the necessary decision processes for system planning. However the rate of innovation is different for various fields of information processing technology. Thus, one finds that the increased speed capabilities of potential candidates for logic elements or the increased storage capabilities of memory techniques will have many candidates. To reiterate constantly the importance of the speed characteristics or other characteristics of each technique to system planning serves little useful purpose. Therefore, tabular and graphic material has been prepared in the sections to summarize these important characteristics and relate them to the evaluation criteria for the areas of technology. Where the investigators were supplied with potential requirements on equipment for different applications by members of the Study Monitor Group, these requirements appear as operational evaluation criteria for the technologies being discussed.

Since the rates of advance in different areas of technology differ, further out technologies were given emphasis commensurate with the rates of advance. For example, in the area of input/output devices, no major theoretical breakthroughs are foreseen; improvements are expected through engineering refinements of current devices and equipment. A good part of the section on this topic therefore treats the engineering aspects of this equipment. In the areas of components and packaging and in that of memories, more emphasis is given to a detailed treatment of the many types of techniques which are capable of realization. Because so many of these sections are dependent on an understanding of the basic physical, chemical and fabrication processes involved, more detailed treatments are given in the appendices.

In the area of machine systems organization many of the newer concepts are treated, delineating their potential value to future naval systems and how they may be employed. However, this is a very rapidly expanding technology with many examples of both military and commercial types to date. Because this area deals with requirements for configuring systems in response to specific requirements, many of which are not now available, the recommendations take the form of guidance in design. In this area, as well as the area of programming, many new formulations are expected in the near and mid-term future which will have bearing on the realization of an ACDS for the 1970 to 1980 period.

Many areas of research now in process could not be treated because of their proprietary nature. Thus, no proprietary information has been included. Investigators were made aware of these areas of research in many cases, but their results were used rather to reinforce or qualify projections on trends for technology so that proprietary rights were preserved. A larger quantity of information was amassed than is presented in this volume but for obvious reasons this could not all be included. This information will serve as references and checkpoints for the ongoing ANTACC Study.

1.3.2 Resume of Chapters

Section 2, Input/Output, deals with the range of peripheral and ancillary devices that may be used to enter and extract information from machines and files both close to these equipments and at remote locations. The limitations of current in/out devices are presented with a treatment of their interaction with the personnel using these devices. Attention is called to such advanced techniques as new graphic in/out abilities, speech recognition equipment and vocal output equipment.

Section 3, Display Systems, treats the overall aspects of using displays for the presentation of information from files and for the control and monitoring of operating personnel in their entry of information to files. The concept of on-line display consoles is treated in depth to show how such systems can effectively be used to simplify the tasks of staff support to command. New capabilities for reducing response time of command support systems to the many queries necessary to support the command decision function are treated in depth,with examples of applications to a future ACDS.

Section 4, Display Technology, projects the materials and device technology for the period 1970 to 1980 for both console type and group type displays.

Section 5, Components and Packaging, reviews the current work in process at laboratories, and projects future capabilities of electronic circuits for a range of applications from logical elements to special purpose circuits. A quick review of non-electronic circuit components is also included. The implications of these technologies for future reliability, availability, and maintainability are shown to be very considerable. A detailed exposition of the technologies is included in Appendix B.

Section 6, Memory Technology, projects the materials and device basis for memories for the 1970 - 1980 time period. It treats also the technical basis for memories working in a wide range of applications, from internal registers to bulk auxiliary storage. Of particular interest is the treatment of technical bases for content - addressable memories which serves as a foundation for their systems attributes in Section 7. The detailed treatment of the technical aspects of many candidate techniques is presented in Appendix A.

Section 7, Machine Systems Organization, deals with those aspects of system configuration and their associated requirements and limitations to meet system performance goals. Current trends in multiprocessing and multicomputing, the use of associative memory or content addressable memory techniques, stored logic and microprogramming techniques, and the concept of memory hierarchies for the realization of simplicity, availability and survivability including cost effective operations are described in detail. Several examples of the uses of these techniques are given. Highly parallel computers are treated for their importance to possible future implementations of naval command support data systems. An exposition of the principles of computer systems organization is given that should be helpful for orienting the future system planner to the many aspects of this topic.

Section 8, Programming, treats of future requirements for the development of programming tools such as assemblers and compilers and for the control of the programming process for many different applications in the fleet. The utility of problem oriented languages and on-line programming makes them desirable areas to foster for the resulting ease in operation, reduced response times and reduction of skill levels for operating and maintenance personnel.

Section 9, Advanced Usage Techniques, deals with the applicability of artificial intelligence to the 1970 period tactical data processing tasks. Hoped for yields have unfortunately not so far reflected their promise for this period. A preliminary treatment of the vast subject of self-diagnosis and its implications for simplified maintainability is also given.

Section 10 presents the source material and references used in support of the technology exploration presented in this volume.

1.4 COMMENTS AND CONCLUSIONS

This survey of information processing systems technology shows that many new techniques are available to implement new or to improve present command data systems. These techniques can serve as a basis for the evolutionary implementation of currently planned systems and for the development of new support systems capabilities required for the future.

The system planner, aware of the newer technologies, is able to anticipate more adequately when new techniques can serve as a basis for updated or new designs. He also has the forewarning necessary to prevent technical surprise and premature obsolescence in the planning for evolutionary system development. The evaluative criteria presented in each section should be considered as a guide to this process. Projected component and equipment technology has been shown to afford increased component speeds, decreased size and power, increased component reliability and increased storage capacity and speeds.

These qualities, with efficient and well thought out designs, should yield simpler easily maintained systems, characterized by decreased acquisition and operation and maintenance costs. New system organization techniques with their emerging hardware and software features will serve well to assure the necessary qualities of survivability, flexibility and adaptability required to support command in stress situations.

The methodology for specifying functional requirements for systems that support command is more complex and less well formulated than that for specifying weapon systems. The technical system performance parameters must therefore emphasize simplicity and the ability to conform to a wide range of situations. The emphasis on system development aspects of tactical command support systems, especially in the areas of displays, machine systems organization and programming is therefore necessary.

This review of technology and systems, and of the progress and innovations being made in each area, shows that uneven progress is being made. Great strides are being made in the technologies of components, packaging and programming design, but there is much less progress in group display hardware, and solid-state auxiliary mass storage. In part, this is due to different levels of support by the military and industry.

Industry is conducting broad research and development into digital systems technology to meet increasing competitive pressure in the data processing field. Much of value to command and control develops from industry's activity for commercial pursuits. Naval planners can use much of the perfected techniques in the form that commercial usage dictates; often, however, additional military-oriented extension or modification is required. It is, therefore, necessary to base recommendations for future concentrations of effort for research and development upon considerations of:

1) The extent of support being given to an aspect of technology or to a technique
2) Technology which remains to be developed
3) At what point must a technique be implemented
4) Alternative techniques to be supported

Decisions on technology for naval command and control must take into account developments for other uses. If other services or industry are actively and adequately fostering some areas of R&D whose yields benefit naval command and control, naval R&D can assure itself of a broader yield by emphasizing complementary areas. With the above thoughts in mind, a series of recommendations for necessary R&D support for achieving a cost-effective ACDS are made here. These represent the technologies deemed most fruitful to ACDS because their potential yield is great, or because their lack detracts from a balanced ACDS. It is not a complete list; many more techniques, concepts, and designs could be included.

Many of the techniques discussed will be available earlier than 1970. They may thus be candidate techniques for incorporation of improvements into current systems. The one common characteristic of the techniques listed is that they could be available by the dates shown if sufficient support is given so that they will have all of the abilities, reliabilities and environmental capabilities necessary for the naval environment.

The areas considered most urgent for R&D support are:

1) Solid state mass memories

2) Improved group displays

3) Improved graphical input/output devices

4) Improved program design and control procedures

5) ACDS-oriented programming languages

6) Advanced maintainability techniques

Though much commercial work is progressing on solid state mass memories, military requirements are not being featured. Emphasis can make such memories available for ACDS.

The military remains the main market for group displays. Additional emphasis will be necessary to get group display hardware by 1970.

Many improvements for an ACDS can be a result of improved machine-to-man information coupling. The ability to express complex requests containing graphic and narrative information, and to receive such information, gives rise to the third recommendation. Also note that such graphic techniques would improve the efficiency for the transfer of such information from remote sources. Current graphic transmission techniques still need too much bandwidth.

The advances in software have been discussed earlier. It should be further stressed, however, that the need to control large programming operations to produce consistent object software is a particular problem which is most pressing for military command and control. The cost advantages of lowered required skill levels and less training required with the use of more capable problem-oriented languages, are worthwhile goals for ACDS. It should be stressed that these advantages can accrue to present command and control systems as well as an ACDS.

New maintainability techniques result from the revolution in fabrication techniques and their attendant reliabilities. The feasibility of more effective computer controlled self- and system-diagnostics will reduce operation and maintenance costs. For example, fault isolation diagnostics need greater emphasis. Methods of assessing maintainability in the environment of new fabrication techniques should also be stressed.

Though selected hardware development is necessary, increased emphasis should be placed upon the systems aspects of tactical command and control. It is useful for tactical system planners to know how tactical requirements reflect on equipment and software design. This is a largely unexplored area. Many starts have been made with varying degrees of success. Physical environments have been adequately dealt with, but the operational usage characteristics of equipment and software have not been adequately explored. The range of tactical environments for naval systems -- on or under the sea, in air and space, and on the ground -- requires continuing research into the philosophy of system design. Such work is now proceeding to support U.S. Marine Corps command and control and ongoing U.S.N. command and control.

More effort should be expended in "research" that is aimed at practical results in the period 4 to 10 years from now. More effort should also be expended in developing methodological and technological approaches which are basic to or common to many command and control processes. The ANTACC Study project itself is an example of an effort aimed at intermediate range results which will produce the greatest benefits.

As time passes the system planner must review the particular tradeoffs and recommendations that have been made in this volume. Unanticipated breakthroughs in technology may revise the present concensus on projections. It should be realized that much of the projections are informed predictions and that the almost explosive growth of certain areas of technology must continue to be monitored. Changing threats may also call systems into being which will require fresh views of evaluative criteria such as are presented in this volume. This volume will have served its purpose if it contributes to the system planners' technical awareness in the same measure that he has developed his project control awareness.

Section 2
INPUT / OUTPUT

2.1 INTRODUCTION

Adequate input/output equipment and displays are of great importance to the Navy in future tactical systems. All data used by the system must pass through this equipment as must all data received by the commander. The tactical data system is therefore completely dependent upon the speed and accuracy with which input/output equipment and displays can operate.

Displays are considered so important that they are given special emphasis in Sections 3 and 4 of this report. They are therefore not discussed in this section.

Our study of input/output technology has included all of the conventional computer input/output equipment, plus a number of technologies that may be developed into useful equipment. All are not discussed in detail. Some are so commonly used in present Navy systems that detailed technical discussions are not necessary. Others are still in the research stage and implementation problems are still unknown.

In subsection 2.2, detailed examination is made of printer, punched card and magnetic tape technology. All are of particular importance to Navy computer systems, and each is an area in which militarized equipment has recently been developed for the Navy. It is hoped that this section will be helpful in the evaluation of new equipment and may provide background that will be helpful in planning equipment improvements.

2.2 MACHINE INPUTS

Most computers contain a man-machine interface in the form of an alphanumeric keyboard and function switches, both of which are used in conjunction with programming and machine debugging operations. Other than this, the man-machine interface is not frequently used except for command and control functions in which the commander and the computer must be interfaced as parts of an open loop control system.

Since little can be done to expand the information output rate of man, because of his physical limitations, improvements in a man-machine interface must come from better use of the data presented to him. This must come about through a more sophisticated man-machine relationship in which the data flow from the man to the machine expresses concepts which are common to the man, by virtue of his learning, and common to the machine, by virtue of its program. In such a manner, it is possible for the man and machine to establish a working relationship in which only a small amount of information need be passed between the two thus relieving the load on the interface. Table 2-1 indicates probable availability of the major man to machine input interfaces and their relative costs, performance, and application.

As this is a study of technology or technical capability rather than a study of existing equipment; performance, cost and reliability indexes indicated are those that can be realized through the proper application of a technology and are not necessarily indicative of performance of present equipment.

2.2.1 Speech Recognition

In theory, voice input represents an attractive means of computer input as speech is the easiest technique which man has of expressing himself and no special training is required for its use. He can speak more rapidly than he can write. He can give commands from a distance, and he can be occupied with some other task while speaking. Unfortunately, the ease with which man communicates vocally is partially as a result of the variety of ways in which he can express himself, and this variety of expression complicates the problem of designing useful voice recognition equipment.

Table 2-1

Input Technology – Man-to-Machine

	Voice Recognition	Keyboard	Graphic	Character Recognition
Available for use in 1970 system	No	Yes	Yes	Yes
Cost	Very High	Low	Low	High
Rate of information transfer	Medium	Low	High	High
System complexity	Very High	Lot of Medium	Medium	High
Subject to background noise	Yes	No	Yes	Yes
Flexibility of use	Good to Excellent	Fair to Good	Good	Good
Types of data	Alphanumeric	Alphanumeric	Graphic	Alphanumeric

A great deal of research has been performed that could eventually lead to a useful voice input system. This work has included frequency analysis techniques and matrix comparison techniques. Electronic, optical, mechanical and digital analysis approaches have been tried. In spite of some limited successes using highly constrained monosyllabic vocabularies, there is no likelihood of militarily applicable voice recognition equipment being available for use in a 1970 command and control system.

2.2.2 Keyboards

Keyboards are designed to enter alphanumeric and symbolic information. These numbers and letters are usually supplemented with other non-spoken symbology, such as %, and punctuation marks. Keyboards may be numeric, alphabetic, symbolic or any combination thereof. They can be designed to meet many special needs.

Although many non-standard keyboards are available for special purposes, there are three standard keyboards that are accepted in this country: they are the alphanumeric or typewriter keyboard, the numeric ten key keyboard, and the numeric bank or columnar keyboard. Many variations occur within each of these standards. However, there is enough standardization to allow the training of personnel in their operation.

Alphanumeric keyboards are designed to operate at a peak repetition rate for a single character of ten or fifteen times per second. As most alphanumeric keyboards are not interlocked to prevent the simultaneous depression of characters, it is possible to operate such keyboards at speeds up to 20 characters per second providing that the same character is not repeated in sequence. Typical operator rates are about five characters per second when copying from legible data.

Ten-key numeric keyboards are designed to be operated by one hand. A trained operator can produce output at the rate of ten to twenty characters per second for reasonably long periods of time.

The bank or columnar keyboard provides a column for each digit position. Each column contains all of the digits which may be entered in that position, usually 1 through 9. This keyboard can be used as a fixed format forced entry device as all zeros or all blanks are automatically entered in each column when no key is depressed.

2.2.3 Function Switches

Function switches are a form of selection device in which the operator indicates to the machine that he wishes to change or initiate a machine action. Function switches are used singly or in groups such that the selection of one function switch from one group modifies a selection of other switches from another group.

One of the biggest problems in the application of function switches is how to get enough of them and where to put them. Since each switch represents an idea or "concept" communication to the computer, there is usually not enough space available on the console to allow expression of all of the ideas that must be communicated. One approach which has been used with considerable success by designers of command and control consoles is to produce a matrix of switches, each of which generates a unique code. This matrix is covered by an overlay which identifies the function of each switch within the matrix (see Figure 2-1). The matrix overlay is itself coded in a manner that the computer can sense which overlay is being used, and by first sensing the overlay in use and then sensing the switch being depressed, can tell the function to be performed. In this manner, a 10 x 20 matrix of switches with 100 overlays could be used to provide unique identification of 20,000 separate functions. The disadvantage of such a system is that it takes an excessive amount of time to sort out the correct overlay and position it.

Another approach to the problem is to allow the computer to generate a series of labeled boxes or points on a display, and allow the operator to select one of these with a light pen or other position indicator. In this manner, it is possible for the computer to keep the operator continually informed from which switches it is capable of accepting information. Further, if there are a large number of "overlays" in use, it is possible to allow the computer to display a number or description for each overlay to allow the operator to select the one he wants.

Figure 2-2 shows a typical series of operator steps in using function keys.

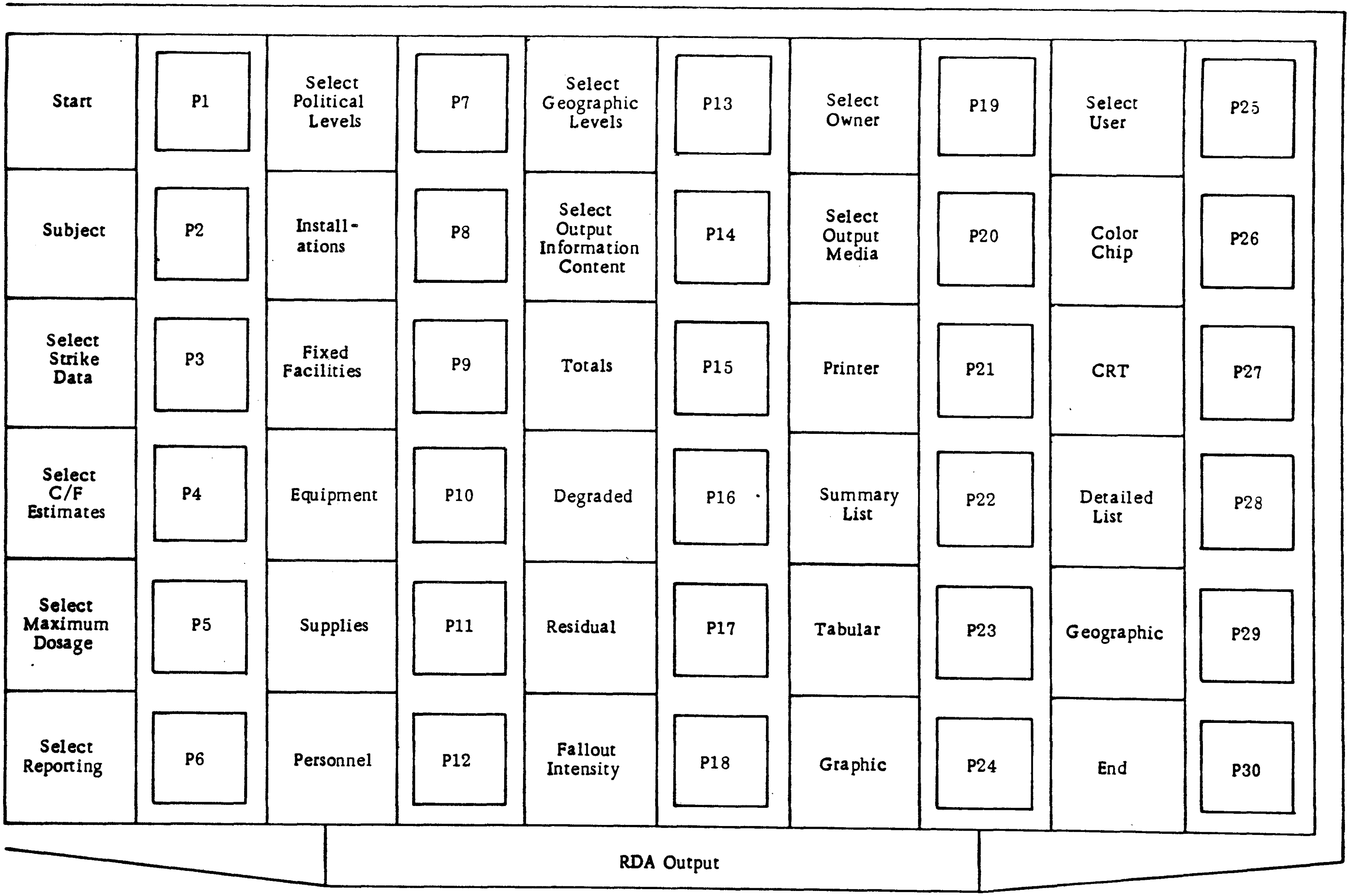

Figure 2-1. Typical Display Overlay

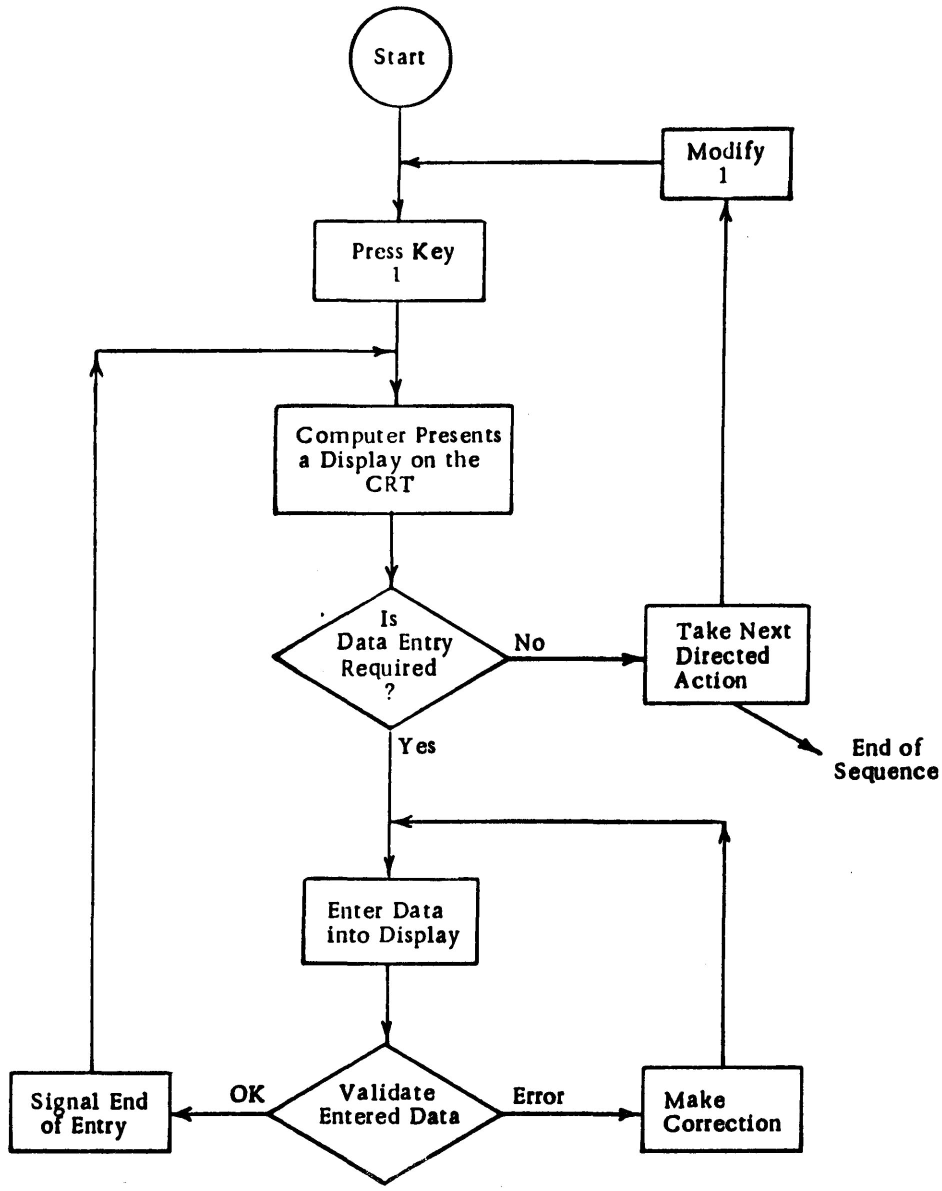

Figure 2-2. Typical Series of Operator Steps in Using Function Keys

2.2.4 Graphic Input Devices

Graphic inputs such as light pens and joy sticks provide a type of input device for geographic and geometric data. They can be used to designate a point or line, the parameters of which are already known to the computer, or they can be used to draw graphical input which can be reduced by the system into useable data.

A wide variety of position indicators and graphic input devices are now in use, and most depend on one of three basic techniques. These techniques are potentiometers and gray-scale coding, scanning and matrix sensing. Each of these techniques is able to indicate a single point to provide a coded X-Y coordinate for computer input, to select a point from a number of computer generated points to indicate "that one", and to generate a line or series of continuous points.

Potentiometers and gray-scale coding technology is used in devices such as the telautograph, joy sticks, ball indicators and panographs. The underlying technique of these systems is to couple the pen, ball or joy stick to an X axis indicator and Y axis indicator. Where analog output is acceptable, these X and Y axis indicators are a pair of linear or rotary potentiometers. As the indicator is moved, the resistances on the X and Y potentiometers vary as a function of the position of the indicator. When digital output is required, a linear or rotary gray-scale indicator is used in place of the potentiometer. The gray-scale indicator is a sensing device which allows a position to be read as a direct binary code.

Gray-scale coding is equally useful for both point selection and line drawing. As the resolution of this type of system is dependent upon the fineness of gray-scale provided, a line drawn between two points will always generate the same number of X, Y coordinates regardless of the speed with which the line indicating instrument travels.

The most commonly used scanning device is the light pen. The basic technique used in all photo scanning devices is to place a photo sensitive receptor (the light pen) over a point on a phosphorescent screen. As the surface of the screen is scanned by an electron beam, the phosphor is activated momentarily and generates visible light. When the beam arrives at the point over which the light pen is resting, the phosphor is activated generating visible light which is detected by the photo sensor in the end of the light pen. This generates a pulse which is transmitted back to the scanning system. This pulse is used to read out the X and Y beam deflections and thus indicate the position of the light pen.

Scanning may take place in a number of fashions including horizontal raster, circular raster and point sequencing. Point sequencing consists of successively activating the phosphor at a number of target points, the locations of which the computer is constantly tracking. When the target indicated by the light pen is sequenced, it can thus be identified. Point sequencing allows the position of computer generated points to be sensed but does not provide for the entry of other graphic data.

Raster scanning techniques may be used with a light pen to produce line input; however, since the pen position is scanned at a fixed interval of time, the number of X, Y coordinates that can be identified along a line will depend upon the speed with which the light pen traces that line. In most cases, the scanning rate (or point sampling rate) is high enough to provide reasonable line resolution.

Matrix sensing is typified in the RAND Tablet (see subsection 2.5.3). The technique of matrix sensing requires a series of horizontal and vertical wires imbedded in a non-conductive sheet. A double-sided printed circuit board is used as the writing surface and the X and Y wires are carried on opposite sides of this board. A clock sequencer furnishes time sequence to a series of blocking oscillators. During each timing period, the blocking oscillator gives a coincidence positive and negative pulse on two lines attached to the tablet. Pulses are encoded by the tablet as a serial (X-Y code). A pen is used to detect the signal at the coincidence of the X and Y wires lying below the point of the pen. This signal is used to generate a binary code representing the X wire position and the Y wire position.

A similar configuration can be used in which the pen provides a coupling between the X and Y wires and in which the wires are scanned in order to determine the point of coupling.

2.2.5 Character Recognition

Although a wide variety of character recognition equipment has been developed, most is special purpose and has not found application in Navy systems. This equipment has potential application in all areas where a hard copy document is originated for human use prior to entry of data into the computer system. Typical applications include inventory control and personnel records. Another interesting application is in the reading of an intelligence data base during the planning phase.

Currently, many techniques are available suitable for reading alphanumeric characters and other symbols from printed copy. Some use special type fonts while others use a variety of conventional type fonts.

Among those suitable for use with limited fonts are: magnetic ink character recognition devices such as those used in the banking industry, stroke analysis techniques, split font techniques in which a code designating a character is carried in a series of fine breaks in the lines forming the character, and bar coding techniques where a code representing the character is carried in a series of fine bars that are printed immediately above or below the character.

Types of character recognition techniques suitable for reading one or more general purpose type fonts are:

1) Scanning techniques in which the character is broken into a series of horizontal or vertical scans, each of which contains a pulse train that can be analyzed in sequence.

2) Matrix techniques in which the character is broken into a series of small areas each of which may be compared for corrolation against a master matrix.

3) Gross comparison techniques in which the total character is compared against a series of masks for coincidence, and corner detection techniques in which line intersections are detected and their number and relationships compared against a coincidence table.

All character recognition techniques are dependent upon being able to segregate the character to be recognized from the background noise of the paper. This noise results from the differences in coloration between various areas of the character, lack of definition of the edges of the character, voids, dirt, and ink deposits on the paper. A printed character is never perfect and can seldom meet all pre-established criteria necessary for recognition. Recognition is a probability problem in which probability of correct reading must be gauged against the probability of misreading the character. Therefore, character recognition equipment is designed to accept a character as valid when it meets a given percentage of total criteria. If the pattern of a character cannot meet an adequate percentage of criteria when compared with each character possibility, it must be considered an unrecognizable character. As character recognition equipment becomes more discriminatory in accepting a character, a greater number of characters that cannot meet criteria standards occur; with the result that a higher number of characters cannot be read. In order to read more characters, it is necessary to lower the criteria necessary for character verification with the result that the error rate increases. By 1970, character recognition equipment should be available that will read multiple fonts with a reject rate of less than 2% with acceptance rates in excess of 98%. This equipment will be able to operate at speeds of several thousand characters per second.

2.3 MACHINE OUTPUTS

In this subsection, the techniques for presenting printed, graphic and vocal information are examined. The technologies examined are line and character printers, plotters and vocal output. Dynamic visual presentations are discussed in the display sections of this volume.

2.3.1 Printer Types

Two basic types of printers are available. They are the line printer and the character printer or mechanized typewriter. The line printer prints one line of data at a time. Printing speed is dependent on the number of lines printed, independent of the number of characters printed per line or of the total number of characters printed. Such line printers can be divided into four classes according to their functional printing characteristics. These classes are:

1) Electromechanical
2) Electro-optical
3) Electrographic
4) Magnetic

Character printers are designed to print one character at a time horizontally across a piece of paper. Printing speed is directly proportional to the number of characters and control actions that must be taken by the printing device. The use of this type of device usually requires a number of special control functions and corresponding special control codes. Typical of these are: space, back space, precedence, e.g. upper and lower case.

All present electromechanical character printers depend upon selecting a character and bringing it into a fixed position in front of a carbon ribbon and paper; then applying the necessary force to transfer an image to the paper. In all cases, the character is not in motion at the time of transfer. The result is that a clear image can be obtained from this type of printing. However, this is done at the expense of possible improvements in speed.

The character printer is usually used as a communications device, as a part of a document originating device, as an output on an operator's console, or as a very low speed output device. Character printers are electromechanical in nature and are, therefore, capable of producing carbon copies. All operate at speeds between ten and twenty characters per second and use alphanumeric type fonts. For purposes of detailed examination, electromechanical character printers can be divided into five classes:

1) Typewriters
2) Drum Printers
3) Ball Printers
4) Matrix Printers
5) Stick Printers

Characteristics of character printers are summarized in Table 2-2. Anticipated characteristics for line and character printers in 1970 are shown in Table 2-3.

2.3.2 Electromechanical Printers

Electromechanical printers have the ability to produce multiple copies. The structure of these printers is such that the paper is set between the controllable mechanical character forming device (type) and a backing. These two are brought into contact at an appropriate time. The pressure created between them transfers ink from a ribbon or other source to the paper. This ink transfer forms the character on the paper. Since mechanical pressure is involved, this machine can produce carbon copies. Because electromechanical printers depend upon an ink transference process, it is necessary to somehow renew the ink supply. An advantage is that unprepared papers can be used with these printers.

Characteristics of electromechanical line printers are compared in Table 2-4.

Table 2-2

Electromechanical Character Printers

	Typewriter	Drum	Ball	Type Matrix	Type Stick
Pressure Source	Character Front	Hammer Back	Character Front	Character Front	Hammer Back
Changeable Type Font	No	Yes	Yes	No	No
Mechanical Conplexity	High	Medium	Low	Medium	Medium
Speed Char/Sec	12	10	20	8	10

Table 2-3.
Characteristics of Printers - 1970

	Class of Printer				
	Electro Mechanical Line Printers	Electro-Optical	Electrographic	Magnetic	Electro Mechanical Character Printer
Available for 1970 system	Yes	Yes	Yes	No	Yes
Cost	Low	Low to High*	High*	High*	Low
Print quality	Good	Fair	Poor	Fair	Good
Number of copies produced	6 to 10	Original only	Original + 1 copy	Original only	6 to 10
Font size (no. of characters)	to 64	to 200	to 64	--	to 88
Speed	1000 to 2000 lines/minute	to 20,000 lines per minute	to 20,000 lines per minute	--	6 to 20 lines per minute
Special paper required	No	on some machines	Yes	No	No
Electrical complexity	Low	High	High	High	Low
Mechanical complexity	High	Very low	Very low	Low	High
Ability to handle graphical material	Fair	Good	Good	Good	Poor
Ability to meet military specifications	High	High	Low	--	High

*requires electronic character generation

Table 2-4.
Characteristics of Electromechanical Printers

	Rotating Wheel	Chain	Matrix	Stylus	Stick and Rack	Hypo-Cycloidic	Impact Wheel
Print Quality	Good	Good	Poor	Fair to Good	Good	Good	Good
Vertical Alignment	Good	Fair	Good	Good	Excellent	Excellent	Good
Horizontal Alignment	Fair	Fair	Good	Fair	Good	Excellent	Fair
Number of Copies Produced	6	6	10	10	6	2	8
Speed-Lines/Min (with indicated type font)	2000	1100	1000	300	150	300	150
Type Font - No. of Characters	64	48	48	64	37	12	12
Type Font - Variable with Change in Speed	Yes	Yes	Yes	Yes	No	No	No
Electrical Complexity	Low	Low	High	High	Low	Low	Low
Mechanical	Medium	Medium	High	Low	Medium	Low	Low
Maintenance Requirements	Low	Low	Very High	Medium	Medium	Low	Low

2.3.2.1 Rotating Drum Printers

The rotating drum printer (Figure 2-3) is characterized by a solid drum or series of wheels joined together on a shaft which contains one or more complete type fonts for each column position to be printed. An inked ribbon is passed slowly in front of the type font to provide the source of ink to be transferred. Paper is fed between this inked ribbon, and a hammer or actuator strikes the back of the paper when the desired character is opposite the hammer position. The pressure of the hammer is thus transferred through the piece or pack of paper to the carbon ribbon and thus to the surface of the character on the drum.

Characters are selected by indexing the position of the drum and firing the hammer at the appropriate time to print the desired character. Rotating wheel printers are characterized by clean, high-quality impressions of individual characters. However, there is a tendency for smear of the horizontal parts of letters and numbers at high speeds. Such printers are plagued by more or less serious problems of horizontal alignment as a result of timing differences between hammers.

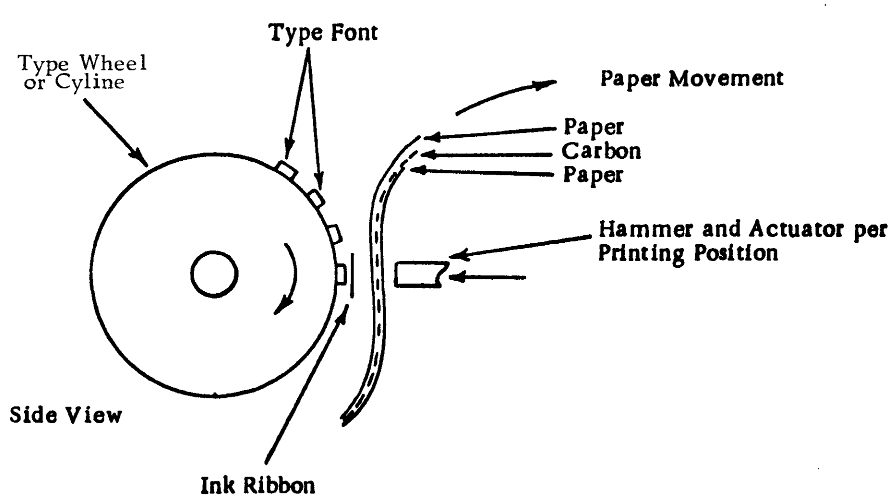

Figure 2-3. Rotating Drum Printer

2.3.2.2 Impact Wheel Printers

Impact wheel printers are a class of line printer commonly used in adding machines. Such printers are usually limited to numerics and a few symbols, and they operate at relatively low speeds. In this class of printer, a separate wheel is provided for each column position containing all of the digits to be printed in that position. An indexed stop is used to cause the wheel to stop rotating at a point so that the character to be printed will be opposite the print position. All wheels are rotated until they reach a stop position, at which time they are thrown forward against a platen. Interposed between the type and the platen is a carbon ribbon and the paper to be printed. (See Figure 2-4.)

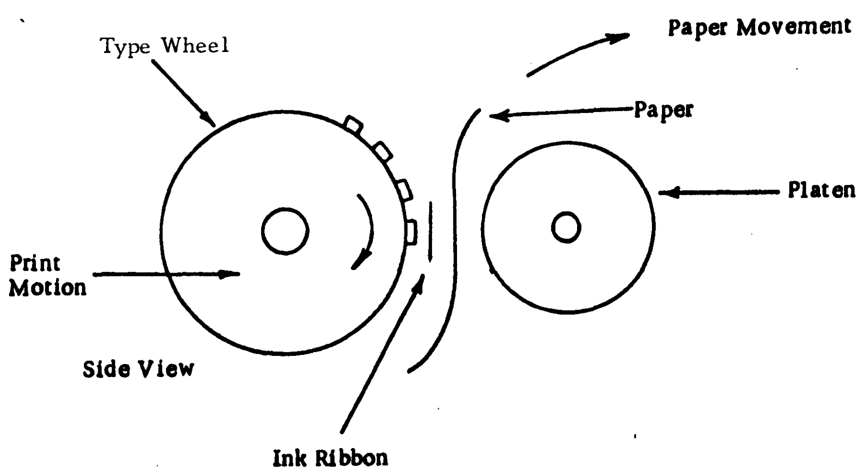

Figure 2-4. Impact Wheel Printer

2.3.2.3 Matrix Printers

The matrix printer (see Figure 2-5) is a mechanism for impressing a number of "dots" on paper to form a character. The dots are formed by the ends of wires which are moved forward by energy supplied from an actuator. These wires are usually placed in a rectangular array causing the printing of a 5 x 7 dot matrix (the smallest matrix which will print all alphabetics and numerics). A character generation device must be used to determine the dots necessary to print the selected character. The number of actuators required for this approach is very large since each wire requires a separate actuator.

As the wires forming the character are fired against the paper through an inked ribbon, the printing occurs from the front rather than the back as with the wheel or cylinder printer. The result is that such printers are capable of producing a greater number of carbon copies than are printers which require that the impact be presented from the back of the pack of paper where about ten multiple copies are usually considered maximum even with relatively thin paper. The use of a small number of wires or dots to form a character results in a low print quality; however, this may sometimes be partially compensated for by the improvement in alignment that results from the simultaneous firing of all wires. Since the character forming matrix is external to the machine, a large number of actuators is required, and since the wires that transfer the force to the paper are small and delicate, these systems require a very high level of maintenance to stay in operation, and they are very complex in their construction.

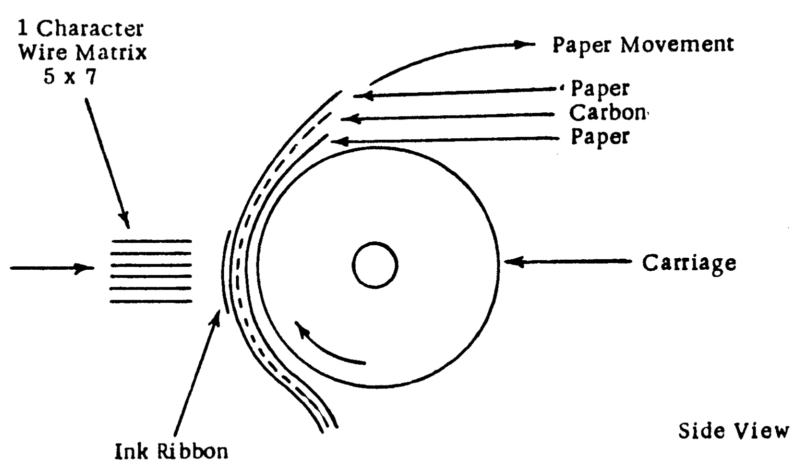

Figure 2-5. Matrix Printer

2.3.2.4 Stylus Printers

The stylus printer, though an outgrowth of the matrix printer, is quite different in its concept and performance characteristics. As with the matrix printer, a web of paper is passed over a carriage behind an inked ribbon. (See Figure 2-6.) Printing is by moving a series of styli horizontally between the inked ribbon and a series of actuators (usually one actuator is used for each character position). As the styli move horizontally across the paper, the actuators press them against the inked ribbon at those points where the black part of a letter is crossed. The result is a line of characters composed of a series of horizontal lines that are spaced closely together. The effect achieved is much the same as that obtained by a television raster.

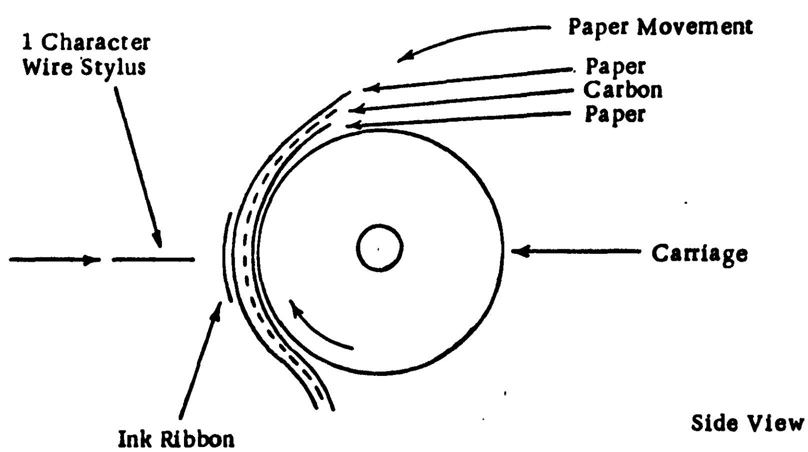

Figure 2-6. Stylus Printer

2.3.2.5 Belt and Chain Printers

Belt and chain printers are much like wheel and drum printers in their configuration in that an inked ribbon is interposed between the type and the face of the paper, and the character to be printed is selected by firing a hammer against the back of the paper when the selected character reaches that hammer position. The major difference between the two classes of printers is that in the chain printer, type travels parallel to the line of print (see Figure 2-7), and in the wheel printers, type rotates perpendicular to the direction of paper travel. Belt and chain printers are able to produce about the same quality of print, the same number of carbons and with the same speeds as wheel or drum printers. The horizontal movement of the type reduces the horizontal alignment problem that results from the vertical type movement of wheel printers; however, substituted for this is the problem of vertical alignment. Specifically, the horizontal movement of the chain tends to drag the paper in a direction of chain movement and thus pulls the printing out of registration with the background printed on the paper.

Flexing required by the chain or belt limits the top speed that can effectively be reached with the chain printer to somewhat below that which can be reached by the wheel or drum printer in which the type does not flex. Since the chain is travelling in a direction orthogonal to the direction of the paper, it must be at least twice as long as the total line length of the paper. If the line length of the paper is 13 inches (130 characters) it follows that the chain must contain more than twice this number of characters to double back upon itself. The result is that the type font is usually repeated several times on the chain.

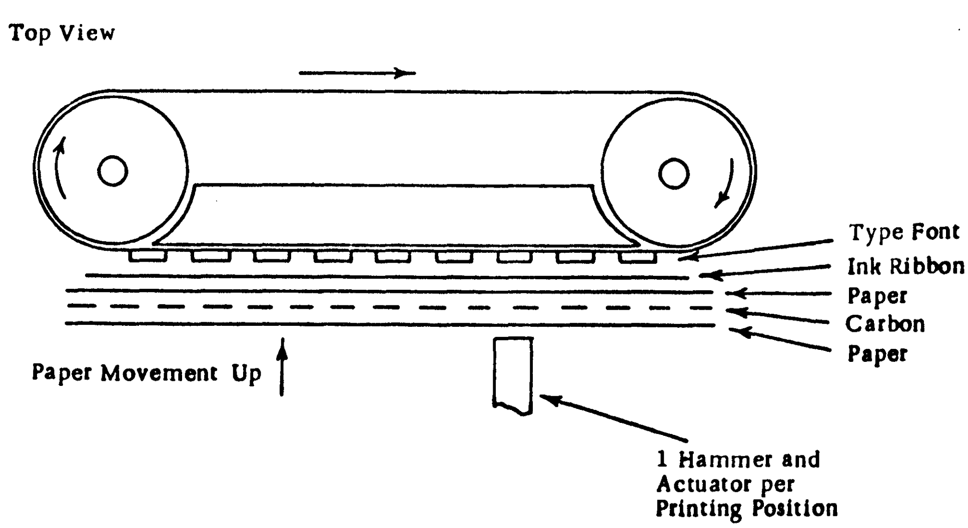

Figure 2-7. Chain Printer

2.3.2.6 Rack and Stick Printers

Rack and stick printers are an early class of line printer widely used in tabulating equipment and adding machines. Such printers use a bar of type for each columnar position. This bar holds individual spring loaded pieces of type for each character to be printed in that columnar position. During each print cycle, the bar of type is raised vertically until it reaches a stop which holds it at the position of the character to be printed. When all type bars have been raised to their print position, the print hammers (one for each type bar) are fired against the type bars, thus extending simultaneously selected pieces of type from the type bars. This type impacts against a ribbon and transfers ink to the paper which is supported on a platen or roller. During the print cycle, no horizontal or vertical movement of the paper or the type takes place. As a result, it is possible to obtain accurate control of horizontal and vertical alignment upon the form. Type impact is through the ribbon to the front of the form allowing a greater number of copies than can be obtained with the back-hitting technique used by the rotating wheel and chain printers.

Rack and stick printers are inherently slow as the stick or rack of type represents a large reciprocating mass. This, combined with the large number of moving parts, tends to require a relatively higher amount of maintenance per million lines printed than do more modern types of printers. (See Figure 2-8.)

2.3.2.7 Hypocycloidic Printers

The hypocycloidic printer, like the stick printer, forces type against the face of the paper with no relative horizontal or vertical movement between the type and the paper during the movement of impact. The type is contained on a type drum in much the same manner as it is on a wheel or drum printer. Unlike the drum printer, the type cylinder of the hypocycloidic printer does not revolve about its center line; rather, it is geared to provide surface motion that advances a line of type perpendicular to the center of rotation, then retracts and rotates one character position.

Although the drum is in continuous rotation at the moment of peak advance, there is no component of relative rotational movement. The result is that printing obtained from such a system exhibits no smear and, except for paper wrinkling, will always be in excellent horizontal and vertical alignment.

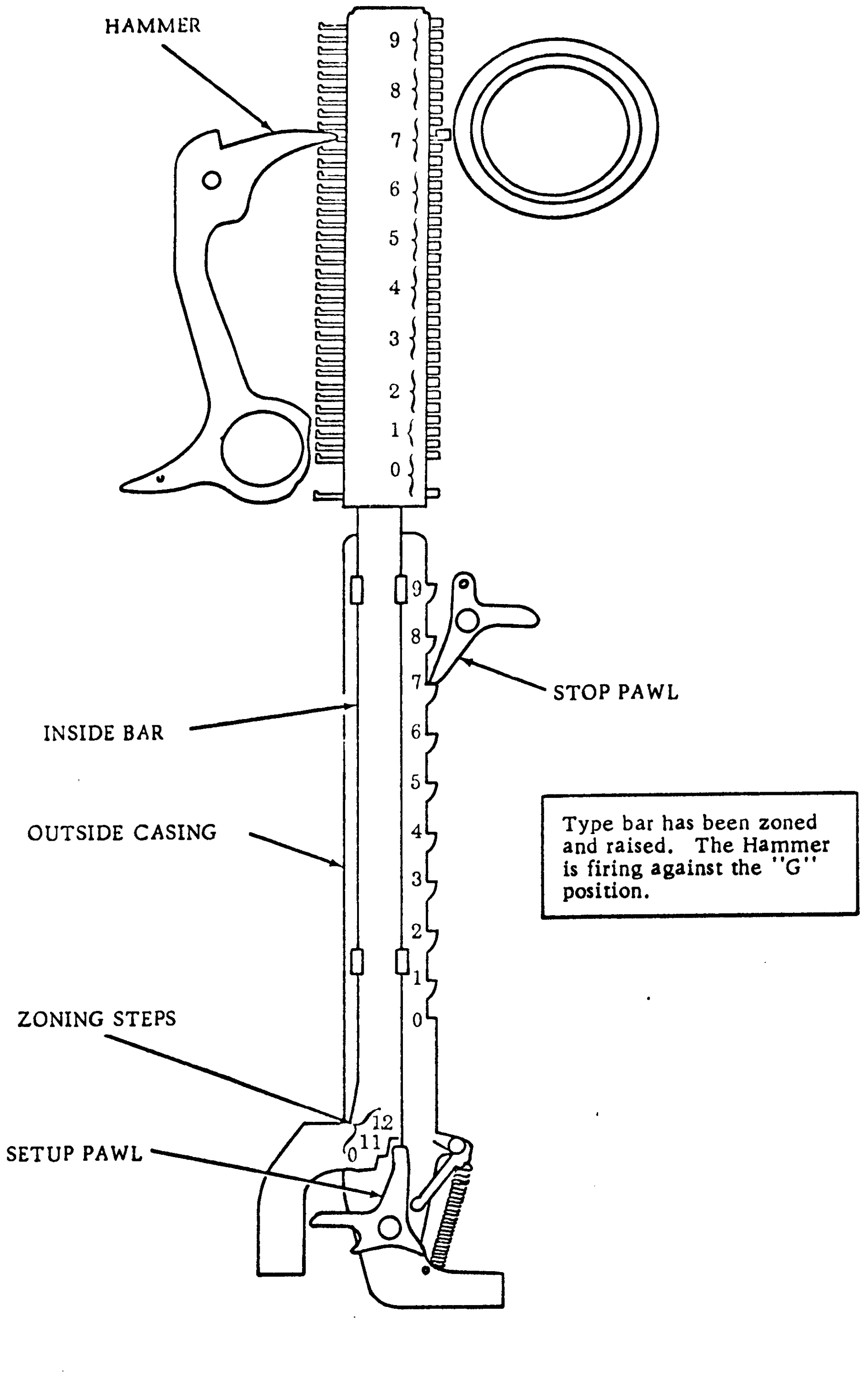

Figure 2-8.

Stick-Type Printer Bars

Printing may be accomplished either by firing a hammer against the back of the paper or by fixing a stop in position at some time prior to the advance of the type. This stop may be fixed in a forward print position or removed to a non-print position. When the line of type advances to the stop, it impinges upon the paper and presses it against the stop when it is in a print position. The stop is not reached and thus no pressure is applied in a non-print position. Such an arrangement requires some flexing in the paper and does not lend itself to the use of a carbon ribbon. Instead, the surface of the type is inked as it would be in a letter press. Conventional inks dry and cake on the face and lead to frequent cleaning of the type. Hence aniline dye ink is used to prevent this undesirable effect.

Hypocycloidic printers are not well suited to printing many columns or large type fonts since the requirement for strength in the central drive shaft becomes too great. They can effectively produce a limited number of columns of numerics or of mixed numerics and symbols. Speed of such devices is relatively slow because the internal drive shaft must make one complete revolution for each character printed. Thus, to print at 100 lines per minute from a 16 character type font, the central shaft must revolve at 1600 revolutions per minute. Hypocycloidic printers have found some application in military situations due to their small number of moving parts and relatively good reliability at low speeds.

2.3.3 Electro-Optical Printers

The electro-optical printers print by the projection of a direct optical output onto a sensitized surface which is then developed to provide a printed output. (See Figure 2-9.) As the optical output and character generation equipment used is the same as that used in displays, it will not be discussed in this section.

Probably the best example of an electro-optical printer is the General Dynamics/ Electronics SC7330 Printer. This printer is rated at 3000 to 5000 words per minute but can operate over a range of 10 characters per second (100 words per minute) to 71,000 characters per second (on a per line basis).* The particular printer is designed to print 128 characters per line.

The image generated on the face of the Charactron tube is projected through an optical system onto a sheet of plasticized paper which has previously been given a surface charge. Since the Charactron tube presents the characters in serial fashion across the

*This is a rate at which characters can be generated on a simple line and does not take into account factors limiting paper advance time.

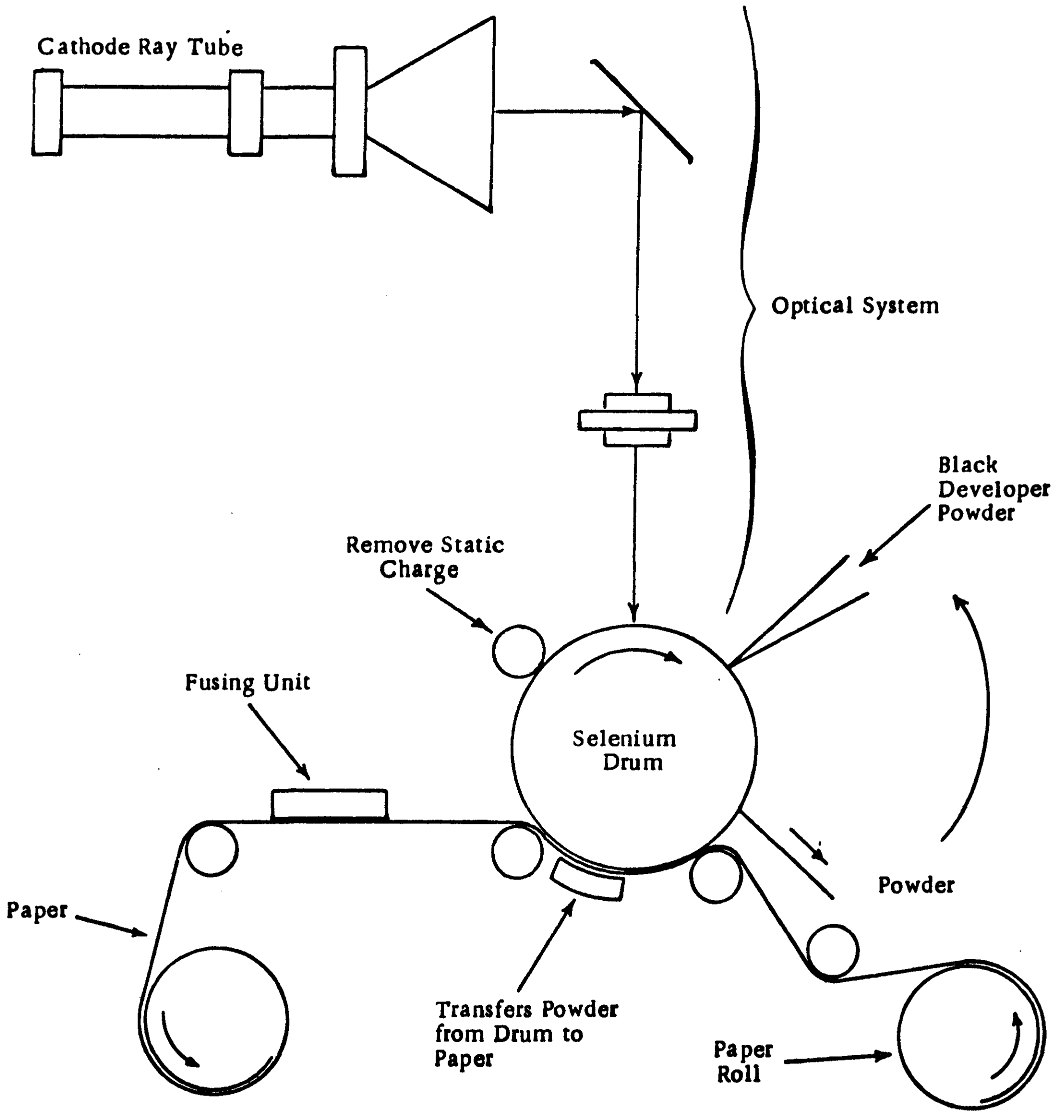

Figure 2-9. Electro-Optical Printer

face of the tube, the character presentation is asynchronous. The light generated from the phosphor is projected through the optical system and falls on the charged surface of the plasticized paper. This charge is held on the paper until it is advanced through a "dusting" bath. At this point, the surface charge in the location of the characters attracts fine particles of black polyethylene dust which temporarily adhere to the surface of the paper. The paper is then advanced at a fixed rate over a heating element that fuses the black polyethylene to the surface of the paper, thus completing the printing process.

The process involved is very similar to the Xerographic process except that the paper is directly charged. The light impinging upon its surface can be used to "fix the charge" and thus attract the "ink" directly to the area to be printed. In the Xerographic process, a selenium drum is used and an electrostatic charge is placed upon it attracting the "ink" to the surface of the drum. The image must then be transferred to an offset roller and then to the paper itself where it is fused in place. Because of the offset nature of Xerography, it is possible to use any type of paper. However, in the process used in the General Dynamics/Electronics printer, a specially plasticized-surface paper must be used. We are informed, however, that this paper is relatively inexpensive and has an indefinite shelf life.

Advantages of a printer such as this are:

1) No moving parts except the paper advance mechanism
2) Very high speed printing
3) Large type font possible (perhaps 200 characters) without decrease in printing speed
4) Type font readily changeable by changing Charactron tube
5) Very quiet printing
6) Long life, high reliability with low maintenance
7) Relatively low cost
8) Essentially asynchronous operation
9) Can be used to present graphical output
10) Printed output may be used directly as a multilith master

Disadvantages of Charactron Printer are:

1) Produces only original - no copies available
2) In its present form, machine is relatively heavy and bulky
3) Requires special paper

A similar printer to the General Dynamics unit is the Rank Printer developed by Rank Precision Industries of England. This unit uses the Xerographic principle and a standard cathode ray tube with a resistive voltage divider in the deflection circuits to form individual letters.

2.3.4 Electrographic Printers

As yet, there has been little commercial exploitation of the electrographic printer as a computer output device. This is probably due to the requirement for special paper and to the difficulties in producing multiple copies.

The electrographic printer (see Figure 2-10) requires the use of specially coated paper with high dielectric properties. This paper is moved across the matrix consisting of wires imbedded in plastic. As the paper moves in front of the matrix, it is charged by the selected application of high voltage to the matrix wires. The charged image is developed by running the paper through a hopper containing a "toner" or powdered ink in combination with dyes and thermosetting material. The "toner" adheres to the charged areas of the paper and is then carried across the surface of the heating element which fixes the image by melting the thermosetting material enough to fuse it to the surface of the paper.

Systems of this type have been built by Burroughs and A. B. Dick. The Burroughs System employs a matrix of wires imbedded in plastic in standard 5 x 7 form as the character generation media. The system is able to print at very high speeds, about one or two microseconds per character. As recording takes place in parallel, paper feed becomes the major speed limitation.

The A. B. Dick electrographic printer uses a special matrix tube built by the Stanford Research Institute. The tube consists of a cathode ray gun aimed toward an assembly of fine wires imbedded in the glass face plate. The electron beam is controlled by character-forming circuits external to the tube. The wires provide a path for the charge from the beam to flow outward to a special coated paper in front of the tube leaving the character

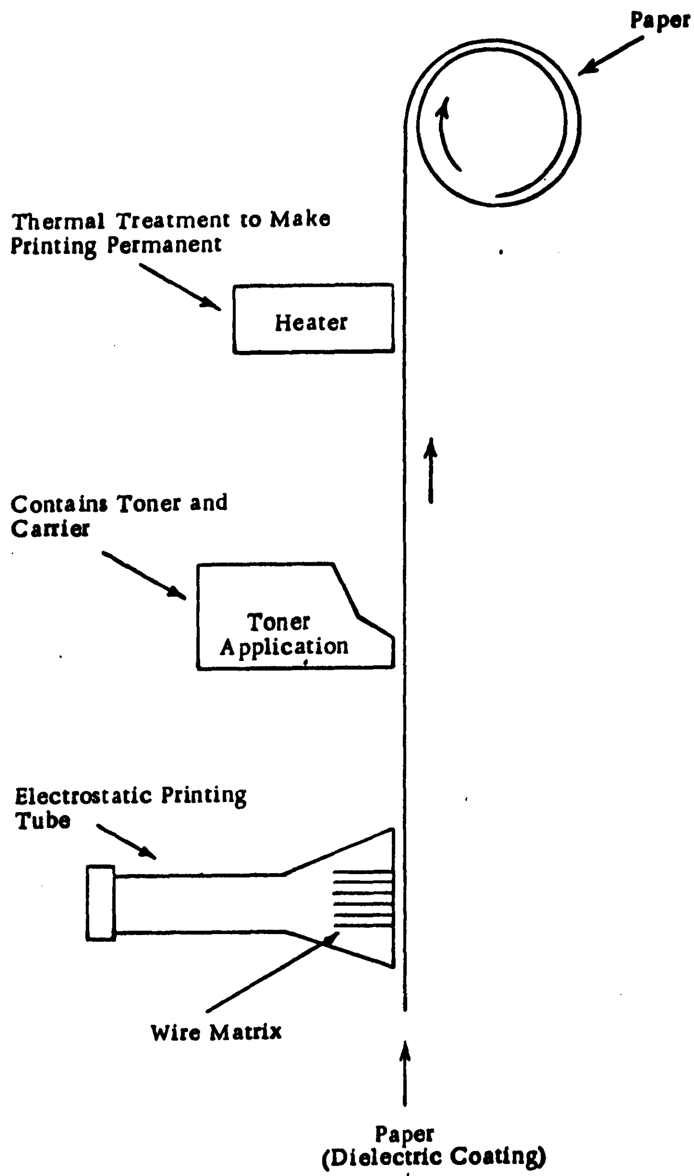

Figure 2-10. Electrographic Printer

as an electrostatic charge on the paper. The use of the vacuum tube is considered a disadvantage for some applications; however, a much higher resolution is obtained than can be obtained with the Burroughs System.

A third family of printers uses a Hogan facsimile stylus print head and amplifiers. Printing is in the form of a 7 x 11 matrix on a 10 x 15 dot field with 100 dots per inch.

It is possible for the electrographic printer to produce at least two copies of the same document in a single printing, since the voltage applied is high enough to pass through two sheets of paper simultaneously. As each copy produced requires its own ink hopper and heating element, it is not possible to quickly change from one number of copies to another.

Advantages of electrographic line printers are:

1) Very high speeds
2) Possibility of more than one copy
3) Ability to form large type font
4) Simplicity of electrical design

2.3.5 Magnetic Printers

Currently, there are no magnetic printers in production. However, developmental work has been done by the General Electric Corporation, Schenectady; Univac Division, Sperry Rand Corporation, Philadelphia; and National Cash Register.

The magnetic printer (see Figure 2-11) produces a shaped magnetic field which is recorded on a magnetizable surface. This surface is then exposed to some form of magnetic particles which are attracted to it and form the shape of the magnetized character. This "inked" surface is brought into contact with the paper and the ink is transferred from the magnetized surface to the paper. The ink is fused to the paper and the magnetizable surface is then erased for reuse.

The shaped magnetic field may be created by the use of a magnetized type wheel, matrix or stylus, and the quality of output depends both upon the character-forming system used and the resolution obtained in magnetization of the magnetizable surface. Like all transfer printing devices, the magnetic printer can produce only original copy. All magnetic printers require the use of magnetic material in the ink.

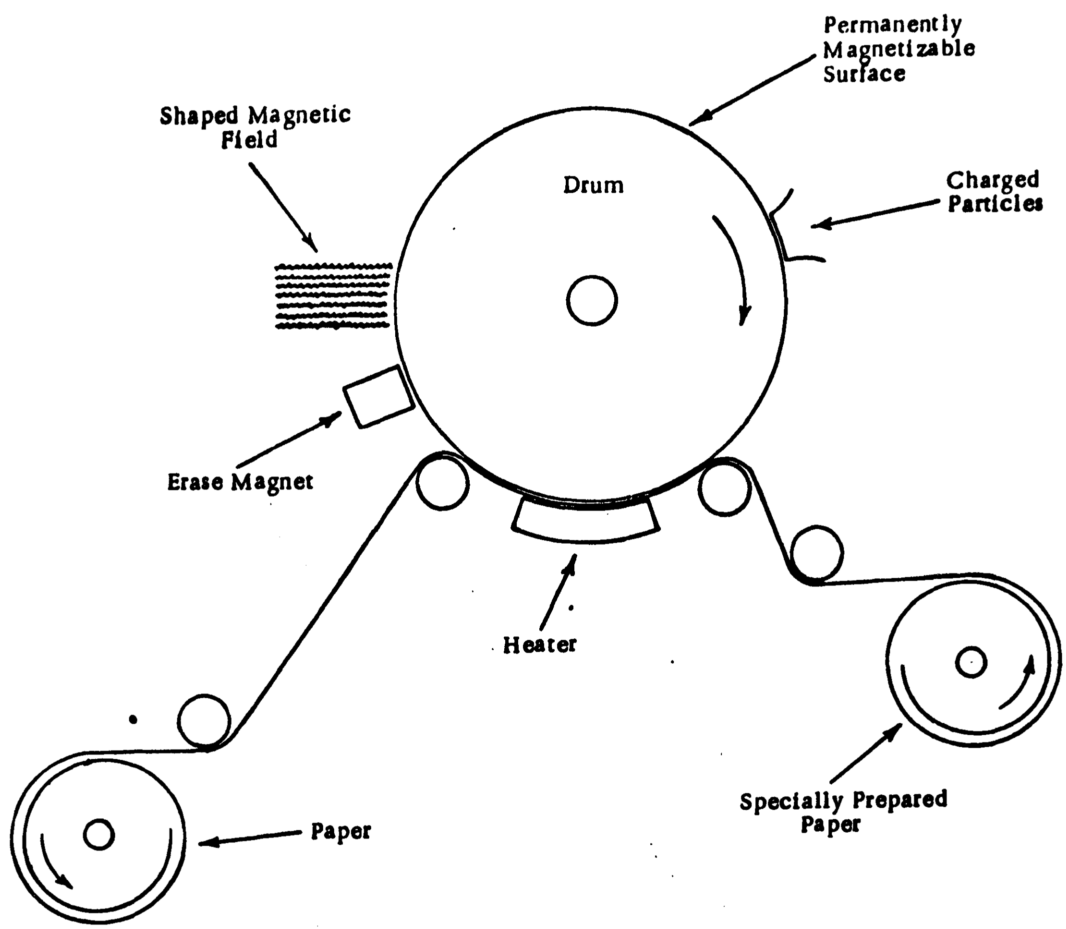

Figure 2-11. Magnetic Printer

2.3.6 Typewriters

One of the early forms of character printers was the modified electric typewriter in which the keys were operated under computer control. This type of device is still frequently used and is often found operating solely as a printer without the keyboard. Most such devices are capable of presenting a font of 44 characters. If a precedence code is used, 88 characters are available; however, 26 of these are usually lower case alphabetics leaving a net type font of 62 characters. Most typewriters operate at a maximum speed of 10 to 12 characters per second. This speed is reduced by the time required for the execution of special function codes, e.g. carriage return, back space, carriage shift.

In operation, the typewriter selects one of many levers, each containing a character, and throws it into engagement with a power source in a manner such that the character on the lever is fired against an inked ribbon bringing it into contact with the surface of paper to be printed. The array of type containing levers, or type basket, cannot be moved, with the result that a carriage containing a platen and paper must be moved back and forth in front of the print position of the type basket. Disadvantages of such a system are that the paper must continually be moved both horizontally and vertically, thus putting unusual stress on perforations. As the type basket is a rather complex mechanical arrangement of levers, springs, clutches and pulleys, there are many moving parts that may fail. An advantage of this system is the front impact hammer which allows many carbon copies to be produced.

2.3.7 Drum Printers

The drum printer is an electromechanical character printer in which the type is contained in one or more rows around the circumference, or partial circumference, of a cylinder. (See Figure 2-12) This type drum is backed by a carbon ribbon, the paper to be printed, and a hammer. The character to be printed is brought into position by lateral and rotary movements of the type drum.

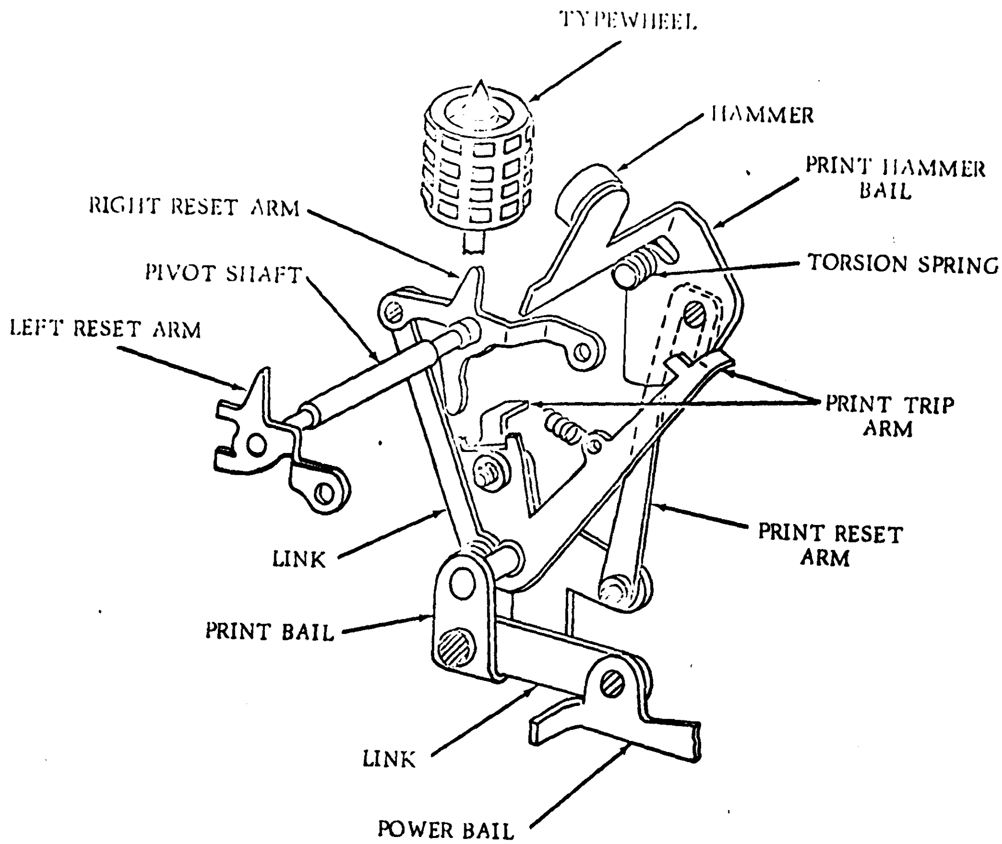

Figure 2-12. Drum Printer

When the proper character is in position, the drum movement is stopped and held in place until the hammer is fired, thus forcing the paper and carbon ribbon forward against the type.

In most present-day drum printers, the paper is held in position by a paper transport mechanism, and the type drum and hammer are moved horizontally across the paper, thus requiring no horizontal paper movement.

2.3.8 Ball Printers

Ball printer operation is similar to that of the drum printer except that the characters are formed on the surface of a ball. The character to be printed is selected by a combination of vertical and horizontal rotary movements of the ball bringing it into the selected print position. When the character is in position, the ball is driven against a carbon ribbon printing the character. Character isolation obtained through the use of a ball allows elimination of the back hammer reducing the inertia of the system and allowing faster operating speeds. It allows a front impacting system which produces a greater number of multiple copies. Like the drum printer, the ball printer requires no horizontal movement of the paper, thus contributing toward systems reliability. Ball printers are capable of operating at rates up to 20 characters per second due to their low inertia. Like the drum printer, the ball printer readily lends itself to changes in type font.

2.3.9 Matrix Printers

The matrix printer, like the ball printer and typewriter, is a front printing device. Spring loaded type is held in a rectangular matrix in front of a carbon ribbon. Characters are selected by horizontal and vertical movement of the matrix which brings the selected character in line with a hammer. When in proper position, the hammer is fired against the character, thus giving it the inertia to imprint on the paper. Like the ball printer and the drum printer, the matrix is carried horizontally across the face of the paper requiring no horizontal movement of the paper itself.

The most common application of the matrix printer is in teletype operation where it is operated in the range of five to seven characters per second.

2.3.10 Stick Printers

The stick printer is similar in concept to the drum printer. The type is held on the face of a hexagonal or octagonal type stick. This type stick is moved horizontally in front of the hammer and rotated to bring the desired character into print position. When in print position, a hammer fires against the rear of the paper bringing it into contact with the carbon ribbon and the selected character. Usually, this type of printer relies more on linear motion than rotary motion in the selection of the character.

2.3.11 Plotters

A wide variety of plotting techniques are now in use. Functionally, they include recording galvanometers, servo potentiometers, sweep recorders, pressure recorders, and X-Y recorders.

The first four of these techniques are used primarily for the continuous recording of physical phenomena. Typically, they employ a moving roll of paper or film which passes under one or more "pens" which are activated by a positioning device, e.g., galvanometer, servo, etc. Characteristic of all these techniques is that they plot variations in physical phenomena against a time base represented by the moving paper. Since the paper moves at a fixed speed in one direction, most are not capable of plotting phenomena that are not time based. Usually, these devices are designed for direct coupling with some form of sensor. To conserve paper they are designed to operate at the slowest time base that allows observation of the maximum anticipated variation of the phenomena under study. Their sensitivity is usually determined by the output of the sensing device to which they must interface. Typical applications include the electrocardiograph, pressure recorders, voltage recorders, temperature recorders, vibration recorders, etc. This class of device is not generally suitable for use with a computer oriented system.

X-Y recorders may have application in a tactical data system. Two types of devices were investigated, namely:

1) X-Y plotters
2) Cathode-ray tube (CRT) camera recorders

These items are discussed in the following subsections.

2.3.11.1 X-Y Plotters

X-Y plotters are suitable for recording both time dependent and non-time dependent functions. This is possible because the X and Y pen positions are independently controlled by two separate servomechanisms.

X-Y plotters can operate in two modes; the point plotting mode and the line plotting mode. In the point plotting mode, X and Y positions are furnished the servos to position the pen and the pen is depressed to record the ploted point. This process is repeated for each point plotted. In the line plotting mode, the pen is initially positioned as a point plot and is kept in contact with the paper while the X and Y servos move the pen from point to point.

Both analog and digital X-Y recorders are available. The analog plotters use conventional servo motors while the digital plotters use digital stepping motors to position the pen.

Accuracy and speed of X-Y plotting techniques is primarily dependent on the accuracy and speed of the digital stepping motors used to position the pen. Motor capacity required is a function of the inertia of the system which will vary with the size and mass of the pen positioning bars (a function of plot size) and whether the pen positioning bar must carry accessory equipment such as small character printers for point identification.

Two implementations of X-Y plotters are in common use; the table plotter and the drum plotter. The table plotter uses the large sheet of paper which is anchored to a flat base. Over this base, horizontal and vertical plotting bars are moved to position a pen holder at their intersection. This pen holder is capable of placing the pen point contact with the paper upon command. Some plotters use a small character printer in place of a pen to print a series of characters or points. Other systems employ the pen in combination with a character printer to imprint point identification next to the plotted points. Typical table plotters can provide pen movements up to 50 inches per second with positioning accuracies of 0.01% of the sheet size. Character identification can be added at rates up to 10 characters per second. When table plotters are used in a vertical position as a group display, it is necessary to sacrifice some plotting speed and accuracy because of gravitational effects on the vertical trace. (See Table 2-5.)

Drum plotters represent another implementation of the X-Y plotter technique. In the drum plotter configuration, the paper is wrapped around the drum which is rotated by a digital stepping motor to produce the Y axis position. The X axis position is produced by moving the pen back and forth on a fixed carrier bar. Because of the mass of the drum, plotting speeds are somewhat slower than can be achieved with table plotters; typical speeds being about three inches per second.

Two major advantages of the drum plotter technique are that it requires less space than the table plotter and that the length of the Y axis used is limited only by the amount of paper that is supplied to the plotter. A major disadvantage of drum plotters is that only a limited portion of the plot is available for examination during the plotting process and this is in motion, making it difficult to read.

Table 2-5

Comparison of Digital X - Y Plotting Techniques

	Table	Drum
Typical chart size	30" x 30"	11" wide, any length
Maximum chart size	78" x 158"	30" wide, any length
Number characters printed	9 to 72	Usually characters are drawn with pen
Printing rate	10 characters/second	---
Plotting modes	Point, continuous	Point, continuous
Speed	50"/second	3"/second
Accuracy percentage	0.01	0.01
Size	Large	Small
Visibility	Paper completely visible except under plotting head	Paper only partially visible and in motion

2.3.11.2 CRT Camera Recorders

The cathode-ray tube camera recorder is a high speed equivalent to the X-Y plotter. Horizontal and vertical deflection plates are used in a cathode ray tube for the same function that servo positioners or digital stepping motors are used in X-Y plotters. The electron beam generated by the cathode ray tube gun is moved across the phosphorescent screen on the face of the cathode ray tube. Depending on the phosphor used, cathode ray tube plotters may be used for direct view or projection, e.g., displays; or in conjunction with photo-sensitive paper or film for a recorded output. This type of plotter is capable of very high speeds; however, it is not too suitable for point plotting because of the persistency of the phosphor necessary to convert the electron beam into visible light. Detailed examination of cathode ray tube technology and software is discussed in Sections 4 and 8 of this volume.

The major differences between cathode ray tube plotters and displays lie in the phosphors used on the cathode ray tube and the availability of a photo sensitive copying technique to produce a hard copy.

Should high speed graphic output be required in future tactical data systems, it is desirable to use direct viewed display equipment to produce this output. An attachment is developed which is capable of using the display oriented phosphors to produce hard copy output.

2.3.12 Vocal Output

In the past few years there has been a rapid rise in the development of equipment which is capable of selecting a pre-recorded audio message and presenting it upon a digital command. There has also been some work on equipment that is capable of selecting a variety of words and phrases and combining them into a meaningful message.
As yet, there has been little such equipment put "on line" with a computer system. This equipment has manifested itself as automatic paging systems and selectable message systems, etc.

Such equipment can be used as a machine-man interface under computer control. Use of the "open loop" concept in the military can allow a computer to present a set of possible decisions to a commander so that he can select from those decisions which one he chooses to make. The computer could be used to issue instructions in a vocal manner just as he might allow it to make up instructions, e.g. orders, texts, etc. in a written mode.

2.4 DATA STORAGE AND TRANSFER

Prerequisite to the successful development of any data processing system is the ability to be able to store data in a form that will allow data transfer between one piece of equipment and another. Such transfers of data frequently occur over a considerable distance, a lapse of time, or after the intervention of some form of human control. Transfer of data therefore requires a common language storage media which is suitable for human handling when necessary.

Systems development is evolutionary by nature therefore it is desirable to allow one part of the system to change while another remains fixed. Where the data involved is not real-time in nature, interface problems can be reduced by the use of an intermediate storage media such as magnetic tape or punched cards.

At an early point in this study it was necessary to define the machine to machine interface in a manner such that it would not include communications equipment and process control sensors. This was necessary in order to allow adequate study of digital systems within the funds available. Thus machine to machine communication techniques discussed in this subsection are those utilizing digital data received on the platform and available under computer control.

2.4.1 Data Storage Transfer Media

Three types of Data Storage Transfer Media are discussed in this subsection. These are:

1) Unit record (e.g., punched cards, magnetic cards).

2) Incremental record (e.g., paper tape, incremental magnetic tape).

3) Block record (e.g., magnetic tape, discs, drums and off-line solid state storage units).

Magnetic discs, drums and transportable core or film storage units may also be used for on-line storage.

Common to all is the capability to store data off-line in a form that can be recalled for later use. Any of these techniques may also be used to transfer large amounts of data from one computer to another; not, however, in real time. Relative speeds, costs and access times are shown in Table 2-6.

Punched cards and other unit record devices provide a much more convenient means for data transfer and storage where the data is transmitted either in small quantities or erratically at one source and is required in small quantity or erratically at another point or at a number of other points. Further, the punched card is particularly advantageous where human intervention may be required between the two systems or where a manual backup system is required.

Advantages of the punched card in such applications are:

1) It provides a unit record which may be added to or removed from other unit records either by machine or by human intervention.

2) The recording on the card is permanent in nature.

3) The recording on the card is visible to the human and may be read directly by him.

4) The card lends itself to machine interpretation of the punched data which allows it to be read by an untrained user.

5) The card may be used to record human notation not useful to the processor.

6) Such cards are relatively transportable.

7) Equipment for the generation and use of punched cards is now very widely available.

Disadvantages in the use of punched cards are:

1) They are a non-reuseable media and thus are rather costly to use in large quantity.

2) Extremes in humidity make them difficult to handle.

3) If a pack of cards is dropped, the sequence of the cards may be disturbed.

Table 2-6

Digital Stored Machine to Machine Communication (Off Line Data Storage)

	Type of Access	Recording Speed	Reading Speed	Cost of Storage Ranking	
Unit Record					
Punched Card	Serial	5×10^3 b/sec	5×10^4	1	Asynchronous
Permanent Magnetic Card	Serial	5×10^3	5×10^6	3	Asynchronous
Removable Magnetic Card	Random	5×10^6	5×10^6	4	Asynchronous
Incremental Record					
Paper Tape	Serial	1×10^3	3×10^4	2	Asynchronous
Magnetic Tape	Serial	4×10^3	4×10^3	6	Asynchronous/ Synchronous
Block Record					
Magnetic Tape	Serial	5×10^6	5×10^6	7	Synchronous
Removable Disc	Random	5×10^6	5×10^6	5	Synchronous

Examination of current Navy systems indicates that the punched card is not in relatively common use when compared with perforated tape. The reason is that the punched card is a child of the business data processing community and not of the communications arts.

As the communications arts are vital to the operations of the Navy, and as the backgrounds of most Naval personnel do not include extensive business data processing, there would seem to have been a tendency to rely on punched paper tape as a substitute for punched cards. For communications purposes where a variable length format is used and where data must be recorded continuously from a line, punched paper tape or incremental magnetic tape is without peer. There are, however, many applications which do require fixed formats. These include such items as programming, inventory control, statistical information, and development of militarized unit recording equipment suitable for use on shipboard.

Where data is generated asynchronously bit by bit or character by character, as in a communications system, perforated paper tape has proved to be a satisfactory and economical storage media. The use of chad (<u>not</u> chadless) tape is preferred when the data is to be used in connection with a computer because of the greater reliability obtained in reading the tape with highspeed reading devices. Chad tape is punched paper tape from which the punched paper discs <u>have</u> been separated. Chadless (that is not generating chads or discs) tape has the chads partially attached to the holes. Many military personnel have extensive familiarity with the use of perforated paper tape as a result of their communications experience and it has, therefore, become common to incorporate it as the only input on many small military computers. This is most unfortunate as paper tape is a most unsatisfactory media for computer input since it lacks the unit record advantages of punched cards and the high speed advantages of magnetic tape.

A new contender in the field of asynchronous machine to machine stored data transfer is incremental magnetic tape. As incremental magnetic tape may be written or read asynchronously in the manner of paper tape, or in block format as magnetic tape, it has the potential to replace paper tape in the communications and computer fields. At low speeds, incremental magnetic tape probably will not be able to compete costwise against punched paper tape, but at higher speeds it should prove to be less expensive. The greatest disadvantage that incremental magnetic tape has in competition with punched paper tape is that it is not possible for an operator to physically read the tape. On the other hand, the tape is reusable and as data is stored at relatively high densities, the cost per bit of storage media is potentially much lower than that for punched paper tape.

Block oriented magnetic tape which provides serial access to fixed or variable blocks of information in computer language is the fastest, most economical and most efficient means of machine-to-machine communication available. Its use requires substantial pre-planning of the programming for both the sending and receiving computer. The nature of the data must be structured and known. Where desirable, it is possible to incorporate very sophisticated error detection and correction techniques without appreciable loss of operating speed. Current operating speeds range up to 180,000 characters per second, and current technology would allow the development of a 1,000,000 character per second transfer rate.

The greatest problem with conventional digital tape transports is their requirement for high maintenance. A relatively high failure rate results from the close tolerances and high operating speeds required to achieve high data transfer rates. With current concepts, little can be done to improve tape transport reliability other than to use sound engineering practice in the design of transports and carefully thought out and effectively designed maintenance programs. Another disadvantage for military usage of tape transports is the sensitivity of the magnetic tape to environmental conditions. With recording densities in excess of 1,000 bits per inch, and tape widths one half to one inch, little damage to the tape can be allowed. Considering that the tape base is one mil thick and large shock loads are placed on the tape during the process of starting and stopping, it is surprising that such systems can operate as reliably as they do. Both the Mylar base material and the oxide coating are affected by humidity and temperature. At extremes of temperature and humidity, the tape becomes completely unmanageable.

In an attempt to solve the problems inherent in magnetic tape, development has been undertaken of a "solid state magnetic tape unit". This development is being conducted in connection with the CCIS-70 Program. In such a tape unit, the electronics and any necessary drive elements will be housed in a cabinet equivalent in function to the present magnetic tape transport. The "tape" would be housed in a separate removable cartridge which could be manually or automatically inserted into the "transport". The cartridge would contain some form of solid state storage, e.g., memory, which could be accessed in a character serial manner similar to that used on a tape transport. The major problem associated with the development of such a "solid state transport" is that of obtaining a cost per bit of storage equivalent to that of current magnetic tape systems.

Although the possibility of such a unit exists, it seems highly questionable whether such units could be available at an economic cost during the 1970-1980 period.

2.4.2 Card Punches

Common to all punched card punches are the following elements:

1) The feeding mechanism

2) The punch mechanism

3) The stacking mechanism

In addition to these three basic elements, many punches include a pre-read station before the punch, a post-read station following the punch, and a reject hopper. (See Figure 2-13)

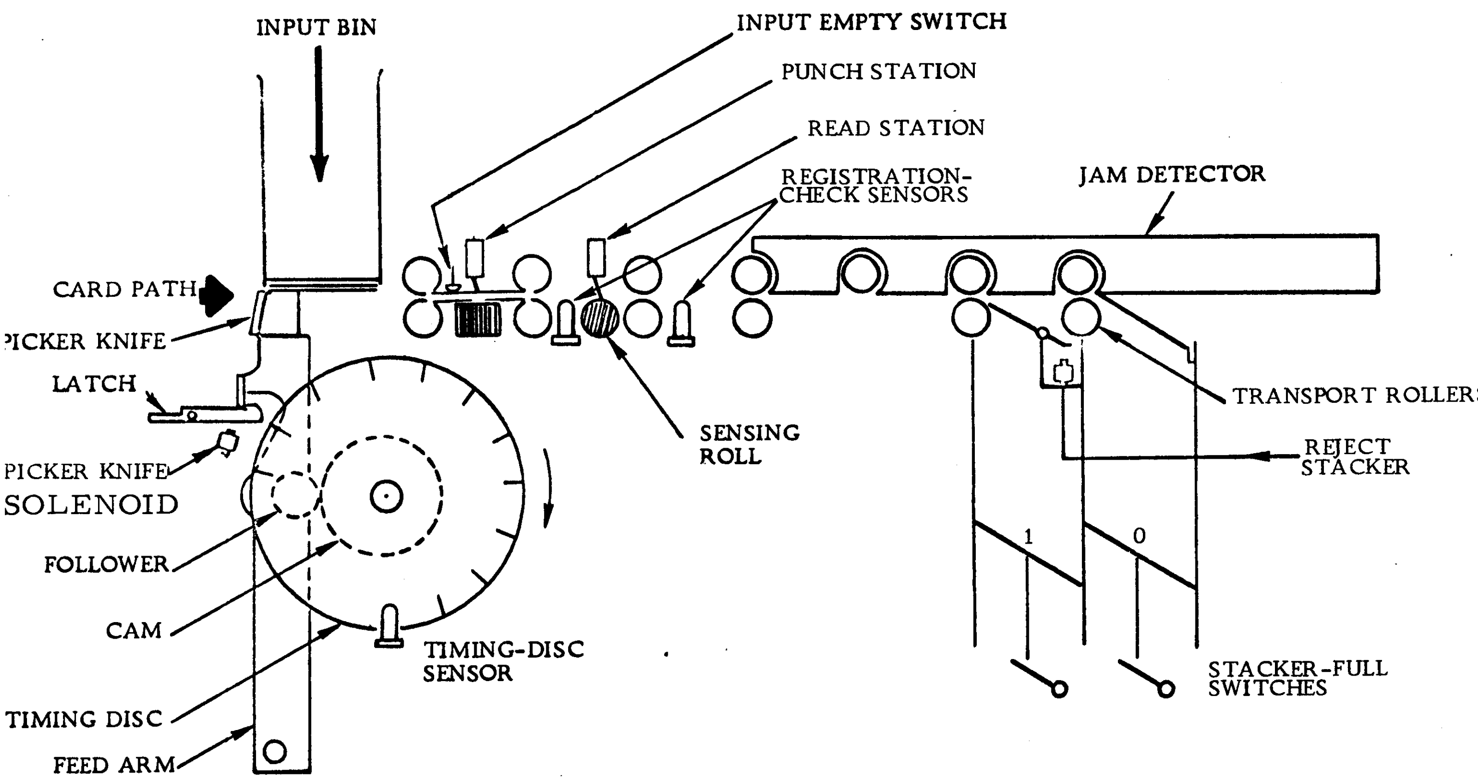

Figure 2-13 Typical Card Punch

2.4.2.1 Feed

The function of the feeding mechanism is to accept a stack of unpunched cards and upon demand of the computer, feed them one at a time into the punch mechanism. For proper operation, it is essential that the feeder be designed as top loading in order to allow the addition of blank cards while the machine is running. Cards may be fed either row by row (long side forward) or column by column (short side first). As the card itself is produced from a continuous web (roll) of cardstock which is 3 1/4 inches wide, the grain of the paper runs in the long direction of the card. As changes in humidity cause paper fibres to expand about ten times as much across the grain as they do with the grain, the card is relatively stable in its long dimension. In order to provide for this instability of size, the rectangular holes used in the card provide maximum tolerance across the grain where the expansion of the card is at its maximum. In addition, the uneven expansion of the card tends to cause cupping or curling of the card which makes it difficult to feed in an endwise direction. It is, therefore, desirable whenever possible to feed the card row by row rather than column by column if reliability of feeding and accuracy of data are the major criteria.

Unfortunately, the data is recorded in the card on a column by column basis, and if the data is to be punched on a row by row basis, it is necessary to provide complete buffering for all 960 bit positions in the card. In most card readers it is necessary to provide dual buffering to allow data to be read into one buffer while the card is being punched from the other buffer. To overcome this high cost as a result of such buffering techniques, there have been a number of column by column punches introduced in the market. In these, the feed mechanism advances the card one unit (of one column, two columns, four columns, etc.) at a time and one or more columns are punched. The card must come to a stop for each increment of advance. Typically, more increments of advance are used in the 80 column direction than in the 12 row direction with the result that column by column punches usually operate more slowly than row by row punches.

2.4.2.2 Punch

Two basic types of punch mechanisms are in common use and the principles are similar whether they be used with a row by row or a column by column punch. These two techniques are the basket punch and the incremental punch.

In the basket punch a card is advanced into a punched station. When properly positioned, it is stopped in preparation for punching. During the time of advance and card stopping, any of the possible 960 punch positions may be activated. When the punches are "set" they are driven through the card and a botton die forcing the chad out into a chad box. The dies are then pulled out from the card and the card is advanced to make room for the next card. With the basket punch, it is possible to set up the punches either row by row or column by column providing inherent buffering of one card. It would appear that the basket punch, because of the larger number of holes available to be punched at a given time, would be faster than any other technique. Unfortunately, this is not so as a considerable amount of energy must be accumulated prior to punching the card in order to drive the punches through the die.

Most basket punches are not able to "lace" a card or punch out all hole positions simultaneously. This limitation comes about from the problems of building a die set with adequate strength to take the forces that would be generated by all 960 punched positions being activated at one time. If this were to happen, the die would bend and the punches would bind in the die.

A much more versatile punch is the column by column or row by row punch. In this mechanism, the card is advanced either in its long direction or its short direction in steps of a row (80 positions) or a column (12 positions) at a time, and that row or column is punched. As indicated previously, the use of some such techniques requires buffering. Although the punching action must be considerably faster than that occurring in the basket punch, this is more than compensated for by the ease of punch design and the advantages gained by being able to "lace" a card. Where greater speed is desired than can be obtained by a column by column or row by row punch, more than one column or more than one row may be punched at a time, thus providing some of the advantages of the basket punch with some of the advantages of the incremental punch.

2.4.2.3 Stack

Although it is necessary to remove a card from a card punch, it is considerably less obvious that the cards be removed in the sequence in which they were punched and that they should be able to be removed without stopping the operation of the punch. Satisfying these two requirements demands that the cards either be dumped into a hopper or turned upside down and stacked at the bottom of a pile. As there are problems in dealing effectively with static electricity and air flow when dumping cards frequently into a hopper, the most satisfactory means of card stacking is by turning the card and stacking it forceably on the bottom of a pile of existing cards under a hold-down device.

2.4.2.4 Read

On most pieces of equipment, one or more reading stations are provided. (See Figure 2-14) They are usually photo-electric or brush readers both of which are described in more detail under the section on punched card reading equipment. The brush reader is usually used because it holds up well under the shock and vibration induced by the punching mechanism. Modern photo-diodes hold up equally well; however, the hot filaments of bulbs which provide a light source for such photo-diodes are subject to frequent failure. In most punched card equipment, the read station is provided immediately following the punched station so that the data punched in the card may be read back to the computer to provide an output check. To provide this readback check, it is necessary for the processor or a buffer to hold the punched data until after the card has been read in order to confirm that the data re-read was, in fact, that which was intended to be punched. On some types of equipment, this may mean buffering another 960 bits of information. Some modern column by column punching equipment provides read brushes in the position immediately following that of the punched station thus requiring the buffering of only one column (character) of information.

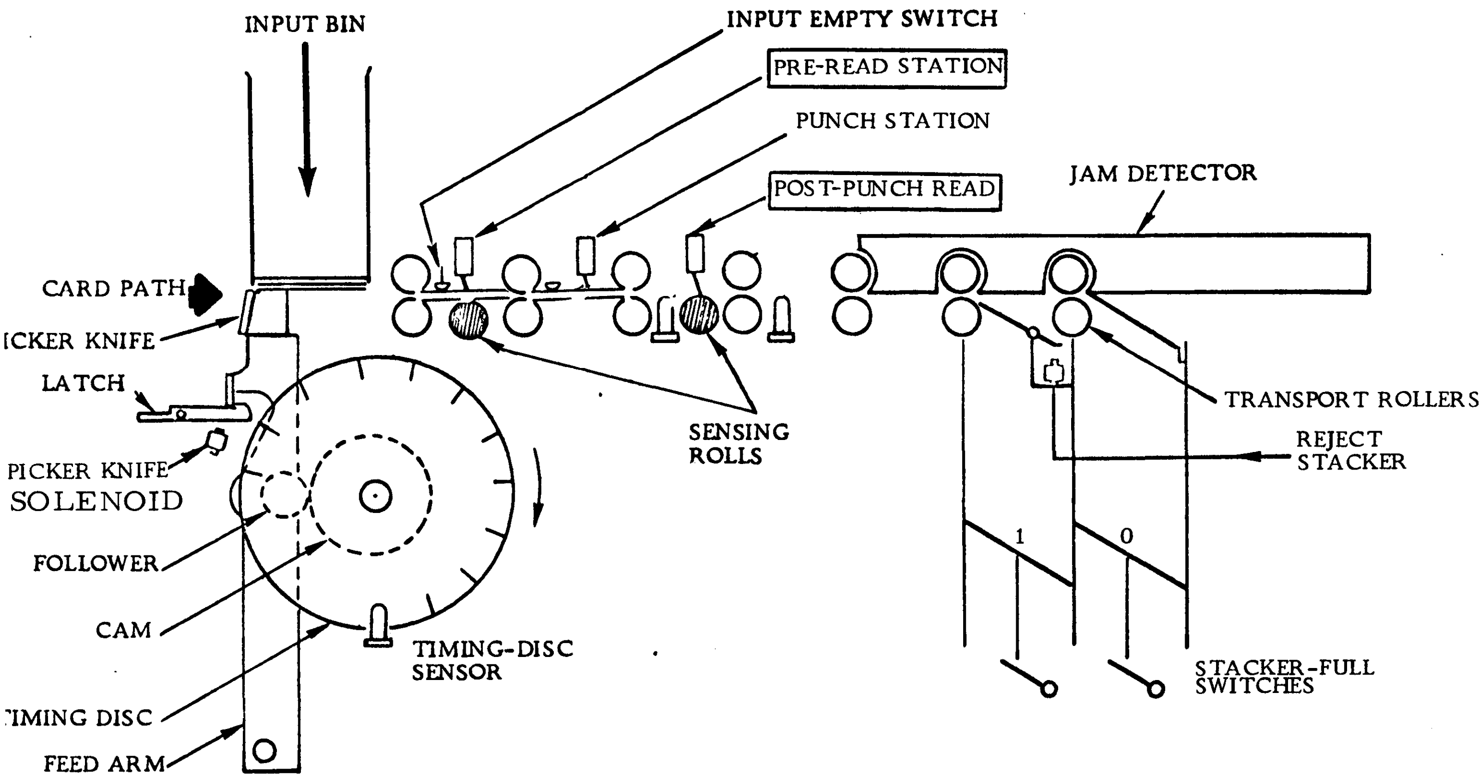

Figure 2-14. Card Punch Read Stations Before and After Punch Stations

In addition to the post-read station, some punched card equipment provides a pre-read station. The function of the pre-read station is to allow a partially punched card to be read into a computer, calculations to be performed on the data thus received, and results or related information punched out into the same card. In all such circumstances, a post-read station is also provided to allow checking of the added information. As indicated in Figure 2-14, the pre-read station comes immediately before the punch station and the post-read station comes immediately following the punch station.

2.4.2.5 Reject

A common device provided on most punched card punches is a reject station. This station is nothing more than an auxiliary output stacker, the entrance to which is operated under computer control. When an error is sensed in a punched card, it is possible to reject the incorrectly punched card and repunch a corrected card. Use of the reject station allows this to occur without reduction in the punching speed of the punch. If the read station were not present, it would be necessary for the processor to stop the action of the machine after punching the incorrect card, thus allowing the operator to intervene and remove the incorrectly punched card. Such a procedure entails the possibility that the operator may accidentally remove a correctly punched card and not remove the incorrectly punched card.

2.4.3 Card Readers

The elements provided in a punched card reader (See Figure 2-15) are similar in most respects to those provided in a punched card punch. In fact, in more modern equipment, it may be difficult for the novice to detect the difference unless the equipment is actually operating. The punched card reader consists of three basic elements:

1) The feeding mechanism

2) The read mechanism

3) The stacking mechanism

Like the punched card punch, a post read station and one or more additional stacking mechanisms are frequently provided.

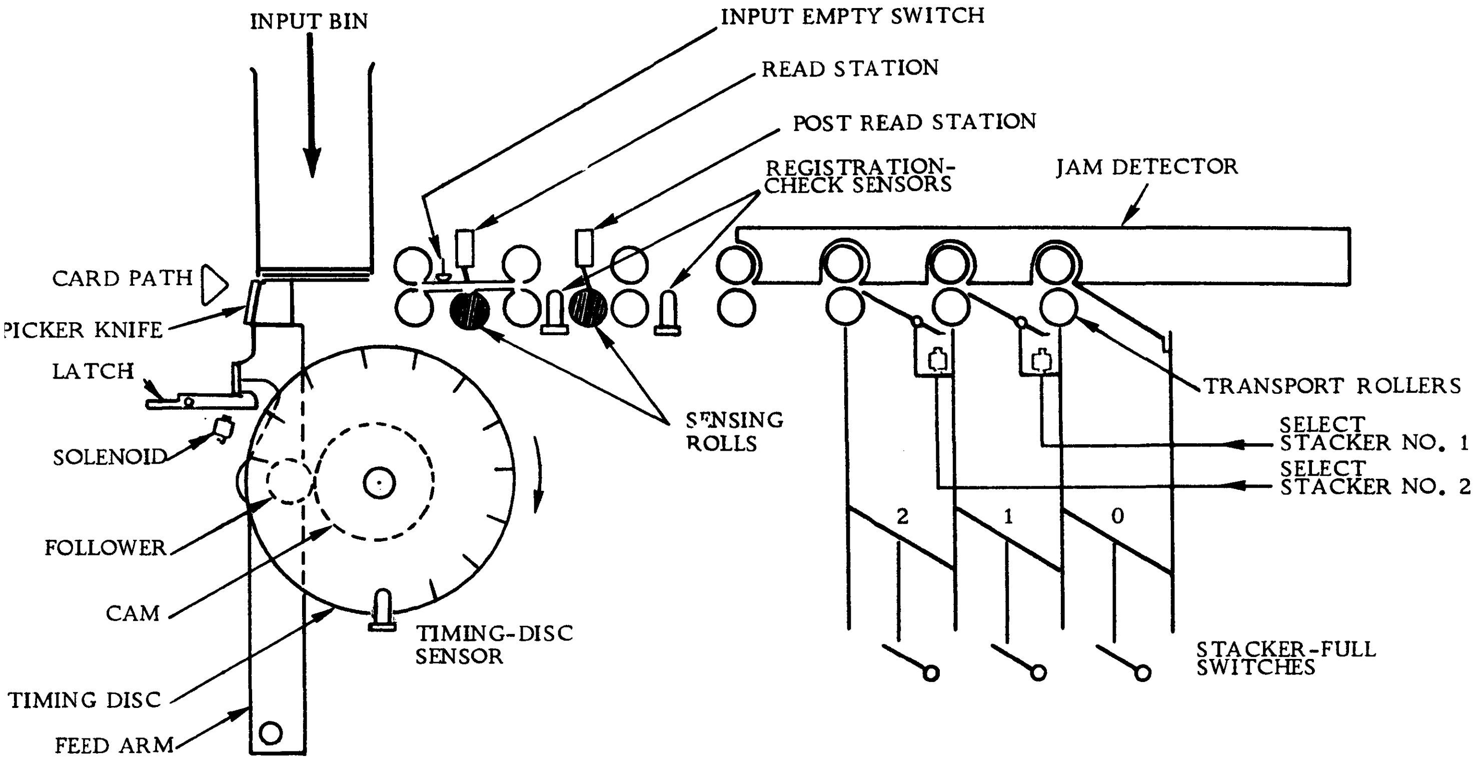

Figure 2-15. Typical Card Reader

2.4.3.1 Feed

The feeding stations of a punched card reader entail the same problems as do those of a punched card punch except that the card is somewhat more difficult to feed having been partially punched and is thus more fragile. In addition, as the reading mechanism is capable of going considerably faster than the punching mechanism, it is necessary for the feeding station to operate at a much higher speed. The advantages and disadvantages of row feeding and column feeding are the same for punched card readers as they are for punched card punches.

2.4.3.2 Read

The card read station is quite different from that of the card punch station in that the punch station requires the physical movement of the card to come to a complete halt prior to driving the punches through the card and the die. The punched card reader, on the other hand, can read the cards while in continuous motion with the result that much higher reading speeds can be obtained than punching speeds. As the card is not physically stopped at each row position or a multiple of row positions, it is necessary to provide some form of card indexing that tells the position of the row or column of the card that is being read. When the card is read a row at a time, only twelve such position indications are necessary and the tolerance of these positions is not a serious problem as the holes are elongated in the position of reading. On the other hand, when the card is being read column by colunn, each row position must be carefully and separately indexed in order to indicate the column being read,and this indexing must be to a considerably closer tolerance due to reading the short distance across the hole.

As punched cards frequently contain a large number of blank columns which may occur at any point on the card, (See Figure 2-16) it is necessary to provide an indexing system that allows a complete and accurate indication of each column position whether it has been punched or not. In photo-electric sensing systems, this is usually provided by a series of photo cells which are covered or exposed as the card passes by the read station. It follows, therefore, that if a card is read column by column, 12 read positions must be provided and 80 indexing positions, or a total of 92 sense positions. If the card is to be read row by row, a total of 80 read positions must be provided and a total of 12 indexing positions, or a total of 92 positions. The advantage of column by column feeding is, therefore, one of interface rather than reduced sensing stations.

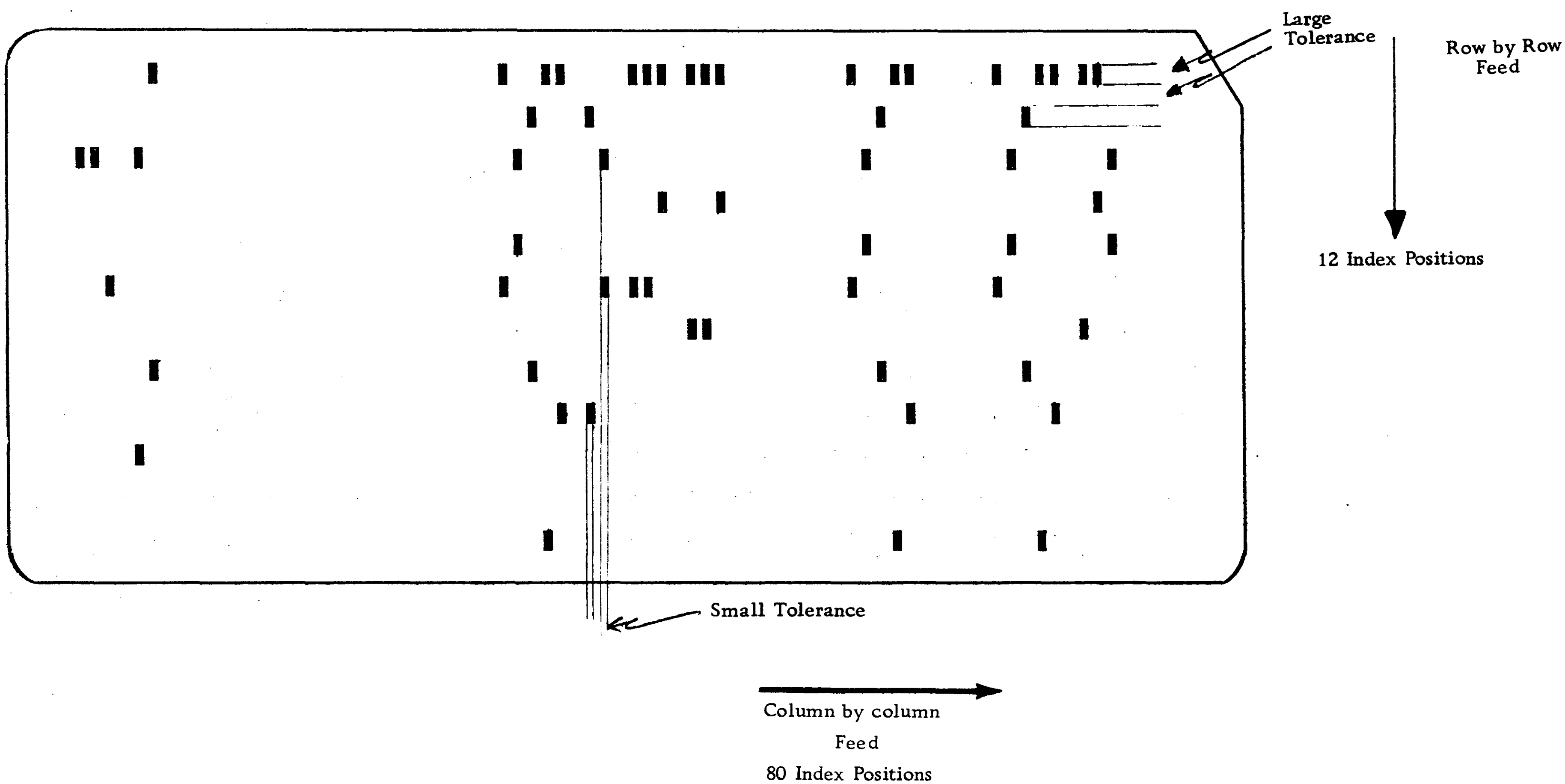

Figure 2-16. Index Positions and Tolerances of Different Feeds

Some manufacturers have taken the approach of sensing the beginning of the card to start a clock which counts the hold positions without actually sensing each position as it passes. This system is usually not too satisfactory as there is no way to detect the slippage of the card as it passes under the read station.

Brush read stations present many of the same general design problems as do photoelectric read stations. Generally, they are limited to lower operating speeds because of the "brush bounce" that occurs as the brush jumps in and out of one hole after another at high speed. Many other systems of hole detection have been used including pneumatics and capacitance; however, the brush read stations and photo-electric read stations have become the most widely accepted and are the most highly perfected read mechanisms; the brush read technique being limited to lower reading speeds than the photoelectric technique.

2.4.3.3 Stacking

The design of the reader output stacker is very similar to that of the card punch output stacker; however, like the feed station, it must operate at a considerably higher speed. Frequently, two, and even three or four auxiliary stackers are provided on readers in order to allow card sorting based on information obtained from the read station.

2.4.3.4 Post Read

Like the card punch, most readers are provided with a post-read station following the initial read station. As punched card readers have frequently been used as a primary data source for computer input, the verification of a read is extremely important. This is usually accomplished by providing a second read station which is used to reread the card. The two read station outputs may be compared on the basis of a bit by bit comparison, a hole count, or with some other statistical technique in order to assure that all holes were read. The post-read station is usually identical in design to the first read station. It is usually desirable to have the post-read station in the card reader follow the read station as closely as possible in order to reduce buffering requirements necessary to hold the information contained by the first read station until it has been confirmed by the second read station prior to its transmission into the computing system.

2.4.4 Magnetic Tape Transports

Regardless of how large a central memory is provided, or how large a random access memory may be available to a computer system, there exists a requirement for storing data for record purposes. This "record data" is information that must be available to be reentered into a computer system at some later point in time. It is desirable, therefore, that such data is in computer language, is recorded at a rate compatible with the speed of the recording computer, and is available for re-entry at a rate compatible with the computer which later uses the data.

There are three areas where the use of magnetic tape proves more advantageous than use of other media.

1) As a buffering device
2) As a storage device
3) As a data transmission device

In the first application, data is accumulated from a low speed input device onto a magnetic tape. The appropriate program is entered into the computer and the data is entered from the magnetic tape. Necessary calculations are performed and results are produced. These results may be produced on an output magnetic tape which is then used to operate an off-line device, e.g., printer, plotter, milling machine.

The advantage gained by the use of the magnetic tape as a buffer is increased efficiency in the use of the computer. This efficiency is gained because a computer need not operate on an on-line basis with relatively slow input or output devices. It can occupy itself only for that minimum amount of time necessary to perform the calculations on the data at hand and produce the results on the highest speed output media available.

In many applications, it is desirable to retain a history of the important transactions that have occurred in the past, of points of initiation of a problem, or of programs. These are retained either for use at a later date or as a form of insurance in case there is a problem with the computer system such that it is necessary to back-track to correct previous errors or to reproduce lost documentation. Magnetic tape is very suitable for such an application since it is able to accept data from a computer at speeds compatible with the rate at which memory can release the data.

Magnetic tape has the lowest cost per bit of storage of any medium available. When properly stored, tape has a long shelf life and is able to store data indefinitely without degradation of the data.

By recording data on magnetic tape and transporting the tape to another location, the tape becomes a highly compact and inexpensive means of non real-time data transmission.

Magnetic tape has two qualities that are valuable in data transmission; it has the lowest cost per bit of storage of any medium available; and it is able to store more bits per unit of volume and more bits per unit of weight than any other medium available.

Although magnetic tape is not insensitive to rough handling, it probably is no more sensitive than other media and, therefore, presents an excellent medium for transporting data from one machine to another.

There are a number of devices that may compete with magnetic tape in any one of the three previously described applications; however, there is no one device that can effectively compete in all of them. The result is that magnetic tape frequently performs combinations of the above functions, and any or all of these may be performed by a single device thus resulting in considerable economy in the use of the equipment. There are devices under development that could compete in all of these areas by copying the functions now performed by magnetic tape; however, there are only two reasons that could justify their replacing magnetic tape in such applications:

1) Lower cost per bit

2) More reliable, and more rugged

As our present use of magnetic tape is a relatively small percentage of its potential, it seems unlikely for a number of years to come that another medium will be able to produce a lower cost per bit than that obtainable on magnetic tape. It is conceivable, that a more rugged "substitute magnetic tape unit" may be produced. If this is so, the unit will undoubtedly have military application in tactical situations.

2.4.4.1 Performance Evaluation Criteria

The rate at which the magnetic recording unit can operate is a function of the following three operating times:

1) Time required by the tape transport to accelerate the tape from rest to read-write speed

2) Time required for the data to be written or read

3) Time required to decelerate the tape to a stop

This may be expressed by the formula:

$$T = A + R + D$$

Where:

T = Total time required to read data from or write data on the tape.

A = Time of acceleration to bring the tape to reading or writing speed. (Sometimes referred to as start time.)

R = Time required to read data from or write data on the tape. (Sometimes referred to as read time or write time.)

D = Time of deceleration to bring the tape to a halt in preparation for another command. (Sometimes referred to as stop time.)

The R term in this equation is a complex term in that it relates to the rate of movement of the tape and the amount of information that is being recorded. If the format of the tape is such that one character is recorded across the width of the tape for each bit recorded along the length of the tape, recording time equals the number of characters being recorded, divided by the recording density used. This yields the number of inches of tape used in the recording process. This term, when divided by the transport speed in inches per second and multiplied by 1,000 yields the number of milliseconds required for the recording process. This may be expressed as:

$$R = \frac{C/d}{r} \times 1000$$

Where:

C = The number of characters recorded

d = Recording density in bits per inch

r = Transport rate in inches per second

When substitution is made in the previous equation

$$T = A + \left[\frac{C/d}{r} \times 1000 \right] + D$$

Where there is not a full character recorded across the width of the tape, C may be arrived at by the product of the number of characters times the number of bits per character divided by the product of the number of bits recorded across the tape times the recording density used on the tape, thus

$$C = (c \times b)/(w \times l)$$

Where:

c = Number of characters recorded

b = Number of bits per character

w = Number of tracks recorded across the tape (track density)

l = Number of bits per lineal inch (recording density)

Incorporating this expression in the original formula, we obtain the generalized formula:

$$T = A + \left[\frac{(c \times b)/(w \times l)}{r} \times 1000 \right] + D$$

Where:

T = Total time required to read data from tape, in milliseconds.

A = Time of acceleration to bring the tape to reading or writing speed, in milliseconds.

C = Number of characters recorded.

b = Number of bits per character.

w = Number of tracks recorded across the tape (track density).

l = Number of bits per lineal inch (recording density).

r = Transport rate in inches per second.

D = Time of deceleration to bring the tape to a halt in preparation for another command, in milliseconds.

To apply this equation, assume the following parameters:

Transport Characteristics:

Transport rate (r)	=	100 inches/sec
Time of acceleration (A)	=	3 milliseconds
Time of deceleration (D)	=	2.5 milliseconds
Track density (w)	=	9 tracks/inch
Recording density (l)	=	1000 bits/inch.

Record Characteristics:

Length (c)	=	500 characters
Character size (b)	=	6 bits

Substituting in the equation for total time:

$$T = 3 + \left[\frac{(500 \times 6) / (9 \times 1000)}{100} \times 1000 \right] + 2.5$$

$$T = 3 + 3.3 + 2.5$$

$T = 8.8$ milliseconds total time required to read one block of data from tape.

Time required to access data is the sum of the start time and the read time. The stop time is then significant only as a delay that must be incurred prior to making another call for information. Since start time and stop time are a constant of the machine, and read-write time is a variable dependent upon the length of information being read or written, it is uneconomical to write short blocks of information with conventional tape transports. The tape transport must, therefore, be considered as a block oriented data storage device.

2.4.4.2 Start-Stop Mechanisms

Start and stop times are closely related to the performance of the drive mechanism which supplies power to move the tape across the read-write head. Three variations in approach are used for this. They are:

1) Pinchrollers

2) Vacuum or pressure capstan

3) Clutch capstan

The pinch roller drive (See Figure 2-17) is designed so that the tape path passes between a constantly rotating capstan and an idler roller. This idler roller may be moved towards the capstan so that is applies pressure against the back of the tape forcing it against the capstan, or away from the capstan to allow the tape to pull out of contact with the capstan. The drive is started by activating a solenoid which moves the pinch roller to clamp the tape between the pinch roller and the rotating capstan thereby causing the tape to be pulled across the read-write head. Some drag is provided against the tape so that it will stop quickly when the pulling force is no longer applied or a braking shoe may be used. When it is necessary to drive the tape uniformly in both directions, two capstans are used and are rotated in opposite directions.

A well designed pinch roller is a very fast acting device and an effective means of driving tape. Pinch rollers are currently in use that accelerate tape from rest to 200 inches per second in 1 1/2 milliseconds. The delays encountered in a pinch roller system are due to:

1) Time required for EMF to build-up in the solenoid.
2) Mechanical inertia of the solenoid and the pinch roller mount.
3) Slippage effect between the pinch roller, the tape and the capstan.
4) Inertia of the tape itself.
5) Shock waves and reflections traveling along the tape from the capstan.

Problems that arise in using of pinch rollers are wear and misalignment. Pinch rollers, therefore, require frequent maintenance and adjustment to give dependable operation.

Another system of driving tape has been developed in which the capstan is perforated, serrated, or porous. Air is either blown or sucked through the capstan to pull the tape against it or to force it away. There are a number of variations in this system which use vacuum, pressure, or combinations of both to achieve the necessary tape-to-capstan contact (See Figure 2-18).

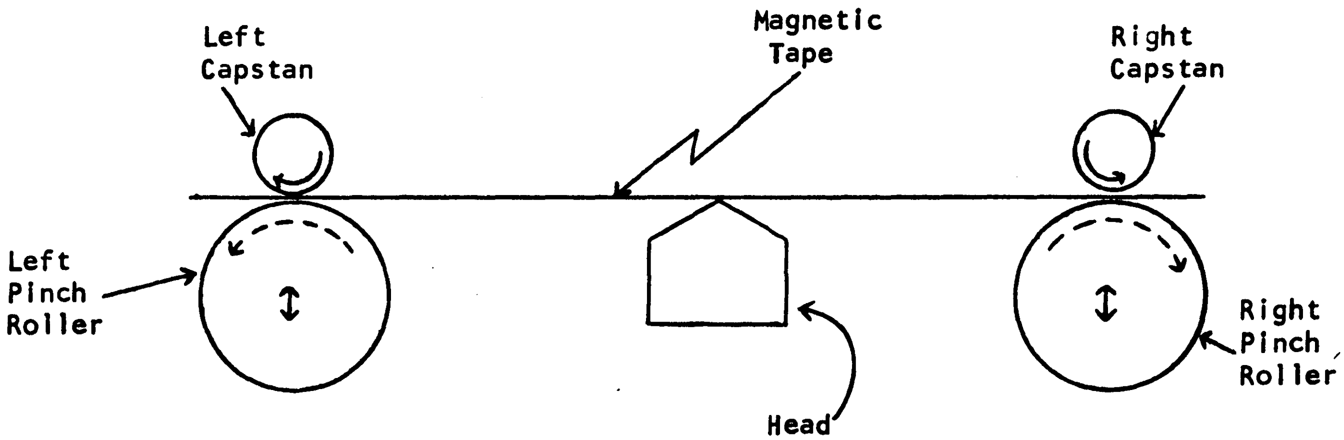

Figure 2-17. Typical Pinch Roller Drive

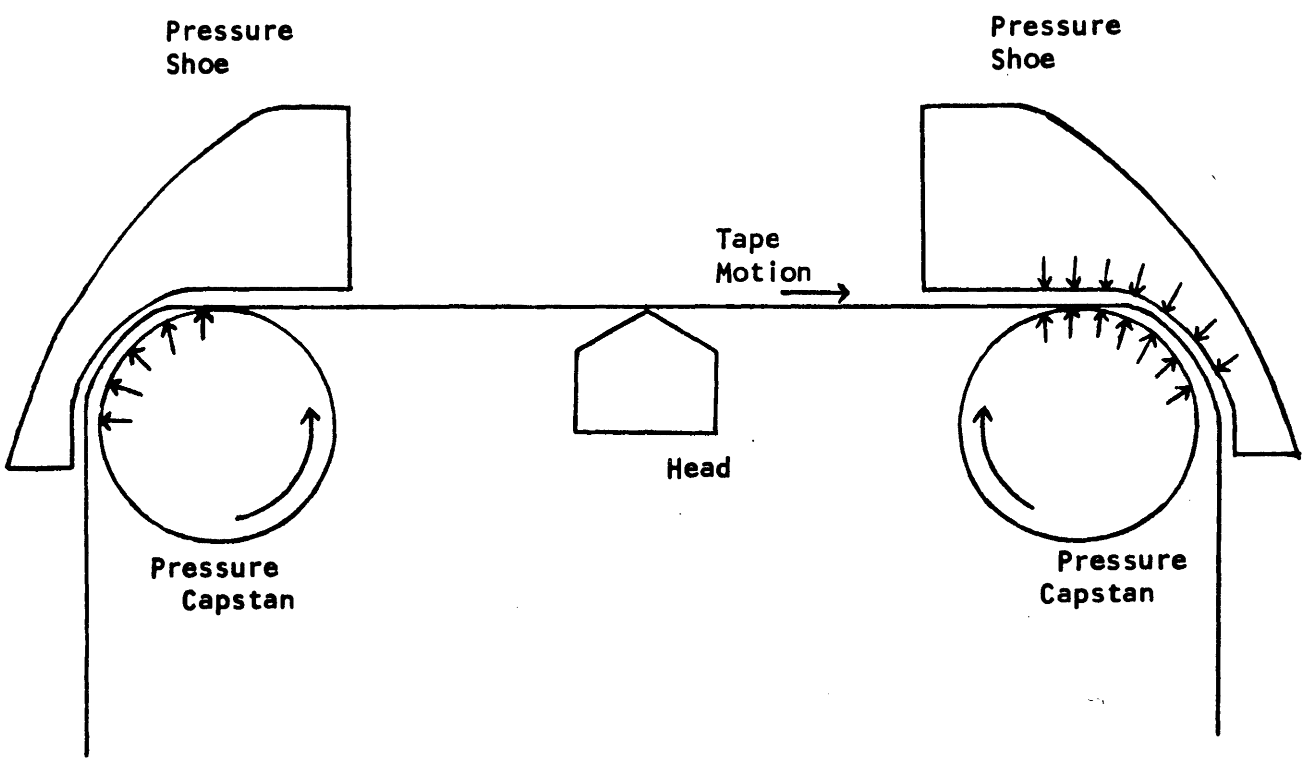

Figure 2-18. Pressure Capstan Drive

Although such systems inherently require lower maintenance than the pinch roller system, none have been developed which can match the start-stop times which a pinch roller system provides. The delays incurred in a vacuum capstan system are:

1) Time for EMF to build-up in an activating solenoid.

2) Mechanical lag of the vacuum valve

3) Rate of transmission of energy through the vacuum system cannot exceed sonic velocity.

4) Time to evacuate capstan or other drive chamber (pneumatic inertia)

5) Tape slippage

6) Shock wave and reflections traveling through tape.

Although some of the effects, such as the tape shock wave, are reduced by the use of a pneumatic system, the necessity of evacuating a finite amount of space in the capstan tends to make pneumatic capstans a slower tape movement technique than pinch rollers.

Clutched capstans were the earliest form of tape movements. The clutch capstan system (See Figure 2-19) uses an idler roller to hold the tape in constant contact with a motionless capstan. The capstan is connected to a motor via an appropriate clutching system and is rotated on demand. The effect is very similar to that obtained by the pinch roller system and the types of delays are the same that are incurred with the pinch roller system. Since the capstan also must be brought into motion, a greater amount of inertia must be overcome than in a pinch roller system. Such capstan systems are, therefore, inherently slower than pinch roller systems.

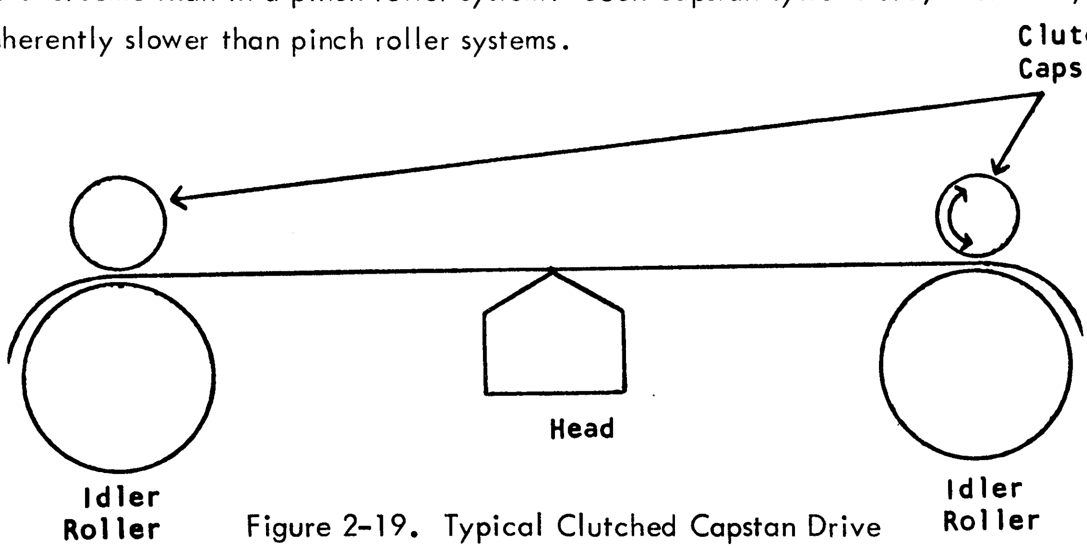

Figure 2-19. Typical Clutched Capstan Drive

Designs exist for use of other tape drive techniques; among them electrostatic and electromagnetic tape drives. None can be currently considered state of the art and are, therefore, not discussed. Table 2-7, illustrates typical and minimum start and stop times for pinch roller, vacuum capstan and clutch capstan drives. The inter-record gap, or amount of space left between the end of one record and the beginning of the next, is a function of the time that it takes to stop the tape after the previous block, plus the time that it takes to start the tape and bring it up to speed for the next block, plus a safety factor. Minimum and typical inter-record gaps are also listed in the type movement techniques chart.

2.4.4.3 Tape Buffering

For a capstan to quickly bring a tape up to speed, there must be a readily available low inertia reservoir of tape from which the capstan can draw, since it must not have to cope with the high inertia of the whole reel of tape. There must also be a corresponding tape reservoir which can absorb tape as the capstan releases it. These reservoirs are called tape buffers. The size of the tape buffer is determined by the relative speed with which the tape servo that winds and unwinds the tape can respond to a demand placed upon it. Although there are a number of other factors involved, there are some limitations placed upon the speed at which tape can be driven by the tape buffering system used; Table 2-7 shows the effect of tape buffering systems on maximum and typical speeds of tape movement and tape rewind time.

The fastest system is the vacuum column buffer (See Figure 2-20) in which tape is unreeled by a servo and looped into a column which is partially evacuated to suck the tape down into a buffer loop. A pneumatic or photoelectric system is used to sense the size of the tape loop. As the capstan removes tape from this loop, the loop becomes smaller until it reaches an unacceptable limit. At this time, a signal is given to the servo to allow more tape to be unreeled into the vacuum column. Likewise, the capstan reels tape into a vacuum column on the other side of the read-write head until the column becomes nearly full. At this point the photoelectric or pneumatic sensing device turns on the pickup servo removes tape from the vacuum column until enough space has been provided for the capstan to dump additional tape. Vacuum column systems are responsive and gentle on tape. Unfortunately, they are also relatively expensive.

Table 2-7

Magnetic Tape Transport Characteristics

Recording Techniques

	Recording Density	
	Maximum	Typical
Non Return to Zero	800	556
Return to Zero	250	250
Phase Modulation	2000	1000

Tape Movement Technique

	Start Time (ms)		Stop Time (ms)		Inter Record Gap (in)	
	Min.	Typical	Min.	Typical	Min.	Typical
Pinch Roller	1.5	3.0	1.5	2.5	0.3	0.75
Vacuum Capstan	2.7	4.0	3.5	4.0	0.5	0.75
Clutched Capstan	-	5.0	5.0	-	-	1.05

Tape Buffering Techniques

	Tape Speed (ins)		Rewind Time (Min/2400 ft)	
	Max.	Typical	Min.	Typical
Vacuum Column	200	120	0.9	1.4
Tension Arms	150	75	1.8	2.0
Tape Bin	150	100	2.0	3.0

Other Typical Specifications

	Maximum	Typical
Tape Length (Feet)	3600	2400
Tape Width (Inches)	1	0.5
Tape Width (Tracks)	20	7
Redundancy	1/2	1/7

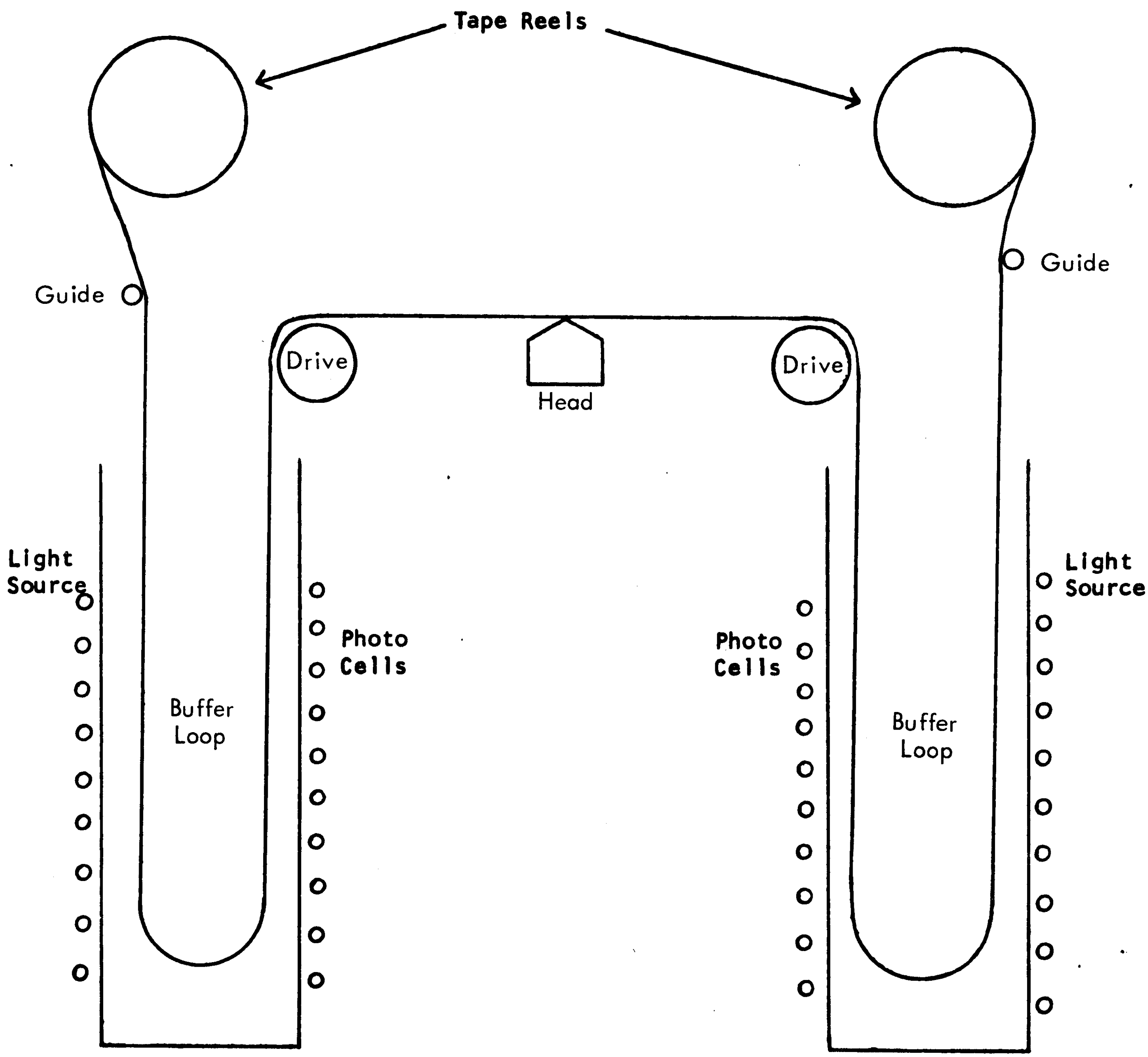

Figure 2-20. Typical Vacuum Column Tape Buffer Using Photo Electric Position Sensing

In the tension arm system (See Figure 2-21), a series of intermediate rollers are provided on a pair of spring-loaded arms. The tape is threaded back and forth between these arms so that as it is used, the arms are brought closer together. When they approach each other, the servo is turned on allowing more tape to be supplied to the buffer. The arms spread out again taking up the additional tape. Such tension arm systems tend not to be as responsive as vacuum column systems because of the higher mechanical inertia that must be overcome. This mechanical inertia also tends to create shock wave problems when starting a high speed system. To overcome these problems, modern tension arm systems are frequently equipped with supplementary vacuum pockets which smooth out the shock waves created by the tension arm inertia. In such systems, the tape supply is actually held and sensed by the tension arms and they are, therefore, the limiting factor in responsiveness and tape speed.

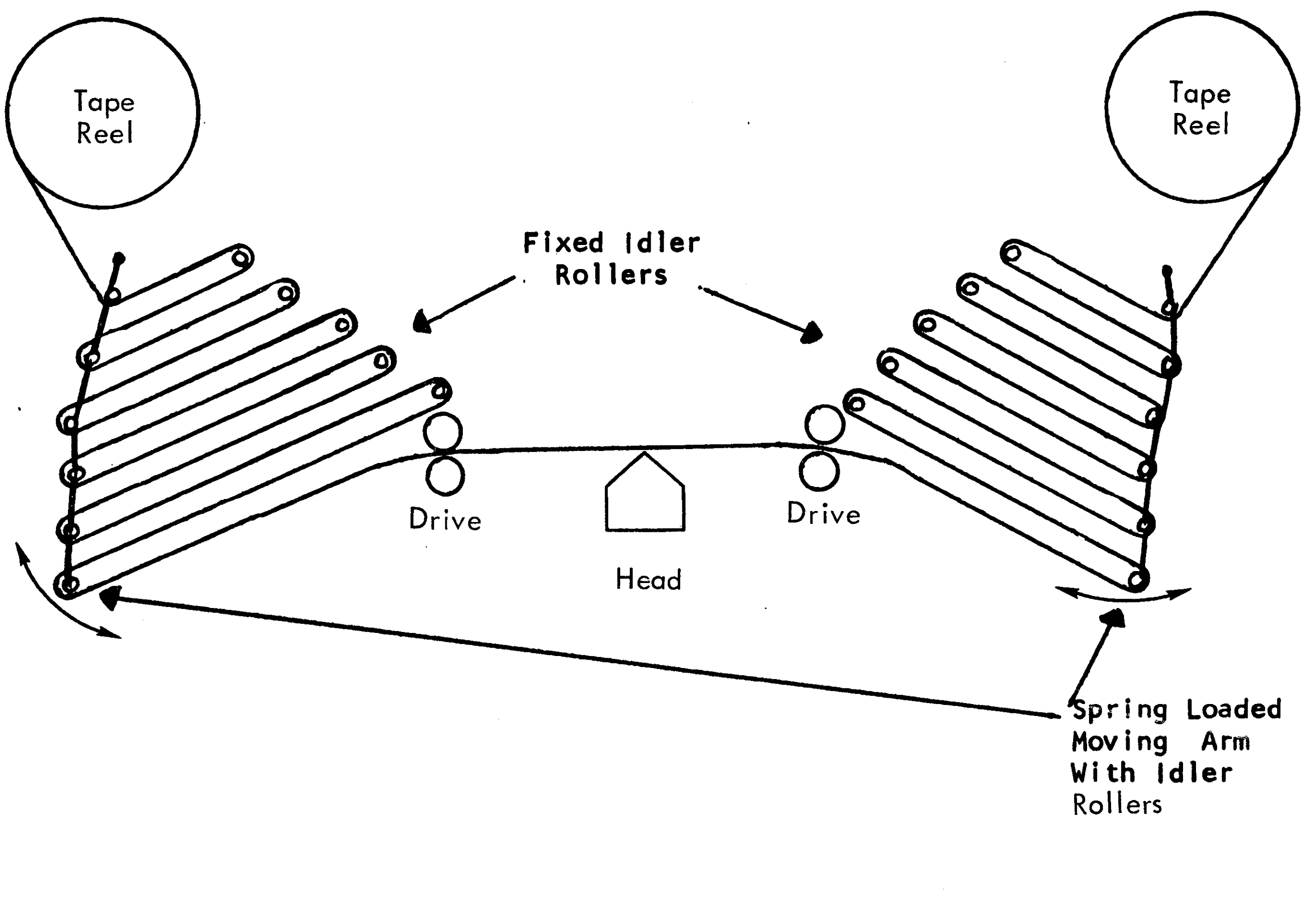

Figure 2-21. Typical Tension Arm or Mechanical Tape Buffering System

The third system that is currently in use as a tape buffer is the tape bin. (See Figure 2-22). The tape bin is much like the vacuum column system in its concept except that it relies on gravity rather than vacuum to hold the tape in the bin. Since the behavior of thin tapes at high speeds is somewhat erratic (the air frequently does not have time enough to get out of the way) the tape bin is not as responsive as the vacuum column. In some systems this is more than compensated for by the low cost of the tape bin technique.

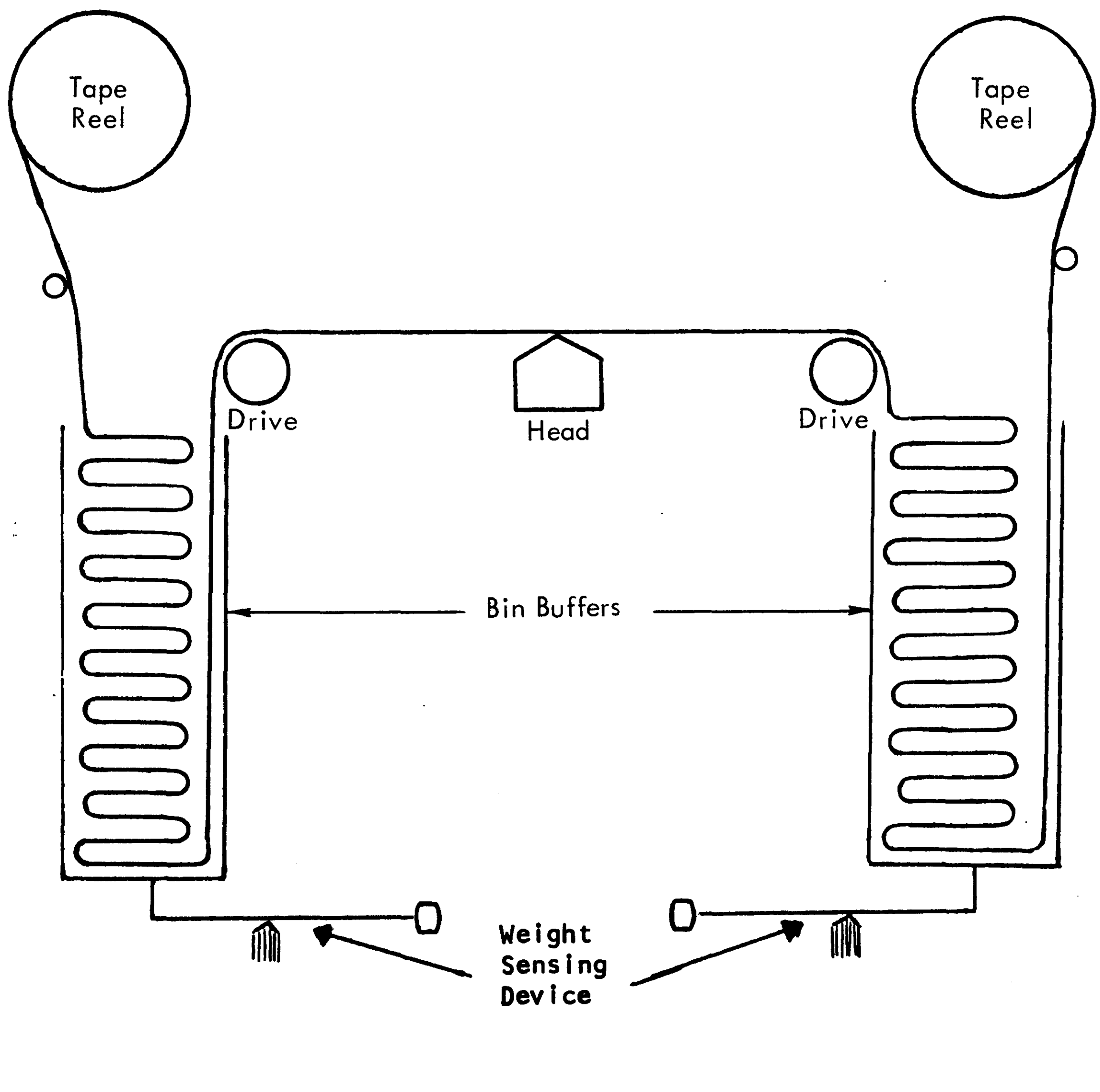

Figure 2-22. Typical Tape Bin, Tape Buffering System

2.4.4.4 Recording Techniques

Unlike the home entertainment tape recorder which records a single track of information or two stereo tracks at a time on the tape, the digital tape recorder records a series of tracks of information in parallel across the width of the tape. In most digital recorders enough tracks are provided to allow a character to be recorded in parallel together with any check bits. The most common technique is to provide six or seven tracks on a 1/2 inch wide or 3/4 inch wide tape. The recent trend has been to go to wider tapes (up to one inch) recording more bits in parallel and not necessarily associating these bits with a particular character but rather to allow them to become a sub-unit of a word. Improvements in manufacturing techniques for magnetic recording heads currently allow the recording of up to 20 tracks across the width of a one-inch tape. Further development of the present state of the art should allow this to be increased to approximately 30 tracks per inch within the time period of the study.

There are a number of techniques which may be used to record the separate bits along a track. Recording techniques (See Figure 2-23), can be divided into two classes, those requiring an additional track of information containing a series of timing pulses, and those which are essentially self-clocking. The non self-clocking recording techniques were the first used because the simpler electronics required allowed them to be produced at a lower cost.

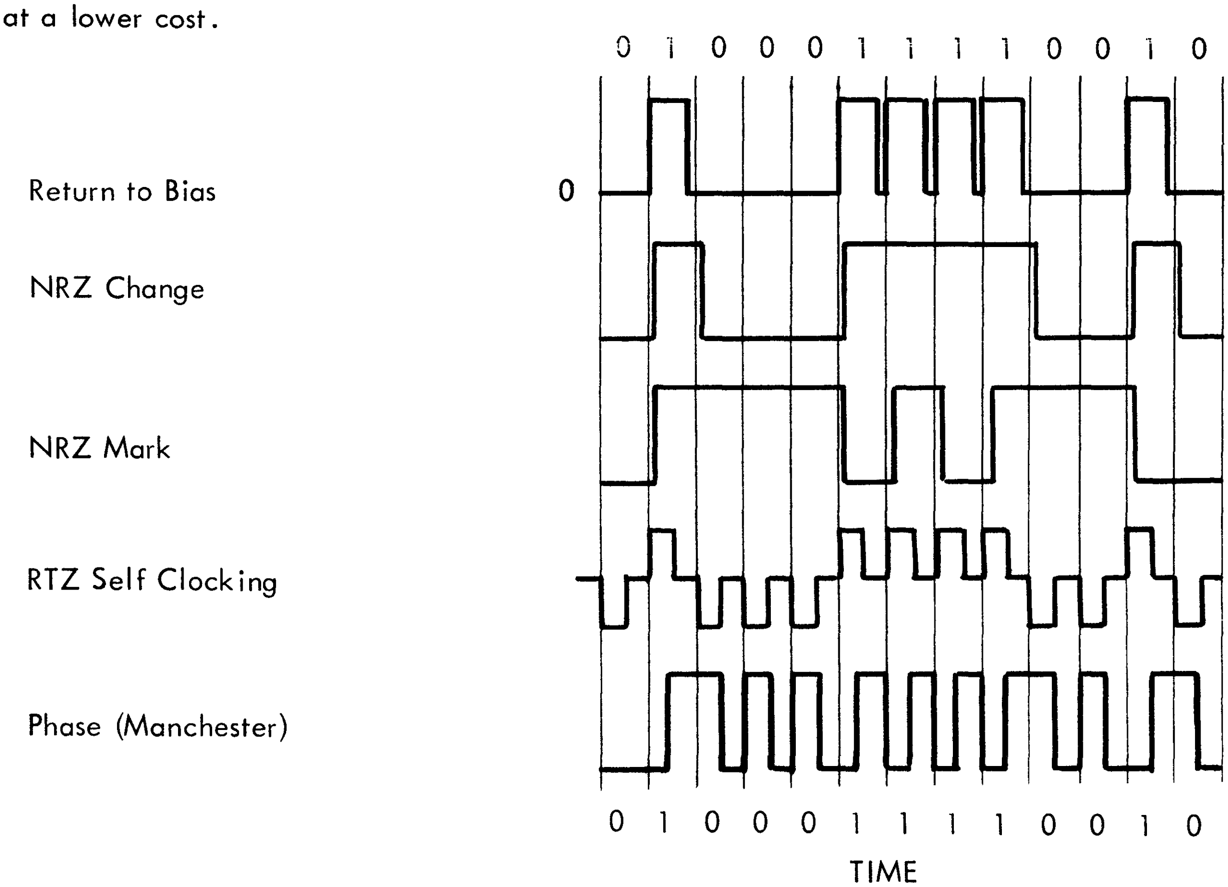

Figure 2-23. Recording Techniques

In return to bias recording, the field of the head is continually polarized in one direction, thus continually recording at zero level. To record a one, the field of the head is reversed momentarily and then allowed to return to the zero bias. Return to bias recording samples all tracks whenever the pulse is sensed in the timing track.

During non return to zero change recording, a bias is maintained until a one is sensed, at which point the polarization of the head is reversed. It remains polarized in the reversed direction until a zero is sensed, when it is reversed again. The action is similar to that of return to bias except that the flux does not return to the bias level after the recording of each one, with the result that fewer flux reversals are required in the head.

Non return to zero mark is similar to non return to zero change except that the flux change is used to indicate the presence of a one rather than the change from a zero to a one or from a one to a zero. Any change in flux level is considered to be a one while any constant flux level is considered to be a zero.

Return to zero recording places no bias on the head except during the period of time in which a bit is being recorded. The direction of magnetic flux, therefore, determines whether the bit is a zero or a one. After recording either a zero or a one, the head is allowed to change to a zero state with the result that each change in the flux from zero represents a bit and the direction of change represents whether the bit is a zero or a one. It is evident that return to zero recording requires many more flux changes than do the previously discussed techniques with the result that more expensive electronics are required to obtain the same speed of operation.

Manchester recording obtains its timing from a series of pulses at the beginning of a tape which are used to start a clock. This clock is set at each phase reversal that occurs within an acceptable margin of a phase reversal time anticipated by the clock. Within this time margin, the direction of phase-phase reversal is sensed, a positive-going phase reversal is considered to be a one, and a negative-going phase reversal is considered to be a zero. Like the return to a zero system, the Manchester system is self clocking; however, it requires less phase shifts than does the return to zero system. Further, since the Manchester system depends upon the direction in which the flux is moving, not upon the level of flux, it is much less sensitive to noise than are flux level sensing systems.

Current Manchester recording systems have the ability to record densities up to 2000 bits per inch and by 1970, it is anticipated that such systems will be able to record well in excess of 3000 bits per inch.

2.5 CONCLUSIONS

The following is a summary of input/output technologies available for use in a naval command and control system of the 1970's.

2.5.1 Keyboards

Currently available technology is adequate to provide for the construction of any desired configuration or speed of keyboard. Although most of the keyboards now in use are electromechanical in nature and involve the use of a large number of moving parts, it is today possible to build a keyboard which senses finger contact electronically and uses solid state logic to generate coded output. Such a keyboard would have the advantage of eliminating the wear problems associated with moving parts and allowing the unit to be sealed against climatic conditions. Unfortunately, such a keyboard would not provide the proper "feel" to allow the machine to acknowledge to the user that he has activated a key. Further, since no key motion would be involved, the operator could not rest his fingers upon the keys. An interesting compromise would be the design of a keyboard with moveable keys, the movement of which would be electromechanically sensed without further moving parts. Such a keyboard would minimize moving parts and allow climate resistant if not climate proof construction.

2.5.2 Function Switches

The same solid state sensing techniques that can be used in keyboards are also applicable to function switches. The effective use of function switches is complicated by the need to periodically change switch designation. Present techniques for changes in switch designation include changeable overlays, back projected titles, and selectable identification roles. No significant improvement is seen in the techniques available to identify switches. Currently, changes in switch identification are under operator control. It is anticipated that present techniques may be modified to allow computer control over the identification of selected function switches,thus allowing the computer to inform the console operator of his ability to select from new modes of operation.

2.5.3 Graphic Input Devices

Present graphic indicator technology is used either to select a target from a series of possible targets or to indicate an X-Y coordinate. A number of reasonably satisfactory technologies are currently in use to perform this function. These include joy sticks, ball position indicators, light pens, and conductive pens on resistive surfaces. Future systems may require the entry of line point information. Technology suitable for the entry of such line information now available in devices such as the RAND Tablet.

The RAND Tablet, uses a free pen-line instrument to draw upon a horizontal surface below which are printed circuit cards containing a series of horizontal and vertical lines. When the tip of the pen is placed against the tablet, a pressure sensitive switch in the tip of the pen provides a pulse which is sensed by the horizontal and vertical wires immediately below the tip. This pulse is used to indicate the position of the pen in a 20 bit binary code. As the pen is moved across the surface, a series of such points are automatically generated indicating the position and movement of the pen. Devices of this type are useful both as position indicators and as graphical input devices allowing greater flexibility of input than do current position indicators.

2.5.4 Character Readers

Character recognition technology have been evolving slowly but steadily over the past ten years. To date, most equipment has been built to order, with the result that there has been little standardization; hence, the cost of the equipment has been very high. Due to the high cost of character recognition equipment, it is doubtful whether the cost per character read will drop below that for punched card, punched paper tape, or other machine language systems. Further, it is unlikely that character recognition will be able to achieve the reading accuracy that can be achieved by machine language systems. Since few of the inputs to a Navy data system need occur in a printed form, it is not necessary that character recognition equipment be used as a part of future Navy command and control systems.

Character recognition equipment may be economical in applications where data must be created in printed form at a number of separated geographic points and processed in a central location. It is also useful where data is generated in a central location by a high-speed printer and is distributed to a number of widely separated points to be used by human beings and later collected for re-entry into the computer system. In both cases, responsible care must be taken of the document for it to later be read by the character recognition equipment. These conditions are not typical of a Navy data system, and it is unlikely that character recognition will be useful in such a system.

2.5.5 Speech Recognition Equipment

Speech recognition equipment has often been suggested as a possible input for use with computing systems. Our investigation has indicated that speech recognition equipment will not be available for use with 1970 ACDS. When useable speech recognition equipment does become available, it will initially require the use of sound isolation booths and accept only a limited variety of fixed format vocal commands by specially trained personnel.

2.5.6 Line Printers

Electromechanical and electronic line printers will be available for use in future Navy data systems. Electromechanical printers will be able to provide printed output of multiple copies at rates greater than 1000 lines per minute using a 64-character type font. These printers should be particularly useful in the preparation of reports, orders, inventories, etc. Electro-optical printers will be available with speeds up to 20,000 lines per minute using type fonts of up to 200 characters. These printers require the use of special paper and will produce only an original copy. They are, therefore, more useful to provide printed message communication than they are to provide documents such as reports and orders.

2.5.7 Character Printers

Character printers are particularly useful in applications where low cost, low power, low weight, and small size are of prime importance. Technology is currently available to allow the production of character printers that can operate in a range of 60 to 120 characters per second using a 64-character type font. All current character printing technology is electromechanical in nature and is, therefore, capable of producing multiple copies if required to do so.

2.5.8 Plotters

Two types of plotting equipment will be available for use in future systems. They are the all-electronic plotting equipment, and electromechanical plotting equipment. The all-electronic plotting systems use cathode ray tube outputs for direct viewing or in conjunction with photographic film or photo sensitive papers. They are so closely akin to displays that it is anticipated that future plotting requirements for command and control systems will be filled by supplying a hard copy output attachment for use in conjunction with whatever ACDS display system is adopted. The limitations of display equipment are discussed in Sections 3 and 4 of this volume and are the same as those that would apply to all-electronic plotting systems.

Electromechanical plotting equipment will also be available; however, it seems to possess few advantages over the plotted output that can be obtained on display equipment. This equipment will be dvailable to plot in either line or point mode and to provide printed output for point identification at rates up to ten characters per second.

2.5.9 Vocal Output Equipment

Two types of vocal output will be available for application in future Navy systems. One type will select from pre-recorded messages; the other will select from pre-recorded words which used in proper sequence produce an output message. Pre-recorded message output will be available with a selection time of 500 milliseconds using any desired speaking rate. Word assembled vocal output should be available that will provide the use of several hundred words with no more than 100 milliseconds pause between the selected words.

2.5.10 Card Punches

Technology is currently available to allow production of militarized unit record equipment for use in a 1970 command and control system. Such unit record equipment could use magnetic cards, printed cards or punched cards. As punched card technology is far more advanced, better understood, and more reliable than magnetic card or printed card technology, and as the use of the punched card is already established in the Navy's integrated operational intelligence center, inventory control, and personnel record-keeping, future Navy unit record equipment will probably be militarized punched card equipment that will punch at rates of up to 300 cards per minute and read at rates of up to 1000 cards a minute. If the equipment is designed to read column at a time rather that row at a time, input/output buffering can be reduced to several characters.

2.5.11 Paper Tape Punches

Little advance is foreseen in punched paper tape technology. Current perforators can operate at speeds of up to 300 characters per second and readers can operate at speeds of 1000 to several thousand characters per second depending upon whether they must stop with the character in the read position. A future substitute for perforated paper tape is seen in incremental magnetic tape.

2.5.12 Incremental Magnetic Tape Equipment

At present, incremental magnetic tape mechanisms are more expensive than equivalent perforated paper tape mechanisms. Typical recording rates are in the order of 300 characters per second and are, therefore, little improvement on present perforated tape systems. As magnetic tape systems use far less moving parts, they should be able to provide higher reliability with less maintenance. Magnetic tape is a reuseable media and is therefore not a consumable supply. It is used at a higher recording density (200-556 bits per inch on magnetic tape as opposed to 10 bits per inch on paper tape); and it requires considerably less storage space than paper tape due to its high recording density in the base material. It is readable in block format at high speeds on conventional magnetic tape transports. As the base material is mylar, rather than paper, magnetic tape is less subject to tearing and can operate over a wider range of humidity than can paper tape. It is, therefore, recommended that the Navy pursue development of digital incremental magnetic tape drives as opposed to further development of militarized perforated tape equipment.

2.5.13 Block Oriented Magnetic Tape Equipment

Current tape technology is suitable to allow the design and production of a militarized tape unit with peak transfer rates of up to 1,000,000 characters per second utilizing recording densities in excess of 1,000 bits per inch, tape movement rates of up to 200 inches per second, and providing 2 milliseconds start time. The present militarized tape unit available to the Navy provides peak transfer rates of up to 90,000 characters per second with recording densities at 450 bits per inch, tape movement rates of 100 inches per second, and provides a start time of 2.125 milliseconds. Although current technology allows improvement in recording densities and speed of tape movement, little improvement can be made in the effective transfer rate because of the efficient start times on the present system.

The present Navy magnetic tape system is well conceived, well designed, and takes advantage of the best currently available technology. It produces start times and transfer rates that should meet the needs of most Navy systems. One deficiency that is seen in the present system is the tape cartridge. This cartridge is pre-loaded with tape which is semi-permanently attached to two 7 1/2 inch diameter internal reels. The cartridge is provided with a snap-on dust cover to protect the tape during handling while it is out of the machine. The use of a tape cartridge and automatic tape loading is a most desirable feature, however, the two-reel tape cartridge requires twice the amount of physical storage of that required for a single reel tape cartridge, thus doubling the shipboard space that must be allocated to the storage of tape.

As the dust cover provided for the present tape cartridge must be removed and replaced by the operator, physical damage to the tape is still possible and additional loading time is required to remove and replace the protective cover. It is recommended, that the Navy investigate the possibility of providing a single-reel self-threading tape cartridge with an automatically opening and closing dust cover.

A possible future substitute for magnetic tape systems is the "solid state magnetic tape unit" which is being investigated in conjunction with the CCIS-70 Program. Although such a unit will not be available for use in a 1970 system, it could become available in the late 1970's and is certainly worth continued investigation.

Section 3
DISPLAY SYSTEMS

3.1 ON-LINE SYSTEM ENVIRONMENT

On-line visual display and communication devices permit a close interrelationship between man and machine. For example, in the CTF Node environment*, the data processing system receives and displays status of forces information from communication devices. The operations staff analyzes the incoming information concerning own forces and those of the enemy. The machine receives additional information from the staff and the external world and updates the situation display. The staff evaluates the military situation based on the information the machine displays and makes additional requests, since it is impossible for the system to cover, under normal output procedure, data reflecting all contingencies in which the commander and staff might be interested. The staff identifies certain courses of action; the machine computes hypothetical effects ** based on various possible choices. The commander makes a decision and the machine communicates related commands and records them. Figure 3-1 depicts this overall process.

The data processing system from the point of view of the military commander and his staff is shown in Figure 3-2. Information is received from the system via console and group displays, and from hard copy printouts. Console displays assist in the preparation and formation of group displays and they respond to particular requests. Group displays represent the major standard output reflecting situations which change fairly rapidly. Hard copy outputs represent backup data which is frequently used for reference. The data processing system is simply a "black box," from the commander's viewpoint.

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*Discussed in detail in <u>Volume III</u>, <u>Integration</u>.

**The function "computes hypothetical effects" is futuristic. At the present time, there is little real-time or operational war gaming capability in command systems to help the commander make his decision during actual operations. This may be feasible by 1975.

MAN/MACHINE COORDINATION

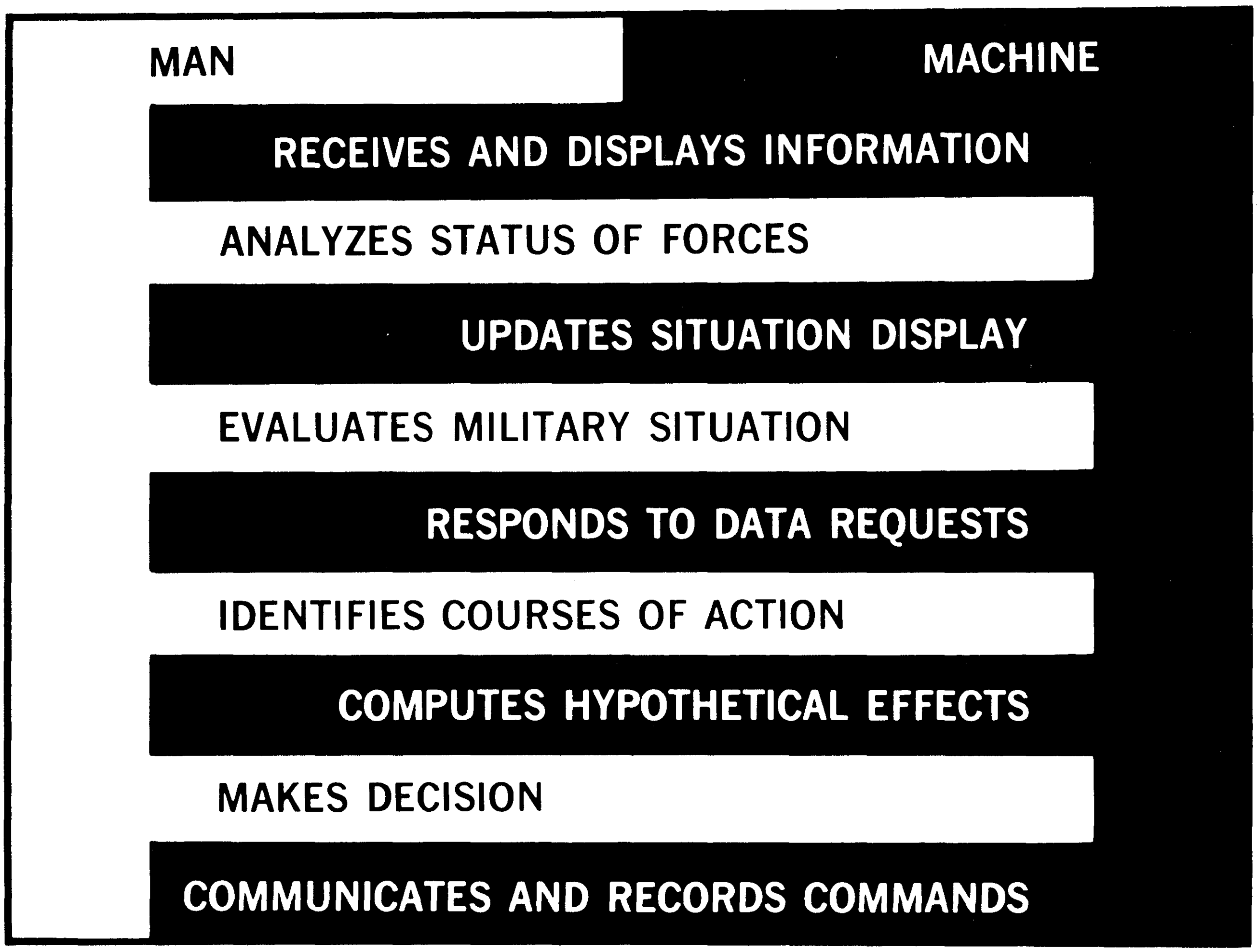

Figure 3-1. Man-Machine Concept

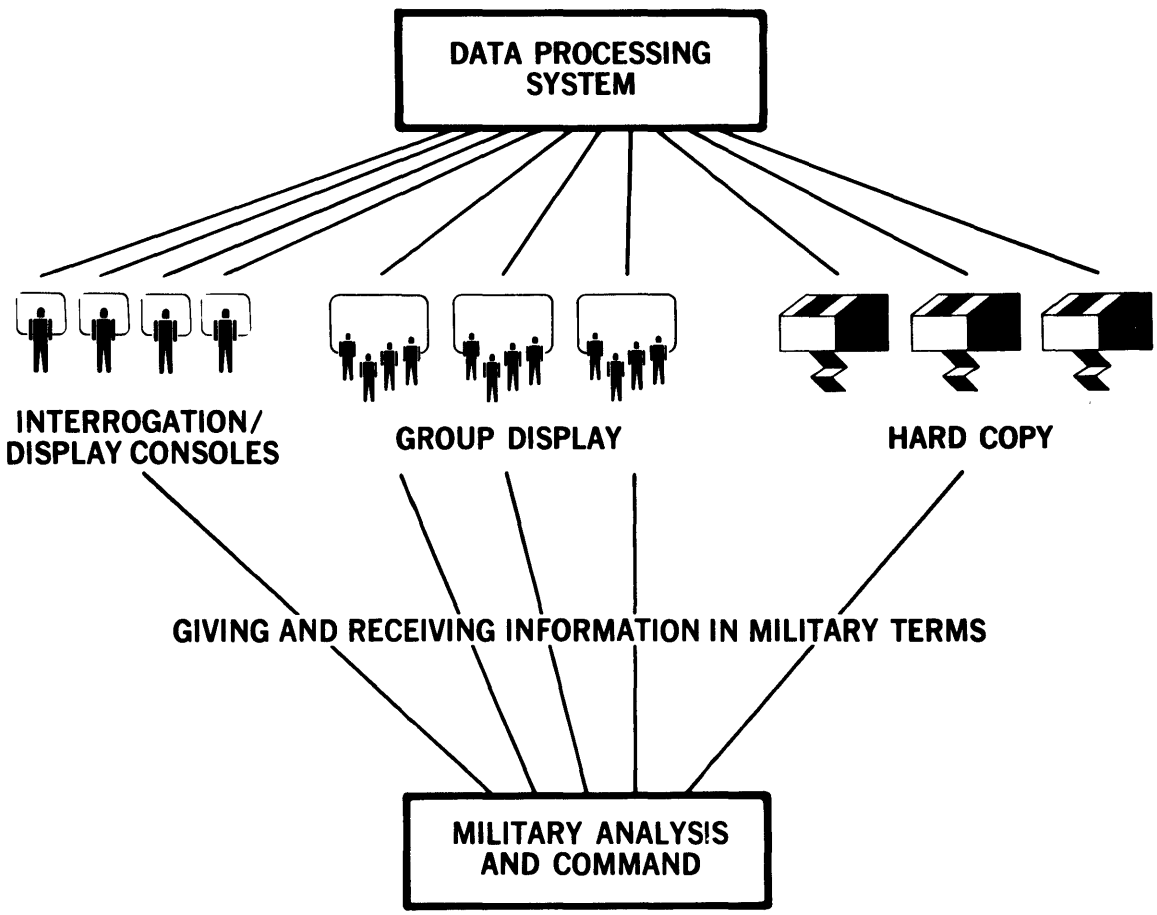

Figure 3-2. Military Command-Data Processing System Relationship

Consider the problem of interrogating the information files in a system. If these files contain status information regarding forces and resources, typical interrogations of the system might be:

1) Tabulate all POL* facilities on Russian and Chinese bomber bases whose capacity is greater than 500 metric tons of jet fuel.

2) List all NATO air defense bases with a probability of survival greater than 85%.

3) List all Navy bases with a greater than 75% probability of survival and whose residual capacity of POL is greater than 20 percent.

The conventional procedure employed in unautomated systems is to require the user to fill out a request form and await the completion of the steps shown in Figure 3-3. The computer input format used in step 4 normally requires a trained specialist to convert the terminology used by the requestor to machine nomenclature. This process requires manual table look-ups and transcription from code books, indexes and tables of acceptable terms. Disadvantages encountered in this process are:

1) Need to carefully adhere to spelling and to form; for example, abbreviations, plurals, possessives, etc. may not be permitted.

2) Requirement to use special words; synonyms may be prohibited. The terminology of multiple users varies so that a common vocabulary acceptable to all is not readily achieved.

3) Use of special punctuation; the compounding and marking of segments of the query may lead to logical errors.

4) Need to learn special rules and codes. Change of codes will effect all users at the problem originating level.

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*Petroleum, Oil and Lubrication.

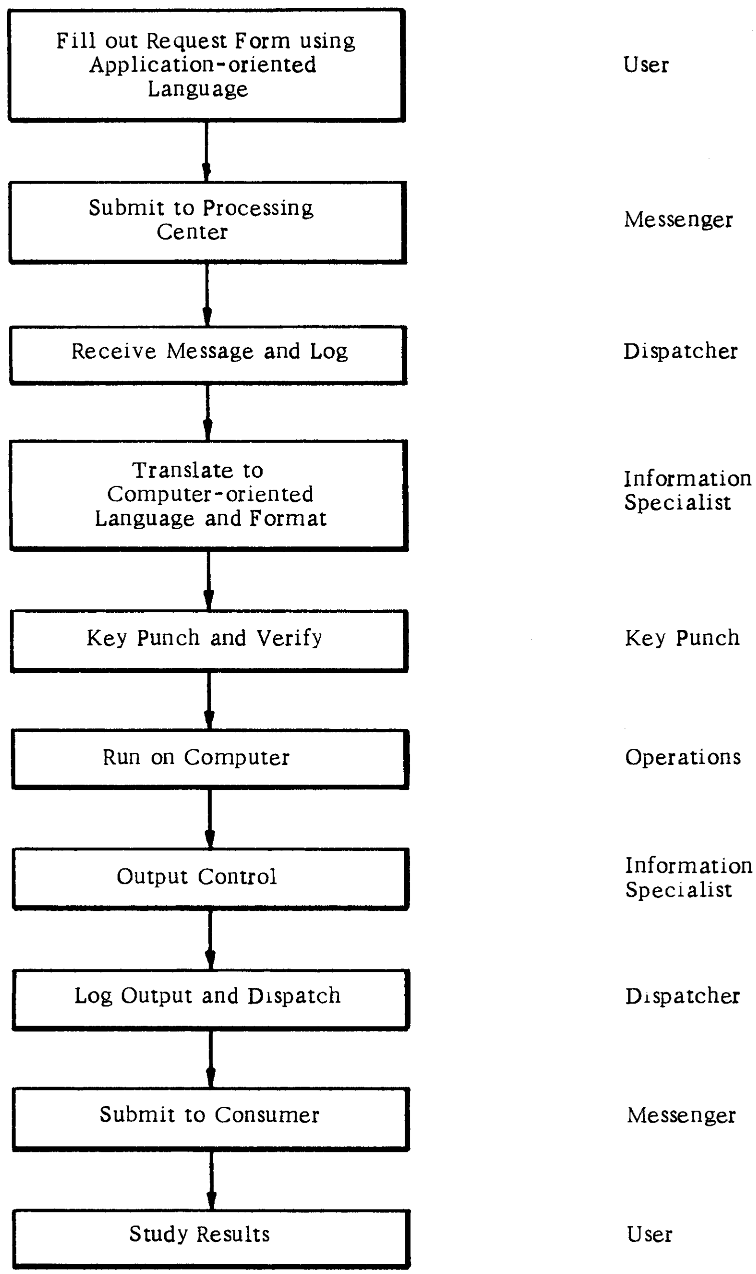


Figure 3-3. Conventional Procedure In Fulfillment of Information Requests

An on-line display console permits automation of most of these rote procedures by providing the consumer a query entry device and subsequent display station. Time delays are eliminated in bypassing at least eight independent steps. Avoided are inconveniences of manually maintaining message security and logs. Most significant, however, is the control of clerical errors.

Thus, typical characteristics associated with on-line display systems include:

1) Real-time Operations. This refers to the responsiveness of the system to individual operator initiated actions and to the performance of the total nodal operation. The former involves entry of information, under program guidance, to make up a complete message or request and processor response to that message or request.

An example of information entry is the step-by-step composition of a message by use of a keyboard. Typically, each key generates one or more characters of information which are collected, operated on and stored by the computer. Pressing a key causes a display to be generated, which provides guidance for the next step or indicates the requirement for additional information. This mode of operation must permit the operator to enter data at his own speed; thus, he must be permitted to press keys at a 60 wpm typing rate or keystroke at 200 millisecond intervals.

Real-time, in this instance, is a measure applied to the ability of a human operator to react. In an assumed "conversation" mode of information entry, requiring a display in return for a key selection, a response time of several seconds is adequate.

The second operation of response is the fulfillment of a particular request by the processor. This may involve:

a) Request validation.

b) Information retrieval.

c) Information transformation.

d) Data formatting.

e) Output generation.

Depending on the specific situation, the response time required of the system will vary. Table 3-1 lists the response times for fulfilling requests in one particular strategic command and control system.

Similar requirements must be developed for an ACDS. If the response time for a group display is reduced to under five seconds, there is a requirement for electronic and not mechanical character generation. Conversely, the response time for consoles employing CRT's is not limited by the console hardware, but rather by the internal data organization and the access time of the data storage devices.

2) Random Transactions. Unlike the periodic radar returns in the case of the NTDS PPI consoles, man-initiated input transactions are generated at random. It is, therefore, desirable to provide servicing of the consoles on a demand basis. Such a requirement is best served by the time sharing of a central processor by many on-line stations.

3) Many Stations. Generally, the on-line system has many transaction stations. A land based logistics system may incorporate thousands of inquiry sets, while a CIC* includes dozens of consoles. These multiple users compete for servicing by the central processor. In the case of an ACDS, for example, several dozen console stations may be employed.

4) Independent Functions. If many users operate in parallel, individual functions or tasks may vary from one station to the next. For example, in the NTDS, many different operations are defined, any one of which may be initiated at any of these stations (threat detection, classification, and weapons assignment). This is also true for CTF Node controller stations.

* Combat Information Center

Table 3-1. RESPONSE TIMES

	Form of Output Presentation		
	Hard Copy	Console	Group Display
Individual	10-30 minutes	3-10 sec.	X
Group	X	3-10 sec.	30 seconds

5) File Access. Multi-users operate on common files. Hence, file order and file integrity must be maintained. The latter is a problem with operations for extracting information and modifying the data base at the same time.

3.2 HARDWARE CHARACTERISTICS

Display hardware is typically designed for specific systems. Hence consoles vary in capability and capacity. Nevertheless, console characteristics currently appear to be more uniform. Large group displays have never been produced in any quantity so that it is almost impossible to speak of their typical features.

It is possible, however, to classify display hardware characteristics and from such a classification develop system building blocks. Furthermore, such an approach permits the development of a software concept and operating system.

3.2.1 CRT Displays

The following features are common to most CRT type displays:

1) Alphanumeric Keyboard. This consists of a set of keys comparable to a standard typewriter keyboard. In addition to the letters and figures, punctuation and special symbols are included. Sixty-four possible characters are usually (some reserved for control functions) available, since 6 bits are conventionally used for symbol representation. Since there are 43 keys on a typewriter, this implies the need for a shift key or augmented keyboard.

2) CRT. This is a cathode-ray tube or oscilloscope unit capable of displaying a set of characters or symbols with line drawing as a possible option. Generally there is a one-to-one correspondence between the symbols available on the alphanumeric keyboard and those that can be generated with the CRT. Tube face sizes are usually 19 to 21 inches.

3) Function Keys. This set of keys is assigned to application-oriented procedures. Individual keys may represent a call for an action, or groups of keys may be associated, forming a message calling for action. These keys are usually under program control. To make

the device general purpose or multi-purpose, it is desirable to have the meaning of these keys vary on demand of the operator. One convenient way to achieve this variability is by a replaceable mask or overlay as incorporated in several commercial products (examples: BR 85, IBM 2250, and the 473L Integrated Console).

4) Status Indicators. Data processing system status, both internal computer and console, is shown by status indicators. These indicators may be labeled neons; their "on" or "off" conditions indicate status.

5) Alarm Indicators. Alarms or error indications are conveyed by a set of labeled neons. Buttons may be associated with these lights for operator recognition and resetting. Audible alarms may also be included.

6) Control Keys. These keys are assigned to specified tasks and support functions by which system control, data entry, and status requests are made. These keys are usually under hardware control.

7) Light Pen. The user/operator can index any symbol on the CRT by using a hand-held photoelectric device.

The following is an illustration of typical assignments to some of the panel elements:

1) Alphanumeric Keyboard

   a) Alphabet.

   b) Numbers.

   c) Punctuation.

   d) Special symbols.

   e) "Carriage" control.

   f) Shift control.

2) Control Keys

   a) Hardware configuration control.

   b) Console off-line function control.

   c) CRT display control.

   d) End of message.

3) Status Indicators

   a) Equipment status.

   b) Queue status.

   c) Processing modes.

4) Alarm Indicators

   a) Data errors.

   b) Procedure errors.

   c) Equipment alarms.

Table 3-2 lists some of the features currently used by display consoles in operational systems (including typewriter and NTDS console items for comparison). More detailed specifications are given in Appendix V-C. This table suggests the range of hardware and mix of features which are "off the shelf" items. The indicated costs were obtained from the manufacturers and probably more than adequately indicate the major deterrant to the wider use of these devices. It is predicted, however, based on our considered opinion, that by the 1970 period the cost of these types of consoles will have decreased to less than 50 percent of the indicated prices.

The basic operation employed with display consoles is step-by-step sequencing through use of the function keys. A desired action is initiated by pressing an individual key, or more typically, a group of keys, in some ordered sequence. The following events represent an operating pattern associated with a single key:

1) Operator presses key i.

2) Operator gets positive response that key i was pressed.

3) Computer presents a display on the CRT.

Table 3-2. On-Line CRT Display Console Characteristics

	A/N Display	Vector Drawing	Variable Size Characters or Fonts	Light Pen	Marker	Cursor	Buffer Memory	Fixed Function Keys	Variable Function Keys	Status Indicators	Blinking	Audible Alarm	Background Projection	Character Rotation	A/N Keyboard Input	Selective Intensity Variation	Cost in $1,000	Remarks
Typewriter (for comparison)	x		x		x										x		3.5	
NTDS Track Console or User Console	x*					x		x				x					30	
Data Display: DD10	x				x			x							x		5.2	Up to 64 displays per control unit at $25K extra
Data Display: DD80	x	x	x	x		x	x		x					x	x	x	125	Has associated film recording capability
General Dynamics: SC1090	x	x						x		x							40	Additional options available
Bunker Ramo: BR85	x	x	x	x	x	x	x	x	x	x	x	x			x		160	
Raytheon: DIDS500	x		x	x	x		x		x	x					x		?	Joystick provides equivalent of light pen
ITT: Information Display Console	x	x			x		x	x	x	x		x	x		x		200	Includes color presentation
IBM: 2550	x	x	x	x	x				x						x		75	Buffer memory optional

* Includes auxiliary numeric readout device.

4) Operator enters data into display.

5) Operator visually validates inserted data.

6) Operator makes corrections to inserted data, if necessary.

7) Operator signals end of entry.

The actual sequence of events followed by the operator for a particular key is shown in Figure 3-4.

3.2.2 Group Displays

Group displays are still in their infancy and have not satisfactorily proven their utility except possibly for stylized displays in NORAD and SAC Command Posts.[1*] The important user oriented characteristics distinguishing these devices are:

1) Alphanumeric Readout. Typically 64 character representation is possible. Variations in size may be an option. Since often the image is generated by the CRT (available in a console system), the capability of the console display can be duplicated with the group display (except for such dynamic capabilities as blinking of characters).

2) Vector Drawing. Two very different technologies are employed in vector or line drawing. They are related to the nature of producing the display itself. One approach, typified by film based systems, will produce the display in its final form having all lines completed. A second approach, represented by systems employing a scriber etching a path on a plate, produces the line while the display is viewed. This difference is essential in tactical systems and is a desirable capability for an ACDS.

3) Color. The question of color, and how many colors, is a fundamental consideration. Typical choices include a black and white system or a system employing the three primary colors from which it is then possible to obtain mixtures which will afford eight colors, including black and white. An interesting question facing the system planner is whether or not the color must be true or whether it is only necessary to achieve sufficient discriminating capability to facilitate

*References are listed in Section 10-5.

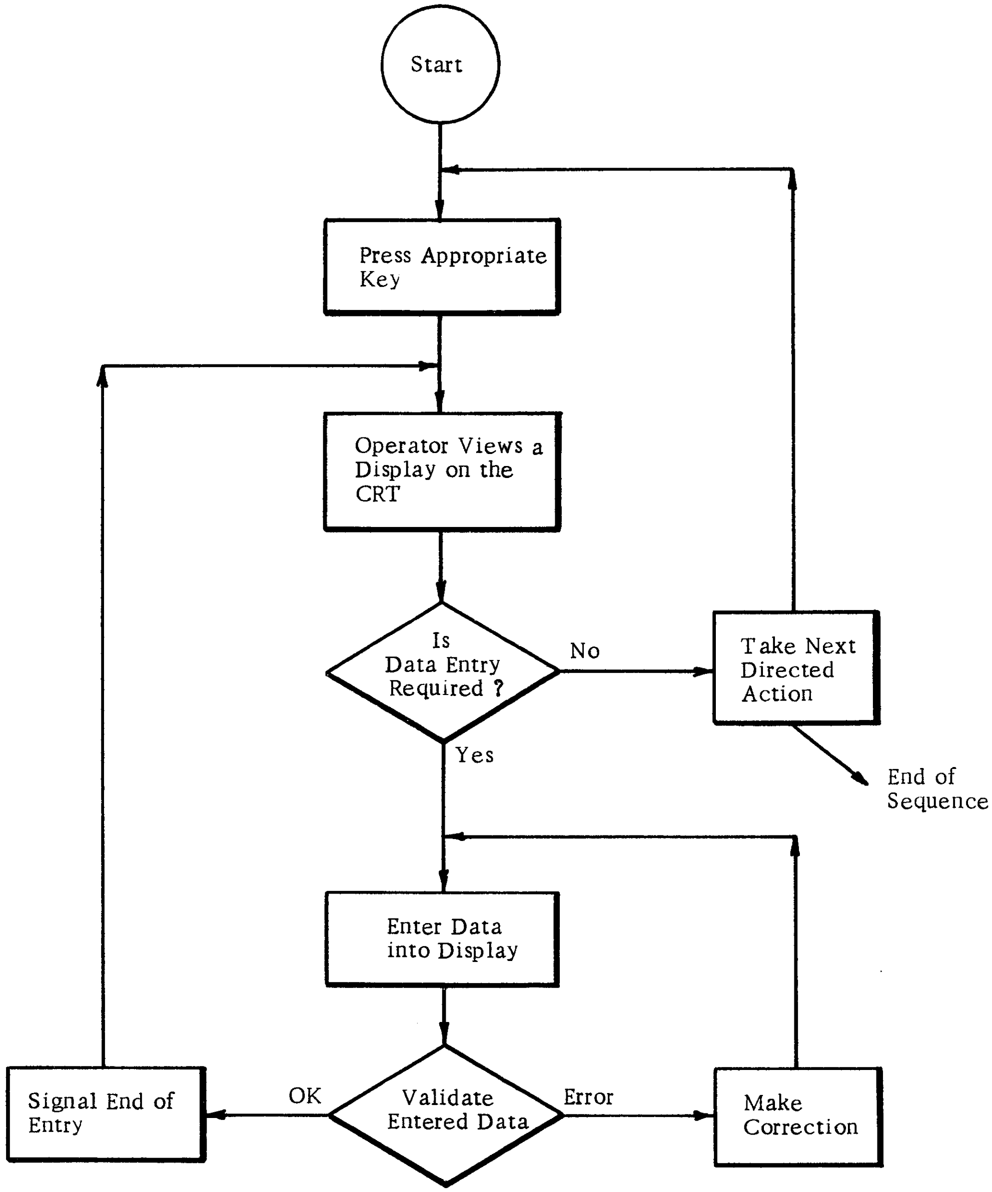


Figure 3-4. Typical On-Line Display Console Operator Procedure

communication of information. Simplification in hardware and cost differentials are possible if the latter capability is adequate.

4) Projection of Overlays. This is an important feature found on many group displays at present. Maps or grids are projected from a fixed set of slides for use as overlays with the computer generated and displayed data. The overlays may also be part of the basic slide, as for example in the case of the NMCS display.[2]

5) Screen Size. The size of the group display viewing area is dictated by the number of required viewers. Popular screen sizes are 4 x 6 ft or 8 x 10 ft. Another parameter to consider is the question of how many screens and the possible requirement of a simultaneous or coupled screen display.

6) Projection Techniques. Possible alternatives are front and rear view projection. Selection of one or the other is a function of the physical layout of the presentation room.

7) Library Feature. Display systems which save and store displays have a library capability. Film based systems typically have this feature when slides are saved for later recall. The implication of the library feature in this case is that it may be necessary to have an off-line library capability with attendant bookkeeping and searching. Display recall may also be implemented by requiring the computer system to remember "old" displays; when they are referenced, the computer will regenerate them.

8) Display Control. A contol panel from which selections and/or requests can be made must be available to the display users. A simpler control unit can be used to access information held in the library. In this case a dial-up process might be sufficient, in which the display of a specified magazine slot or film position is requested.

9) Alternate Hard Copy. This is usually a function of the data processing system and is normally implemented through a printer device. It could also be a hardware function in that a hard copy film record could be produced by the group display at the time of presentation.

10) High Ambient Light Viewing. This is a most desirable feature in a command area where written messages and discussions are extensively utilized.

The above features are found in several of the group displays now available. Characteristics for samples of such displays are presented in Table 3-3.

Features which are currently not state-of-the-art but will prove to be important for ACDS operations include:

1) Pointing. A desirable capability to facilitate two-way communication between the computer system and the display viewer is that of pointing to information displayed and having the computer recognize the particular location so selected. This pointing function may be a result of requesting a particular option that is available and not indicated on the display or for calling attention to an item or area.

2) Data Insertion. The ability to insert new data or change data on the group display may be desired. This can be achieved by using a pointing feature and employing a display console to insert the desired data.

3) Selective Enlargement. The ability to change scale is a useful feature, especially with respect to the dynamic aspects of task force operation. It may be desirable to focus on different points of a display and increase or decrease the scale of the display.

Table 3-3. Group Display Characteristics

Group Display	Alpha-Numeric	Operator Participation	Color	Dynamic	Library Feature for Old Display	Background Projection	Selective Enlargement	Alternate Hard Copy	High Ambient Light Viewing	Remarks
Data Display Central 465L	x	x	x		x	x		x		Alternate hard copy comes from printers defined in the request statement
Opconcenter GPL/DDI	x	x	x		x					Uses Lenticular film for color display 3
Iconorama Norad	x		x	x					x	A stylized display using an etched plate to produce symbols
Bunker Ramo - Full Color, NMCS	x	x	x		x	x			x	Eight-color, background is fixed to slide at time of display (cannot change the background)
Opconcenter Norfolk	x	x								
LTV 7000 High Speed Display System	x		x	x		x				Uses a plotting projector and support projectors. Uses etched plate for display
Budd Electronic Group Display **	x	*		x		x	x		x	Photo-chromic display

* To be defined
** Under development

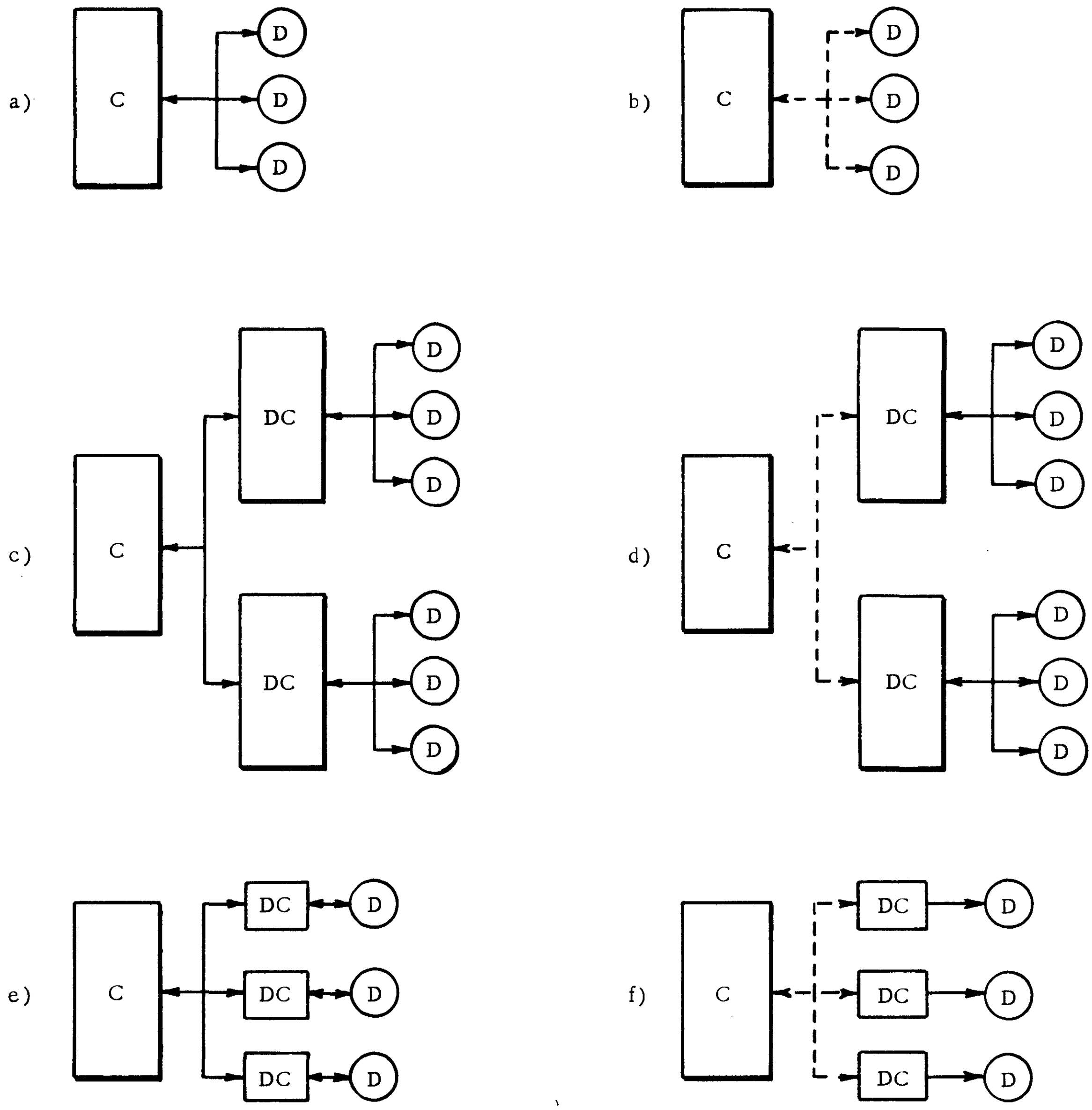
3.2.3 Interfaces

There are several methods for tieing the on-line display device to the computer. The appropriate method is a function of number of on-line devices and the expected duty cycle to be placed on the data processing equipment as a result of the applications. Various configurations are illustrated in Figure 3-5. The following is a description of the configurations:

Configuration	Description
a) and b)	The on-line device is directly connected to a computer I/O channel. Additional devices may be connected to the same channel up to some maximum number which would be specified by the manufacturer. Additional devices over that maximum must then be assigned to another channel.
c) and d)	The on-line device is connected to a separate control unit which in turn is connected to a computer I/O channel. Additional on-line devices may be connected to the control unit up to the maximum number for which it is designed.
e) and f)	The on-line device is connected to its own control unit which in turn is connected to the computer via an I/O channel. Each on-line device requires a separate control unit.

The separate control units appearing in configurations c), d), e) and f) perform such functions as automatic CRT display regeneration and character-by-character message accumulation for subsequent transmission to the computer on input,or to the on-line device on output. Actual operational examples of these configurations are as follows:

Configuration a)	Console tied to a CDC 160 computer at the Development Center of the National Military Command System Support Center (NMCSSC).
Configuration b)	NTDS consoles tied to the AN/USQ-20.



C = Computer
DC = Display Controller
D = On-Line Device

——— Unbuffered I/O Channel

– – – – Buffered I/O Channel

Figure 3-5. Computer/On-Line Device Configurations

Configuration c)	Consoles tied to a core memory buffer which is connected to an IBM 1401 or 1410 at the Air Force Command Post (OTC of 473L).
Configuration d)	SAGE consoles tied to a drum buffer which is connected to an AN/FSQ-7.
Configuration f)	Console and associated control unit connected to a CDC 1604B in a major command and control system.

The particular configuration selected during a design study varies depending upon the application, the selected display and the computer with which the console must interface.

A further detailing of the control unit gives the subsystem shown in Figure 3-6. The logic unit converts signal levels,and packs or unpacks, as appropriate, data words to match the computer and display system word formats,and routes data and control signals from the computer to the desired display. Each display may have its own character and vector generator and a buffer memory. These components may also be time shared by several individual displays. This arrangement can be used when messages to be displayed are short enough so that the symbol generator can handle the cumulative rate required for all displays.

3.3 DISPLAY SOFTWARE

From the user/operator point of view, the display subsystem for an ACDS should possess the following attributes:

1) Standard Procedures. Clear rules with regard to console functions and operation must be established to insure a minimum of confusion by the operator. These rules include:

    a) Maintain uniform groupings of keys. If the console keyboard has several physically distinct arrays of lights or buttons, each grouping should be functionally consistent. For example, all alarm indicators should be grouped together.

b) Define simple steps for using console buttons that are consistent within each physical panel grouping. Thus, when each alphanumeric key is depressed, the associated character immediately appears on the display. System alarm indicators should show either positive or negative conditions.

c) Whenever possible, require data input via the alphanumeric keyboard according to prescribed format. This has the advantage of allowing the computer to guide the operator and to permit computer transformation of data from external to internal representation.

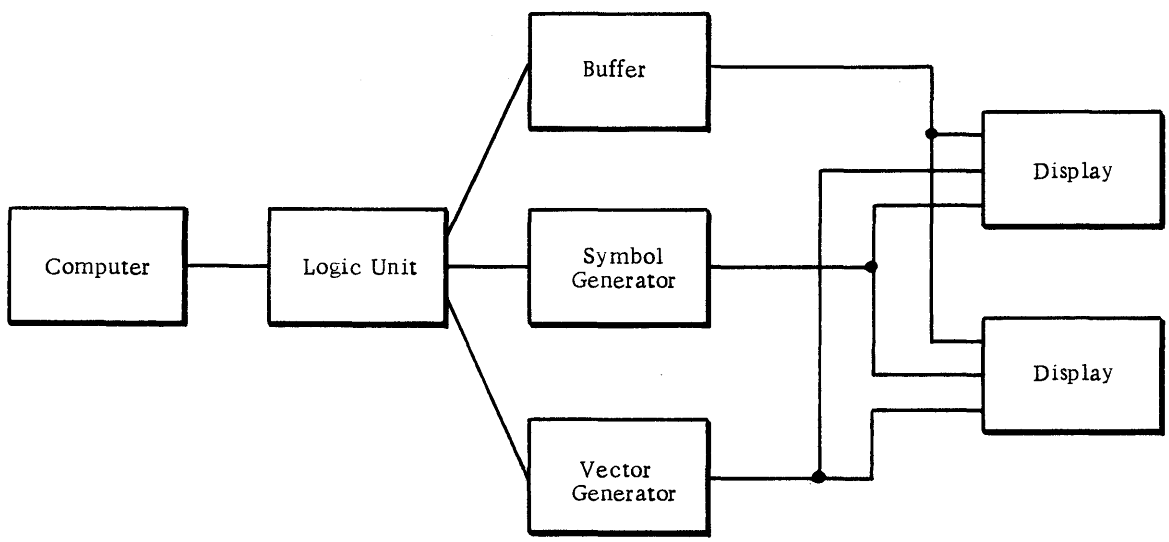


Figure 3-6. Multiple Console with Shared Components

2) Flexibility. Usage of display devices will invariably lead to improvements in procedure and technique. Hence, changes may be made often and easily. This implies providing the ability to alter individual steps, the logic flow and the content of pre-stored displays.

3) Possibility of Growth. Applications will grow as new uses are found for the displays, especially if the devices are general purpose. Therefore, it should be possible to add new functions to the programming system.

4) Provision for User Orientation. The display subsystem should be as much user oriented and user understandable as possible. Hence, it is desirable that the design, implementation and modification of specific functions be as much "professional" programmer independent as possible. Optimally, the system should be manageable by the user, once the basic programming has been done.

From a usage standpoint, displays may be classified into four basic types:

1) Message displays, which do not require modification in any manner by the operator.

2) List displays, which require the operator to make selections from a prepared list of items.

3) Format displays, which require the operator to make entries in specified positions.

4) Free displays, which allow the operator to make entries into any position.

Of these four display types, the first is computer generated (e.g., outputs), the next two are computer presented for operator use, and the last is operator generated. Typically, the first three are totally under control of the programming system while the last is useful for entering free text or graphics for later reference.

The list and format displays are the fundamental tools of the system. The former consists of a list of items from which the operator may choose alternatives, for example, as shown in Figure 3-7 for the case of military installations. By use of special selection keys or the light pen, the operator selects any number of items from the list. Choice of an item from one list leads to the presentation of a second list, permitting further choices. Such an arrangement leads to the concept of multi-level sequencing through an indentured index taking the analyst from the general category to the specific by the most direct route. For example, if the operator selects air bases from the choices open to him, the system presents him a breakdown to this category at his request. This process could, of course, continue to any level. The item chosen at the lowest level serves as a selection parameter in the next message generated. In effect, the selection parameter is the logical AND of this item together with all the higher level choices needed to get to this particular list.

In a list display, it is also possible to make multiple selections within a particular level. If a multiple choice is made, the operator is prohibited from going to a next lower level in the manner shown in Figure 3-8, Case b. However, it would be possible to define branch points and follow each one independently as shown and then connect such paths by logical connectives.

The format display facilitates input of data that is structured. It has a well established form and the input data must conform to the limits set by the format. An example of such a display is given in Figure 3-9. Emphasis is made of the user-oriented format and the utilization of application oriented languages, leaving the necessary conversions and data packing to internal machine operations.

An important feature that should be available with CRT displays to aid the operator in data entry is visual awareness of the correct entry point. That is, the position on the CRT where the next character will be placed. This may be handled either by hardware or by programming. In either case, some symbol is dedicated to serve as a "marker" to move one character position to the right (or to the first location of the next row, if it now occupies the last position of a row) whenever an alphanumeric key is pressed. The position previously occupied by the marker is taken up by the data symbol just entered.

MILITARY INSTALLATIONS

* ALL
* NAVAL PORTS
* AIR BASES
* MISSILE BASES
* COMMAND, CONTROL CENTERS
* DEPOTS
* ARSENALS
* HOSPITALS

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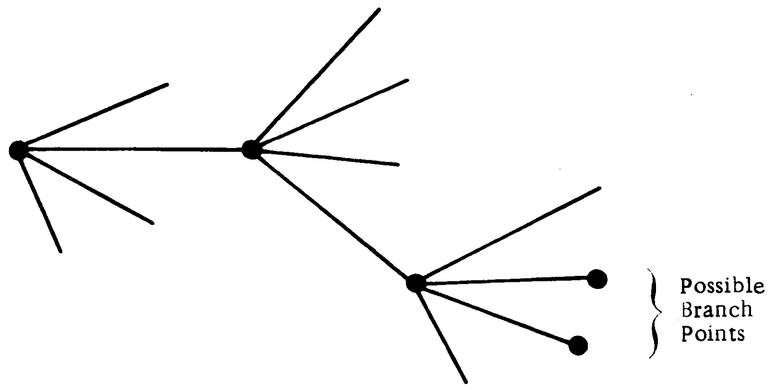
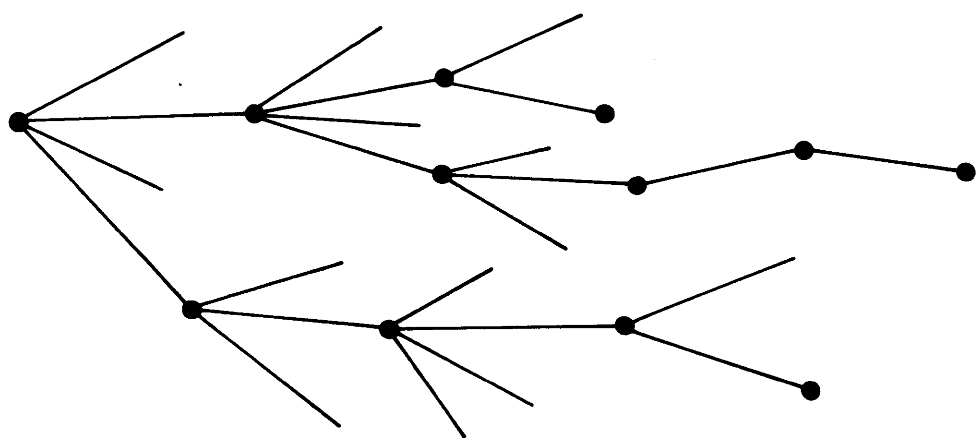
.
.

Figure 3-7. Example of List Display



(a)



(b)

Figure 3-8. Multiple Selection of List Displays

The relationship of CRT display console features to generic man-machine functions is shown in Table 3-4. Consider the first function. To initiate an action, a key must be pressed. This will usually be one of the variable function keys. For purposes of illustration, let such a key be labeled MILITARY INSTALLATIONS. The pressing of this key may cause, under program control, the display of a list of alternatives shown in Figure 3-7. The desired category is then selected by pointing the light pen at the appropriate asterisk, for instance, opposite Naval Ports. It may be that the item selected requires further detailing. In this instance, a second display automatically appears to force the operator to make a further choice. Actions for manipulating the "list" display require only the variable function keys, an alphanumeric display capability and a light pen. The sequencing of the displays is the responsibility of the display subsystem software package.

To include all possibilities, the entry of parameters is also illustrated. For example, the format of Figure 3-9 may appear on the CRT, requiring the indicated input from the operator. A symbol represents a "marker" and indicates the first entry point where the alphanumeric keyboard is used for data entry. This marker moves either under hardware or software control to the next succeeding underline as each character is entered. To accomplish this latter action for handling "format" displays, the marker and data entry keyboard is required, completing the explanation of features needed to accomplish the first function in Table 3-4.

REFERENCE POINT

LATITUDE: __ __° __ __ '

LONGITUDE: __ __ __° __ __ '

DATE: Y __ __ ,M __ __ ,D __ __

TIME: __ __ __ __ Z

Figure 3-9. Example of Format Display

Table 3-4. Relationship of Console Features to Generic Man/Machine Operations

Function	Console Features										
	Alpha-Numeric Display Capability	Symbols	Cursor	Light Pen	Marker	Keyboard (Alpha-Numeric)	Fixed Function Keys	Variable Function Keys	Line Drawing	Blinking or other Alarms	Background Projection
1. Initiate Action of Program	x			x	x	x		x			
2. Send a Message to other Consoles or to the Computer	x				x	x	x*	x			
3. Request a Hard Copy Output Product	x				x	x	x*	x			
4. View an Output	x	x							x	x	x
5. Perform a Logical Operation	x			x	x	x		x			
6. Control of Background Projection	x		x or	x	x	x	x	x			
7. Generate Visual Displays for Storage and Later Retrieval	x	x	x or	x	x	x	x*	x	x		x

* Can be implemented hardware or software

3.3.1 Programming Requirements

To meet the requirements posed by an on-line system environment, hardware and software interaction must be considered. These interactions must be translated to specific data processing operations to a basis for which the software can be designed. In developing programming system concepts for an ACDS, the following "internal" operating characteristics must be recognized:

1) System Loads. The most important characteristic regarding the operation of multiple, on-line stations is the occurrence of numerous short duration service demands. These demands are made on the computer in the process of generating information entries that are built into a complete message by employing the list and format display described in the previous section.

   A fundamental consideration, therefore, to a system load analysis is the message entry rate at a keyset station. The operator presses a key indicating his desire for service. The computer responds with a ready signal (display) or presents a message (display) requesting that the operator select a format number. The operator enters a selected code (for example, 2 characters) and presses the "end of message" key. The selected format is displayed, and the operator enters his data.

   The sequence performed by man and machine up to, and including, the first character of data entered into the selected format is, (using the steps shown in Figure 3-10) as follows:

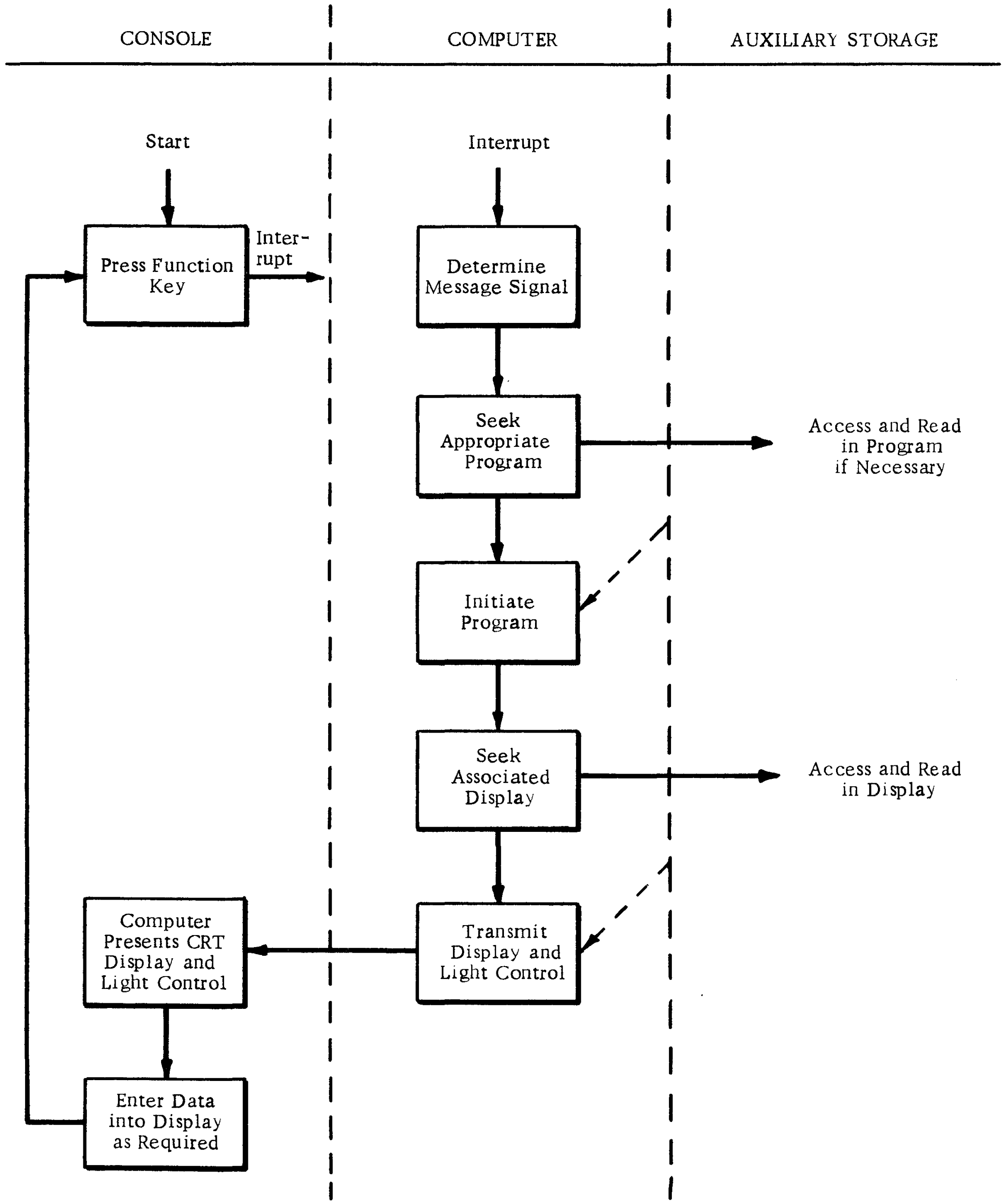


Figure 3-10. Console Processor System Operation

Man	Machine
1) Indicates desire for Service	
	2) Searches Auxiliary Storage for Appropriate Program. Then obtains associated format. Transmits display to Console.
3) Notes CRT presentation	
4) Enters first character of desired format number	4') Validates character if computer controls data entry
5) Enters second character of desired format number	5') Validates character if computer controls data entry
6) Validates entry	
7) Selects "End of Message"	
	8) Validates entry
	9) Obtains appropriate format from Auxiliary Storage

The total internal processing time for the above actions may be about 50 milliseconds for a medium speed computer. In addition, up to several hundred milliseconds may be required for accessing and presenting displays if they are needed and if auxiliary storage is used. Since the total elapsed time for the limited entry of the above examples may be about 10 seconds, very little total computer capacity has been used. If the I/O transfers are buffered, then the references to auxiliary storage will not be additive with the processing time. On this basis, a single station would use $\frac{50}{10,000}$ or 0.5 percent of computer processor capacity, and k stations would require 0.5 k percent of capacity. It is interesting to note that, for larger and faster computers, the denominator remains constant whereas the numerator decreases. In conclusion, a single processor may be capable of servicing many stations in message entry and have large capacity left over for other functions, assuming the availability of multiple I/O channels.

2) Processor Time Sharing. Based on the foregoing, a considerable amount of processor capacity is available for tasks other than the routine servicing of message entries. A large part of this capacity will of course, be required to actually execute the functions that are requested by the entered console message. In addition, other computations, related to the total ongoing problem will require the excess capacity. Because of these interactions and the step-by-step processing associated with each console, the entire system must be time-shared, and more than likely, multi-programmed with special preferences given the console operator.

3) Special Timing. The special nature of the display device interface and possible electromechanical responses may impose special timing requirements on the computer program. This depends of course upon how much the detailed bookkeeping and control is actually committed to hardware. Consideration must be given to the following representative items:

   a) Refresh. If automatic buffers are not provided to refresh the volatile CRT's, the computer must retransmit the information sufficiently often (for example, every 20-25 milliseconds).

   b) Scanning. It may be necessary periodically to insure the clearing-out of the console output register, perhaps every 200 milliseconds, if keyboard entry is to continue at an operator's pace.

   c) Output Timing. Special devices may require data that must meet specific timing. This may be true, for example, of electromechanically driven devices where start/stop problems may arise.

   The actual implementation of these response requirements depends on the availability of suitable interrupt features, an active or passive clock, and sufficient buffer capacities. If none of these features are available, detailed programming may take place at the expense of total efficiency. In this regard, an important point is that timing may not always be critical, and cycles may occasionally be skipped. For example, a CRT image does not suffer from occasional misses at refreshing, or from a 5-10 milliseconds delay in a cycle. However, while random pertubations will not adversely affect the viewer, periodic misses will be noticed.

4) Auxiliary Storage. The requirement for rapid response and the servicing of many stations, each active over a long period of time relative to the effective computing rate, indicates a need for large capacity auxiliary storage. This store will hold programs, working displays and the basic data base. While this discussion points to the need for random access - bulk storage, such as drums and discs - it is still possible under appropriate program design to be reconciled with magnetic tapes for certain functions. For example, this would be feasible if a distinct tape transport were assigned to each console.

As discussed in the foregoing, multi-station, multi-purpose display systems require random and unscheduled servicing by the computer. Further, the interactions between man and machine take place over relatively long periods of time and are asynchronous with respect to each of the users.

The CTF Node of an ACDS is this type of system, requiring access to programs, pre-stored displays and data on a random basis, if reasonable response times are to be met. Because of time sharing the central processor between multi-stations for intermittent servicing, console "history tables" reflecting user transactions must be maintained to the current time. In addition, the "position" in a particular procedure must be maintained, since unpredictable time lapses will occur due to intermittent human responses.

Effectively, the program must wait (or do something else) whenever a display is presented to the operator. As the operator enters data (if required), the computer must momentarily return control to the specific console and monitor each entry. Upon completing the entries for a single display, an appropriate "end of message" dictates the initiation of the next logical step. At the end of the final step, a complete and meaningful message or direction is the basis for the computer's independent determination of action. It is thus possible to continually generate directions and have the computer respond to them on an overlapping time basis.

It is possible to separate specific ACDS application oriented functions from those that are general purpose and apply to most on-line display system applications and processes. A division is made between processes required in generating a message and procedures for executing an action that may be called for. The former concerns the mechanics of handling displays and composing messages, whereas the latter is concerned with actual file handling, retrieval, processing, summarizing and formatting.

Thus, the objectives for a display subsystem programming system are as follows:

1) Provide a general capability and flexibility so that virtually all applications can be accommodated.

2) Standardize techniques and procedures so that individual program segments or subroutines can be shared by as many functions as possible.

3) Maintain order among contending users for the same files.

4) Service each console as if its operator is the only user making demands on the processor.

Based on the foregoing, the display programming system for an ACDS must include:

1) <u>Display Subsystem Executive Control</u>

   This program performs the basic scanning, sequencing and queue control for servicing on-line devices. In addition, it serves as a link to the Master Executive Control which may be supervising the total processing system.

2) <u>Function Monitor</u>

   This program maintains the history tables and establishes action sequences to be carried out as a function of the keys pressed.

3) <u>Utility Program Package</u>

   This is a collection of service routines used primarily by the Function Monitor and Executive Control programs. The availability of these general purpose programs precludes recoding of common functions.

4) <u>User Language</u>

This is a language used by the application programmer in writing his program which is operated upon by the Function Monitor. The system must provide the programmer with the ability to express his program in both the symbolic language of the computer where each command generates one machine instruction, and in higher order languages where each command generates many machine instructions.

To be effective, the higher order language must possess the following chief attributes:

a) It must be powerful enough to express the application problem in terms of the man/machine environment.

b) It must be so simple that nonprogrammers can use it with a modest amount of training.

c) It must be readily expandable so that new commands and functions can be added.

This programming approach to on-line display devices for ACDS will require that application programmers conform to coding restrictions and procedures so that all possible programs be accommodated. While this may seem a disadvantage:

1) It simplifies the programming because advantage can be taken of service routines.

2) It simplifies the implementation of a new application which must fit within the logical framework set forth by the system.

The importance of the second point cannot be over-emphasized. Without a well defined organizational and procedural philosophy, the programming design and implementation of the individual application can unnecessarily become a major undertaking.

The above approach to on-line display software is the foundation for a programming concept which has yet to be realized. Current compilers, monitors and operating systems fulfill the requirements of batch processing software. No comparable display oriented software exists. The beginnings of such software are described in the following paragraphs. A strong recommendation is made that adequate research and development be pursued in on-line software techniques which would simplify the implementation of ACDS procedures in the 1970 to 1980 period.

3.3.2 Executive Control

The real-time requirements associated with on-line displays present a problem of priority in interrupt handling and servicing. Hence, an executive system must be designed that is responsive to these requirements. Such a program is equipment-dependent in the sense that many hardware/software trade-offs are possible.

The basic requirement of the display subsystem is control of a great number of I/O devices. This control includes:

1) Scanning the input lines for messages.
2) Refreshing the CRT's.
3) Accessing programs, displays and data from auxiliary memory.
4) Communicating with other processors that may be in the system.
5) Maintaining timing responses for special purpose on-line display equipment.

Typical timing requirements range from refreshing the CRT within 20-25 ms periods to scanning of inputs from the console keyboards every 200 ms. Unless certain hardware features are available, such as automatic interrupts and I/O buffering, the programs will have to take these into account.

Assuming no dependence on hardware, the executive program must maintain continuous cognizance and control over the I/O. This is done by the basic control loop shown by the dotted lines in Figure 3-11. Each of the five indicated functions could potentially generate a processing task as the cycle is traversed. For example, the tasks associated with scanning the input message lines are shown in Figure 3-12.

To meet real-time requirements, this loop must be passed at a rate which will insure return to the task which has the tightest timing constraint within a specified amount of time. This time will be called the "basic cycle time." If CRT refreshment is the critical task, then the basic control loop must return to that task within a basic cycle time.

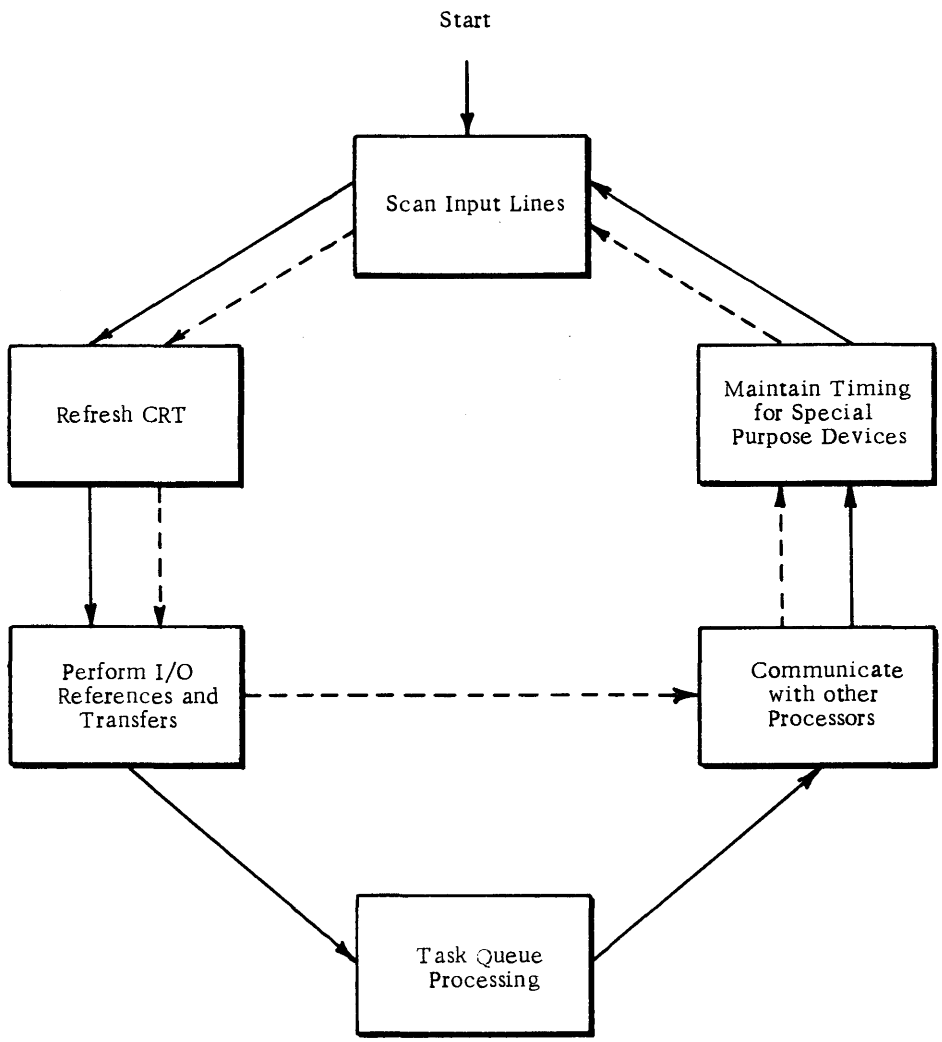


Figure 3-11. Basic Executive Control Loop

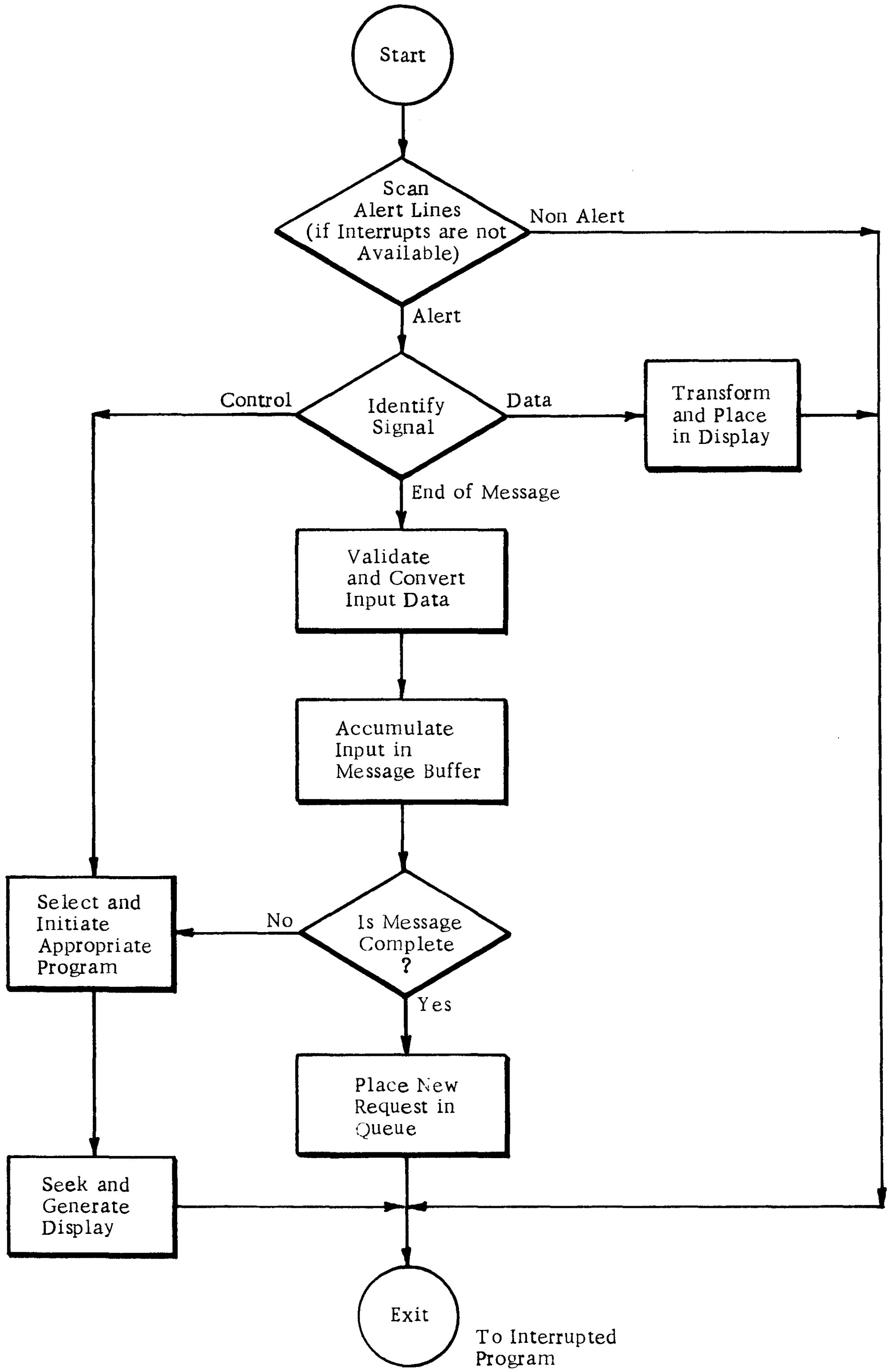


Figure 3-12. Computer Steps in Conjunction with On-Line Communication

Processing requirements for each of the five identified functions must be completed within a time which will not compromise the total cycle time. There are three ways of achieving this:

1) Allow processing to proceed in increments of the basic cycle time so that temporary return to the cycle is permitted after each such segment. This leads to difficulties of recursive entries into the various processing tasks.

2) Spot-place a particular task in more than one position in the loop. For example, the "refresh CRT" might be placed in every other position in the loop if the other functions have a period which is very much larger than that of the CRT refresh cycle.

3) Permit only a minimum of processing as each of the tasks are reached and place in a queue those functions not completed. This queue is then processed during the residual time which left over during every cycle. This is shown in Figure 3-11 by the box which is part of the loop indicated by the heavy lines. It is, of course, necessary that the residual be non-zero enough of the time if any processing is to occur. The system planner may select any combination of these possibilities depending on the details of the system interface and hardware characteristics. The example shown in Figure 3-12 employs the last of the foregoing alternatives.

The following comments are presented concerning the implementation of the executive control with respect to the presence or absence of the indicated hardware features:

1) If neither an external interrupt nor a real time clock are available, the tasks associated with each of the control loop functions and all other calculations must be programmed in segments so that each segment will permit return to the control loop and maintain the timing.

2) If a clock is available, the executive can preset it at the beginning of each cycle so that it will interrupt the processing of the queue at the proper time.

3) If external interrupts are available, the function of the basic control loop has been absorbed by the hardware and no executive function is needed. Consoles are serviced on demand.

3.3.3 Function Monitor

The function monitor is a specially designed program to facilitate responses to a special set of keys on the console. Although not all consoles have keys of this type, it is necessary that a general purpose console have such a set. Labels and identifying codes for these keys can be changed by the operator.

The primary purpose of the function monitor is to ease the process of entering information into the computer for the purpose of making a request. Knowing that different applications will require different displays and different sequences of presentation, the devised program must not be application oriented or professional programmer dependent so that the user can design his own data entry scheme and query language.

The function monitor is an interpretive program which operates on a very special language useful in display manipulation. When one of the special keys mentioned above is pressed, the executive control recognizes this and passes control to the function monitor. There, the specific key is identified, and an associated table of instructions in the special display language is executed. It is the ease with which a user can modify this table of instructions which makes the function monitor so valuable. To illustrate the capability of the display language, some of the possible instructions are:

1) Turn the specified console lights on (off) - the lights are specified in parameter words following the instruction.

2) Display the following characters on the CRT - the characters along with their location coordinates are listed following the instruction.

3) Locate a display in auxiliary storage - the identification of the display follows the instruction.

4) Clear a specified buffer - the buffer area may be either pre-established or specified in the words following the instruction.

5) Enter the specified characters in the buffer - the characters are listed following the instruction.

6) Process the "list" display - special codes (specified by the query language) are extracted from the list display as dictated by the selections of the operator and are placed in the buffer.

7) Process the "format" display - the parameters entered by the operator are extracted from the format display and stored in the buffer.

A more sophisticated language can easily be designed to cover more applications. The above language, however, is completely adequate along with its function monitor to service the kinds of retrieval requests set forth as examples in subsection 3-4.

3.3.4 Utility Programs

Utility or service programs extend the hardware capability in a general way so that certain functions become automatically available to the application programmer. This software is primarily concerned with facilitating the entry of alphanumeric information onto the CRT in an expeditious manner. Also included are useful functions for data handling and the control of displays.

In some instances the recommended features described below may be part of the hardware, thereby precluding a need for programming.

1) Marker Routines

The marker is a special symbol which indicates the current writing position on the CRT. The following control keys are defined for manipulating this marker:

a) Marker Enable. Causes the marker to appear at some fixed location on the CRT. This position could be, for example, the (1,1) character location. As alphanumeric characters are entered, the marker is displaced one character position to the right; the newly entered character taking its place. The marker moves from the end of one row to the beginning of the next; upon reading the lowest right hand position, it will return to the (1, 1) position. A character that is dislocated by the marker will be replaced when the marker is moved again, unless a new character has been entered.

b) Marker Disable. Removes the marker from the CRT.

c) Marker Backspace. Causes the marker to move one position left, or to the end of a previous line, if at the beginning of a line.

d) Marker Up. Causes the marker to move to a position in the preceding line which is directly above its current position. If the current position is in the first line, the marker is moved to a position in the last line vertically below its position in the first line.

e) Marker Down. Causes the marker to move exactly opposite to the motion described in "Marker Up."

f) Marker Left. Causes the marker to move in positions to the left in the same line. The marker moves "end around" from the first to the last position of a particular line. In n=1, this key is identical to the backspace key except that the latter is not restricted to a specific line.

g) Marker Right. Causes the marker to move exactly opposite to the motion described in "Marker Left" except that the number of positions moved is n'. A relationship should exist between n and n' such that one of them is equal to one and the other is some small integer greater than or equal to one. A recommended system is n=5 and n'=1.

h) Advance Marker. Used in conjunction with the format display, i.e., a display in which the operator enters A/N data into various labeled slots. Depressing this key causes the marker to be moved from its current position in some slot to the first position of the next slot. If the current position is at the last slot, the marker is moved to the first position of the first slot.

i) Accept Item. Affects the marker only with respect to list displays. The depressing of this key will move the marker along the first column, from one row to the next, replacing the marker by "X," indicating that a particular item was selected.

j) Reject Item. Affects the marker only with respect to list displays. The depressing of this key will move the marker along the first column, from one row to the next, replacing the marker by "space." This feature is used to reject a previously accepted item.

2) Display Control Keys

The operation of the CRT display is aided by the availability of the following keys. For convenience, a distinction is made with respect to the CRT display viewed by the operator and the CRT display image which is the computer stored analog of the CRT display.

a) Display On. Causes the CRT display image to be presented on the CRT.

b) Display Off. Removes the CRT display, leaving the image in a passive state.

c) Clear Display. Causes the CRT image to be completely cleared except for the marker which, if on, is restored to its origin.

d) End of Message (EOM). Used in conjunction with data entry to indicate to the processor that a message has been completed. It serves as an interrupt which signals the computer to act on the CRT data.

e) Data Insert. Used to insert a set of alphanumeric data on the CRT between two consecutive characters. The marker is first positioned to the left of the two characters. The Data Insert key is pressed and new data is entered as it is generated, causing all data to the right and down to be shifted by one position. Exit from this mode is made by pressing the EOM key.

f) Data Delete. Used to delete a set of continuous alphanumeric data on the CRT, followed by a closing up of the display. The marker is first positioned at one end of the set; the Data Delete key is pressed and the marker set at the other extreme. Pressing the EOM key causes the desired action and exit from this mode.

g) Sequence Display. Used to call for the next part of a multi-part display should the size of the CRT prohibit the display of the entire message at one time.

h) Display to Printer. Generates a hard copy version of the CRT display on an associated typewriter or line printer, whichever is available.

i) Monitor Display. Permits the selection of any CRT associated with another console for purposes of monitoring that console's activity.

j) Save Display. Interchanges the CRT image with the contents of an alternate location. Thus, it effectively permits saving information for future reference. Typically, after pressing this key, one will also press Clear Display if disinterested in the display brought forth from the alternate image location.

3) System Control

The following represents control keys and their functions. In a particular system, more descriptive and extensive keys may actually be called for.

a) Display Message. Permits interruption of the current CRT display for purposes of viewing the message which is being held by the computer for the operator. The availability of a message is indicated by a status light. Return to the current procedure is accomplished by pressing the Display On key.

b) Display Queue. Causes the internal tasks queue (if there is one) to be displayed. Shown are priority ordering and status. The operator is then able to modify this queue by manipulating the CRT display and using the Modify Queue key.

c) Modify Queue. Can only be operated after the Display Queue key is pressed. It causes the CRT display to be sent to the processor where the queue is then modified.

d) Change Procedure. Provides a display which permits the operator to modify, select or cease system operation. Typically, this feature is an overall control procedure which should be assigned to only one of the on-line stations.

e) System Breakpoint. Essentially an external interrupt which performs two functions. The first is to save-store system status for rollback purposes in case of hardware failures. The second is for modifying the system configuration or operating procedure.

4) Status Indicators

Status indicators reflect the composition of the configuration, intermodule communication situation, internal machine control situation and system operating modes.

a) Power On. Indicates whether a console is in operating mode.

b) Processor not Communicating. Indicates if the communication between console and processor has lapsed more than some pre-established period of time (e.g. 500 milliseconds).

c) Queue Full. Indicates that the internal task queue is full and that no further inquiries can be made of the system.

d) Message Ready. Indicates that a message has been generated by the processor for the operator. The operator can select this message on the above-mentioned Display Message key, which, when selected, turns this indicator off unless a second message is also present.

e) Operating Mode. Indicates which mode is currently in operation. An indicator is dedicated to each operating mode identified by the system.

f) Configuration. Indicates which peripherals are on-line with the system. An indicator is dedicated to each of the relevant devices. This indicator is useful as a means of assigning peripherals to different consoles. It is used to display legal or illegal connections for any one console.

5. Error Indicators

The following alarm indicators are indicative of the signals that are useful to the operator. These indicators have an associated button with which the operator can cause a "reset" action to take place and attempt the procedure once more. The indicators should be placed in an obvious position so that the operator is cognizant of alarms. One procedure is to cause the indicator to blink on and off at an appropriate rate, e.g. twice/second.

a) Parity. Indicates parity error in transmission from, or to, the console.

b) Keyboard Locked. Indicates that illegal use was made of the keyboard, such as pressing two keys within a disallowed time interval.

c) Data Entry. Indicates that some rule regarding data entry on the CRT was violated.

d) Procedure. Indicates violation of order regarding the use of the function keys.

e) Control. Indicates violation of rules regarding the use of a control key.

3.4 ACDS APPLICATIONS

The feasibility and utility of on-line display console devices for an ACDS has already been demonstrated within NTDS. Individual console displays of the PPI type shown in Figure 3-13 are successfully being employed in the Combat Information Center (CIC) for target tracking, weapon assignment and target interception with respect to an air war.

A review of the technical functions in Volume II - General System Requirements, indicates needs for the following on-line displays:

1) CTF Node

    a) Task force situation and status displays.

    b) CTF console.

    c) AAW/EW consoles and displays.
    (AAW status display, TEWA consoles, Force AAW Controller console, Air operations console, Tactical communications console, Force EW controller console)

    d) ASW Consoles and Displays.
    (ASW status display, ASW-OTC/console)

    e) Strike Consoles and Displays.
    (Target console, Status consoles, Analysis consoles, Air operations console)

2) CVA Strike Planning Node

    a) Status of forces consoles and displays.

    b) Strike mission assignment display.

    c) Air operations controller console.

    d) Flight planning consoles.

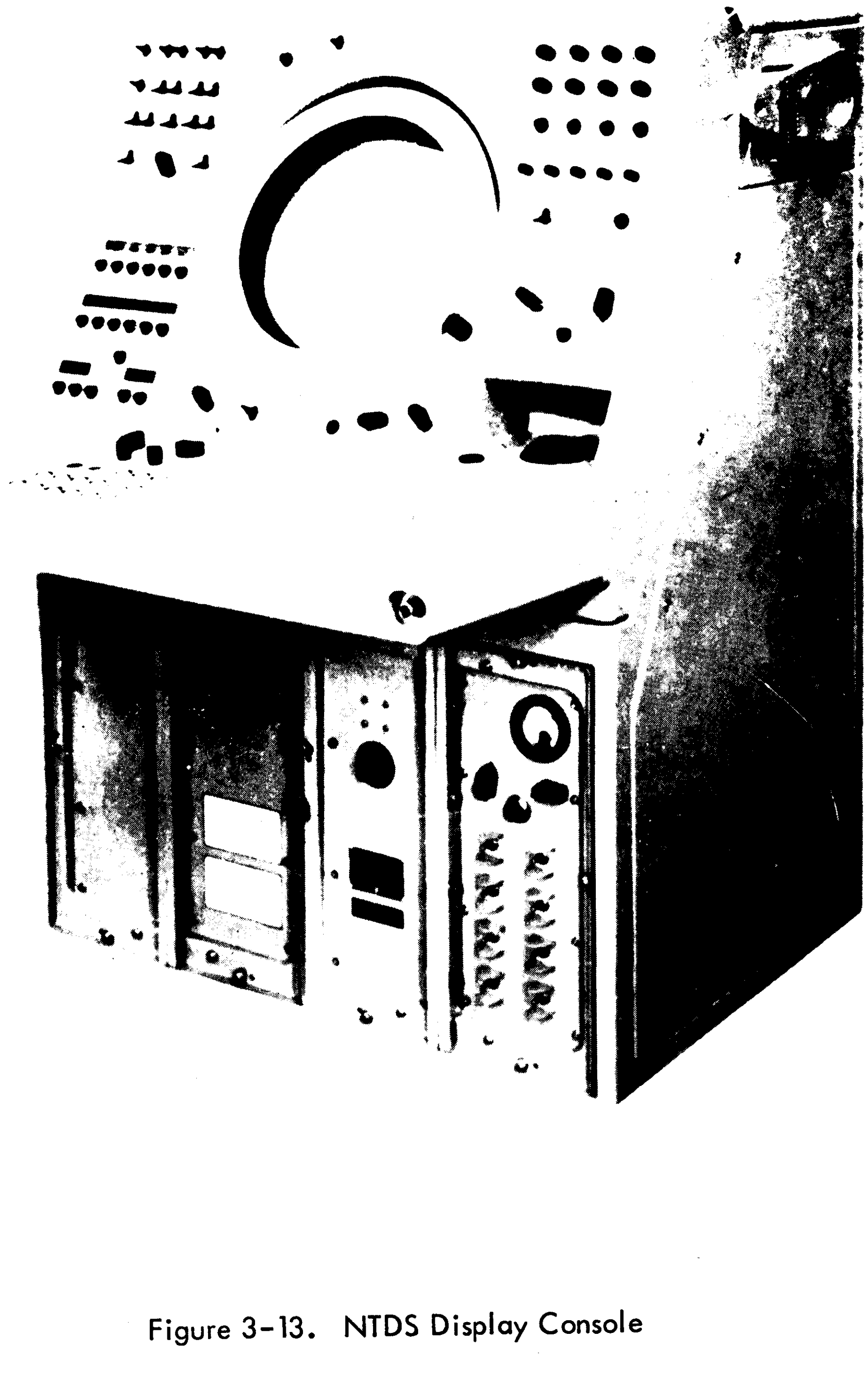


Figure 3-13. NTDS Display Console

3) Escort Ship Node

   a) Detectors consoles (AAW).

   b) Trackers consoles (AAW and ASW).

   c) Status consoles (AAW and ASW).

   d) Classification consoles (ASW).

   e) EW console.

4) AEW/C Aircraft Node

   a) EW console

   b) Signal analysis console.

   c) Status of forces console.

   d) Manual track and identify console.

5) ASW Screen Commander or Combat Area Commander Node

   a) CIC console.

   b) Status display.

6) ASW Aircraft Node

   a) Tracker console

   b) Classification console.

   c) Status console.

7) ASW Submarine Node

   a) Status console.

   b) Tracker console.

   c) Classification console.

The requirements posed by the above examples suggest the utility of individual display consoles and also larger, group displays.

3.4.1 Display Concept

Currently available CRT type display consoles are capable of alphanumeric and graphic presentations. Examples of such display consoles are shown in Figure 3-14, 3-15, and 3-16. The console shown in Figure 3-14 is representative of devices employed in a strategic command and control system. The console of Figure 3-15 is designed and packaged for a tactical intelligence system. Figure 3-16 shows a console directed to the commercial market. In addition, static displays, such as maps and charts, can be rear-projected into the CRT face in parallel with computer generated electronic information. Such consoles are now operational and will certainly be off-the-shelf in the 1970 to 1980 period.

It is important to differentiate between display console requirements of the CIC and those for the command and control function of an ACDS. In both cases the objective of the displays are to:

1) Improve decision-making.
2) Reduce reaction time.
3) Improve coordination.
4) Improve control.
5) Simplify operations.
6) Provide flexibility.

In the case of the CIC, display console utilization is well defined for several functions including:

1) Height Size Console - operates in an analog mode using verniers and a modified "A" scope to compute the height, size and range of targets.

2) Input Console - operates with the height size console to define sensor signals and provides track information to the computer. Radar video, IFF video, and computer readouts may be viewed simultaneously at this console. The console's function within the complex may be selected manually.

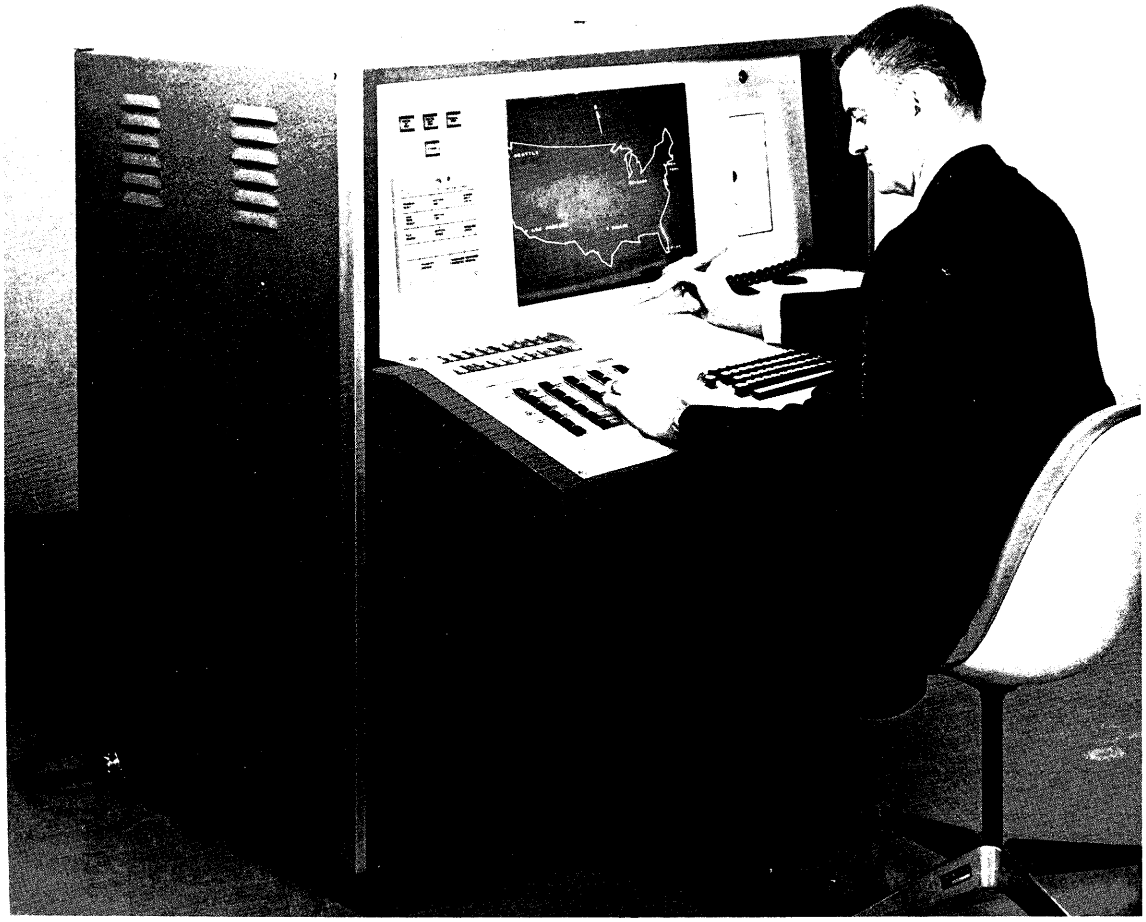


Figure 3-14. Bunker-Ramo 85 Control/Display Console

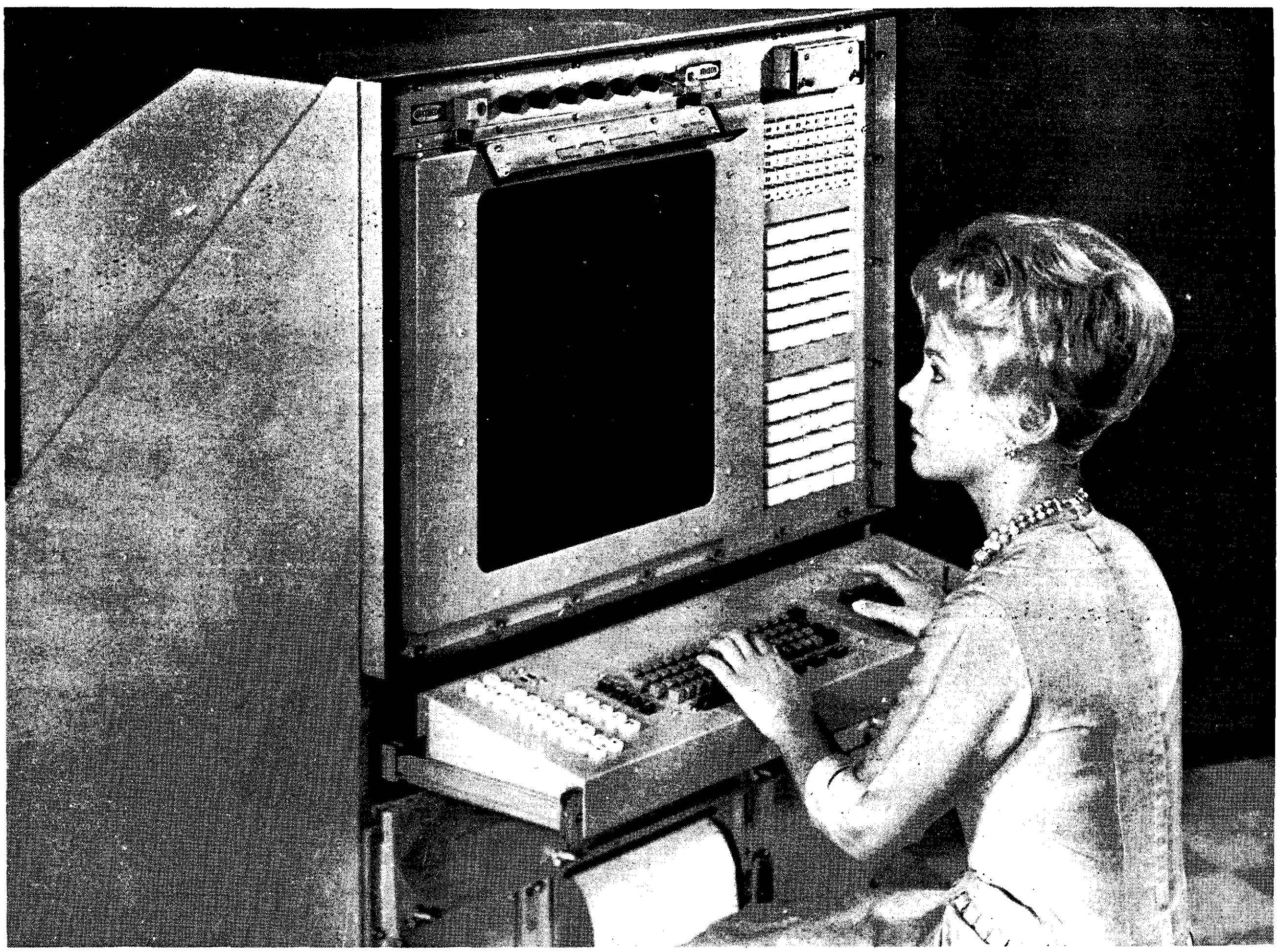


Figure 3-15. Raytheon Digital Information Display System 500

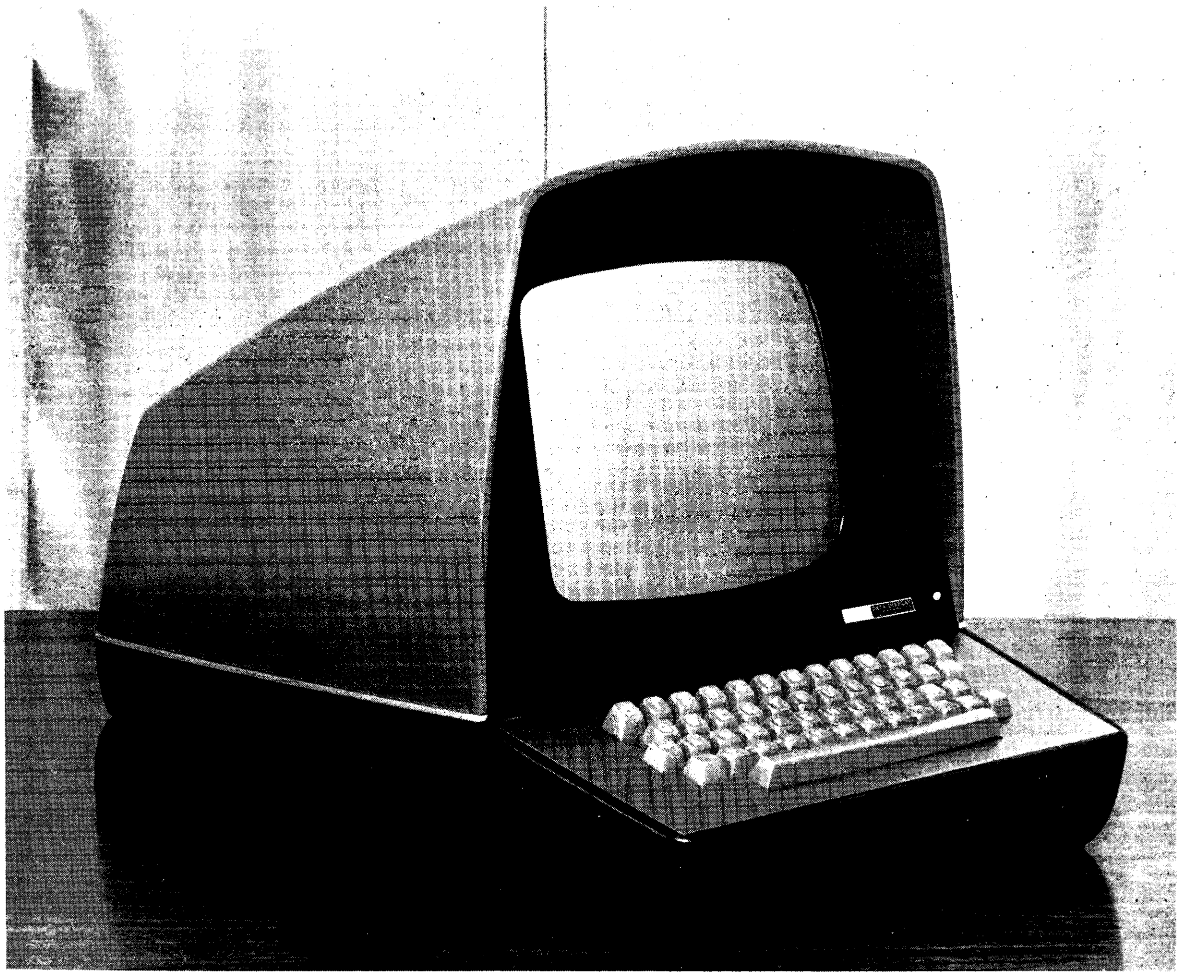


Figure 3-16. Data Display Inc's dd 10 Data
Entry and Retrieval Device

3) User Console - operates like the input console for viewing radar video, IFF and/or computer readouts and is used for command evaluation and decision action entry.

These consoles present raw radar data which is generated by sensors and is directly input to the displays. The actions and decisions required of the CIC console operator are well specified and must be performed under stress. Communication between man and machine is therefore highly encoded and limited. The typical operation is as follows:

1) The radar blip is displayed (raw) on the console screen.

2) The operator moves a marker to "hook" on the blip.

3) This action is transmitted to the computer and the blip is symbolized on the presentation.

4) Using various function keys and the marker, the operator computes intercept points, target assignment, etc.

In the case of the command and control modes of the task force, display console requirements broaden. There is still a requirement for display of target information for purposes of force TEWA. However, the data sources are all digital, being processed and sent at a slower rate than the data generation rate of the sensors. The additional tasks performed are those concerned with mission planning and monitoring. This requires the entry of file queries, generation and correction of plans, initiation of selected computations and the generation of inputs and orders.

Typewriter keyboard operations require:

1) Initiating an action or program in the system.

2) Sending a message to one or more other console stations, the group display or the computer.

3) Requesting a hard copy output.

4) Viewing an output generated for the CRT display.

5) Performing a logical operation at the console by a man/machine oriented procedure (e.g., data base query or special computations).

6) Controlling access to and viewing of background projections.

7) Generating visual displays for storage and later viewing, specifically with reference to background projections.

Some general observations concerning the types of features desired in display consoles to implement these functions are:

1) Higher information regeneration rate in order to display more information and maintain a flicker free presentation.

2) Variable keyboard labeling capability for the diversified procedures which must be servicable.

3) Entry devices such as a light pen, electronic writing tablet, and typewriter keyboard.

Acceptable automated group displays will be available for an ACDS in the 1970 to 1980 period. These devices are on-line, computer driven and capable of presenting information in both graphical and textual form. They employ discriminators such as color and blinking, and have the ability to mix computer generated data with prestored background information. These displays are used primarily for presenting status information to the commander in the form of briefings and information displays as a result of specific requests.

Group displays include:

1) Stylized displays which present status or monitor a well defined situation such that (almost) everything is preprogrammed and presentation formats are well established. Examples of such displays are the System & Traffic Status Boards of the Defense National Communication Control Center and the ICONORAMA System of the Combat Operation Center of NORAD.[4,5*] Displays for the ICONORAMA System are modified dynamically, in a predictable and fixed manner.

2) Ad hoc displays which present information in a variety of formats such that it is impossible to prepare, a priori, all of the programming necessary for the system to be responsive to all contingencies. Examples of such display applications are the query responses and briefing displays which a staff officer may wish to show his commander in environments such as the National Military Command System or the Commander Task Force Node of ACDS.

Both types of displays may be required to permit an ACDS to present:

1) Task force and enemy positions over the area of operations; status of forces presentations (stylized displays).

2) Command briefings on order of battle and mission planning (ad hoc display).

Display consoles and group displays are commonly considered to represent distinct hardware technologies. In point of fact, however, the user technology aspect for these devices is not separable. Indeed, systems employing large screen displays must have associated display consoles, especially in the case of ad hoc automated displays.

Group displays are currently uni-directional, i.e., information flows only from the computer to the display. In an ACDS, however, viewers should have the capability of communicating directly with the data processing system.

The display concept advanced for the Task Force Commander as analyzed in Volume III, Integration, is shown in Figure 3-17 where it is assumed that the commander's staff is charged with the task of preparing scheduled reports, preparing answers for direct requests, and anticipating the information requirements of the commander. The environment of the system includes a variety of files which may be undergoing continuous updating. The system is also capable of integrating inputs from the other nodes of the task force with outputs from the Task Force Commander's staff and of presenting this information through the group display.

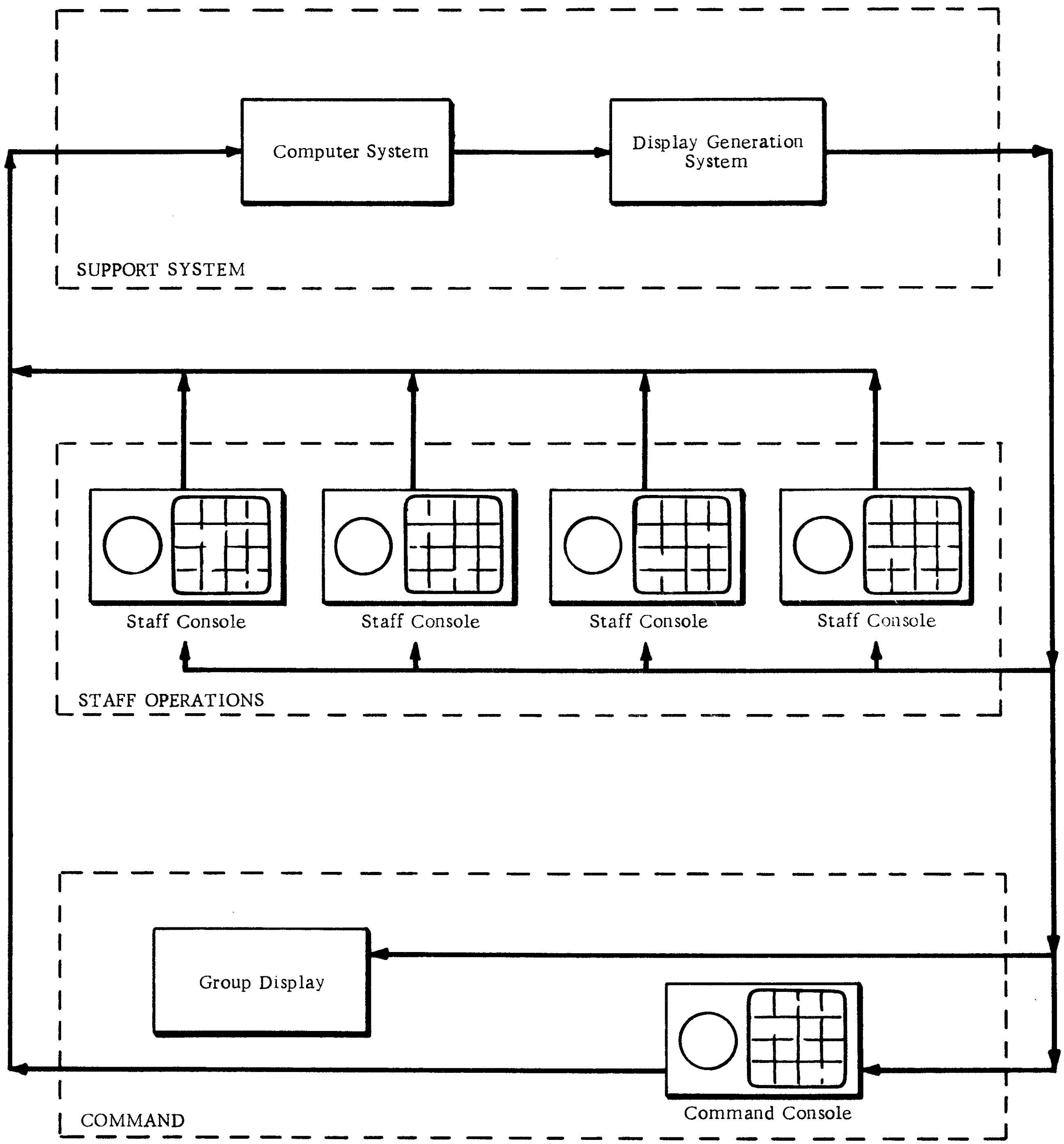


Figure 3-17. Command Node Configuration

The hardware system includes both staff stations and briefing stations. The staff station is an individual operator's console capable of quering the system and subsequently displaying the response. The briefing station represents a group display.

The typical mode of operation is for the staff analyst to make information requests of the system, review the content and format of the response,and make decisions concerning the disposition of the output. Some of the disposition alternatives that should be available to him include:

1) Item rejection, if the content or physical state is unacceptable.

2) Item selection for library retention and later recall, either physically or by computer regeneration.

3) Item transmission to any other station in the system.

3.4.2 Interrogation and Display

One of the most important command and control applications is interrogation and display. This function is a primary concern of the CTF Node which must formulate and transmit to the data processing system complex questions having many quantifiers, covering a wide range of possibilities. In this function, the computer-display combination participates in the question formulation, allowing a simple, straightforward operation as opposed to the manual process described in subsection 3-1. Examples of data which might be desired are:

1) Location and status of ships.

2) Communication system status.

3) POL residuals after attack.

4) Personnel status.

For example, consider the CTF's Own Forces Status file. A typical query by the operational staff may be:

> "Summarize by aircraft type all strike aircraft on board the carrier, HAWK, on 15 minute alert."

Display console function keys would include the following labeled keys:*

1) Operations.
2) Logistics.
3) Intelligence.
4) Administration.
5) Geographical Limits.
6) Current Totals.
7) Task Force Units.
8) Alert Time.
9) Hard Copy Output.
10) CRT Output.
11) Group Display Output.

The steps for query are:

1) The operator depresses the function key labeled OPERATIONS and the display shown in Figure 3-18 is presented. The operator selects STRIKE by use of a light pen or comparable device.

2) The selection of one item, STRIKE, causes a second display to automatically appear, as shown in Figure 3-19. The operator selects AIR ORDER OF BATTLE (AIR O.B.).

3) The selection of AIR O.B. causes a third display to appear as shown in Figure 3-20. It represents the possible choices in selection AIR O.B. data to be used in planning a carrier strike. The sample query dictates that the operator choose READY AIR UNITS.

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* Two techniques are popularly employed to extend the utility of the function keys to many applications. In one approach, the key labels are externally modified through use of overlays. In a second approach, the keys are simulated on the CRT itself and the selections are made with the light pen.

OPERATIONS

* AAW
* ASW
* STRIKE
* AMPHIBIOUS
* MINE
* ECM
* RECONNAISSANCE

Figure 3-18. List Display of Operations

STRIKE

* TARGET LIST
* RECON SUMMARY
* DAMAGE ASSESSMENT
* AIR O.B.
* ASW O.B.
* AAW O.B.

Figure 3-19. List Display of Strike Parameters

AIR ORDER OF BATTLE

* CVA STATUS
* READY AIR UNITS
* RESERVE AIR UNITS
* EOB, RADAR
* EOB, SAM
* EOB, AIRCRAFT

Figure 3-20. List Display for Air OB

READY AIR UNITS

* LIGHT ATTACK A/C
* MEDIUM ATTACK A/C
* HEAVY ATTACK A/C
* ESCORT FIGHTERS
* TANKER A/C
* EARLY WARNING A/C
* ASW A/C
* RECONNAISSANCE
* HELICOPTER

Figure 3-21. List Display for Ready Air Units

4) The next display, shown in Figure 3-21, modifies READY AIR UNITS and four selections are made: MEDIUM ATTACK A/C, HEAVY ATTACK A/C, ESCORT FIGHTERS, and TANKER A/C, completing this sequence of displays.

5) The operator next depresses the function key labeled TASK FORCE UNITS. This results in the display shown in Figure 3-22 and one selection, HAWK, is made.

6) Next, the ALERT TIME button is pressed, causing the format display to appear as given in Figure 3-23. This is a partially complete display, which permits the operator to enter numerical or other widely varying criteria. He selects the LESS THAN line, and enters 15 in the blank space, via the typewriter keyboard.

7) Next, CURRENT TOTALS is depressed, followed by the selection of the output media, e.g., CRT. This latter choice is dictated by urgency for results, amount of detail desired, size of list likely to be generated and desire for permanence of copy. In any event, the selection of either of the output media terminates the request procedure and causes the request to be added to the internal processing queue.

Ultimately, the output is generated and made available for viewing. The selection of delimiters in the query process suggests header/title information; a possible end display may have the appearance as shown in Figure 3-24.

3.4.3 Formatting

In the previous example, the operator had no control over the format of his displayed output. It is desirable in some cases to make ad hoc format statements at the time of the request. This is especially true with respect to the requesting of displays to be presented for group viewing.

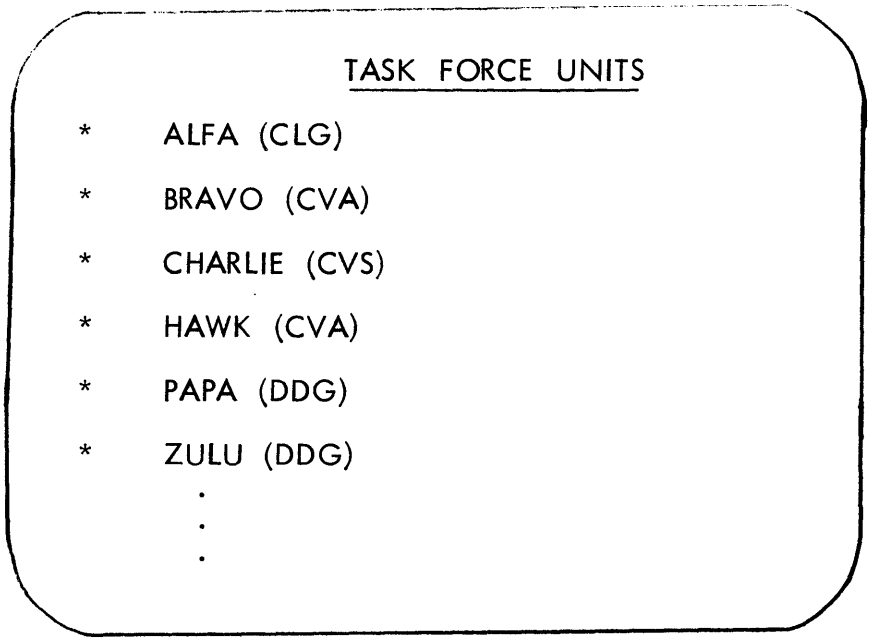

Figure 3-22. List Display, Task Force Units

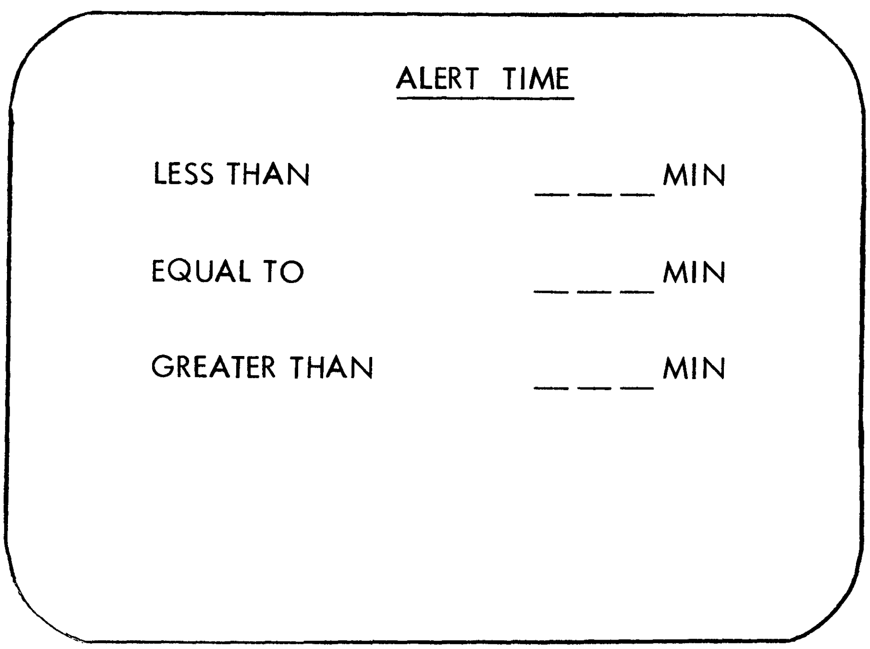

Figure 3-23. Format Display, Alert Time

OPERATION/STRIKE/AIR O.B.

READY AIRCRAFT

HAWK, 15 MINUTE ALERT

LIGHT ATTACK A/C	5
MEDIUM ATTACK A/C	10
HEAVY ATTACK A/C	5
ESCORT FIGHTERS	23
TANKER A/C	8
TOTAL	46

Figure 3-24. Sample Query Output

The steps for processing a query request are identified in Figure 3-25. The steps are:

1) Request is divided into its two parts, the retrieval request and the formatting request.

2) Internal representation of the items mentioned in the request is taken from the dictionary of item definitions.

3) Item definitions are linked to the format parameter.

4) Data is retrieved.

5) Selected data is linked to the format.

6) Display is presented.

Consider now the problems associated with format specification for a large group display. In the past, two projects were undertaken to produce a generalized formatting system for displays. The first resulted in a display assembler requiring programming and compiling. Whenever a format is required this technique utilizes subroutines to provide the computer code for generating a display. The second project resulted in a generalized control-card driven display routine, which utilizes formatting statements at the time of the request to arrange the retrieved data.

Examples of the former approach are the Color Output Generation System (COGS) produced for the National Military Command System; General Motors Design Augmented by Computers project, and the production of movies at Bell Telephone Laboratories [6,7,8]. The second approach is typified by the Task Test Tool (URDRO) produced by SDC for the 465L system.[9] URDRO is strictly a printer program and is representative of systems in which format statements are made at request time.

The systems cited are directed towards specially trained personnel and are not oriented to the general user in an ACDS. One system utilizes a complex formatting statement while the other must first be assembled before it is usable. All require many computer runs to produce the final product.

Extensions to features available in present systems can be postulated to arrive at a description of a generalized automated display system which can be operated on-line and which should be considered for future ACDS applications. The formats that are allowed in this system include tabular, graphic, geographic and bar chart displays.

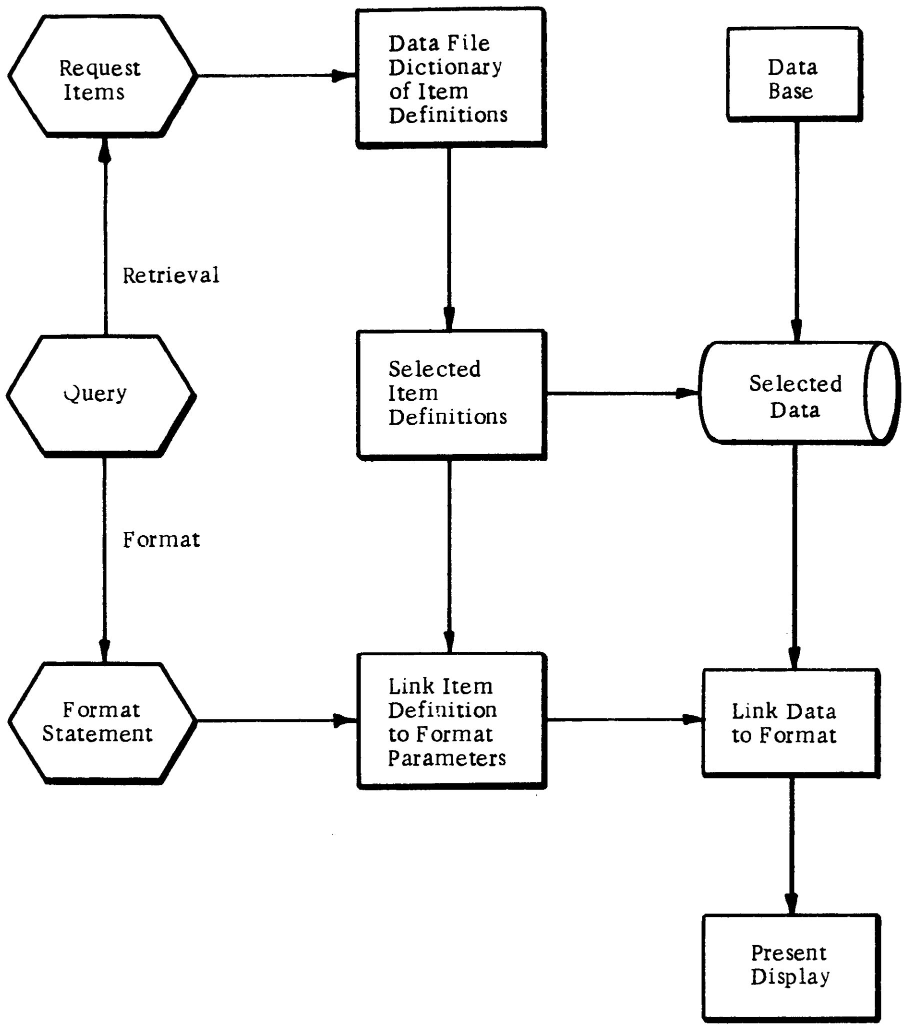

Figure 3-25. Display Request Flow

An example of how formatting can be accomplished in an automated display system is now in order. It is assumed that users of the system will work at individual consoles such as the staff stations mentioned earlier. These consoles have the following features:

1) CRT display capability.

2) Light pen to select positions on the CRT screen.

3) Keyboard with alphanumeric symbols and special characters.

4) Function keys to specify actions to the computer.

The sample query is: Find the number of 3 inch and 5 inch rounds and the number of Terrier missiles aboard ships Alpha, Bravo, and Charley. Plot as a bar chart. For this example, the function keys are labelled as follows:

WEAPONS AMMUNITION	LINE GRAPH	RED
OWN FORCES	GEOGRAPHIC PLOT	BLUE
GEOGRAPHICAL AREAS	TABULAR	GREEN
TIME LIMITS	BAR CHART	BLACK
TOTALS	ACCUMULATE	'
'	'	'
'	'	'
'	'	'

The query is structured by appropriate key action and subsequent parameter selections or data entry as described in the previous subsection.

Upon pressing the AMMUNITION key, the display of Figure 3-26 is presented, from which the operator selects 5 inch and 3 inch rounds and TERRIER MISSILES by use of the light pen. He then selects OWN FORCES and from an appropriate list of alternatives he chooses, again with the light pen, the desired ships, Alpha, Bravo, and Charley. On selecting TOTALS, he is offered a number of choices such as Value, Number on Hand, Number on Order, Allowance Quantity, etc. He chooses On Hand.

AMMUNITION

30 CALIBER

50 CALIBER

•

•

•

3" FIXED

5"SEMI FIXED

•

•

•

SIDEWINDER

TALOS

TERRIER

•

•

•

Figure 3-26. Ammunition on Hand Display

This ends the retrieval request portion of the query. The output format selection process is then initiated by selecting the desired presentation format, in this case the key labeled BAR CHART. The display shown in Figure 3-27 is presented to the operator. This display may be thought of as divided into two sections. On the left are the limiters mentioned in the retrieval request. On the right are the bar chart parameters that must now be specified or linked to the retrieval parameters.

The operator determines the base axis by selecting the word HORIZONTAL with his light pen. Next, he selects the quantity to be measured using the light pen to indicate his decision by pointing in succession at the asterisk preceding MEASURED QUANTITY and then the asterisk associated with NUMBER ON HAND. He next selects the grouping hierarchy. Based on the query example, there are two candidates for such selections: AMMUNITION and OWN FORCES. He chooses OWN FORCES as the primary group and AMMUNITION as a secondary group.

To associate colors with the measured quantities, the appropriate color function key is pressed; the light pen is applied to the item to be assigned that color. A remaining task is to assign a title. At this point the computer could arrive at a title such as:

"OWN FORCES AMMUNITION ON HAND".

The operator may override computer selection by supplying his own title in the indicated position on the CRT.

The operator has now provided the display system with enough information to generate a bar chart such as the one shown in Figure 3-28. More complicated bar charts are possible, for example, to group the two projectiles (3 inch and 5 inch ammunition) together as shown in Figure 3-29. This can be accomplished by making the same selection as before except that the light pen is pointed at 3 inch and 5 inch, followed by activation of the key labeled ACCUMULATE.

Retrieval Parameters

*Ammunition

    *3" Fixed

    *5" Semi-Fixed

    *Terrier Missiles

*Own Forces

    *Alpha

    *Bravo

    *Charley

*Totals

    No. on Hand

Bar Chart Specifiers

Base Axis

    *Vertical

    *Horizontal

*Measured Quantity

*Primary Group

*Secondary Group

TITLE _

_ _

Figure 3-27. Ammunition on Hand
Query Retrieval Parameters and Bar Chart Specifiers

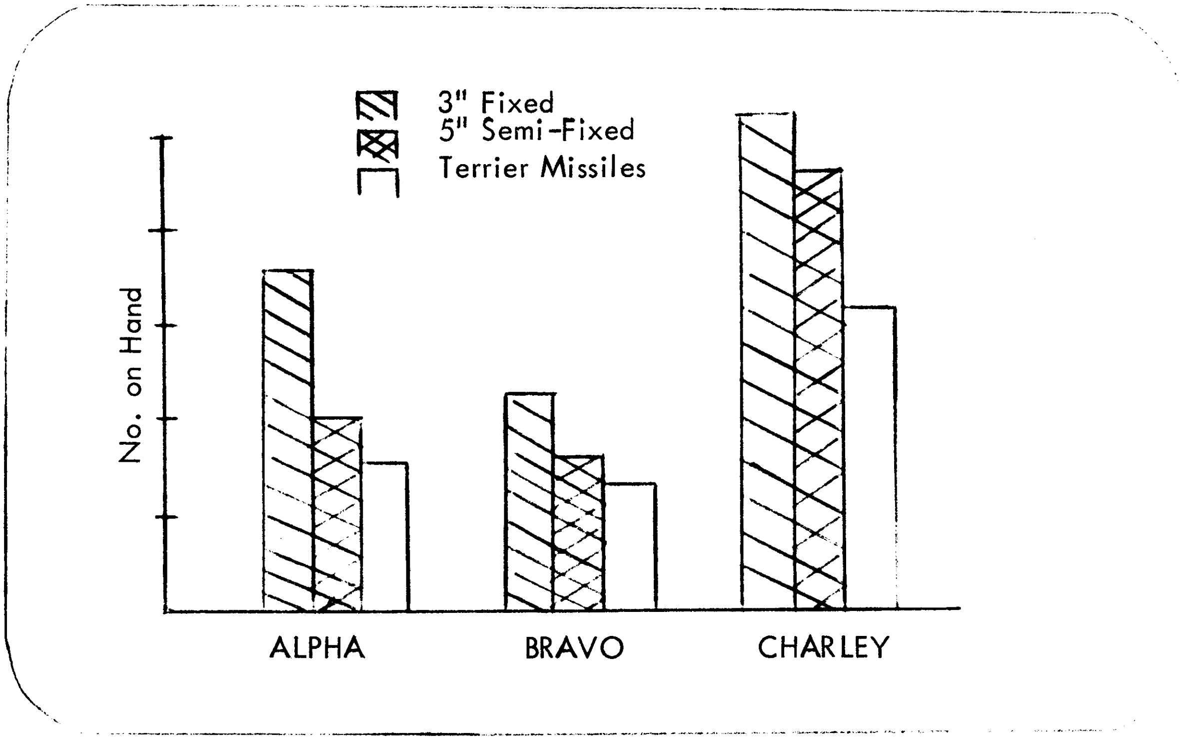

Figure 3-28. Ammunition on Hand Display (Bar Chart)

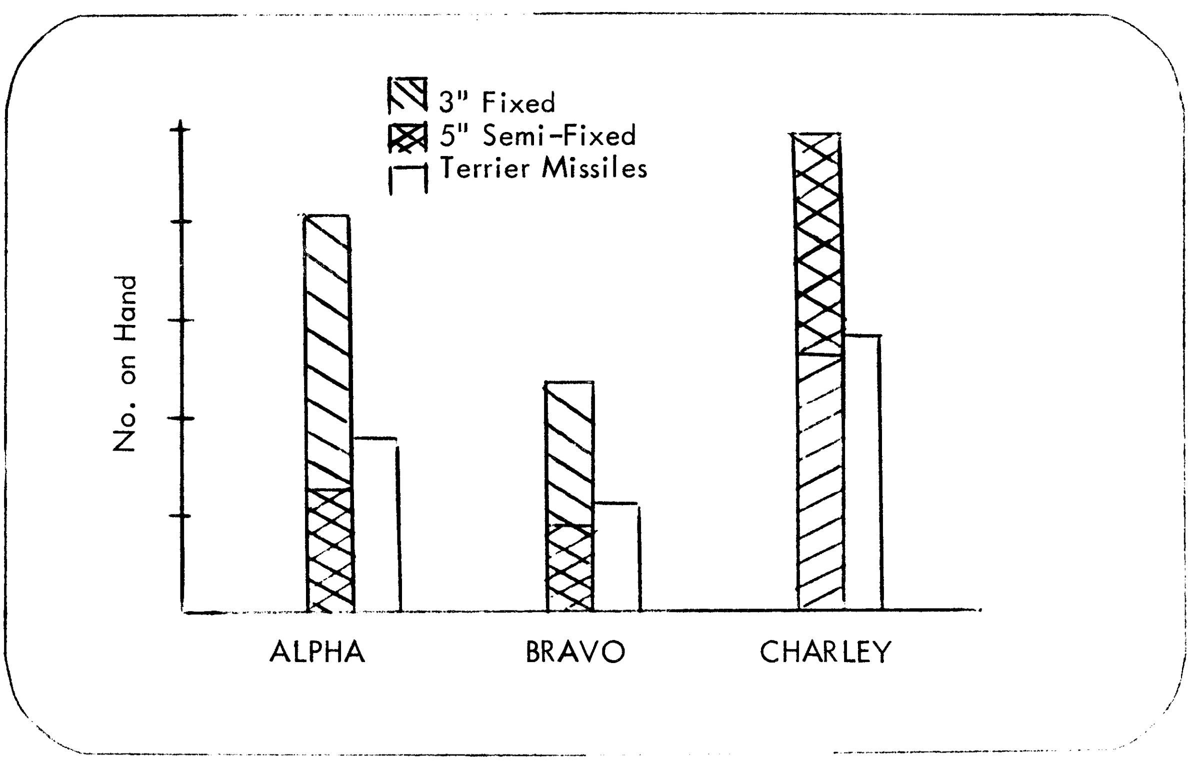

Figure 3-29. Selective Ammunition on Hand Display

The operator then awaits the generation of the display and reviews it. If it does not appear to be satisfactory, he may resubmit his request or change the format through the use of function keys and/or the light pen. If it is satisfactory, the display may be transmitted to other consoles or to the group display. This is accomplished by pressing the function key labelled TRANSMIT TO. A list of stations appears from which the operator selects recipients for the display.

What has been described is a proposed method for handling output formatting. It is not a complete solution but is suggestive of the software research and development needed to exploit the power of automated displays for an ACDS.

3.4.4 Data Input

Another application is data input. Frequently, data comes into a system in unstructured form, or in a wrong format, or correctly and in the right format but in hard copy form or contains minor errors which preclude automatic handling. With the help of a console, information is structured or corrected by humans employing judgment which is difficult to program for a machine. Examples are:

1) Text intelligence reports.

2) Telephone (voice data).

3) Formatted messages such as Ship Movement Reports, SITREPS.

An automated ACDS system may use the approach shown in Figure 3-30 where the computer presents messages which do not pass the validity checks to the console operator for disposition.

3.4.5 Internode Communications

Communications may be handled easily by the console operator. In querying the data base, he has received a good deal of information and he may now wish to transmit it to some other station. At his discretion, he may format or edit the information so that it will be more useful to the recipient.

Passing a function key labelled TRANSMIT TO might produce a listing of stations. The operator could select the desired stations with a light gun.

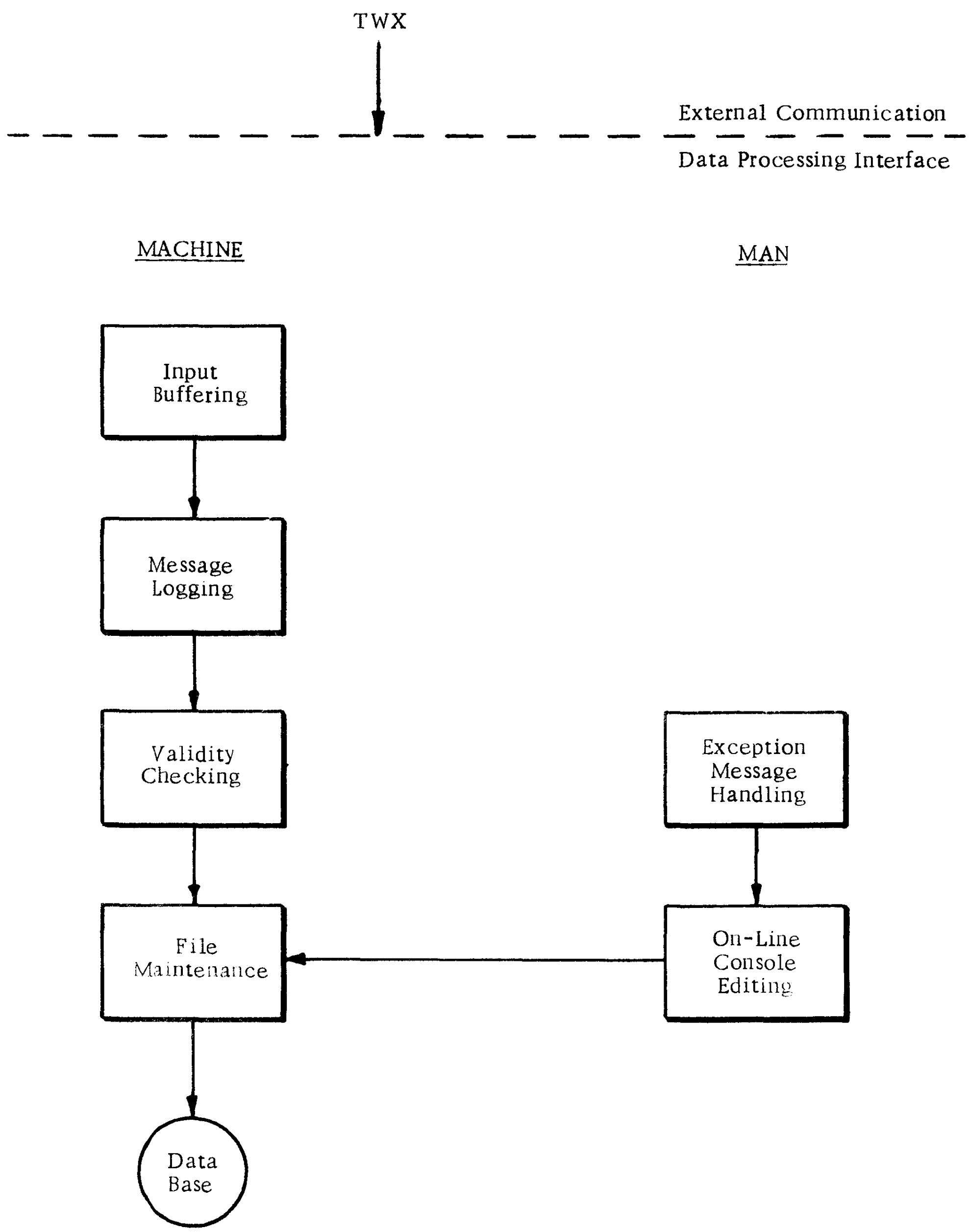

Figure 3-30. Automated Input Message Processing

Query information is not the only type of data that might be transmitted. Text could be typed at the console and then transmitted in the manner mentioned. Orders could be preformatted and also transmitted in this manner.

Receipt of messages on a console is complicated by the fact that a receiving console may already be in use. In such a case, a signed (perhaps a blinking two or three letter) identifier is displayed that does not interfere with the console operation, and it is left to the receiver to request the message when he is ready.

3.4.6 Problem Analysis

Problem analysis refers to the process of examining complex problems, breaking the problems into their component parts and defining interrelationships. Consoles may be used in the analysis of problems of an ACDS for which no explicit programmed model exists. In particular, the console could be used to provide pictorial information which might be difficult to describe mathematically. This allows a man to analyze problems requiring reasoning processes which are not readily possible using a previously described data processing machine program. It might be easier, for instance, for a man to observe and compare unknown sensor returns with known patterns to establish the reflected target classification or identification. Going one step further, multi-source sensor information might be observed using a console, with man correlating the information to increase confidence in target classifications and identification. The reasoning processes involved in problems of the type described could include simple comparisons as well as complex inferences.

Another example of an analysis problem is the iterative process in producing strike plans. For instance, man may use a console to initiate machine processes by indicating the targets and the general paths, profiles and tactics to be followed by the strike aircraft. The machine may then compute detailed path and profile information and solve a probability of mission success model by comparing the plan with counter enemy capabilities. The console may then present the computation results. Man then decides whether the mission should be ordered, based on the model computation and other factors, or he alters the plan and repeats the process with machine assistance until he is satisfied with the expected mission results.

3.4.7 System Monitor and Control

System monitor and control is generally a support function, important to the operation of the computers or input/output equipment. It may be desirable, for example, to change the status of equipment on stored data for another function. Or, it may be important to keep a log of operations or to command a certain output for a group display. Examples are:

1) Monitoring status of communications equipment.
2) Program read-in for mode change.
3) Generation of group display output.
4) Logging of communication input.
5) Quality control of display and hard copy outputs.
6) Maintaining cognizance of queues and schedules.
7) System break point initiation for start over.

In addition to the computer controlled portion of this function, there are also monitor and control activities which must be performed by the console operator. Since these activities must be performed whenever the system is in operation, status lights and control keys are normally reserved for monitor and control functions. The computer uses the status lights to indicate equipment and program conditions to the operator. The operator uses the dedicated keys to indicate (to the computer) the equipment configuration to be used, the mode of operation, etc.

3.4.8 Program Debugging and Maintenance

Program debugging and maintenance in this discussion involves the checkout and maintenance of computer programs by means of display consoles. This application is not directed so much to operational use in an ACDS, but rather as a tool for developing and maintaining the programming system. It is interesting to note that the very consoles that are used in tactical operations for command purposes can be used in the sense described here. Considerable economy may be realized in streamlining and automating the costly program checkout phase in implementing military systems. Additional savings may be realized by using consoles to aid in making the inevitable modifications and additions to the programs after they are checked out. Examples of operations in this function are:

1) Determining data status.

2) Checking of input statements.

3) Examining program logic.

4) Diagnostics and output control.

5) Accessing and modifying programs in mass storage.

Currently, a programmer must depend upon dump and trace routines to check out his program. These routines usually generate large quantities of printed data which the programmer then uses to determine whether or not the program performed correctly. Some disadvantages to such a system are:

1) Most of the data is not used. The programmer requests it only because some of it may be useful.

2) The run must be repeated because some important piece of data was not dumped. This occurs when the programmer dumps only that data which he thinks will be of use.

3) The programmer must decide what to dump before he runs his program. He cannot change his mind during the course of the run, unless he builds into his program the ability to make complex analyses of its own performance.

4) The programmer does not have the ability to make corrections in a timely on-line fashion, thereby incurring costly time delays with the off-line process of error detection and correction.

In an on-line system, program checkout can proceed much more efficiently and rapidly. The programmer, from a display console, is able to control the operation of his program such that he can stop at any time and look at any of the data in the computer. Dump and trace information is stored in auxiliary storage instead of being printed out. The programmer subsequently looks only at the data of interest and asks for it in the program source language.

Other system checkout routines which must be considered include a flow trace, address analyzer and a generalized driver routine. The last named routine would enable a programmer to check out his program more easily and completely. This is accomplished by removing the requirement that the programmer construct his own driver routine and plant it in his program. Rather, the linkages and program controls would be introduced automatically.

The data base used in program maintenance consists of all system programs and displays. The operator has the capability to:

1) Modify any part of a program or display.
2) Replace any program or display.
3) Delete any program or display.
4) Add new programs and displays.
5) Rearrange the order in which the programs and displays are stored.

For this example, assume that the programs and displays are stored as records on magnetic tape. A representative operation would be to modify an instruction in one of the programs; for example, the program stored in the third record in the second file.

Assume that the display console function keys include the following labeled keys:

Read Record	Read Paper Tape Record
Write Record	Backspace Input
Display Program Record	Rewind Input
Display CRT Record	Backspace Output

Copy to Identified Record	Write EOF
Copy "n" Records	Read Merge Tape
Copy File	Backspace Merge Tape
Copy Tape	Rewind Merge Tape

The steps which the operator must perform are:

1) Depress Copy File. The computer copies the contents of the first file from the input tape (the current program tape) to the output tape (the new program tape). The end of the copying operation is indicated on the CRT.

2) Depress Copy "n" Records. The display shown in Figure 3-31 appears. The operator types in a 2, and the first two records in the second file are copied from the input to the output tape.

3) Depress Read Record. The third record in the second file is read in and its identification displayed on the CRT, as illustrated in Figure 3-32.

4) Depress Display Program Record. Depending upon the size of the record and the size of the CRT, all or part of the program record is displayed on the CRT in a format similar to that shown in Figure 3-33. Each successive depression of the Display Program Record key causes the next part of the record to be displayed.

5) When that part of the record to be modified appears on the CRT, the operator uses the alphanumeric keys to key in the new instructions.

6) The operator depresses Write Record to transfer the modified program record to the output tape and then Copy Tape to copy the remainder of the input tape on the output tape.

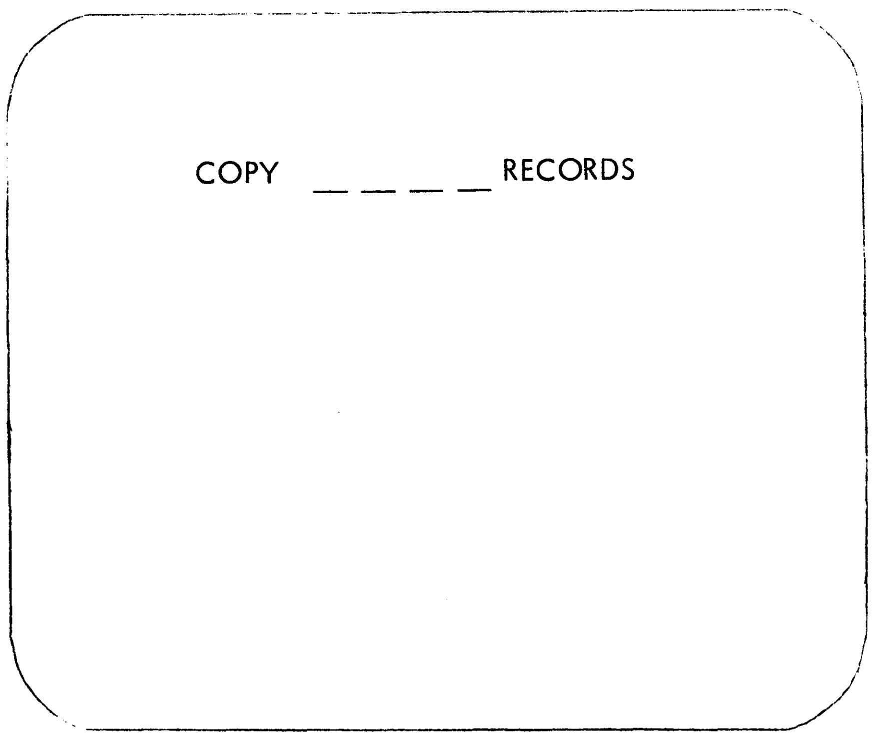

Figure 3-31. Display for "COPY n RECORDS"

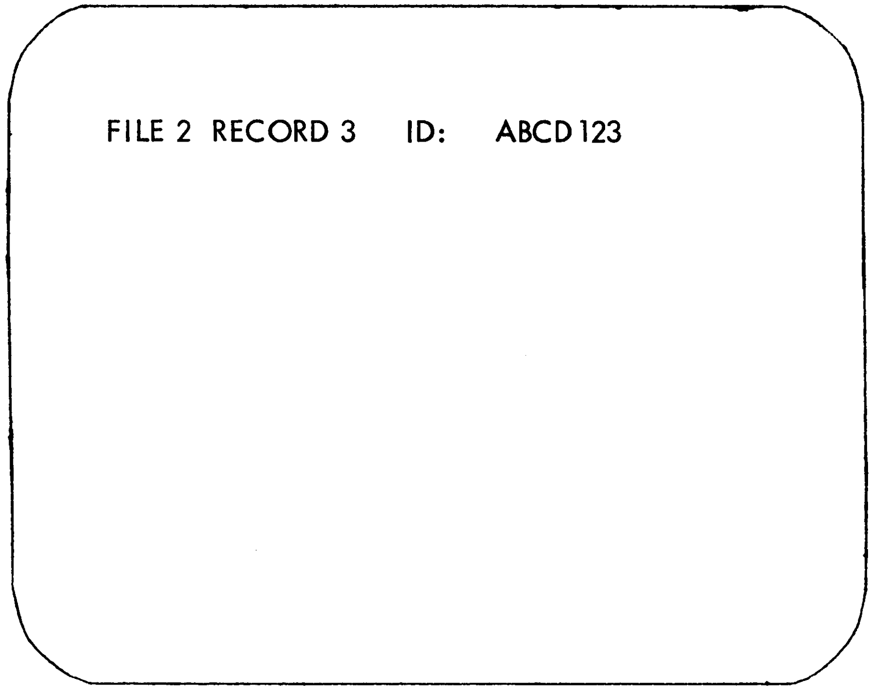

Figure 3-32. Display for "READ RECORD"

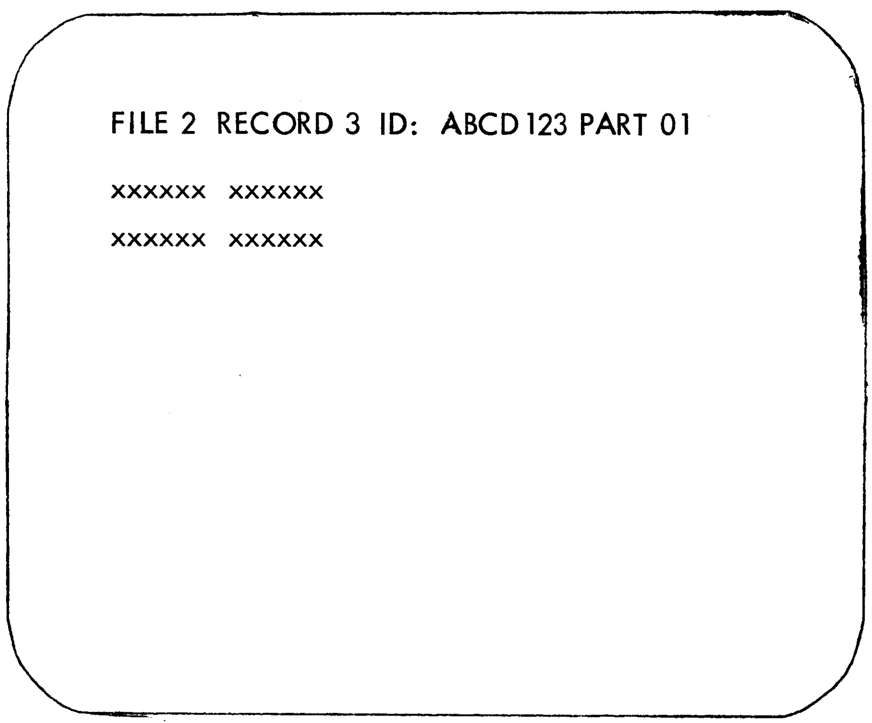

Figure 3-33. Display for "DISPLAY PROGRAM RECORD"

3.5 COST CONSIDERATIONS

The determination of a "best" display is a function of system balance where hardware cost, computer programming requirements and demands on the computer are measured for the application. While the first of these is evident and simple; i.e., a dollar cost for the display and all interface boxes and cables, the second is more elusive. The third is often a neglected consideration.

3.5.1 Display Hardware Costs

Display hardware costs are not only measured by the cost of the particular keyboard and CRT unit but must also include the cost of the black boxes and cables which connect the device to the processor. Total display subsystem costs are also a function of number of units. Since displays are often custom designed to user's specifications, single unit purchases are usually more expensive than buying displays in lots of five or more. Also, in many cases, parts of the hardware can be time shared, and the unit price may not increase as the number of units increases. It is therefore desirable to consider alternatives in system configurations since cost is related.

Generally speaking, console examples of the type discussed here range in cost from 30 to 200 thousand dollars per unit. Group displays range from several hundred thousand dollars to over one million dollars.

The most important cost consideration for the system planner is that display hardware prices can easily be reduced by 50% if quantity purchases are made. This must be coupled with expected improved production techniques for the 1970 to 1980 period. Hence, it is possible that display consoles including all necessary modules, will range in price from $3,000 to $30,000 in that decade. Similar conclusions concerning group displays have not been reached.

3.5.2 Computer Programming Requirements

The use of on-line communication devices imposes programming requirements upon the total system. The extent of the software developed depends on the specific features provided by the hardware. For example the presence or absence of a CRT buffer will affect the executive control program.

The computer requires resident programs in core memory as well as buffers for data assembly and dispersal. The requirements for storage are based on design considerations relating to the accessing time required to obtain program overlays from auxiliary storage. Reducing the core storage dedicated to displays will increase the required number of program overlays, resulting in a reduction in response time. An optimal allocation of core memory must therefore be arrived at for each node of an ACDS.

Estimates of general purpose computer programs necessary to implement a display system are given in Table 3-5. The data presented here is based on experience in implementing a display system for a strategic command and control system and suggests that 8000, 24 bit words of high speed storage must be allocated to a display subsystem.

These estimates are for general purpose software and hence are applicable to actual systems. In addition to programming, specific procedures necessary for an ACDS must be implemented. It is noted, however, that a general software framework will provide a basis for each ACDS node, requiring therefore only one such implementation. Subsequently, specific procedures must be implemented for each node as required.

3.5.3 Demands on the Computer

The demands on a computer system by on-line displays affect the efficiency of the computer. The tieing of on-line displays to a computer requires dedication of core memory to service the displays with reasonable response times. A second demand concerns the amount of computer time actually used by the displays for display activity independent of retrieval, formatting and presentation. If there are m consoles in the system and each console is generating input at the nominal 60 wpm rate, then m consoles would, on the average, require servicing every 200 milliseconds. Based on experience, the typical processing time/character (command) entry is one millisecond for computers of the six microsecond memory class. Hence, if m is 20, then 20 milliseconds out of every 200 (or 10 percent of the available processor time) is spent in console servicing if the entry rate is sustained.

TABLE 3-5. PROGRAMMING REQUIREMENTS FOR TYPICAL DISPLAY SUBSYSTEM

Programming Requirements	Required Message Storage 24 bits/word
Core Resident	
Programs	
Display Executive	250
Function Monitor	500
Utility Programs	700
Input/Output	500
Console Program Service Area	350 (each console)*
Buffers and Data	
Constants	100
CRT Image	400
Queues	150
Working Core	800
Input/Output	1600
Total	5350
Auxiliary Storage Resident Programs	
Start-up	100
Service Routines	1600
Restart	200
Total	1900
TOTAL	7250 (one console system)

*Multiple console service areas can share this memory portion by overlaying program pieces from an auxiliary storage.

TABLE 3-6. PROCESSOR SERVICING REQUIRED IN SUPPORT OF CONSOLE MESSAGE ENTRY

	Rate of Occurrence	Average Processing Time	Number per Message	Total Processing Time	
				Computing*	I/O (Assumes disc with 150 ms average access)
Alphanumeric Entry	200 ms	1 ms	50	50 ms	
Display Change	4 sec	150 ms (I/O)	7		1050 ms
		10 ms (Computer	7	70 ms	
Function Key	6 sec	50 ms	5	250 ms	
Complete Message	30 sec	200 ms	1	200 ms	
Total				0.57 sec.	1.05 sec.

*Assumes 6 microsecond computer memory cycle.

A more realistic analysis of processor support to displays is given in Table 3-6. Here, it is shown that if messages can be entered in 30 seconds, a single console requires a total of 0.57 second of processing and 1.05 seconds of I/O time, assuming a six microsecond computer memory cycle and the availability of a fast random access auxiliary storage. Assuming a 30 console system, a requirement exists for 17.1 seconds of the processor's time and almost 32 seconds for I/O. Such an amount of I/O time is impossible in a 30-second period. Multiple buffered channels must be part of the system to overcome this limitation.

In a multiple console configuration, the computer capacity must be sufficient so that all console actions are serviced and processing tasks generated by these actions are satisfied.

The third demand concerns the potential traffic problem which multiple consoles may cause with respect to the data channel to which they are connected and to the I/O transfers required between auxiliary storage and the processor and in the processor itself. Using the theory associated with Poisson processes, we can estimate the waiting time from the service factor, which is the ratio of service time to total elapsed time between requests. This factor is 1.5/30 or 0.05 for the assumed case. The result of the traffic analysis is given in Table 3-7 where a service factor of 0.03 is also added. Table 3-7 leads to a model which assumes buffering and an optimum organization of the processing tasks.

Results show that a waiting time will exist 19% of the time for the 0.05 service factor. Since the service time is 1.5 seconds, the average wait on the waiting line is slightly under three seconds. For the second model, a waiting line will exist about 7.4% of the time.

TABLE 3-7. PROBABILITY OF n CONSOLES OF TEN REQUIRING SERVICE AT THE SAME TIME

Number of Consoles	Number of Consoles Waiting	Probability of n Consoles requiring service		Cumulative Waiting Probability	
		Service Factor = .05	Service Factor = .03	Service Factor = .05	Service Factor = .03
0	0	.538	.712		
1	0	.269	.214		
2	1	.121	.057	.121	.057
3	2	.049	.013	.170	.070
4	3	.017	.003	.187	.073
5	4	.004	.001	.192	.074
6	5	.001	.000	.193	
7	6				
		1.000	1.000	.193	.074

3.6 CONCLUSIONS AND RECOMMENDATION

3.6.1 Conclusions

The following conclusions are drawn from the study on display user technology and software:

1) The ANTACC, Phase I, Requirements Study (Volume II) indicates a need for a large number of on-line console stations and group displays for the various ACDS nodes.

2) Display hardware technology has reached a point of development which easily affords a capability for CRT console displays in the time period 1970 to 1980. Group displays, while not currently satisfactory, will be available for an ACDS in the stated time period.

3) The major problem concerning displays at present is cost. It is expected that console costs will be substantially less in the 1970 to 1980 period; group displays will continue to be relatively expensive.

4) The number of console applications in an ACDS is substantial. General purpose consoles, with variable keyboard labeling, are feasible and can be employed to satisfy ACDS requirements. In addition, these consoles differ from the NTDS consoles in the following:

   a) Require higher transfer rates to preclude flicker.

   b) Require full typewriter keyboards and other entry devices such as light pens or electronic writing tablets.

5) There are two kinds of group displays, stylized and ad hoc. The former includes displays which are planned and deterministic; the latter includes the capability for presenting arbitrary displays. Both types of displays may be dynamic and are required in an ACDS.

6) Display consoles and group displays are distinct hardware entities but must be jointly considered in determining usage and software requirements. Group displays cannot function without adequate entry devices or preview stations, as provided by console displays.

7) The user/data system interface via consoles and displays must be in the military language of naval personnel.

8) Major ACDS application areas for on-line consoles and group displays are:

   a) Interrogation and display.

   b) Format requesting.

   c) Data input.

   d) Inter-node communication.

   e) Analysis functions.

   f) System monitor and control.

   g) Program debugging and maintenance.

9) It is possible to categorize display hardware features and operating concepts to provide a basis for a general purpose display software system.

10) The general purpose display software subsystem is a framework for all on-line display operations within an ACDS, independent of the particular node in question. Specific nodal problems may then be implemented as required using this software system.

11) Man actions may be made discrete, and the display hardware features needed for implementing these actions may be identified.

12) Display subsystem costs are a function of three important and independent considerations.

   a) Actual hardware costs.

   b) Implementation programming.

   c) Additional processing load on the computer.

3.6.2 Recommendation

The most important recommendation with respect to the applicability of on-line display to an ACDS in the period 1970 to 1980 is for the satisfactory development of a man/machine oriented language for implementing on-line procedures. Development efforts in such on-line software techniques are now in order, as was the development of compilers, monitors and operating systems for batch processing in the period 1954 to 1960.

Section 4
DISPLAY TECHNOLOGY

4.1 INTRODUCTION

The ability to present dynamic real-time graphical data and associated alphanumeric characters and symbols, status information, and tabular alphanumeric data is required in displays for naval tactical data systems. Existing technology is adequate for console type displays, but new approaches to large-screen displays are necessary to meet shipboard operating conditions as well as performance requirements for future naval tactical systems. The operating conditions, maintainability and logistics requirements encountered in Navy shipboard equipment impose severe limitations on the use of currently available large-screen display techniques. Current cathode-ray-tube technology used in console displays, on the other hand, is satisfactory. The use of CRT console displays will probably continue into the 1970's although continuing improvements in performance characteristics can be anticipated. The mechanical and photographic aspects of film-based projection systems, which constitute the major large-screen display technique in use at this time, do not meet the requirements for mobility, ruggedness, reliability, and ease of maintenance. This is also true of other techniques, such as light valves and mechanical inscriber systems, currently used for large-screen displays. For this reason, most of the study of display hardware technology has been concentrated on new technology for large-screen displays capable of handling real-time data while meeting shipboard operating conditions.

The study of display hardware has concentrated on the major hardware problem facing future naval tactical systems - what technologies will be available for the mechanization of large-screen shipboard displays. The investigation has considered display technology rather than the actual design of display equipment. The basic technologies that can be used in console or large-screen displays have been analyzed, but little attention has been given to the details of how to put these technologies together in a specific piece of equipment. For example, a number of storage techniques discussed in the Memory section of this report are capable of providing storage required in certain types of display equipments, but the use of these techniques in console or large-screen displays is considered an equipment design function. On the other hand, for some display technologies, such as photochromics, the fact that storage capability is inherent in the media has been considered an advantage of this technology over other technologies, such as electro-luminescence, where either computer regeneration or external storage must be provided. Character generation techniques have not been analyzed in detail since a number of satisfactory electronic character generators are available and numerous comparisons have been made in the literature. Emphasis has been placed on basic display technology in this section - not on equipment design.

Questions such as the kinds of operator functions to provide in a display, how to select the data to be displayed, the types of data to be displayed, and the format or organization of data to be displayed are not dependent upon the hardware technology.

The technologies that can be used for the mechanization of display logical components and storage are discussed in other sections on components and memories. This section on display hardware technology is concerned primarily with the media and technologies for achieving the presentation of data. This section considers the question of whether the technology in the present NTDS displays is inherently capable of being improved or replaced by advanced technologies, rather than whether the NTDS displays are satisfactory from the functional and use standpoint. Improvements in technology are possible and a number of advanced technologies applicable to a 1970 shipboard tactical system are discussed and compared.

A number of techniques now being investigated offer some promise of permitting the design and fabrication of non-mechanical, essentially solid-state, large-screen displays capable of dynamically displaying real-time graphical and alphanumeric data in a mobile, rugged, reliable, easily-maintained unit.

In the remainder of this section, the classification and uses of display technology and the requirements for different types of displays in future shipboard naval tactical systems are discussed. Different display technologies are compared and related to Navy requirements. Particular emphasis is placed on the ability to fulfill shipboard operational requirements - environmental conditions, ruggedness, maintainability, reliability, and logistics. Technical descriptions of the major display technologies anticipated for large-screen displays in 1970 are given, conclusions are drawn, and recommendations for display development projects are made.

4.2 CLASSIFICATION AND FUNCTIONAL USES OF DISPLAY TECHNOLOGY

Display technology can be classified in a number of different ways that are not mutually exclusive. Associated groupings of display technology will vary with the method of classification. Among the ways in which displays can be classified are:

1)	Functional	Single or few users (e.g., Console) Group users (e.g., Large-screen)
2)	Nature of data to be presented	Status Real-time or dynamic data
3)	Type of data	Alphanumeric and symbols Graphical and pictorial
4)	Display principle	Cathode-ray tube - conventional or storage Electroluminescent Character lights Photographic projection Light-valve Thermoplastic Photoplastic Mechanical inscriber Photochromic Electrochemical Opto-magnetic Laser-luminescent

Displays could also be classified on the basis of factors such as persistence (e.g. self-storage or refreshing required) or ability to provide permanent records. However, these factors are used in later discussions as characteristics to be considered when comparing displays rather than as categories of displays. Other bases for classifying displays include operator functions, computer interface and software requirements, and whether intended for command or operational use. However, classifications of this type are not directly a function of the hardware technology and are more closely related to the user technology and software discussed in a subsequent section.

From a functional standpoint, requirements will exist for situation displays, tabular displays, and special displays that are fixed in format and under computer control. The functional uses of displays will include individual consoles, group displays, intercommunicating individual consoles, and hard copy display units.[1*] From a hardware technology standpoint, these functional uses imply three basically different types of display equipment: console (individual users), large-screen (group display), and hard copy. Since present technology can meet requirements for console displays and hard copy displays, the time available for display investigations during this study has been concentrated on the significant problem area -- large-screen or group displays.

For the purposes of shipboard tactical systems for the 1970 era, large-screen displays capable of presenting alphanumeric characters, symbols, and graphical data in real-time are considered the most critical requirement. This report classifies displays by the type of mechanization with particular emphasis on those techniques capable of meeting this type of requirement.

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* References are listed in Section 10.6.2

4.3 REQUIREMENTS FOR DISPLAY TECHNOLOGY IN A 1970 NAVAL TACTICAL SYSTEM

The present Naval Tactical Data System uses real-time cathode-ray tube console displays that are primarily operator oriented. Requirements for this type of display will continue to exist in future tactical data systems and can be handled by existing technology. Requirements will continue to exist for hard copy displays that can also be handled by existing technology.

The major requirement for significant improvements in display capability for a 1970 tactical system lies in the need for non-mechanical, large-screen displays capable of providing rapid updating of real-time data. Large-screen displays will be needed that can present the same type of data now handled by console displays, and with essentially the same response times. These large-screen displays should also be capable of presenting status information in the form of charts and tables of alphanumeric data. Hence, a large-screen display is required that can present large volumes of rapidly changing real-time data (e.g. moving targets with symbols and alphanumeric characters associated with each target), historical data (e.g. target track history), and static alphanumeric and graphical data. The presentation of status information must be oriented to the commander and ship's officers rather than the operator.

In large-screen displays, multi-color capability is desirable. This can be achieved by a number of techniques; but, unfortunately, the technologies that are well suited to multi-color displays (e.g. photographic film) are, in general, not desirable from the standpoint of performance and operational characteristics. Achieving multi-color with some of the more promising future large-screen technologies (e.g. electro-luminescence, lasers, light valves, etc.) will increase maintenance and logistics problems, and may impair reliability. As a result, for shipboard tactical data displays, it may be necessary to sacrifice multi-color capability in favor of simpler equipment, easier maintainability, simplified logistics, and higher reliability.

The requirements placed on display equipment in a shipboard tactical data system will differ significantly from those for fixed installation strategic military systems and commercial systems. This is particularly true with respect to operational requirements such as mobility, ruggedness, reliability, and maintainability. These operational requirements impose severe limitations on the use of much of the display equipment and many of the technologies available today. The mechanical and photographic aspects of film-based projection systems, mechanical inscriber systems, and currently available light valves cannot meet these requirements. Although performance characteristics are important, the ability to meet these types of operational requirements are of overriding importance.

Displays for a shipboard tactical data system must have a long mean time between failure, must be capable of being repaired quickly, must not use large quantities of non-reuseable media, such as photographic film, and must be capable of operating under military shipboard environmental conditions. Typical characteristics desired for large-screen displays are listed in Table 4-1.

TABLE 4-1. LARGE SCREEN DISPLAY CHARACTERISTICS

Size	6 x 8 ft.
Brightness	20 - 25 ft-lamberts
Viewing Angle	$\pm$ 40° at half brightness $\pm$ 60° at one third brightness
Color	2 or 3 colors desirable, but may be sacrificed for size, cost, and maintainability
Linearity	0.2%
Rapid Update (Blink Time)	<1 sec.
Resolution (Optical)	2,400 optical lines (if photos or maps required)
Resolution (Digital)	512 to 2,048 positions in X and Y
Symbol Types	64 to 128 plus vector drawing capability
Symbol Generation Speed	20,000 to 100,000 symbols/sec.
Lumen Output	5,000
Contrast Ratio	50 : 1
Reliability	2,000 hrs. MTBF
Environmental	MIL-E-16400

The following comments amplify and explain some of the desirable characteristics listed in Table 4-1:

Size: A 6' x 8' screen has the conventional 3:4 aspect ratio of TV and standard motion pictures. Up to 72 rows of one inch characters will be visible at distances up to 30 feet (one inch at 30 feet equals approximately 10 minutes of arc).

Brightness: 20 to 25 foot-lamberts approximates the brightness of a sheet of newsprint on a properly illuminated deck.

Viewing Angle: A viewing angle of 80° is the best that can be obtained (for half brightness) with a rear projection screen with a gain of one. Lower gain screens are undesirable because the combination of lower gain and higher reflectivity degrades the contrast.

Color: Three colors plus white are desirable but two may suffice. The use of seven colors (three primaries plus the three complements plus white) is not recommended since blue is not easily legible, and yellow and white are confused. Recommended colors are cyano, yellow green, and orange red, plus white. However, it should be emphasized that the number of colors, and even the use of multi-colors, may be sacrificed to minimize the amount of equipment and hardware desired.

Linearity: It is possible to obtain 0.1% but the added benefits do not justify the costs. The figure of 0.2% is a good compromise between cost and image quality.

Resolution (Optical): 1200 TV lines will permit 80 lines of characters (at 15 lines/character). Since 600 optical lines correspond to 1200 TV lines, the 2,400 optical lines are more than enough for 80 lines of characters. However, if photos or maps are required on the same display, 2,400 optical lines are marginal.

Screen width of 8 feet is approximately 100 inches; hence, there are 25 lines per inch on the screen. The eye can resolve 250 lines per inch at 10 inches distance; hence, at 100 inches (or 8 feet) lack of resolution will be apparent - i.e., 8 feet is the nearest viewing distance. To get 2,400 optical lines on a film with 60 l/mm resolution (typical of color film) requires a 40 mm format. It can be done easily on a 70mm film chip.

Symbol Generation Speed: 80 lines of 100 characters requires 8000 characters per second. If the display must be refreshed at 48 cycles/second, (flicker threshhold at 20 foot-lamberts), the characters per display must be multiplied by 48 to get the character rate. This gives 384,000 characters per second. Hence, a display that must be regenerated at flicker-free rates would require a higher symbol generation speed or would permit displaying fewer characters. However, for a display with inherent storage, or for a regenerated display with graphical type drawings and fewer characters, the rates shown are sufficient.

Lumen Output and Contrast Ratio: 5,000 lumens will produce approximately 100 foot candles on the 48 square foot screen (6 x 8 feet). With a screen gain of one, the initial brightness is 100 foot-lamberts. Using a 4x neutral density filter coating over the screen will cut this to the 25 foot-lamberts shown. The 4x filter, traversed twice, and the 50% reflectivity factor of the screen will produce a 32x attenuation of ambient light. Thus, 16 foot-candles of ambient light are permissible since the ratio of 25 foot-lamberts to 1/2 foot-lambert (reflected ambient) gives the 50:1 contrast ratio.

Reliability: Xenon lamps used in film-based systems have MTBF of 2,000 hours. Replacement time is 10-15 minutes. It is hoped that some of the new technologies will provide higher reliabilities and better maintainability (MTBF's) in excess of 2,000 hours and MTR's less than 10 minutes), but these are minimum goals.

Some of the film-based projection systems under development representing the advanced state of that art can meet or exceed the performance type requirements listed above, but fall short with respect to reliability, maintainability, and environmental conditions. For satisfactory large-screen displays in naval tactical systems, it is necessary to develop display technologies that can also meet the performance requirements but with significant improvements in reliability, maintainability, and environmental conditions that are needed in mobile tactical applications.

Since the large-screen display will be in the same room as the CRT type console displays, a semi-darkened room is anticipated. Several promising large-screen display techniques offer sufficient brightness and contrast for use in this type of environment. The most promising candidates are electroluminescent, light valve, photochromic, and laser generated displays.

4.4 COMPARISON OF DISPLAY TECHNOLOGY

In evaluating and comparing different display technologies, some of the major characteristics that should be considered are:

Screen size

Brightness

Linearity

Update time

Resolution

Character or symbol generation rate

Contrast ratio

Reliability

Color capability and

Environmental conditions.

The above parameters are important for both console and large-screen displays. Secondary characteristics that should be considered in the case of alternative approaches that are considered acceptable on the basis of the parameters above include:

Storage and regeneration requirements

Capacity

Registration requirements

Stability

Physical space requirements

Weight and power requirements.

Other characteristics of interest (e.g. legibility and image quality) result from some of the parameters listed above (e.g. resolution, registration, contrast, etc.).

In comparing or specifying brightness and contrast ratio, it is necessary to state them within the context of some assumed or specified ambient lighting conditions. In current systems a semi-darkened environment is used because the phosphor on CRT devices is used as the basic storage of radar data. A semi-darkened environment is not necessary for alphanumeric and graphic displays generated by a computer since the repetition rate can be much higher than that for conventional radar displays. The low brightness from radar displays results, to a large extent, from the low sweep rate and the low duty cycle for any individual point on the display. The persistence of the phosphor is used to maintain the image in a radar display, while in a TV type scan display, the image is regenerated at a sufficiently rapid rate (e.g. 30-40 frames per second) to avoid visual flicker. In a sense, brightness problems in cathode-ray tube consoles result from equipment and system design considerations rather than basic cathode-ray tube capability.

Cathode-ray-tubes are currently available that provide 30-40 foot-lamberts. This is sufficient to permit a very presentable display with a contrast ratio of about 20 to 1 under normal room lighting conditions. On a working surface such as a desk top, 25 foot-candles is considered satisfactory illumination. Since the display console screen can be tilted and partially hooded, only part of this incident light actually strikes the screen. By reasonable design, this incident light striking the screen can be held to approximately eight foot-candles.

A cathode-ray tube producting 40 foot-lamberts can be used with a 50% neutral density face plate to provide 20 foot-lamberts on the face of the console. Eight foot-candles of incident light striking this screen is attenuated by a factor of two in passing through the face plate, by another factor of two by the screen gain of the phosphor (approximately 1/2),and by another factor of two as the reflected light passes back through the face plate. Hence, the incident light striking the screen is reduced by a factor of eight by the face plate and screen giving an effective light of one foot-candle. Thus a contrast ratio of 21 to 1 can be achieved if the regeneration rate is sufficiently high. If the display is not regenerated by the computer, then some type of scan converter may be required to realize the brightness capability of the cathode-ray tube.

This is considered a reasonable assumption for large-screen displays in naval tactical environments since console displays will be used in the same application. Cathode-ray tubes are expected to be employed in the majority of console type displays in the time frame under consideration. Stocker has also recommended equal readability for hard copy and self-luminous displays as a criteria for brightness and background illumination.[2]

For any specific application, the systems planner will give greater or lesser weight to particular parameters depending upon the requirements of the application. A systems planner may also need to consider some additional factors that are peculiar to his application. For example, in an airborne display, size, weight, and power become more critical parameters; in shipboard applications, a larger screen size is needed; and in some Marine mobile ground-based systems, portability and ease and speed of set-up are of significant importance.

The major types of displays considered for use in a 1970 era system are compared in Table 4-2. The values shown and the comments made in this table are based on the technical discussions in Section 4.6. In viewing Table 4-2, the planner should consider the comments about some of the parameters made in Section 4.3 (following the list of desirable characteristics). In using the comparisons shown in Table 4-2, the planner should remember that the selection of the appropriate display technology is not made on the basis of one or two characteristics but rather on the composite ability of the technology to best meet the needs and requirements of specific applications. It will be necessary to make compromises in some characteristics to accept a display that meets other essential requirements that are more important to the particular application. As noted previously, the relative importance of different characteristics will vary for different applications. The planner should also note that the choice of compromises is a function of the requirements of the particular application.

In deciding whether to use a multi-color system in a large-screen display, the planner must make compromises. The use of several colors in a display offers definite advantages in terms of the ability to distinguish between different types of items (e.g., in a simple case, friendly and hostile ships or aircraft). Hence, from the user standpoint, a multi-color system is desirable. Although most of the technologies discussed are capable of providing multiple colors in one way or another, this usually

Table 4-2. Summary of Characteristics of Display Technologies

DISPLAY TECHNOLOGY	CAPABILITY FOR 6x8' SCREEN SIZE	BRIGHTNESS (Ft-Lamberts)	UPDATE TIME (Sec.)	RELIABILITY	COLOR CAPABILITY	POSSIBILITY OF MEETING MIL-E 16400	FEASIBILITY	COMMENTS
Cathode-Ray Tube	Poor	40	1/30	Good	Color tube can be used	Good	Readily available	Basic technology for consoles & for image generation in many large-screen systems; Not solid state; Requires vacuum & high voltages; Continued use through early 1970's expected
Mechanical Inscribing Systems	Very good	25	1to2	Poor	By use of filters & multiple projectors	Poor	Readily available at present	Permanent record; Flexible; Available; Electromechanical
Film Projection Systems	Very good	25	10 to 15	Poor	By use of filters & multiple projectors	Poor	Readily available at present	Permanent record; Flexible; Available; Electromechanical; High operational costs due to expending film & processing chemicals; Color film can be used but film and processing costs are even higher
Photochromic/CRT Display	Very good	20	<1	Good	By use of filters or different color photochromics but require multiple systems	Good	In prototype stage at present	Direct real-time CRT image generation but requires optical projection system; Material fatigue; Temperature sensitive

Table 4-2. Summary of Characteristics of Display Technologies (Continued)

DISPLAY TECHNOLOGY	CAPABILITY FOR 6x3' SCREEN SIZE	BRIGHT-NESS (Ft-Lamberts)	UPDATE TIME (Sec.)	RELIA-BILITY	COLOR CAPA-BILITY	POSSIBILITY OF MEETING MIL-E 16400	FEASI-BILITY	COMMENTS
Oil-Film Light Valves	Good	20	1/30	Poor	By use of fil-ters & multiple systems	Poor	Avail-able at present	TV scan type picture; Pres-ent systems require digital to video conversion; Con-tinual vacuum pumping required; Oil contaminates cathode; High maintenance cost and low MTR (e.g. 20-200 hrs.)
Thermo-plastic & Photoplas-tic Light Valves	Good	20	1/30	Good	By use of fil-ters & multiple systems	Good	In proto-type stage at present	Needs CRT for image generation and uses optical projection; TV scan type picture at present; Sealed vacuum
Solid State Light Valves	Good	Not avail-able	Not avail-able	Good	By use of fil-ters & multiple systems	Good	Uncer-tain	CRT or laser needed to control device; Attractive if feasibility is proven
Electro-lumines-cent Displays	Good	20	1/30	Good	Multiple-dot-color using different color phosphors	Good	By 1970	Requires development of cheap integrated storage inherent to display panel; Direct view; No CRT required; Matrix addressing

Table 4-2. Summary of Characteristics of Display Technologies (Continued)

DISPLAY TECHNOLOGY	CAPABILITY FOR 5x5' SCREEN SIZE	BRIGHTNESS (Ft-Lamberts)	UPDATE TIME (Sec.)	RELIABILITY	COLOR CAPABILITY	POSSIBILITY OF MEETING MIL-E 16400	FEASIBILITY	COMMENTS
Opto-Magnetic Displays	Unknown	Not available	Not available	Good	Color is a function of viewing angle	Unknown	Uncertain	Direct view reflective type display; Promising but feasibility is uncertain
Electro-Chemical Displays	Good	Not available	Slow	Good	Multiple-dot-color using different chemicals	Unknown	Uncertain	Direct view reflective type display; Matrix addressing; Interesting but feasibility by 1970 is unlikely
Laser Inscribing Systems	Good	25	<1	Good	By use of filters & multiple projectors	Good	By 1970	Digital positioning; Non-mechanical, but requires optical projection; Promising and feasibility by 1970 anticipated
Laser/Luminescent (or Electro-luminescent) Displays	Good	Not available	Not available	Good	Unknown	Good	Uncertain	Digital positioning promising but feasibility is uncertain; Very attractive if proven feasible

involves a significantly greater amount of equipment and hardware and may magnify other problems, such as resolution or registration. The increased hardware also implies an increase in space and cost and may imply adverse effects on reliability and maintainability. Hence the systems planner must balance the need for multi-color displays from the user standpoint against the penalties that may result in other performance characteristics, in cost and size, and in reliability and maintainability. This decision, of course, becomes even more significant if the requirement for multiple colors necessitates the use of a completely different technology than would be used otherwise.

A comparison of present state-of-the-art large-screen displays has been presented in an RADC report prepared by LaSalle.[3] A table showing "Status and Features of Group Display Systems and Techniques" in that report is reproduced here as Table 4-3.

The difficulty of establishing quantitative measures of display system effectiveness has been aptly stated by Loewe:

> "A thorough understanding of display objectives and criteria is essential to good display system design. Unfortunately, there usually are no quantitative measures of effectiveness for display systems. In fact, it is often difficult to state clear-cut qualitative criteria. ....Lack of a single all-inclusive objective forces consideration of many display objectives and criteria."[4]

In the referenced article, he identifies and discusses display system objectives and criteria, many of which are non-quantitative.

Table 4-2 indicates those technologies that are expected to be feasible for use in a 1970 system. However, some of the other technologies that are not expected to be feasible for an early 1970 system may develop sufficiently rapidly that they can be included in a system becoming operational during the later 1970's. These other technologies should be followed closely to permit their consideration for use in a later system if future developments indicate earlier feasibility or additional advantages. Other display technologies will probably be developed for use in the latter 1970's that are not envisioned at this time. Close attention should be given to the emergence of such new technologies. New laser techniques and applications may well fall in this category.

Table 4-3. Status and Features of Group Display Systems and Techniques

Class of Display	Status	Applications	Data Capacity	Response Speed	Permanent Record	Optical Quality	Cost Per Update	Remarks
Projection Plotters	Off-the-Shelf	Plotting-Printing Non-Pictorial	Very High clutter-limited	5-20 Symbols per second	If Required	Exc.	50¢/ slide	Multi-color
Rapid Process Film	Off-the-Shelf	General Purpose Command & Control	Very High clutter-limited	5-30 Seconds per update	Yes	Exc.	6¢-$1.20 per frame	Multi color
Oil Film Light Valve	Off-the-Shelf	General Purpose Dynamic	Up to 1000 TV lines	30 cps display speed	No	Very good	N/A	Multi-color
Projection Cathode Ray Tube	Off-the-Shelf	Low volume dynamic General Purpose	525 TV lines	30 cps display speed	No	Fair	N/A	
Electro-luminescent Matrix Display	In Re-search	Plotting-Printing Non-Pictorial	Very High	Very Fast Not Estab-lished	No	Should be Excellent	N/A	
Scanned Laser Beam Display	In Re-search	General Purpose	High Not Established	30 cps random or sequential writing	No	Should Be Excellent	N/A	
Reuseable Film Systems	In Re-search	General Purpose Non-Dynamic	Very High	Not estab-lished	If Required	Probably Exc.	Not Established Low	
Alpha Numeric Indicators	Off-the-Shelf	Status Boards limited to symbols	Determined by No. of Indicators	Very Fast for intended use	No	Usually Excellent	N/A	Initial Cost very high

Finally, in any consideration of display technologies and selection of display media or techniques, display user technology and software considerations discussed later will play an important role. Since usually in a naval tactical system, the display image is initially generated by a computer, consideration of hardware technologies cannot be divorced from the accompanying user functions and programming and computer interface techniques. For any selected hardware technology, the requirements of the user and of the computer will place differing requirements on the actual design of specific display equipment or subsystems using the technology. In the same way, the choice of different technologies will affect the requirements placed on the user and the computer.

4.5 ANTICIPATED CAPABILITIES VS. NAVY REQUIREMENTS

The capabilities of display technologies compared in Section 4.4 and discussed in Section 4.6 must be considered in terms of their ability to meet Navy requirements as discussed in Section 4.3.

In previous discussions, the adequacy and suitability of cathode-ray tube technology for console type displays have been emphasized. Cathode-ray tube technology with continuing evolutionary improvements is believed to be capable of meeting the requirements for console displays for naval tactical applications during the 1970's. Hence, there is no urgent requirement for the development of a different technology for console displays. On the other hand, if some of the new display technologies considered for large-screen displays also offer promise of meeting the requirements for console displays, these should be carefully investigated to determine whether they offer advantages over cathode-ray tubes. Even though cathode-ray tubes represent an established technology that is adequately meeting the needs of console type displays, other approaches should be considered if they provide equivalent performance and, at the same time, offer other advantages such as smaller size, higher reliability, all-solid state, or lower voltages.

All of the more important and more feasible types of displays that may be applicable to naval tactical systems in the 1970 era have been analyzed, evaluated and compared. Particular emphasis has been placed on large-screen displays since they represent the major problem area due to the unsuitability of present electromechanical and photographic approaches with respect to the naval environment.

Since military tactics change and functional requirements are difficult to state explicitly, flexibility is an important factor in military display systems. Duffy and Smith have listed four major areas of concern from the standpoint of flexibility -- distribution of information, symbology and coding, format, and growth capability.[5] Flexibility in such areas should be a strong consideration in planning display equipments and subsystems for naval tactical systems.

Table 4-4 presents estimated ratings for each type of display technology for console and large-screen display applications. The ratings shown represent the following categories rather than specific relative values:

1) Devices that will be feasible and that are recommended for serious consideration for use in 1970 naval tactical systems.

2) Devices whose feasibility by 1970 is questionable at this time but that may be feasible if sufficient emphasis is placed on them. Devices in this category are recommended for consideration for 1970 naval tactical systems if available and proved feasible.

3) Devices that will be obsoleted for mobile tactical use by newer technologies by 1970. These devices are not recommended for consideration.

This summary is based on the comparisons in Section 4.3 and on the technical discussions in Section 4.6. Fewer types are listed as candidates for console displays because of the difficulty of competing with cathode-ray tubes. On the basis of these discussions and comparisons, the following are believed to be the most promising technologies for mechanizing large-screen displays in 1970 era naval tactical systems:

Table 4-4. Display Technologies for 1970 Era Naval Tactical Systems

DISPLAY TECHNOLOGY	CONSOLE DISPLAYS	LARGE-SCREEN DISPLAYS	RATING
Cathode-Ray Tube (Direct View)	X		1
Mechanical Inscribing Systems		X	3
Film Projection Systems		X	3
Photochromic/CRT Display		X	1
Oil-Film Light Valves		X	3
Thermoplastic and Photoplastic Light Valves		X	1
Solid State Light Valves		X	2
Electroluminescent Displays	X	X	1
Opto-Magnetic Displays		X	2
Electro Chemical Displays		X	2
Laser Inscribing Systems		X	1
Laser/Luminescent (or Electroluminescent) Displays	X	X	2

NOTE: Numbers in rating column have the following meaning:

(1) Recommended for consideration for 1970 naval tactical systems.
(2) Feasibility by 1970 questionable, but should be considered if proven feasible.
(3) Will be obsoleted by other technologies for naval tactical type applications by early 1970's and not recommended.

Photochromic/CRT displays

Thermoplastic and/or photoplastic light valves

Electroluminsescent displays

Laser inscribing systems.

If subsequent developments indicate that they will be feasible and available, consideration should also be given to:

Solid-state light valves

Opto-magnetic displays

Electrochemical displays

Laser/luminescent (or electroluminescent) displays.

It is difficult to decide whether laser/luminescent displays should be placed in the first or second category. This is a very promising technology, but its feasibility depends upon the development of adequate power lasers in the proper frequency range and the ability to deflect cheaply laser beams with high resolution. Power lasers will be developed, but it is not certain that this will occur by 1970.

For large-screen displays, cost, reliability, maintainability, and ability to meet naval environmental conditions are criteria of equal or greater importance than the ability to meet performance requirements. Unfortunately, most of the new technologies recommended for consideration in a 1970 system have not been developed far enough at this time to permit a determination of their relative advantages and disadvantages with respect to these characteristics. It will be necessary to follow these closely during the next year or two to determine whether indications arise that any one of them will be more or less suitable from the standpoint of cost, reliability, maintainability, and ability to meet environmental conditions.

The major need is for a new technology that can provide an all-solid-state large-screen display using batch-fabrication techniques. The development of suitable batch-fabrication techniques is a goal for display systems, but this is more difficult and is not considered as critical as in the case of memories and logic components. If a large-screen display technology suitable for batch-fabrication can be developed, serious consideration should be given to the use of the same technology in console displays as a future replacement for cathode-ray tubes.

4.6 TECHNICAL DISCUSSION OF DISPLAY TECHNIQUES

Since a number of satisfactory techniques for console type displays are now available, no problem is anticipated with respect to the availability of console type displays for a 1970 system. Existing cathode-ray tube technology and anticipated improvements in this technology should meet all requirements for small-screen console type displays, even if none of the new technologies prove to be superior.[6,7] However, with respect to large-screen displays, the situation is much less favorable. In an RADC Technical Documentary Report[8] published in 1962, the state-of-the-art and development efforts for large-screen displays were described as follows:

> "Display developments are being undertaken in three major technological areas. These areas may be differentiated in terms of the basic processes being applied and on the basis of development time required to provide fully operational subsystems.
>
> The first of these processes is based on projection and employs a stable light modulator, such as film or selenium plate, to provide the display. Operational subsystems of this sort are considered to be achievable within months.
>
> The second process, the light valve, in theory should provide adequate performance for systems applications, and it has the dual advantages of operation at electronic speeds and of the elimination of expensive film. However, the performance potentials have not been realized in practice, and major technological improvements must be made before the light valve can be useful for most systems applications. The . . . available models exhibit major weaknesses in their capability to provide high resolution and brightness.
>
> This low brightness makes it impossible to use the light valve in the high-ambient lighting conditions of most of the systems. The interactions of the oil film and the lens systems are such that it is not possible to increase the display brightness level without major improvements in the characteristics of the modulation surface. Improvement, very likely, is contingent on the development of suitable thermoplastic

materials. Light valve techniques show considerable promise, and with suitable development may eventually supersede film systems. However, it should be clearly recognized that full realization of the light valve's potential may require years of additional research.

The third process, electroluminescence, does not require projection since the display surface itself acts both as light source and modulator. Only small laboratory devices for demonstration and experimentation are available at the present time. Electroluminescence is appealing in its apparent simplicity, its capability to eliminate projection, and its characteristic of non-catastrophic failure. In addition, there is a potential for full color operation at high brightness levels, and the large surface reduces the problems of obtaining high resolution. Unfortunately, there is an impressive number of technical obstacles that must be overcome before electroluminescent devices can meet the requirements of the systems. The most immediate problem is that of modulating the display surface, and a number of promising efforts are underway in this area at the present time. This effort is concurrent with others that are aimed at the development and application of new phosphors to obtain high brightness levels and multiple colors. However, even allowing for impressive technological improvements, years will be required to advance the capability of electroluminescent displays to the point where they can serve as dynamic large scale displays for system applications.

Desirable as these advanced displays are, most immediate requirements of Command and Control Systems can only be met by projection techniques using film or xerographic techniques for light modulation."

Unfortunately, developments during the past two years have not significantly altered the status described above, except that improved technologies, such as light valves and electroluminescent displays, are of course somewhat closer to practical realization now than they were in 1962. These are discussed in greater detail later.

Photographic projection techniques are still the only feasible means available for meeting requirements for large-screen displays in command and control systems. Significant progress has been made in light-valve type displays during the last two years, but the reliability and life of these devices makes questionable their use at this time in an operational system in which minimum down time is an important requirement. However, new and improved light-valve type devices offer great promise for a system to be operational in 1970.

Display techniques that have been developed or that appear promising for the future include individual character lights, cathode-ray tubes, mechanical inscriber systems, film or photographic projection systems, light-valves, photochromic systems, electro-luminescent devices, opto-magnetic devices, electrochemical and laser systems. Of the above techniques, it is believed that mechanical inscriber systems and photographic type film projection systems will be obsolete by 1970. Improved light-valves, electroluminescent panels, photochromic displays and, possibly, laser/luminescent displays appear very promising for that time period. Types of displays, systems considerations and the more promising display technologies that have been investigated are discussed briefly in the following parts of this section.

4.6.1 Types of Display

Several different methods of classifying displays were discussed previously. It was pointed out that since this section on display hardware is concerned primarily with technologies available for mechanizing display equipments and systems, those methods of classification are used that are directly related to technology. Other sections on display user-technology and programming are more properly concerned with classifications relating to the functions included in the equipment, the use for which the equipment is intended, user considerations, and programming and format considerations. There are four major types of displays in a category that directly affect the technologies involved:

1) Individual character displays and indicators

2) Consoles or individual user display

3) Large-screen or group displays

4) Hard copy displays.

These can further be subdivided by the technology involved and most of the subsequent parts of this discussion are on that basis.

A number of techniques are currently available for the mechanization of individual character and indicator type displays. These are perhaps not ideal, but they are certainly adequate for present requirements; and normal evolutionary improvements and developments should permit these devices to meet the requirements imposed by 1970 systems without requiring new technologies or breakthroughs. Hence, these are discussed very briefly.

Console displays are at present mechanized satisfactorily with existing cathode-ray tube technology. Improved console type displays are desired for future systems, but these improvements are basically a matter of engineering design and better determination of user functions and requirements. Some of the new technologies discussed for large-screen displays (e.g. electroluminescent matrix) may also be applicable to certain types of consoles, and these are pointed out in discussions of different technologies. However, continued improvements and evolutionary developments in cathode-ray tube technologies will permit console displays that will meet all the requirements of a 1970 shipboard tactical system without the necessity for new technologies or breakthroughs.

The same is true for hard copy displays - present techniques are, in general, satisfactory and adequate, but there is, of course, room for improvement. Continuing improvements of an engineering nature are anticipated. Several types of hard copy displays are discussed as printers in the section on input/output.

Little time during the study has been devoted to these three types of displays since existing technology can meet present requirements, and it is anticipated that normal engineering improvements and evolutionary developments in existing techniques and technologies will meet the requirements for a 1970 system. Most of the effort during this study has been devoted to the type of display that presents the major problem from the standpoint of technology -- large-screen or group displays. The console is probably the most important single type of display. However, large-screen displays present the major problems. This is the area in which present systems and approaches are inadequate for real-time shipboard tactical data systems - the area in which new technologies are required to meet the requirements for a 1970 shipboard system.

Cathode-ray tube technology, which is the heart of most console displays, also plays an important role in many current and future large-screen display systems. For example, current photographic film projection displays depend upon cathode-ray tube generation of the original image on the film.

4.6.2 Systems Considerations Affecting the Selection and Performance of Display Equipment and Technologies

A display system consists of more than a display medium. For example, a typical large-screen film projection system may include:

1) A buffer for storing data from the computer

2) A symbol generator for converting coded characters into alphanumeric symbols.

3) An image generator for positioning the symbols and graphical information properly on the face of a cathode-ray tube to expose the film.

4) Processing equipment for developing the film and possibly making copies

5) Film handling mechanisms for transporting the slides or film strip to the projector at the proper time

6) A projector, including light source and optical system

7) A screen

8) Necessary controls.

Some of these are unique to film projection systems, but some kind of character or symbol generator and a viewing screen are basic to most types of displays.

4.6.2.1 Symbol Generation

For almost all types of displays, it is necessary to convert coded information in computer language to shaped characters and symbols on the viewing screen. This operation, usually referred to as character or symbol generation, may be accomplished digitally (e.g. conversion from a 6 bit alphanumeric code to a 35 bit 5x7 dot matrix), or it may be accomplished by beam shaping (e.g. a Charactron tube). In a Charactron tube, the particular alphanumeric coded character causes a deflection of the beam to a particular aperture on a mask through which the beam is passed shaping it into the corresponding character.

Many types of character and symbol generators have been used, including dot matrix generators, stroke generators, raster scan generators, and the shaped beam, (Refer to Figure 4-1). Since these techniques are well established, it is not necessary to discuss them in detail here, but a table comparing character generation techniques published by Boyd is reproduced as Table 4-5.[9] Similar techniques can be used for generating a larger complement of symbols including special military symbols as well as alphanumberic characters.

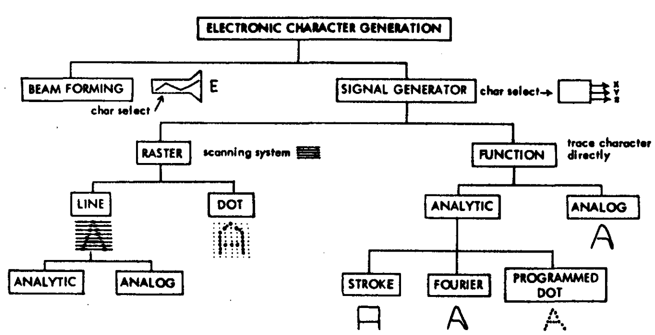


Figure 4-1. Character Generation Techniques

Table 4-5. Comparison of Character-Generator Techniques

Generation Method	Character Storage	Resolution	Approximate Beam-Utilization Time (%)	Character Changeability	Typical Character Writing Time (Microsec)
Dot, fixed matrix	Magnetic cores	5 x 7 dot matrix	25	Rewire cores	100
	Storage drum	5 x 7 dot matrix	25	Rewrite program	100
	Weighted resistors	5 x 7 dot matrix	25	Change resistors	200
Dot, quasivariable matrix	Diode matrix	16 dots (max) in 15 x 16 matrix	75	Relocate diodes	8.5
Dot, variable matrix	Weighted resistors	20 dots (max)	85	Change resistors	40
Stroke	Diode matrix	32 lines (max)	70	Rewire diodes	.4
	Diode matrix	16 strokes (max)	70	Rewire diodes	12
	Variable-density mask	-	80	Change mask	20
	Magnetic cores	20 lines (max)	70	Rewire cores	40
	Weighted transformer ratios	-	80	Rewire transformer	30
Raster	Monoscope	20 lines	25	Replace tube	100
	Monoscope	14 lines	25	Replace tube	30
	Core planes	20 lines	25	Rewire cores	20
	Shaped-beam mask	-	100	Replace tube	100

4.6.2.2 Ambient Light Devices

Display devices are of two types: ambient light reflectors (e.g. hard copy or dial settings), and self-luminous (e.g. CRT or projection screens). Devices which have a built-in source of illumination purely to illuminate a reflective type surface (for example, aircraft instruments, or other conventional dial or meter type indicators) fall in the first category, since the purpose of the built-in illuminant is either to replace or supplement ambient lighting. Fluorescent marked dials or indicators do not fall into this category except that they are frequently used as combination ambient-light and darkness viewed devices, (again, as an example, in aircraft instruments.) The advantages of fluorescent indicators are two-fold, first, contrast is increased since the non-fluorescent areas reflect no visible light, and secondly, the illuminating ultra-violet light source, if shielded from direct view, will not affect dark adaptation. In this latter connection, where dark adaptation is important, "ambient-light" reflectors are built with their own self-contained illumination, whose color and intensity characteristics may be adjusted to suit the particular applications.

The important considerations here are the provision of adequate contrast (both color and brightness) and sufficient grossness of detail to provide legibility at the required viewing distance and viewing angles. The latter requirement imposes the necessity for reducing parallax and avoiding recessing and distorting glass or plastic housings.

Contrast for ambient light devices is controlled by adjusting the reflectivity of the information and of the background surfaces. If glass or plastic protective cover surfaces are required, these should be hooded or tilted to prevent the front surface from producing distracting reflections of high brightness or contrast. Since hooding or tilting the protective surface reduces the viewable angle, non-reflective coatings may also be required. Circular polarizing shields will be effective only in the control of specular reflections from the display surface; these are not present, in general, on ambient light devices, or may be eliminated by the application of high reflectivity diffusing paints of the required color.

A special type of "ambient-light" device is available in which the indicator surface (for example a spinning drum containing the characters to be viewed) is in continuous motion, and a flash lamp is synchronized to illuminate the surface at the proper rate. Since this device must be shielded from all extraneous light to avoid blurring of the information, it is more properly classified as a self-luminous device in a special category of its own. Another version of this type of device has the strobe lamp mounted inside an opaque drum with transparent (cutout) characters, and belongs properly in the group of self-luminous devices.

4.6.2.3 Projection System (Self-Luminous)

The amount of light reaching the projection screen is a function of a number of parameters, but for well designed optical systems certain rules of thumb are applicable. Several useful ones are:

1) A light valve TV system using a Xenon arc lamp has an output of between 0.7 and 1.5 lumens/watt.

2) A 35mm slide projector using an incandescent lamp has an output of between 1 and 2 lumens/watt.

These are typical figures only and the limits may be exceeded by exceptionally well designed or poorly adjusted equipments.

For a uniformly diffusing matte screen, the screen brightness in foot-lamberts is equal to the luminous output of the projector divided by the screen area in square feet. For example, the screen brightness produced by a 2000W xenon light valve operating at an output of 1 lumen/watt on a 10 ft. square screen is 20 foot-lamberts. Both front and rear projection screens may appear either brighter or dimmer than a uniform diffuser, depending on the nature of the screen and the line of view. The ratio of brightness is a maximum when the line of view extends directly back to the projector for a rear projection screen, or along the reflected ray from the projector for a front projection screen. This maximum value is referred to as the gain of the screen. Typical useful screen gains lie in the range of 0.5 to 2.0, although higher gain screens are used when the restricted viewing angles associated with them are not objectionable or are desirable.

The higher the screen gain the higher the contrast, in general, for both front and rear projection screens. This is true for rear projection screens since the reflection of ambient light from the front surface is low with high gain screens and for front projection screens, the directivity of higher gain screens is such that off-axis ambient light is not directed into the viewing area. An additional degree of contrast control is available with rear projection screens in that a neutral density frontplate may be incorporated. If the (one way) transmission is x%, the two way attenuation of reflected light is x^2%. A 50% faceplate thus attenuates the projected beam by a factor of two and the undesirable ambient reflection by a factor of four.

4.6.2.4 Brightness and Contrast

Measures and standards for some display system parameters, such as brightness and contrast ratio, are difficult to establish because of variations in viewing conditions and ambient light. Because of all of the variables introduced by the screen parameters and the ambient lighting conditions, it is not practicable to assign a brightness and contrast value to a projection system without defining the viewing conditions. It is for this reason that projection systems are best defined in terms of lumens output. Brightness in foot-lamberts for a unity gain screen is obtained by dividing by the screen area in square feet. Contrast is obtained by multiplying the ambient light in foot candles by the screen reflectivity coefficient, and computing the ratio of "light" to "dark" values.

Typical values of brightness and contrast are given in Table 4-6 for several media as an indication of relative levels and variability. In Table 4-6, note that pulsed EL mosaic panels have brightnesses comparable with TV raster, or open gate theatre screens. If the contrast level shown for white-on-dark textual copy is increased, the legibility of fine detail degrades with increasing contrast if the eye is adapted to darker background level because of the dazzle effect.

Table 4-6. Typical Values of Brightness and Contrast

TYPICAL BRIGHTNESSES - FOOT LAMBERTS	
Surface of the Sun (photosphere)	480,000,000
Surface of a 60W frosted incandescent bulb	36,000
Surface of a 60W "white" incandescent bulb	9,000
Surface of a 15W fluorescent tube	3,000
White paper in direct sunlight	9,000
Clear sky	2,000
Theatre screen open gate	16
Surface of the Moon, average bright area	750
White paper on office desk	25
Pulsed El mosaic panel	20
TV raster on CRT	20
Light valve, 10 x 10 foot diffusing screen, 2KW lamp	20

CONTRAST LEVELS	
Textual copy (white-on-dark)	10:1
Line drawings and black-on-white text	25:1
Photographs	100:1

NOTE: Figures above were extracted from an unpublished technical manuscript prepared by Dr. H. R. Luxenberg.

4.6.2.5 Logistics, Maintainability, and Availability

Since some types of large-screen displays, such as silver-halide or Kalvar film-based projection systems use expendable material, logistics can become a serious problem for shipboard applications. Along with considerations of reliability and ruggedness, logistics constitutes one of the major arguments against this type of system for shipboard use. This problem concerns not only the film that is expended, but also the processing materials used in developing and processing the film. In addition to the amount and volume of material used, some of the processing chemicals are expensive and are sometimes of a critical nature.[10] This is a particularly serious problem for silver-halide film, but it becomes much more severe if color film is used, since film costs, processing costs, processing material, and processing time are all increased.

The failure rate and maintainability directly affect the availability of the equipment for operational use. Cathode life in light valves (about 25 to 100 hours at present) and light sources for projection systems (about 25 hours for incandescent lamps and 1,000 hours for xenon lamps) both lead to frequent failures. A directly related consideration is that of mean-time to repair (MTR). Failures are particularly serious if they shut the system down for a significant length of time. Replacing some of these elements may require from several minutes to several hours. This is not satisfactory for shipboard applications where failures may occur during a rapidly moving situation, such as an anti-air operation. Specific reliability figures are difficult to obtain for display equipment, but failure rates are extremely high compared to those for the semiconductor logical components and the memory devices used in the central processor. Certainly, electromechanical systems, such as those used in the majority of large-screen displays at present, cannot meet shipboard requirements for high reliability, easy maintainability, and simple logistics.

4.6.3 Character Lights and Indicators

Status indicators or small displays consisting of a few digits or a few characters are needed for presenting limited amounts of data. Cathode-ray tubes or other technologies discussed in subsequent portions of this section are not economic for this type of display because of the small size involved. However, it is sometimes feasible to group a number of display items of this type together in a small cathode-ray tube display. Usually the cathode-ray tube display in a console is supplemented by a number of small displays of this type, frequently referred to as read-out devices. The major types of read-out devices are:

1) Rear projection
2) Edge lighted
3) Electro-luminescent
4) Gas ionization
5) Electromechanical

The use of devices of this type has an advantage over grouping a number of indicators together in a small cathode-ray tube in that the read-out devices can be distributed over the face of the console in positions that are more meaningful or easier to use from the operator's standpoint. A number of read-out devices have been described in a recent series of articles.[11]

4.6.4 Cathode-Ray Tubes

Cathode-ray tubes, represent one of the earlier electronic display technologies and are used in almost all present console displays and as components in many of the present large-screen display systems. Cathode-ray tubes are so well established and so well known that their principles of operation are not described here.

Cathode-ray tubes are used in three basic ways in display systems:

1) Direct viewing
2) Projection
3) Image generation for film systems.

The direct view cathode-ray tube is used primarily in console type displays, but very large cathode-ray tubes are being investigated for possible direct view large-screen applications.

Techniques for projecting cathode-ray tube images onto a screen date back to the Schmidt optical systems of early television. A very high intensity tube capable of developing thousands of foot-lamberts of light at the tube face is required. As the image is enlarged and projected through an optical system onto the screen, only a few foot-lamberts (perhaps 5) are available on the viewing surface. This level is not sufficient for viewing under ambient light conditions in a shipboard data system environment.

The major use of cathode-ray tube technology in large screen displays at present is in the generation of an image on the face of a cathode-ray tube that can then be used to expose film (e.g. silver-halide, Kalvar, photochromic, etc.). After it is developed, the image on the film is projected onto the screen by a high-powered light source and an optical projection system, providing useable light levels on the screen under ambient light conditions.

Mrs. F. R. Darne of the U. S. Navy Bureau of Ships summarized the state-of-the-art for cathode-ray tubes in the Spring of 1962.[12] This summary gives an excellent picture of cathode-ray tube characteristics and capabilities and is reproduced here as Table 4-7.

Table 4-7. State-of-the-Art of Cathode-Ray Tubes

CATEGORY	STANDARD TUBE
PLAIN CRT's	
Large raster display (TV rates) magnetic deflection	1,000 TV lines at 100 ft-lamberts, medium persistence 22-in. flat face (prototype 22CP4)
10-in. PPI radar indicators magnetic deflection	0.01-in. spot size, long persistence, low light output (prototype 10KP7A)
5-in. PPI primarily for camera recording, magnetic deflection	1 mil 0.001-in. spot size, short persistence, moderate light output
5-in. flying spot scanner tube magnetic deflection	1 mil spot, extremely short persistence relatively high light output
5-in. high writing speed oscilloscope tube, electrostatic deflection	0.025-in. spot size at 150 ft-lamberts light output, medium persistence (prototype-5BHP2)
Multibeam tubes, electrostatic	2-gun, 3-gun, 5-gun, various shapes and sizes
PROJECTION TUBES	
Theatre TV	25,000 ft-lamberts on tube face at 80 KV, 525 TV lines, 5 ft-lamberts from 20 x 15-ft screen
Projection storage tube	17,000 ft-lamberts at 13 kv, 600 lines 15 ft-lamberts on 4-ft screen
Light valve projector	1,000 TV lines, light from external lamp
Fiber optics faceplate tubes	Record on film for later projection
Wire matrix faceplate tubes	Provide electrostatic printing on paper for later projection
CHARACTER TUBES	
Charactron (or scriptron) shaped beam tubes	20,000 characters per second, medium persistence, relatively low light output, sizes 5 to 19 in.
Typotron or storage scriptron	Charactron with storage (brightness and persistence) 25,000 characters per sec. 5-in. and 21-in. sizes
Sympix	Wire matrix tube with charactron gun, 50,000 characters per second
Character generators	Not a tube but peripheral equipment for use with CRT's

Table 4-7. State-of-the-Art of Cathode-Ray Tubes (Continued)

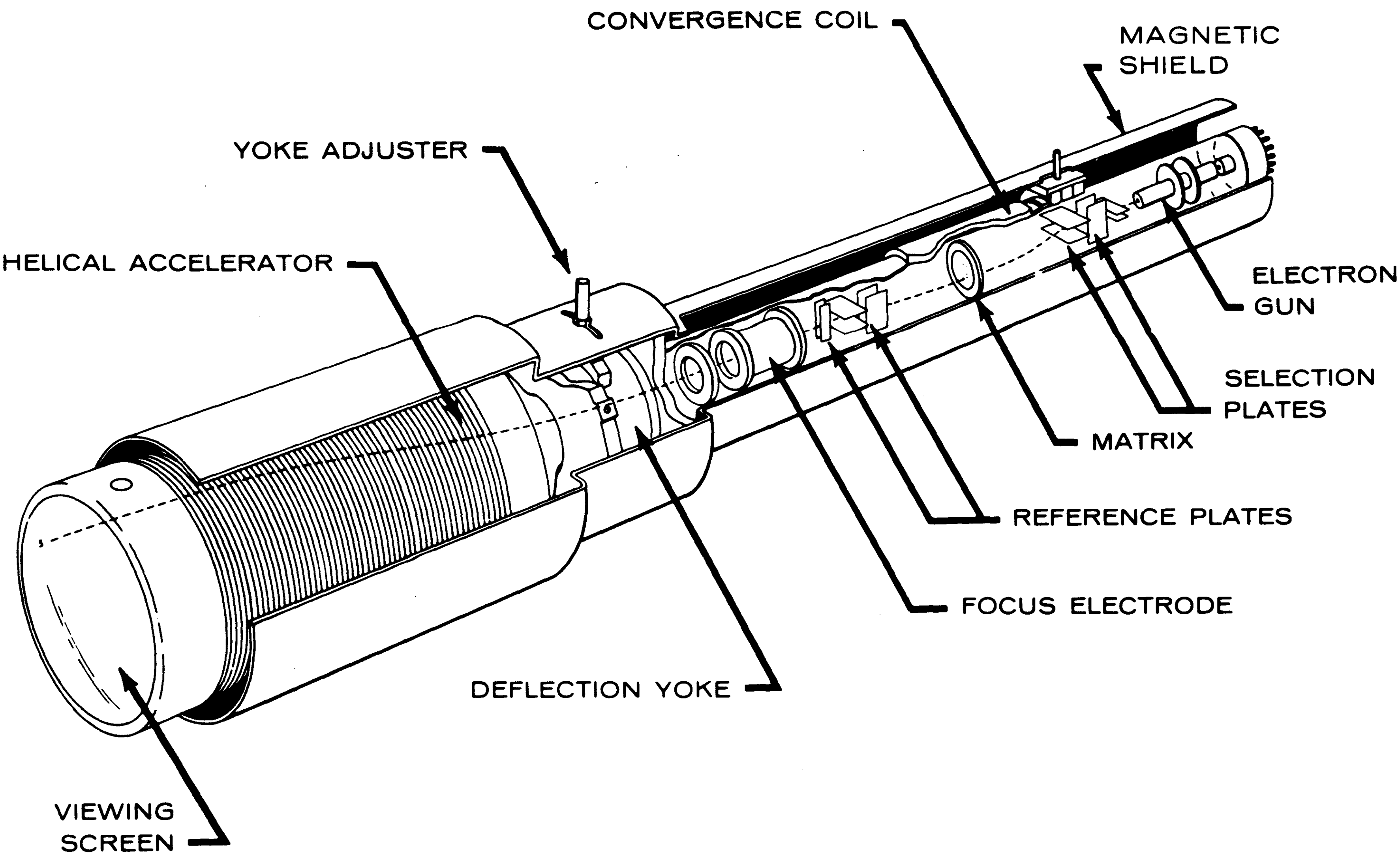
CATEGORY	STANDARD TUBE
MULTI-COLOR TUBES	
Shadow mask	3-color dot sequential - 500 TV lines at 18 ft-lamberts
Chromatron (Lawrence tube)	3-color line sequential - 300 TV lines at 75 ft-lamberts
Color storage	2-color, 450 raster lines, 90 ft-lambert long-persistence, 10-in. tube
DIRECT VIEW STORAGE TUBES	
5-in. high brightness	10,000 ft-lamberts, 50 lines per inch, 75,000 in./sec. writing speed; also available in 3-in., 7-in., 10-in. sizes
5-in. high resolution	200 ft-lamberts, 100 lines per inch, 3,000 in./sec. writing speed
5-in. high writing speed	2,500 ft-lamberts, 50 lines per inch, 250,000 in./sec. writing speed
5-in. multimode storage tube	400 ft-lamberts, 50 lines/in. - light writing mode 100,000 in./sec., 100 lines/in. - dark writing mode
21-in. Tonotron	200 ft-lamberts, 475 lines per diameter, 40,000 in./sec. writing speed
ELECTRICAL OUTPUT STORAGE TUBES FOR SCAN CONVERSION	
Recording type (secondary emission, transmission, storage grid) single and double ended	1,000 TV lines, 0.01 microsec per element writing speed, 20,000 to 30,000 "reads" storage without affecting stored charge
Electron bombardment induced conductivity (ebic) type, continuous storage surface double ended	820 TV lines, higher writing speed but shorter storage than recording type; solid storage surface eliminates crosstalk between read and write beams
THREE DIMENSIONAL DISPLAY	
Stereoscopic use of two display tubes with polaroid glasses	
Spinning disk in CRT	
Moving plate (face) in CRT	
Stacked "thin" tubes	

Normal cathode-ray tubes have phosphor coating on the inside face of the tube which emits light when excited by the electron beam. The persistence or rate of decay depends upon the particular phosphor, with decay times available from several seconds down to a fraction of a second. Since the normal cathode-ray tube has a definite decay rate, it is necessary to regenerate or refresh the image on the cathode-ray tube from the computer or from some storage device, if the image is intended for direct viewing. Refresh rates below 30 per second result in visible flicker and reduce the brightness. Filters sometimes used to help alleviate the effect of flicker on the viewer further reduce the brightness. As an indication of cathode-ray tube brightness, the light output of a standard television picture refreshed 30 times a second is about 30 to 50 foot-lamberts.

Some special cathode-ray tubes provide a storage mechanism within the tube itself - usually some form of dielectric coating on a metal mesh. Such storage tubes can keep the visible image on the face of the cathode-ray tube refreshed continuously. These tubes cost approximately one hundred times more than a normal cathode-ray tube.

The Charactron as shown in Figure 4-2, is a special cathode-ray tube that includes a character generating mask and the necessary electrodes for shaping the beam inside the tube to generate characters and symbols.[12] The electron beam is deflected to the proper position in the character mask corresponding to the character to be generated. As the beam passes through the mask, it is vignetted into the shape of the character. The shaped beam is then returned to the axis of the tube by deflection electrodes and deflected to the desired position on the face of the tube.

Random display rates of 50,000 characters per second are possible with this technique. The limiting factor is the time required to position the character on the face of the tube rather than the time required to shape the beam. The Charactron tube is not limited to the generation of alphanumeric characters but can also generate any symbol fabricated in the mask. A typical mask has 64 different characters or symbols, but 144 symbol masks have been used, and several hundred are considered possible.



THE CHARACTRON® SHAPED BEAM TUBE

Figure 4-2. Typical CHARACTRON Shaped Beam Tube

The Charactron is said to have three major advantages over the stroke or dot matrix method of symbol generation:

1) Reliability

2) Legibility or definition

3) System simplicity

Since the Charactron is basically a cathode-ray tube, it can be operated as a conventional cathode-ray tube to generate graphical data and target traces in real time. Any shape and size of symbol can be chosen since shape and size are determined by the fabrication of the mask. Charactron tubes are useful for image generation in photographic projection systems for large-screen displays as well as for direct viewing in console displays. Recent development permits the simultaneous generation of alphanumeric and real-time video information by the use of two electron guns in the tube. Another recent development provides a rear window in the tube so that a photographic image can be projected through the window and super-imposed on the face of the tube with the electronically generated picture.

Some other types of special cathode-ray tubes worthy of mention are:

1) Color tubes for generating color displays

2) Fiber-optic face plate tubes where the image from the inside of the tube is brought to a plane outside the tube through a fiber-optic bundle to avoid parallax and to permit direct printing

3) Electrostatic face plate tubes in which a matrix of fine wires replace the face of the tube so that a charge image can be produced on a dielectric surface (e.g. paper) held in contact with the wire face.

The major type of light valve available today is also basically a cathode-ray tube, but light values are sufficiently different and more complex that they are discussed later under a separate heading.

Because of the length of time they have been in use and the large amount of experience gained in their use, cathode-ray tubes offer great capability and flexibility in equipment and systems. The capability and flexibility available through the use of cathode-ray tube technology is illustrated by a list of typical options prepared by James and Dittberner which is reproduced here as Table 4-8.[13]

4.6.5 Inscribing Systems

Inscribing display techniques are ones in which a glass slide or mylar film, coated with an opaque material, is "scratched" by some form of stylus. Light from a high-intensity source is then projected through the glass slide, reproducing on the screen the image cut in the opaque material by the stylus. Two basic ways of accomplishing this have been considered. The first uses a mechanical stylus controlled by a servo-mechanism. (See Figure 4-3). This type is in widespread use and is probably the major method available today for achieving a real-time dynamic tracking type display on a large-screen. The second method, which is only in the research stage at this time, involves the use of a laser beam to evaporate the opaque material from the glass slide.

4.6.5.1 Mechanical Inscribing Systems

A mechanical inscribing system permits the large-screen display of real-time dynamic information at a relatively slow rate.[14] In this type of display, a glass slide or mylar film coated with an opaque material is inserted into a projection system. A glass plate with a transparent stylus mounted in its center is positioned parallel to the first slide so that tipping the glass plate causes the stylus to penetrate the opaque material. When the stylus is moved in the X and Y directions by a servo-mechanism under the control of external signals, a trace is inscribed in the opaque material on the face of the slide. The light from a lamp is projected through this trace on the glass slide and focused on a projection screen. Thus, a trace that can be drawn in real-time will appear on the screen.

Table 4-8. Typical Options Available with Cathode-Ray Tubes (1968-1970)

OPTION DESCRIPTION	ADVANTAGES
1. Quality - Direct view - under 1,000 TV lines/ inch; Display recording - over 1,000 TV lines/ inch. Trade-off between electronics and optics.	Direct view trades quality for greater character selection; display recording trades selection for resolution.
2. Mixing video with fixed graphics - integrates or superimposes CRT images with film images.	Integrated, real-time displays.
3. Color (3-5) - practical uses up to six colors.	Increased information content readability and comprehension.
4. Hard copy of film recording.	Information storage, make-up dissemination, delayed reading.
5. Light pen - hand held.	Permits 'sketching' or line drawing, editing message composition. Hence facilitates computer-aided design.
6. Keyboard - Normally a typewriter keyboard; can be programmed keyboard.	Adds general purpose use of keyboard where computer defines functions of keys.
7. Variable character sizes - 7 to 9 TV lines required to form reasonable resolution of character.	Permits reducing or enlarging character geometry.
8. Simultaneous alphanumeric and video display - two gun tube co-displays (computer-generated data and video image).	Permits co-display of data where lacking system time.
9. Time sharing - one tube displays, in series, video or alphanumeric images; can be superimposed.	Greater writing flexibility.
10. Fiber optics tube - 'Pipes' image to outside surface of CRT.	Offers undistorted images for photographic reproduction purposes.

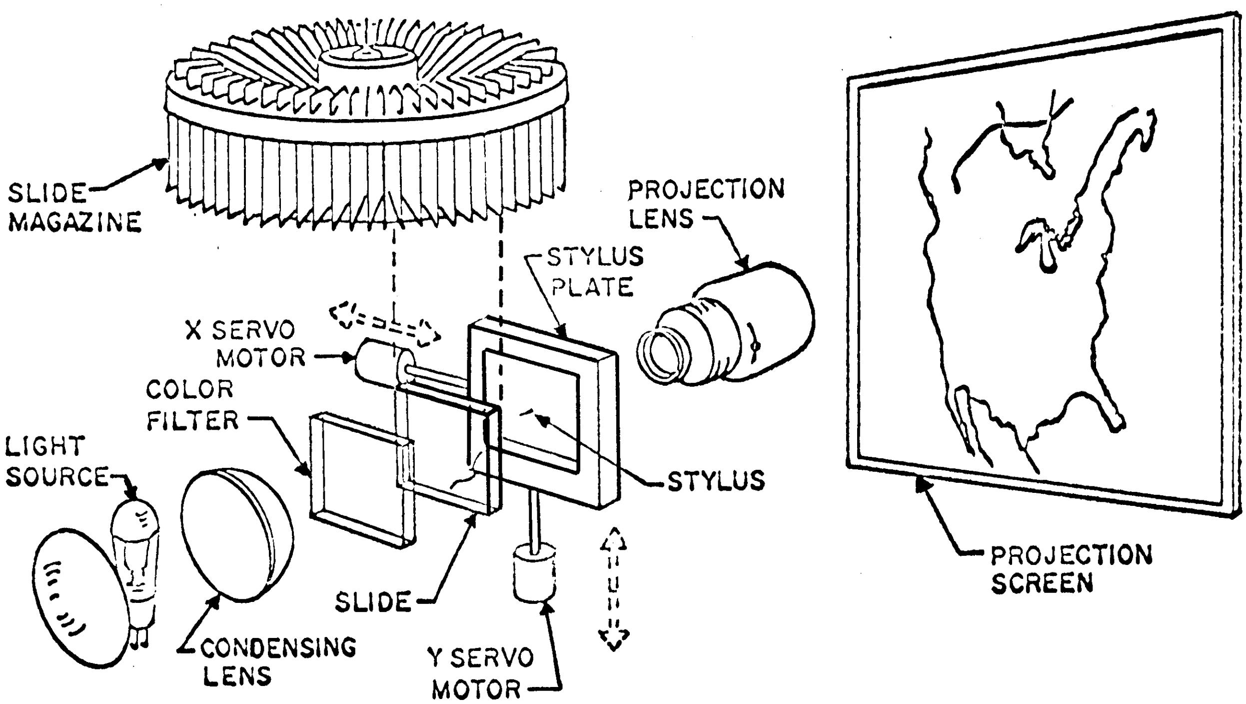


Figure 4-3. Mechanical Inscribing System

The use of color filters in the light path permits color traces to be generated. A composite multi-input or multi-color display can be generated by superimposing the images from several projection systems. Additional projectors can be used to superimpose static information, such as maps, on the dynamic information. Since the inscribed trace remains on the glass slide, no external memory is required for this type of display.

With a trace width of 0.001 inches on the slide, the projected trace will be about 0.1% of the screen size. Recent systems require approximately 50 milliseconds to inscribe a trace across the full width of the screen. Alphanumeric characters can be inscribed at a rate of approximately 20 characters per second.

4.6.5.2 Laser Inscribing

A laser inscribing system can permit the large-screen display of real-time dynamic information at a fast rate. This technique is similar in concept to a mechanical inscribing system except that in place of a mechanical stylus, a laser beam is used to inscribe by vaporizing metallic film on the glass plate. The vaporization of the metal on the glass plate by the laser beam permits light to shine through, projecting the image onto the screen. The satisfactory development of this technique depends upon the ability to deflect laser beams. Binary digital deflection by crystals has been satisfactorily demonstrated in the laboratory for 256 positions in each direction. For a practical display system, 2^{10} positions in each direction (X and Y), are desirable. Digital deflection of laser beams is discussed further in a later discussion of laser displays. The display department of the U. S. Army Electronics Research and Development Laboratory at Ft. Monmouth, New Jersey is quite interested in this approach and has planned to issue a Request for Proposals for the development of such a system. This approach may provide the first use of lasers in large-screen display systems since it requires neither the intensity needed in a direct viewing laser system nor the generation of an ultra-violet laser beam needed for a photochromic system.

4.6.6 Film Projection Systems

Large-screen display systems based on projection of film images have been used in a number of existing command and control systems and several specific systems have been described in the literature.[15, 16, 17] In essence, these systems involve:

1) A symbol generator for converting the digital information to a shaped symbol or character on the face of a CRT.

2) An image generator for positioning the symbols and generating graphical data on the face of the CRT.

3) Processing equipment for exposing film to the image on the CRT, developing the film, and, if necessary, making prints.

4) Slide or film storage and selection equipment for storing the film images and making them available upon call.

5) A projector and screen for projecting and displaying the selected image.

Cathode-ray tube displays may be imaged on film in three ways - optical projection, optical contact printing through a fiber optics face plate, and direct charge deposition through wires embedded in the face plate. These methods and the recording media used with them have been summarized in a table by Luxenberg which is reproduced as Table 4-9.[18]

Usually, a multiple projection system is used to permit the simultaneous projection and superposition of multiple images to generate multi-color displays or to superimpose multiple overlays over a map background. (See Figure 4-4) Color film could be used, but the film cost is greater and the processing is more difficult. For additive color, a positive image (clear symbols on an opaque background) is required. Where the initial CRT recording is a negative, a contact print on a suitable material (Kalvar for permanence or a photochrome for reuseability) may be made.

Table 4-9. Methods of Recording CRT Displays for Projection

PRINTING TECHNIQUE	MEDIUM	PROCESSING	COMMENTS
Optical Projection (Variable magnification)	Silver-halide	Chemical (Full color is available)	Permanent Fastest Either negative or positive
	Photoconductive plate	Toning (Color is selectable)	Permanent or eraseable Either negative or positive
	Photothermo-plastic	Heat	Permanent or eraseable Requires Schlieren optics for projection Usually a positive
Contact Printing (Fiber optics faceplate and UV phosphor)	Kalvar	Heat	Permanent Negative only
	Photochromes	None	Eraseable Negative only
Direct Charge Deposition	Any dielectric, mylar film, etc.	Toning (Color is selectable)	Permanent or eraseable Either positive or negative
	Thermoplastic dielectric	Heat	Permanent or heat eraseable Requires Schlieren optics for projection Usually a positive

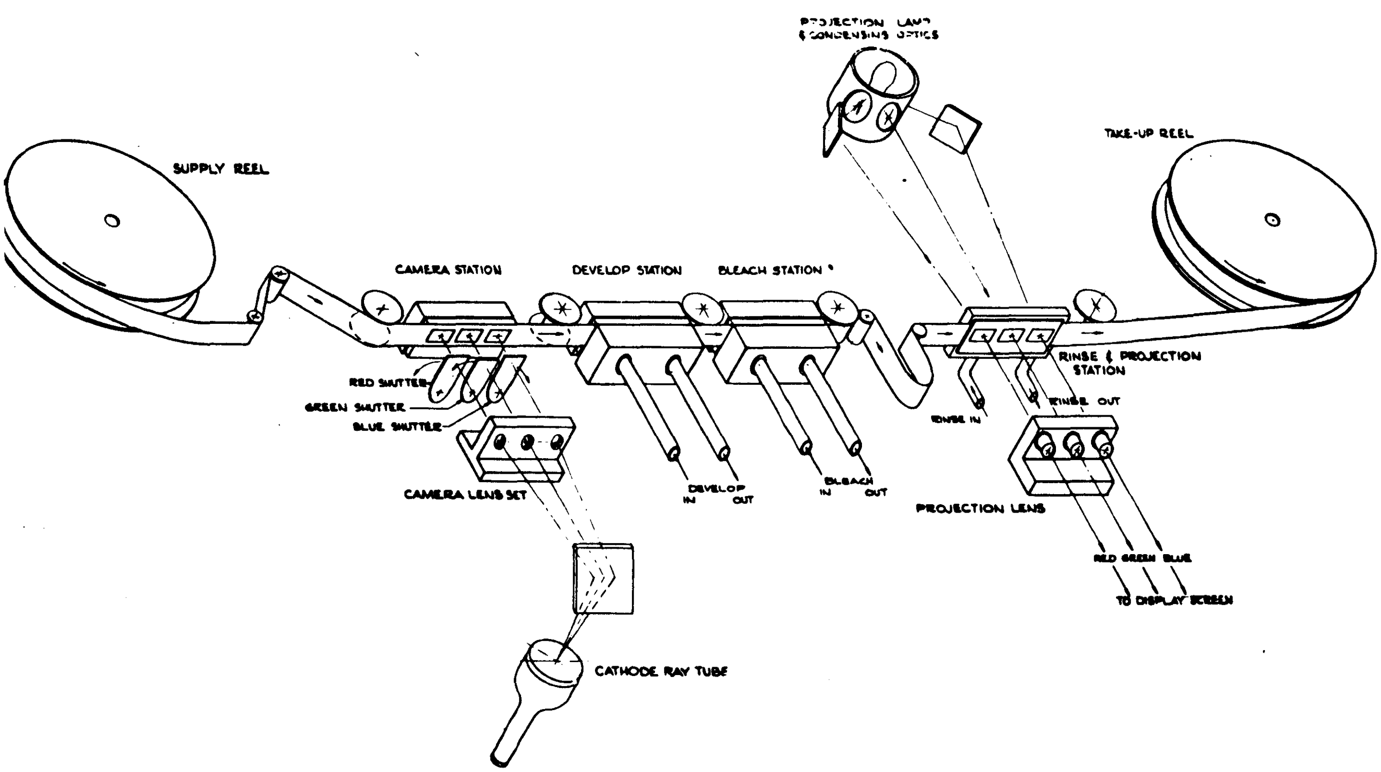


Figure 4-4. Multicolor Film Projection Display System

Systems that superimpose three or four independently selected images encounter difficult registration problems in the final projected display. Other systems that contain the multiple images on a single film chip overcome the registration problem, but the image size is reduced and flexibility in selecting the combination of images to be displayed simultaneously is lost. A recently revived approach involves the use of a lenticular film in which the three separate color images are line-interlaced (at 25 line triples per millimeter) into a single frame of reversal processed silver-halide film. This approach completely eliminates registration problems, and requires a much simpler optical system than the triple frame methods.

Most of the film projection systems in current use employ discrete slides, but a few use a continuous film strip to provide more rapid updating of the display and to permit a simpler mechanical system than one in which individual slides are selected independently.[15] The flexibility offered by random slide selection is sacrificed. The continuous film strip type projection system is more suitable to rapid updating (approximately 15 seconds) of pseudo-real-time displays where the same type of information is displayed continuously but updated rapidly. It uses a much larger amount of film if the display is updated rapidly. The individual slide approach is more suitable to situation displays where a large number of different kinds of situations or pictorial combinations are available, any of which may be required at a given time and in any sequence.

4.6.6.1 Silver Halide Film

Most film projection systems use conventional silver-halide film similar to that used in amateur and commercial photography, but Kalvar and photochromic films and xerographic techniques have also been used. The use of silver-halide films is well established and well understood. Handling and processing techniques are well developed. Silver-halide films are very fast and require energy levels for exposing that are compatible with cathode-ray tube output levels. However, they possess several disadvantages. Three of the major drawbacks of a silver-halide film projection system are:

1) The logistic requirements for continual replenishment of the film and processing materials.

2) The relative complexity of the chemical processing, as compared to electrostatic and heat processing films.

3) The inability of the film emulsion to withstand the heat of projection, particulary where the projection image consists of small areas of clear symbology on a predominantly dark background.

It is the third difficulty which has made the use of Kalvar so widespread as the projection medium in the majority of current command and control projection display systems.

4.6.6.2 Kalvar Film

The use of Kalvar is very attractive from the processing standpoint since it can be developed simply by means of heat (approximately 120°C for 1 to 2 seconds).[19] Unfortunately, Kalvar (like the diazos and photochromes) is sensitive only to a narrow band in the ultraviolet region and is much slower than silver-halide film. The energy required to expose Kalvar is 2×10^6 erg/cm^2 (0.2 watt-seconds) at 3850A° for Kalvar as compared with 0.2 ergs/cm^2 at 4300A° for Plus-X film. This energy level (projected to the reciprocal of "speed" in photographic terms) makes direct photography of the face of a cathode-ray tube impractical when using Kalvar.

In some systems, silver-halide film is used first to develop a negative from the face of a cathode-ray tube. Multiple positive copies are then printed on Kalvar using a high-intensity xenon or mercury arc lamp. The temperature of 120°C required for developing presents no serious problem and good resolution can be obtained from Kalvar. In the ARTOC display subsystem, the image from the cathode-ray tube face is recorded on silver-halide photographic film which is developed, fixed, washed, and dried within 8 to 10 seconds.[16] Positive prints are then made automatically from the negative in less than one second by contact printing of the negative on the Kalvar film. The Kalvar film is exposed by high-intensity U.V. and the image is developed by heat.

4.6.6.3 Photochromic Film

The exposure and developing processes for both silver-halide and Kalvar film are non-reversible. Hence, these films cannot be reused, and they cannot easily be used in a dynamic or plotting type display. One of the most attractive features of photochromic film is that the process is reversible. Hence, the film can be reused and can be used in a dynamic or plotting type display. Since there is a finite decay rate at normal temperatures and since some fatigue occurs, there is a limit to the number of times the photochromic film can be used. Photochromic material will withstand the heat of projection as well as Kalvar, and is self-developing. Its speed is comparable to Kalvar; but since it is heat eraseable, it has not been used in command and control systems where the permanency of Kalvar is a requirement. The reversible process and the relative insensitivity to ambient light are special properties that also permit photochromic film to be used in other types of display systems where silver-halide and Kalvar cannot be used. Special types of photochromic displays are discussed later.

4.6.6.4 Other Film Techniques

Xerographic techniques have been used for developing an image on film from an electrostatic image. The electrostatic image can be created on the film by a cathode-ray tube with a metal fiber face plate. Electrostatic photography and photochromic material both offer the advantages of reuseability and simplicity of processing. In addition, panchromatic photoconductive materials have been developed with an ASA rating of 15 (comparable to Kodachrome I-type A). There are a large number of other photographic and reproductive processes that can be considered for film projection display systems. Robillard has compared a large number of these, some of which meet certain requirements that cannot be met by silver-halide.[20] He describes the general scheme for photographic systems consisting of exposure of a latent image and the development of this by local energy sources resulting in the final image. He presents one table classifying existing photo and reproduction processes and another classifying new photographic systems for the three steps of photosensitive system, amplification, and image formation. These tables are reproduced here as Table 4-10 and Table 4-11 to illustrate the large number of possible systems and the range of characteristics. The potentials of film based

Table 4-10. Classification of Existing Photo and Repro Processes

					PHOTOSENSITIVE SYSTEM		AMPLIFICATION (Development)			IMAGE FORMATION			
Type of Process	Process (Examples)	Nature and Color of the Image	Spectral Response	Uses	Phenomena Involved	Material Involved	Phenomena Involved	Nature of Energy Added	Material Involved	Phenomena Involved	Material Involved	Image Forming Material	Fixation
Silver Halide	Photography	Negative - Black	Visible - UV IR	All Photographic applications	Photo-reduction	AgBr	Chemical Reaction	Chemical	Reducing Agents	Chemical Reduction	AgBr ↑ Reducing Ag	Ag	Chemical (Hypo)
Print out Emulsions		Negative - Brown	Visible - UV	Recording Photocopy	Photo-reduction	AgBr	Photo-lysis	Radiation (UV)	None	Photo-lysis	AgBr	Ag	Chemical (Hypo)
Diazo	Ozalid	Positive - Blue Brown	UV	Recording Blueprint Photocopy	Photo-reduction	Diazonium Salt + Coupling Compound	Chemical Reaction	Chemical	NH_4OH	Chemical Reaction	Diazonium Salt + Coupling Compound	Coupling Product	-
Diazo	Kalvar	Negative - Brown	UV	Recording Microfilms Data Process	Photo-reduction	Diazonium Salt + Coupling Compound	Chemical Reaction	Heat	None	Chemical Reaction	Diazonium Salt + Coupling Compound	N_2	UV
Electro-static	Electro fax	Positive - Black	Visible - UV	Recording Photocopy Data Process	Photo-conductivity	ZnO	Material Transport	Electro-static	Carbon Black or Dyes	Selective Deposit	Carbon Black or Dyes	Carbon Black or Dyes	Heat Fusing
Electro-static	Xerography	Positive - Black	Visible - UV	Photocopy Recording Data Process	Photo-conductivity	Se	Material Transport	Electro-static	Carbon Black or Dyes	Selective Deposit	Carbon Black or Dyes	Carbon Black or Dyes	Heat Fusing
Electro-lytic	3M	Negative - Black	Visible UV	Microfilm Repro. Data	Photo-conductivity	ZnO	Electro-lysis	Electrical	Silver salt or Other	Selective Plating	Metallic Salts	Ni, Au or other Metals	None
Electro-static	Photo-plastic Recording (1)	Light scattering image	Visible UV	Experi-mental	Photo-conductivity	Plastic film	Electro-static deformation	Heat	Plastic film	Electro-static de-formation	Plastic film	Plastic film	None
Electro-lytic	Redox	Negative or Positive Black	Visible	Experi-mental	Photo-conductivity	Cds or CdTe, Sb_2S_3	None	None	None	Electro-Reduction or Oxidation	-	Sb	None
Electro-lytic	(2)	Positive - Black	UV	Experi-mental	Photo-polarization	InSb	Electro-oxidation	Electrical	KOH	Electro-Oxidation	InSb + KOH	InO_2	None
Electro-lytic	(3)	Negative - Grey	UV	Experi-mental	Photo-polarization	Al	Electro-oxidation	Electrical	PO_4NH_4	Electro-Oxidation	PO_4NH_4 + AL	Al_2O_3	None
Photo-polymer-ization	Photopoly-merization (4)	Negative - Black	Visible UV	Experi-mental	Photo-polymeriza-tion	Vinyl-monomers	Chain Reaction	Chemical (Self Con-tained)	Vinyl-monomers	Poly-merization	Vinyl Compounds	Polyvinyl Compounds	Heat
Free Radicals	Free Radical Photo System (5)	Negative - Yellow & Black	UV	Experi-mental	Photo-chemical Reaction	Styryl Base + CBr_4	Chemical Reaction	Chemical	Styryl Base + CBr_4	Chemical Reaction	Styryl Base + CBr_4	Styryl Hydro-bromide + Quater-nary Dimer	Heat
Dichro-ism	Photo-Dichro-ism (6)	Positive - Brown	Visible	Experi-mental	Photo-Dichroism	O-NITRO Benzalde-hyde	Chain Reaction	Chemical (Self Con-tained)	O-NITRO Benzalde-hyde + TiO_2	Chemical	O-NITRO Benzalde-hyde	O-NITRO Benzoic Acid on TiO_2	Elec-trical
Thermal	Thermo-fax	Positive - Brown or Black	IR	Photocopy	IR Absorp-tion	Lead Salt + Thioacé-tamide	None	None	None	Chemical	Lead Salt + Thioacé-tamide	Pbs	None
Mechani-cal	(7)	Negative - Grey	UV	Experi-mental	Photo-conductivity	Se	Allotro-pic Transform.	Mechanical	Se	Plastic Deforma-tion	Se	Se	None

NOTE: Numbers in parentheses refer to References at the end of Robillard Paper.

Table 4-11. Classification of New Photographic Systems

Type of Process	Process	Spectral Response	Quantum Yield	Nature and Color of the Image	PHOTOSENSITIVE SYSTEM		AMPLIFICATION (DEVELOPMENT)			IMAGE FORMATION			Fixation
					Phenomena Involved	Material Involved	Phenomena Involved	Nature of Energy Added	Material Involved	Phenomena Involved	Material Involved	Image Forming Material	
Catalytic	Barrier Layer	Visible - UV	10^5	Negative - Black	Photo-Conductivity	Cds or CdTe or Sb_2S_3	Material Transport & Chain Reaction	Chemical & Electrical	Cu + SiO_2 + Cobalt Complex	Catalytic Reaction	Cobalt Acetyl Acetonate or Others	Co	None
Catalytic	Electro-Dissociation of a Catalyst Compound	Visible - UV	10^5	Negative - Black	Photo-Conductivity	Cds or CdTe or Sb_2S_3	Electro-Dissociation + Chain Reaction	Chemical & Electrical	CuX_n + Cobalt Complex	Catalytic Reaction	Cobalt Acetyl Acetonate or Others	Co	None
Catalytic	Photo-Dissociation of a Catalyst Compound	UV	10^5	Negative - Black with Blue Back-ground	Photo-Dissociation	CuSCN or Others	Chain Reaction	Chemical	Cobalt Complex	Catalytic Reaction	Cobalt Acetyl Acetonate or Others	Co	Electrical
RF	Photo-Dielectric	Visible - UV	10^2	Negative - Black or Brown	Change in Dielectric Constant	ZnS	Dielectric Heating	RF	ZnS + Binder	Thermo-Sensitive Reaction	Lead Xanthate or Other Thermo-Sensitive Materials	Pb or Others	None
Electro-Optical	Two Steps Reduction	Visible - UV	10^7	Negative - Black	Photo-Excitation	CeO_2	Ionic Migration in Crystals	Chemical	Ag + CeO_2	Reduction	CeO_2	CeO	None
Electro-Optical	Photo-Reduction	Visible	10^2	Negative - Black	Photo-Conductivity	TiO_2	Electron Trapping + Ionic Migration in Crystals	UV Radiation	Ag + TiO_2	Reduction	TiO_2	TiO	None
Color Centers	Color Centers	Visible - IR	10	Positive - Various Colors	Quenching Color Centers	KCl or CsCl	Return to Ground States	X-rays (previous to exposure)	KCl or CsCl	Quenching Color Centers	KCl or CsCl	Color Centers	Electrical

systems have not been fully exploited. Processing time for all film media is a few seconds. Even full color film can be processed in less than a minute. It is reported that one company will shortly announce a color film for display application which can be processed in 15 seconds.

The film projection type systems are currently the most practical solution to large-screen displays where continuous operation is required. However, because of the relatively slow response time, the inability to display dynamic information, and the mechanical equipment involved, this is not a desirable long-range solution for shipboard tactical data systems. It is believed that film projection systems will be obsolete for this type of application before the 1970 period and should not be considered for a 1970 system.

4.6.7 Photochromic Displays

Photochromics have been discussed briefly previously as one type of media for use in film projection systems as an alternative to silver-halide and Kalvar. Three properties of photochromic film that permit it to be used in other types of display systems, where silver-halide and Kalvar cannot be used easily, were considered. These properties are:

1) A reversible process, hence eraseable and reuseable
2) Self-developing, hence requires no processing
3) Relatively insensitive to ambient light, hence can be exposed without light shielding (if the ambient light does not contain significant amounts of ultraviolet or infrared)

These properties permit photochromic material to be used in real-time dynamic or plotting type displays that offer promise for future display systems.

Photochromic materials are organic dyes which become opaque when exposed to ultraviolet light, and return to the transparent state when exposed to heat or infrared light. By coating a transparent film with a thin layer of photochromic material, a "photographic" type media can be produced in which the chemical process is reversible. An image can be exposed with ultraviolet light and erased with infrared light. A number of new photochromic materials with different characteristics are in the research stage at this time. One of these can be written upon by light in the blue range of the spectrum and is not bleached by visible light. Another is bleached by visible light and is not bleached by heat.

The exposed image will decay at room temperature at rates depending upon the particular chemical compound. Typical persistency times for photochromic materials used in display systems range from approximately two seconds to 15 minutes. Faster decay times can be obtained, but for display purposes, this requires regeneration of the image. Longer persistence times can be achieved by cooling the image since the decay is inhibited by low temperatures.

Photochromic materials exhibit a fatigue characteristic at present, after a few hundred cycles of a particular spot. Red, blue, or green colors can be obtained with a resolving power capability in excess of 1,000 lines per millimeter. The sensitivity varies with the photochromic material but is about 1/3-watt-second per square centimeter. The persistency of the image can be controlled by varying the temperature, the material, or the method of applying the material to the base.

Early work on photochromic display systems generated a dynamic display by focusing an ultraviolet light through a lens system onto a photochromic film; the ultraviolet light being mechanically positioned by a servo-mechanism.[21] This approach is conceptually similar to inscribing systems discussed previously, but it generates a reverse image (i.e., a dark trace on a light background). Since the photochromic material becomes opaque at the point at which the ultraviolet strikes, projection type displays can be generated by inserting the photochromic material between the lamp and the lens of a projection system. Moving the lens through which the ultraviolet light is focused causes the opaque spot on the photochromic film to move, generating a dynamic display on the screen. Shining an ultraviolet light beam through a character-matrix mask can generate alphanumeric characters or special symbols on the display screen. This type of display is interesting for tracking a limited number of targets or for generating displays that change relatively slowly. However, the speed of the photochromic material and the mechanical motions involved in deflecting the ultraviolet light limit the useful speed.

In a newer development, a cathode-ray tube is combined with the photochromic film to permit the electronic generation of an image (See Figure 4-5). In this approach, a fiber-optic face plate cathode-ray tube is used to generate an image on the outer surface of the face of the tube by conventional techniques.[22,23] The ultraviolet light from the phosphor on the inner surface of the face of the cathode-ray tube is transmitted through the fiber-optic face plate to generate an opaque image on the photochromic film. A dichroic mirror that transmits ultraviolet light and reflects visual light is sandwiched between the fiber-optic face plate and the photochromic film. Visual light from an external source is projected through the photochromic film onto the dichroic mirror which reflects it back to a viewing screen. The opaque image on the photochromic film prevents the light from the projector from striking the dichroic mirror. Hence, this image is reflected onto the screen. Since the light passes through the photochromic film twice, the optical density is effectively doubled. For target track type applications, this technique not only provides a real-time target track, but also provides target track history in the form of a trace with "intensity" decreasing with time. The time period covered by the visible target track history can be changed by replacing the photochromic film with another of a different persistence photochrome. For example, a long persistence material used for an ASW operation could be replaced with a short persistence one for an AA operation. It should be noted that this approach provides a dynamic real-time display where the photochromic material is reused. This is in contrast to the film projection systems discussed previously which are not dynamic and where film is continuously processed and expended.

At the present time, the speed of photochromic materials limits the character generation rate to 20 to 50 characters per second in this type of display. If work on faster photochromic materials is successful, this approach could provide an attractive electro-optical large-screen display with no nechanically moving parts.

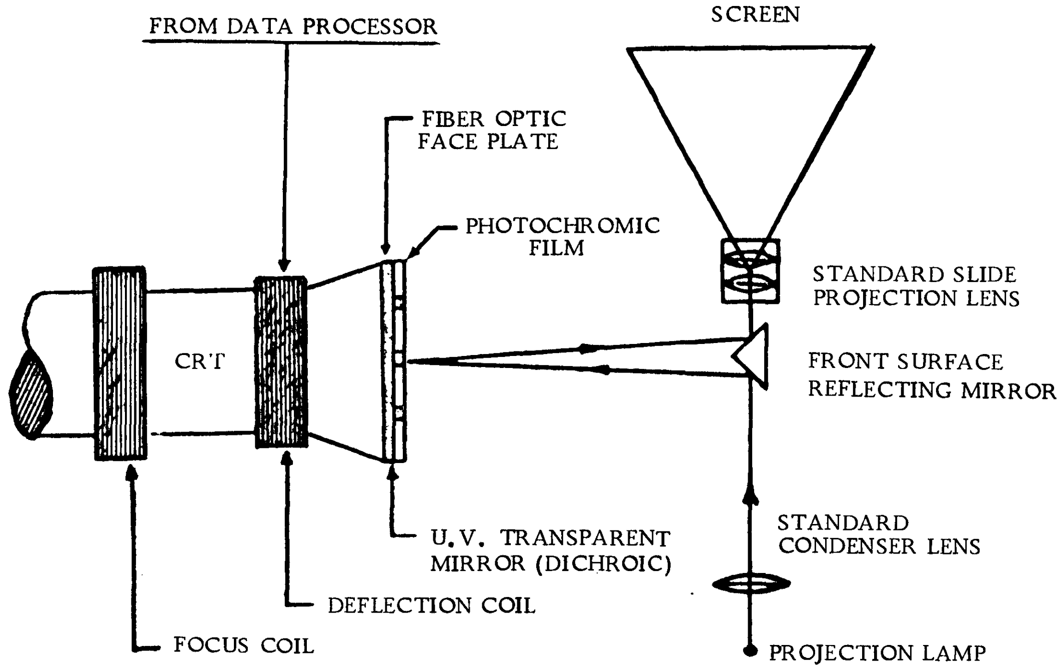


Figure 4-5. Photochromic/CRT Large Screen Display

The Army and the Navy have supported similar photochromic display system developments at two different companies using photochromic materials with different persistencies. The development effort supported by the Navy, uses a photochromic material that has a shorter persistence which is further accelerated by permitting the infrared in the visual light to strike the film rather than filtering out the infrared. The computer is expected to regenerate the display periodically to compensate for the short persistence. The development effort supported by the Army, on the other hand, uses a longer persistence material and filters out the infrared in the visual light. The appropriate light colors must then be recombined to get white light on the screen without infrared. This approach gives a longer persistence picture with less requirement for computer regeneration, but the picture cannot be changed as rapidly unless infrared is used to erase the previous image.

A more advanced, but somewhat similar, photochromic display has been proposed that may be feasible in three to four years. This is a combination photochromic-laser display in which an ultraviolet laser beam is digitally deflected to write on the photochromic material. This combination can provide a very high resolution since a 10 to 20 micron spot size can be obtained with a laser beam compared to a one mil spot size for a cathode-ray tube.

Photochromic display systems combining electronic, photochromic, and projection techniques are promising for future display systems but, in the long run, will probably be superseded by other techniques such as electroluminescent, magneto-optic, or laser displays. Photochromic displays are more attractive as an interim large-screen display technique that can be operational within the next two to four years. Their use is more questionable for systems to become operational during the 1970's. Photochromic displays using cathode-ray tube writing and optical projection, similar to the ones discussed in this section, are being developed. This appears to be a feasible technique for the next generation of large-screen displays if development efforts are adequately supported.

4.6.8 Light-Valve Systems

The term "light valve" in a generic sense refers to any system in which light passing through the system is modulated. The CRT/photochromic system discussed in the preceding subsection is a light valve in that sense. However, the term is usually used in a narrower sense to refer to a cathode-ray tube projection display system using a schlieren optical system or to certain types of liquid or solid crystal devices.

4.6.8.1 Oil-Film Light Valves

The most common example is the "oil-film" light valve used in theatre projection TV systems. In a typical system of this type, a metallic mirror-like surface covered with a thin film of oil is placed inside an evacuated cathode-ray tube type device. The oil film is scanned with an electron beam to generate a television type image, (raster scan), on the oil film. This is similar to the operation of a normal cathode-ray tube except that the image is generated on the oil film rather than on a phosphor face. The electrons impinging on the oil film create electrostatic forces that cause a temporary deformation of the oil film. When a high intensity light source is focused on the oil film, the light is reflected at a different angle for those areas that have been deformed by the electron beam than for the remainder of the oil film. Passing the reflected image through a ladder-like grating (a schlieren optical system) permits selective passing of the light, depending upon whether it was reflected from a deformed area or a non-deformed area of the oil film. Hence, the desired image is displayed on the viewing screen.

At present, oil-film light valves suffer from the severe disadvantage of a short cathode life (20 to 200 hours MTBF). Since it is necessary to have an oil film inside the vacuum, it is difficult to maintain a good vacuum. As a result, there is a tendency for the cathode to be poisoned by evaporated oil. Light-valve systems of this type are in common use in large-screen theatre-television systems. However, these systems are operated for short periods of time for special events, and considerable time can be allotted prior to the event for bringing the system up to proper operation. Unfortunately, in the military command and control environment, the system is required to be in almost continuous operation.

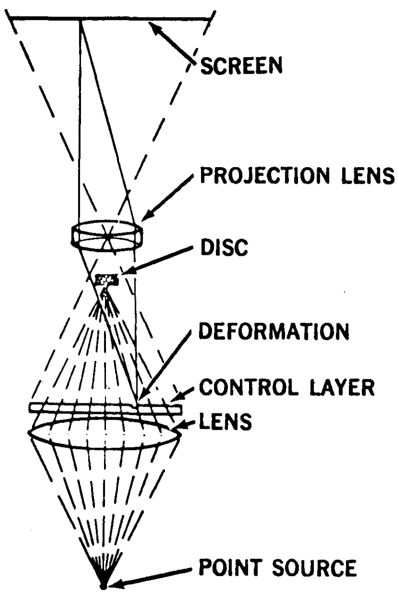
Another disadvantage is that multi-color displays require multiple projection units with consequent cost and registration problems. One company has combined several colors in one frame by using two scan rasters at right angles to each other with a dual schlieren optical system.

Considerable development efforts are being expended toward improving the performance, reliability, and life of light-valve systems. The Rome Air Development Center, in particular, is sponsoring extensive efforts toward improving light-valve systems. It is their belief that light-valve projection systems will constitute the next generation of large-screen display systems. Although oil-film light valves are promising for future display systems, size, reliability, and maintainability considerations are likely to restrict their applications to fixed-site land-based strategic command and control systems. Their use in mobile tactical systems, such as those required for Navy shipboard and Marine ground applications, is not promising. In any event, they offer only an interim solution. However, it will be a number of years before some of the other newer display techniques (e.g. electroluminescence) can provide the same brightness, resolution, and gray scale capability. These factors must be balanced against other factors such as size, cost, reliability, and maintainability. Although oil-film light valves will be used for a number of years for TV presentations wherever group viewing of TV is required, such systems will be surpassed by other techniques by 1970.

4.6.8.2 Thermoplastic Light Valves

The problems of cathode contamination caused by the presence of an oil film in the vacuum system can be avoided by the use of thermoplastic and photoplastic media in somewhat similar light-valve systems.

The thermoplastic media is used in a manner almost identical to the oil film. An electron beam in an evacuated cathode-ray tube type device is used to write on the thermoplastic media by depositing electrons on the surface. (See Figure 4-6). If the film has been heated to the softening point, the electrostatic forces cause the surface of the film to become distorted in a pattern corresponding to the image. This image is projected with a schlieren optical system, as in the case of the oil-film



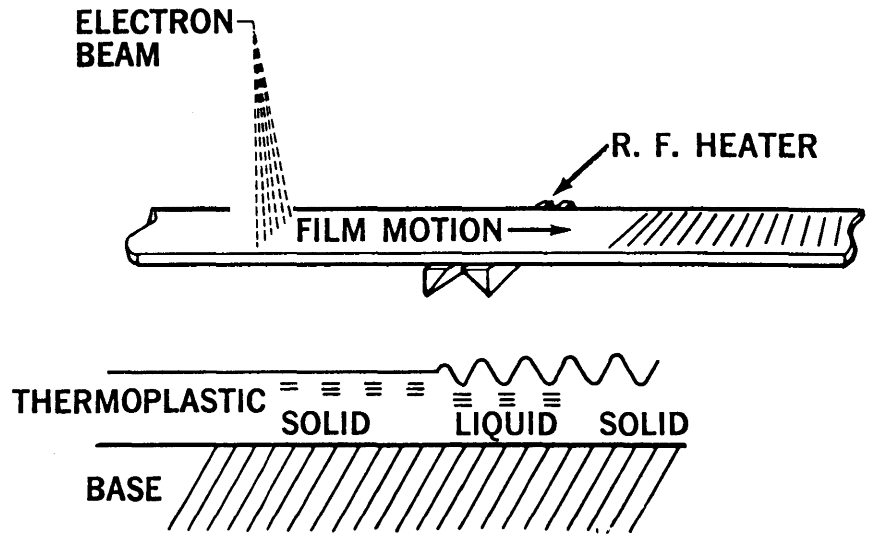


Figure 4-6. A Typical Light Valve Projection System
(right) The Principle of Thermoplastic Recording

light valve. In a thermoplastic system, a permanent record could be retained by permitting the surface of the media to cool and harden while holding the distorted pattern. However, this is not desirable in a light valve since it would require the ability to remove the thermoplastic media from the evacuated chamber.

Other thermoplastic techniques have been investigated. One is the use of a tube with a wire matrix face plate to place the electrostatic charge on the thermoplastic medium external to the tube. Another is the use of a crossed matrix of conducting lines which deposit charges at the line intersections.

Thermoplastics can also be used as the medium in a film projection system by using powder-dust toning to produce a visual image that can be projected like silver-halide or Kalvar film. Some advanced work in this area indicates the possibility of a single frame multi-color picture using different colored powders for dusting.

4.6.8.3 Photoplastic Light Valves

A photoplastic medium is a combination of photoconductive and thermoplastic techniques in which a conducting layer, a photoconductive layer, and a thermoplastic layer are combined. If the thermoplastic layer is transparent and the medium is exposed to a light pattern in the form of an image, the charge from the conducting layer can move through the photoconductor in the areas corresponding to the light pattern. If the surface of the thermoplastic layer is first charged with respect to the conducting layer prior to the exposure to the light image and then discharged to the conducting layer after exposure, a charge pattern is retained on the surface of the thermoplastic film. This charge pattern on the thermoplastic film corresponds to the light image as a result of the charge pattern in the photoconductive layer. Briefly heating the plastic permits the electrostatic forces to deform the thermoplastic surface. This deformation can be retained by cooling (hardening) the plastic if desired.

This image can be projected by a schlieren optical system also, but it has an advantage over the straight thermoplastic medium in that the recording is by light rather than by electron beam. Hence, it is not necessary to place the photoplastic medium inside the vacuum chamber, nor to use the lower density of matrix techniques such as a wire mesh face plate tube. This permits an "open-air" light-valve system that avoids many of the disadvantages of the oil-film and thermoplastic light valves.

Using the light from the face of a cathode-ray tube to write on a photoplastic medium, when combined with a schlieren optical system for projection, provides a dynamic, real-time, large-screen display with a sealed vacuum system. The medium is reuseable and heat is utilized for both instantaneous development and for erasure. Resolving power of 360 line pairs per millimeter, spot size of approximately one millimeter, and contrast ratios of 30:1 have been achieved with photoplastic light valves.

Although photoplastic light valves are not as far along in the development cycle at this time as oil-film light valves, they offer more promise for use in tactical display systems because of the use of more conventional cathode-ray tubes and the fact that it is not necessary to place the medium inside the evacuated chamber. A sealed light valve is achieved that avoids problems of maintaining the vacuum, re-evacuating the chamber after maintenance, and low reliability and poor maintainability due to cathode contamination. Many display experts and users believe that photoplastic sealed light valves are the most important current display development from the standpoint of feasibility in the near future.

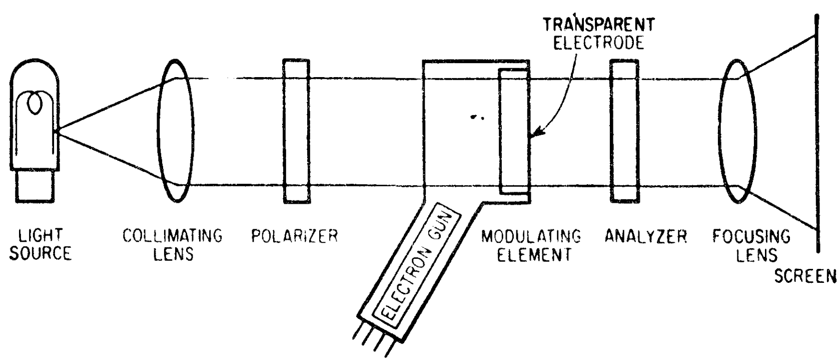
Many of the adverse comments made about oil-film and thermoplastic light valves will not be applicable to photoplastic light valves. As a result, if light valves of this type are satisfactorily developed, they will be competitive with, and probably faster than, the dynamic real-time photochromic displays discussed previously.

Photoplastic light valves should be considered one of the major competitors for the next generation large-screen display systems and for use in systems during the early 1970's if other techniques, such as electroluminescent, magneto-optic, or laser displays, are not perfected as rapidly as might be expected.

4.6.8.4 Solid State Light Valves

Solid state light valves are an interesting and promising technique for long-range consideration since many of the problems associated with oil-film, thermoplastic, and even photoplastic light valves, are avoided. In some approaches, even a cathode-ray tube may be unnecessary.

One approach that has been proposed uses a solid-state crystal for light modulation, but it is not really an all-solid-state device since an electron beam is used to control the crystal.[24] In this approach, as illustrated in Figure 4-7, an electron beam in a cathode-ray tube is used to control the passage of light through a birefringent KDP crystal in the face of the tube. A polarized light is projected through a rear window in the cathode-ray tube, through the crystal modulating element in the face of the tube, and onto a screen. The electron gun in the cathode-ray tube generates an image on the crystal modulator; the polarized light passing through the modulator then projects this image onto the screen. The electron gun serves as a control element but is not required to supply the light output.



Light path through electro-optic light modulator. Modulating element is between polarizer and analyzer, and is scanned by electron gun at bottom.

Figure 4-7. Solid State Light Valve

The crystal light modulator is but one example of a class of light modulators where electrical or magnetic fields are used to modify the optical properties of an electro-optically active crystal (or liquid in some approaches) - to modify its transparency, index of refraction, plane of polarization, color, etc. Such crystals can be used to modulate laser beams in both direction and intensity.

Although the medium controlling the light is solid state, the medium must be controlled by some method to generate the image. Unfortunately, the most practical method of accomplishing this at present is with a cathode-ray tube. In the more distant future, a practical solid-state combination may use a low-power laser to control the crystal, which in turn controls the light from a high power optical projection system.

These approaches are being followed with interest, but there is no indication at this time that they will be feasible for use by 1970.

4.6.9 Electroluminescent Displays

Electroluminescent displays offer the advantages of an all-solid-state display without moving parts or projection optics, a flat display requiring very little depth, and sufficient brightness for viewing under properly controlled room lighting conditions. An electroluminescent element (See Figure 4-8) consists of a thin layer of phosphor powder that is embedded in a dielectric medium and sandwiched between two parallel plate electrodes, one of which is transparent.[25,26] The application of an alternating voltage to the electrodes causes the phosphor to emit light.

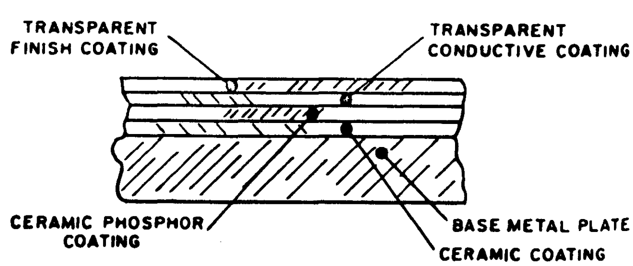


Figure 4-8. Electroluminescent Element

4.6.9.1 Alphanumeric and Symbol Lamps

The major applications of electroluminescent materials in display equipment so far have been in the form of individual character or symbol indicators.[26,27] In these devices, each character position in an alphanumeric display is represented by an electroluminescent panel which can be caused to display any one of a predetermined set of characters depending upon the electrical signals applied to the device. However, extensive research and development efforts have been devoted to the use of electroluminescent materials to fabricate a complete display screen capable of displaying graphical data as well as alphanumeric characters.

4.6.9.2 Crossed-Grid Display Panel

Aside from the discrete character display, the electroluminescent display which has been developed further than others to date has been the electroluminescent cross-grid display.[27,28] This display uses a continuous electroluminescent sheet with the electrodes on one surface subdivided into parallel strips in the X direction and with the electrodes on the other surface subdivided into parallel strips in the Y direction. Applying excitation to an X and a Y strip causes the electroluminescent material to emit light at the intersection, and, to a lesser degree, along each strip. The contrast ratio between the light output at the intersection and that along each line is approximately ten to one. To reduce this "cross-effect," a continuous sheet of non-linear resistor material is coated on the electroluminescent material between the two sets of electrodes. This results in an increase to 10,000 to 1 in the contrast ratio between the light output at the intersection and that along each line. The non-linear resistor material also reduces the capacitance and hence the driving power required.

This approach is useful for both large-screen and console type displays. Real-time dynamic displays, such as target tracks, can be generated by properly sequencing the selection of X and Y grids. Alphanumeric characters and symbols can be drawn on the same display. However, it is necessary to regenerate each spot on the display periodically since it has no storage characteristic. As a result, this type of display requires either an external storage or computer controlled regeneration. To avoid noticeable flicker, the picture must be regenerated more than 30 times per second.

The frame rate of 30 per second and the fact that approximately 5 microseconds are required to energize each spot on the display limit the total number of positions that can be activated. If many spots are to be energized, it may not be possible to regenerate each spot for a long enough period to maintain the desired level of light output. This will decrease if each spot is not energized for a long enough period and sufficiently frequently. Periodic action is required for active spots that remain static as well as for those that are changing. A typical mosaic panel operated at 250 v, 10 kcs with pulses of 20 μsec duration repeated thirty times per second (to avoid flicker) provides an average 20 foot-lamberts of luminance.

One display of this type that is being built provides a 256 x 256 matrix in a 16 x 16 inch display panel. This display panel is 3.5 inches thick. The spot size is approximately 0.1 inch. It is expected that spot sizes of 0.025 to 0.020 inch are realizable in the near future, and that 0.01 inch is feasible.

4.6.9.3 Analog Display Panel

In another type of electroluminescent display, a continuous sheet of electroluminescent material is deposited over a sheet of piezo-electric ceramic.[29] With the proper voltage applied to the electroluminescent material, a mechanical shock wave traveling through the piezo-electric ceramic can generate sufficient voltage to energize the electroluminescent material in the vicinity of the shock wave.

Introducing a shock wave to one edge of the ceramic causes a light signal to propagate across the electroluminescent material as the shock wave propagates across the ceramic beneath it. A reduced shock wave on one edge, combined with a shock wave on a perpendicular edge, can cause a point of light corresponding to the intersection of the two wave motions to propagate across the display. A non-linear resistor material is again used to suppress partial excitation. Controlling the timing of the two shock waves provides the ability to position the spot of light as it moves.

4.6.9.4 Electroluminescent/Storage Panels

In a crossed-grid electroluminescent display, the necessity to regenerate the entire display periodically limits the number of spots that can be energized and may decrease the light output. To overcome these problems, considerable attention has been given to the development of matrix addressed electroluminescent display panels that include a storage capability for each spot on the display. Providing an external storage such as a core matrix is not satisfactory since it does not eliminate the necessity for scanning through the display periodically. A method is required that provides separate storage directly coupled to each spot or position so that individual spots can be turned on and will remain on until intentionally turned off.

Two different approaches have been taken to this problem. The first is to fabricate a display panel with a matrix of discrete electroluminescent elements, each having an associated semiconductor storage circuit. An XY selection matrix is used to turn on the storage element that energizes a specific electroluminescent element. This storage element then maintains the electroluminescent element in that state until it is cut off by another XY selection operation. At present, the addressing rate is limited to a switch-on time of approximately 10 microseconds per element. The switch-off time is approximately 30 microseconds, but it is not necessary to maintain the electrical signal for this length of time. It is anticipated that the switch-on time can be reduced to 5 microseconds in the near future. Resolving powers of 0.4 lines per mm. can be realized now with 0.6 - 0.8 lines per mm. considered feasible by 1970.

This approach provides a true dynamic large-screen display with exact registration and positioning, without mechanically moving parts, and without an optical projection system. Since the individual storage elements eliminate the necessity for periodically regenerating the picture, only those elements that change must be activated and energized or de-energized.

This type of display is quite expensive due to the electronic selection of individual elements and the electronic storage associated with each element. However, it is a practical display in that a dynamic large-screen display of this type can be built in a relatively short time with a high assurance of success. Development of an integrated circuit storage array may lower the cost of the electronic elements, but it would still be necessary to make physical connections between each bit of storage on the semiconductor chip and the corresponding electroluminescent element.

The major fabrication and cost problems associated with the type of electroluminescent storage panel discussed above result from the fabrication of a semiconductor storage circuit for each spot on the display. A more desirable solution is one in which the storage is provided by overlaying a sheet of electroluminescent material with another sheet of material that provides storage in conjunction with the electroluminescent material. Electroluminescent elements and photoconductive elements have been combined for this purpose. The electroluminescent element provides sufficient light to keep the photoconductive element in the conducting state, while the photoconductive element provides a path for keeping the electroluminescent element energized. The result is an EL-PC storage element with both electrical and optical feedback. Electroluminescent panels with this type of storage have been built with a resolution of 0.2 lines per mm. Approximately 1 line per mm. resolving power is anticipated in future devices.[27]

One company has placed over the layer of electroluminescent material a layer of cadmium selenide (CdSe) that provides two stable states with an 8-1 change in resistance between the two states. With a layer of CdSe in series with the layer of electroluminescent material, the hysteresis, effect in the CdSe can be used to provide both switching and storage for an array of electroluminescent cells. It is said that this approach can produce 100 foot-lamberts for approximately 1500 hours with a turn on time of five microseconds.

It is too early to determine whether the technical problems in this approach can be overcome, but it is particularly attractive if it proves feasible. It may provide a means of batch-fabricating a complete electroluminescent display panel with associated storage. The ability to fabricate the storage medium directly on the electroluminescent panel without the necessity for making connections between each spot and its storage element is very advantageous.

Matrix addressed electroluminescent display panels with semiconductor integrated circuit storage for each spot or position on the display definitely will be feasible for use in a 1970 system, but the cost may be prohibitive for a large display screen. Electroluminescent display panels with storage material fabricated on the panel itself are attractive and will be economic if the techniques prove feasible. However, it cannot be stated with certainty at this time that this will prove feasible by 1970.

4.6.9.5 Multi-Colored Electroluminescent Displays

A multi-colored electroluminescent display is difficult but can be achieved by segmenting each element of the display into three elements corresponding to a three color system. Green, blue, yellow, and white electroluminescent phosphors are available, but the green has approximately twice the light output level of the other colors.

4.6.10 Opto-Magnetic Displays

A different approach to solid-state displays is based on the magnetic properties of certain thin-film materials that affect their reflection of light. If a thin-film of magnetic material of this type is deposited on a substrate, areas that have been magnetized will reflect light in a different way than other areas of the film. An XY matrix selection can be used to generate a magnetic image on the surface. If a high intensity light is projected on the magnetic film, a visual image will appear as the result of the effect of the magnetic image on the reflection of the light.

Contrast ratios of 75 to 1 under "normal" room ambient light conditions have been obtained. Only a few percent of the incident light is reflected. Resolving powers of about 8 lines/mm. have been obtained in the laboratory. The intensity varies with the viewing angle in one axis and color varies with viewing angles in the other axis. There is very little intensity variation within angles of approximately 90°.

The U.S. Navy Bureau of Ships has awarded a study contract for a display of this type. This is an interesting approach to a dynamic large-screen display, but it is too early in the development stage to determine with confidence whether it will be available and feasible for a 1970 system.

4.6.11 Electrochemical Displays

A number of display techniques based on electrochemical phenomena have been investigated. Several electrochemical devices are available in which the color, the opacity, or the reflectivity of liquids or solids are changed by the application of local voltage or current signals.

One approach uses reversible electroplating techniques. Each cell or spot on the display panel consists of an electrode in a silver solution. The silver can be plated or deplated on the surface of the electrode under the control of an electrical signal to give a reflective type of display. Another approach uses a liquid in a honeycomb-like structure where the pH of the liquid can be changed chemically by an electrical signal to provide selective color. Most of the devices of this type are ambient light viewing devices although some self-luminance devices are experimentally available.

One type of electrochemical display that has been under development for several years is Electroflors.[30] Electroflors use liquid phase materials that either exhibit fluorescence or change color when activated by electrical signals. Three elements comprise Electroflor liquids - carriers, indicators, and activators. Basically, an electric potential across two electrodes emersed in an Electroflor liquid sets up an ion unbalance that causes color change. The ions represent a localized increase in pH of the solution that results in a color change in the pH sensitive indicator. A reverse polarity current can be used to neutralize the color. This action is relatively slow requiring approximately one millisecond to provide a useable color change. Such cells have inherent storage. It takes several minutes for diffusion effects to dissipate the color indication.

Individual Electroflor cells have been built but the most promising approach from the standpoint of large screen displays is a matrix selection technique in which a matrix of horizontal and vertical electrodes is used with each crossover corresponding to a spot or display element. An experimental display with 120 lines in each direction of the matrix has been constructed under an Air Force contract. This experimental project uncovered problems with smearing of the image by spurious side currents from surrounding electrodes. Further investigation revealed that these effects can be overcome by the use of anodic electrodes which act as rectifiers. However, the use of anodic electrodes made it impossible to erase the image electrically. The image will decay and fade with time, but this seriously affects the speed of the display if it is necessary to change the image frequently. Selective colors can be produced that are visible under bright ambient light.

Electroflors and other electrochemical displays are of interest for the long-range future, but it is unlikely that they will be developed sufficiently for use in a 1970 system.

4.6.1.2 Laser Display Systems

The use of lasers to evaporate opaque material on a glass slide in an inscribing type display, and the use of ultraviolet lasers to write on photochromic material have been covered in previous discussions. However, lasers have the potential of being used in other ways that offer promise for future large-screen displays.[31,32,33] For example, a laser beam may be used to write directly on a large luminescent screen. This is somewhat equivalent to an "outdoor" cathode-ray tube in which the laser beam replaces the electron beam and the luminescent screen replaces the phosphor coating on the face plate of the tube. This offers advantages over a CRT in that a vacuum is not required and a large-screen image can be generated directly.

The major development problems associated with laser displays are:

1) Obtaining sufficient power at the desired wave length to provide adequate luminance at the desired color, and

2) Obtaining deflection and intensity modulation devices with sufficiently fast response to provide the necessary resolution.

The nature of these development problems can be illustrated by considering the raster scan type of presentation (the random positioning method offers higher luminance but requires equally fast modulation response). The luminance L on a screen of area A and gain G provided by a laser of output power $P\lambda$, at wave length λ for which the luminous efficiency is $E\lambda$, is given by

$$L = \frac{680 P\lambda\ E\lambda\ G.}{A}$$

L is in foot-lamberts if A is in square feet. Assuming a screen of $G = 2$ and $A = 100$ square feet, a laser for which $P\lambda = 1$ watt, $\lambda = 550$ mu (for which $E\lambda = 1$) the luminance L is 13.6 foot-lamberts. While this luminance is comparable with the open gate screen brightness of the average motion picture theatre, it should be recalled that the most powerful laser available today, operating at $\lambda = 633$ mu (for which $E\lambda = 0.26$) has a power output of about 0.05 watts rather than 1 watt. With these values of $P\lambda$ and $E\lambda$, and with $A = 100$ square feet and $G = 2$ as before, the luminance is only 0.18 foot-lamberts.

To provide a resolution of one part in 1000 along each of the two axes of the screen at a flicker-free rate of about 30 cycles requires a horizontal deflection sawtooth frequency of 30 kc for deflection and an intensity modulation square wave response of 30 mc. These requirements are not believed to be within the current state-of-the-art in lasers. Hence, improvements in power and efficiency available from lasers at the desired wave lengths (particularly ultraviolet) and adequate laser deflection techniques must be developed before laser-controlled luminescent screen displays will be feasible.

Binary digital deflection of lasers by crystals has been satisfactorily demonstrated for 256 positions in each direction, but 1024 positions in each direction are needed for a practical display system.[34] The results accomplished to date indicate an 85% to 90% transmissivity of light through the deflectors. Calcite and sodium nitrate are the two crystal materials that have been used for deflecting laser beams. Deflection angles are about 6% to 8% for each crystal.

A recently-developed display panel appears very attractive for use with an ultraviolet laser in a system similar to that described above. This panel provides an electroluminescent screen controlled by a variable impedance dielectric material. The exact nature of this material is proprietary and has not been disclosed in detail. This variable impedance material is used in series with the electroluminescent material between the plates of a capacitor formed by two thin-film electrodes. The result is a four layer panel (a thin-film electrode, the variable impedance material, the electroluminescent material, and another thin-film electrode) in which the impedance material layer controls the voltage across the electroluminescent layer. Hence, the energizing of the electroluminescent layer can be controlled by changes in the impedance layer since the energizing voltage is applied across the series combination of impedance layer material and electroluminescent material. The impedance of the material is changed by ultraviolet and infrared light. An image can be written with an ultraviolet light and erased with an infrared light.

The variable impedance material does not provide an on-off type storage but has a finite decay time -- up to approximately two hours. A very interesting property of this display panel is that the decay time is a function of the frequency of the supply voltage across the electrodes. The image is actually stored in the impedance layer which controls the electroluminescent layer. Changing the excitation frequency does not change the stored image but rather changes the effect of the impedance layer on the electroluminescent layer. This type of display media has some interesting possibilities from the standpoint of Navy applications. For example, a display could be viewed showing only the immediate real-time image, but historical data such as target track history could be recaptured by changing a switch setting to change the frequency. A dial controlling a continuous frequency range could permit varying the time period covered by the historical data linearly. The persistence can be varied from five or ten seconds to one or two hours.

This display panel is a proprietary development by one company and very little information has been released on it to date. Apparently, effort has been concentrated on the panel itself with little work yet on the development of a display system using the panel. It is necessary to develop methods of addressing, writing, and erasing. One possibility is the use of an ultraviolet laser beam for writing and an infrared laser for selective erasure. The screen could be flooded with infrared for complete erasure. It appears that the display panel can be developed satisfactorily, but that the feasibility and the timing of its use in a high-speed real-time display system depends upon developing ultraviolet lasers and the ability to adequately control the deflection of a laser beam. Addressing and writing could be accomplished with a servo-controlled ultraviolet optical system, but this would limit the speed to approximately that of mechanical inscribers discussed previously.

4.6.13 Three Dimensional Displays

Some types of applications have lead to an interest in the development of a three-dimensional display. There are two major types of three-dimensional displays. The first is volumetric displays that use intersections (e.g., of light beams, of fine wires, etc.) in three-dimensional space to produce light at the intersection points. The second is illusory displays in which the illusion of three dimensions is produced on a two-dimensional screen by techniques such as the viewing of steroscopic pairs.[35] Approaches that have been investigated include:

1) The use of a three-dimensional wire matrix grid in a gas-filled tube to produce localized glow discharges at selected grid intersections.[36]

2) A "fish-bowl" tank of clear, colorless Electroflor liquid with a fine mechanically-controlled electrode (probe) moving through the liquid forming a colored trajectory.[30]

3) A cathode-ray tube mechanically oscillated in the axial direction with axial position information synchronized with the axial displacement.

4) A projection cathode-ray tube optically projecting an image onto a rotating or oscillating screen with the image position synchronized with the screen motion.

5) Steroscopic viewing of two direct-view storage tubes presenting steroscopic pairs.

6) Holograms in which a gas laser is used to illuminate a specially-prepared photographic plate.[37]

In general, the techniques listed above are limited to relatively small displays, have poor resolution, have poor light intensity, and are relatively slow. None of them are currently suitable for large-screen displays, nor have they been proved feasible on other than an experimental basis.

The hologram deserves special mention because it is a new and significantly different technology.[37] In preparing the photographic plate, a laser beam is used to illuminate the subject directly. The beam is also reflected onto the photographic plate by mirror to establish a reference. The coherent light establishes an interference pattern on the photographic plate which bears no visual resemblance to the subject. However, if the developed photographic plate is illuminated by a laser beam, a three-dimensional image of the subject is created. The laser beam passing through the hologram on the photographic plate creates the illusion of a three-dimensional reproduction -- even to the extent that the viewing point permits seeing around corners. No lens or optical system is required.

Holography is very interesting from the standpoing of long-range potential for three-dimensional displays. However, it has several disadvantages: long exposure time (e.g. 5 to 20 minutes), light inefficiency, and power requirements. Although holography is discussed here because of its potential long-range value, it is not expected to be feasible for use in display systems in the early 1970's.

4.6.14 Other Potential Display Techniques

There are a number of other possible techniques for achieving large-screen displays.[38] One of these is exemplified in a research contract sponsored by the U.S. Navy Bureau of Ships to develop a low-voltage, high-resolution solid state display panel using electroluminescent diodes (injection electroluminescence). In this approach, the display panel would consist of an array of gallium-arsenide-phosphide electroluminescent diodes controlled by an array of silicon integrated circuit flip-flops.[39] Another approach uses a self-luminous gas matrix discharge panel with external storage. Other approaches that have been considered or investigated include gas-discharge matrices and matrices of magnetically-controlled moving elements. Of these approaches, only the use of a matrix of electroluminescent diodes controlled by a semi-conductor integrated circuit array is believed to offer promise for large-screen displays in the 1970 era. At present, it is too early in the development cycle to determine with confidence whether even this one will be feasible or economically competitive with other technologies discussed previously.

4.7 CONCLUSIONS AND RECOMMENDATIONS FOR DISPLAY TECHNOLOGY

Existing cathode-ray tube technology and continuing engineering improvements that can be anticipated will be adequate for console type displays and for image generation in the 1970's. Although some breakthrough may occur that will provide a better method of mechanizing consoles, there is no strong requirement for a new technology.

On the other hand, present approaches to large-screen displays are not satisfactory for naval tactical use, and a new approach is needed for the mechanization of large-screen displays during the 1970's. Several technologies now under investigation and development offer promise of meeting these needs. Present approaches to large-screen displays are primarily electromechanical and photographic in nature. Such approaches may meet performance requirements, but they are not well suited to meeting the operating conditions for naval tactical equipment -- particularly environmental conditions, and the need for ruggedness, reliability, maintainability, and to logistics requirements. Approaches are needed that offer relatively long life, that involve a minimum of mechanical parts and motions, that are easy to maintain, and that do not require the use of expendable media or processing chemicals that pose difficult logistics problems.

Several technologies offer promise for new large-screen displays meeting the requirements of naval tactical applications. The following are the most promising that are believed to be feasible by 1970:

1) Photochromic displays with cathode-ray tube or laser image generation
2) Thermoplastic and photoplastic light valves with cathode-ray tube or laser image generation
3) Crossed-grid electroluminescent displays with integrated storage
4) Laser inscribing systems.

Several additional technologies under investigation offer promise, but at this time it is too early in their development to predict whether or when they will be feasible. These include:

1) Solid-state light valves
2) Opto-magnetic displays
3) Electrochemical displays
4) Laser/luminescent (or electroluminescent) displays.

Of this latter group, laser/luminescent displays are particularly attractive, but their feasibility depends upon the development of adequate power lasers in the proper frequency range and the ability to deflect laser beams cheaply with high resolution. These abilities will be developed but it is not certain that this will occur by 1970. Injection electroluminescent matrix displays using light-emitting diodes also appear promising for some time after 1970. These approaches should be followed closely if further research and development proves that any of them will be feasible for 1970 era systems.

Some of the technologies recommended for large-screen displays may prove applicable to console displays as well. Although there is less pressure for a new technology for consoles since present cathode-ray tube technology can provide the necessary characteristics, other approaches should be followed carefully if any develop to the point of being more desirable or advantageous than cathode-ray tubes for console displays. For example, crossed-grid electroluminescent displays with integrated storage offer promise for large-screen displays. Since this is an all-solid-state approach that provides image generation inherent in the display itself, smaller, higher resolution panels might also be useful for console displays. There is probably little reason for considering any of the technologies that require a cathode-ray tube for image generation for use in consoles since the cathode-ray tube can be viewed directly.

In considering future large-screen displays, it is necessary to consider not only the display presentation viewed by the user, but also the method of image generation required, the method of addressing and selecting individual positions on the display screen, and the required interface with the computer. For example, systems based on cathode-ray tube image generation are basically analog in nature while other techniques, such as crossed-grid electroluminescent display panels, are strictly digital. An approach that is basically digital in nature will be more desirable from the standpoint of computer interface, reproducibility, and maintainability. However, this is not an over-riding consideration since some of the analog approaches may be more desirable in terms of cost or complexity.

It is essential that the final selection of a display technology be closely coordinated with the determination of user functions and software implementation.

Section 5
COMPONENTS AND PACKAGING

5.1 INTRODUCTION

Developments now underway in component and packaging technology will permit revolutionary changes in the design, fabrication, and capability of the logical portions of computers and digital equipment even prior to 1970. This will be particularly true for tactical equipment where high reliability, easier maintainability, small size and weight, and low power are important considerations. A 1970 era naval tactical system can realize all these advantages, plus achieving increased performance and capability as a result of advances in integrated circuits and other batch-fabrication techniques.

The development of monolithic silicon integrated circuits with improved techniques for component isolation is the major factor. However, developments in hybrid circuits, metal-oxide-semiconductor circuits, and active thin-film circuits are also playing important roles in the changes in computer technology. Other methods of mechanizing logical functions have been investigated and some of these may offer advantages in certain applications or under certain conditions. However, integrated circuits are by far the most significant component development with respect to the impact on the logical circuitry in a 1970 system. Integrated circuit techniques are also applicable to a large percentage of the other types of circuits in the system such as the memory electronics.

Consequent to and concurrent with these component developments are increasing efforts in the development of new packaging concepts and techniques. Components and packaging techniques have been investigated and are discussed together as intimately interrelated topics. The method of packaging arrays of components cannot be considered independently of the nature of the component itself. The selection of specific types of components also imposes unique requirements on the packaging techniques. The ultimate goal is the maximum degree of batch-fabrication possible to permit relatively large segments of a computer, or other digital equipment, to be fabricated as a unit in a single set of processing operations.

Until recently, it has been necessary to package individual discrete components (e.g., transistors, diodes, resistors, capacitors, etc.) into circuit arrays by techniques such as printed circuits or welded connections, and to further interconnect groups of these modules into subassemblies. Frequently, cables and cable connectors interconnect such subassemblies into units of equipment. With integrated circuits, it is no longer necessary to interconnect physically discrete individual components into a circuit module. Some work is also underway toward developing techniques for fabricating combinations of circuit functions without requiring separate packaging and interconnection operations. Ultimately major subassemblies will be made as a single unit by batch-fabrication processes.

If the full potential of integrated circuits is to be used, significant changes in methods of packaging components into an overall computer will be required. To realize many of the advantages that can accrue from the use of integrated circuits, it is desirable to place as many of these circuits as possible in a single package and to place as many of these packages as possible on a single plug-in or other replaceable unit so that the interconnections, wiring, and connectors will be minimized. With the increased reliability obtainable with integrated circuits, the major sources of failures will be in the connectors and wiring unless new methods of interconnection and packaging are developed. This is one of the most difficult problems in the widespread application of integrated circuits. Questions such as the maximum size of a "throw away" unit, spares and logistics, maintenance, and flexibility are involved. For example, is it advantageous to have a computer fabricated with a few hundred modules or packages, each of which is unique, to minimize the total amount of equipment and cost? Or, is it desirable to use five or ten times as many modules or packages, of perhaps 20 - 50 different types, to permit stocking fewer spares? These types of questions will have to be answered in designing 1970 era systems for tactical applications.

5.1.1 Batch Fabrication

The key concept in considering components and packaging for 1970 era systems is batch fabrication. The batch fabrication of storage devices, discussed in another section of this report, coupled with the batch fabrication of logical components and other electronic circuits by integrated circuit techniques will result in dramatic improvements in future computers. These will include improvements in capability, speed, cost, reliability, size, weight, power requirements, and susceptibility to environmental conditions. In the long run, lower costs and increased reliability will be the most significant improvements in future systems. However, the lower costs may be offset by additional functions and greater performance requirements. From the overall systems standpoint, the improvement will appear as increased capability rather than as lower cost.

Batch fabrication of individual circuits is not an expectation for the future but something that has already been realized in existing computers. The expectations for the future are not that they can be used, but that the cost of these circuits will be reduced. In addition, the reliability and performance will be increased, and multiple rather than single circuits will be fabricated on a single silicon chip. Batch fabrication of interconnections on a large scale will also be feasible. This latter point is discussed later in this section.

In the remainder of this section, the classification and uses of different types of logical circuitry is discussed. The major types of components that have been proposed for the mechanization of logical functions for future systems will also be discussed. Particular emphasis will be placed on several types of integrated circuits. Requirements for logical circuitry in future naval tactical systems will be considered and related to the potential characteristics of integrated circuits that will be feasible and readily available prior to 1970. Technical problems and considerations such as cost, yield, speed, reliability, maintainability, and packaging will be discussed. Conclusions and recommendations for specific developments and additional investigations needed in the areas of components and packaging will be made. Particular consideration will be given to Navy problems of reliability, logistics, and maintainability.

5.2 CLASSIFICATION AND FUNCTIONAL USES OF COMPONENTS

Components discussed in this study are the logical components used in mechanizing the control, arithmetic, and other logical functions in a digital system. Memories and peripheral equipment are not considered components in the context of this discussion. Components considered here are those necessary for performing logical operations, providing temporary storage of the results of logical operations, and amplifying or shaping signals. Examples are diode gates, flip-flops, and transistor amplifiers respectively.

5.2.1 Classification

These components can be classified by the following: whether they are active or passive; the method of fabrication; whether they are electronic, magnetic or optical; by what circuit or logical function they perform; and by certain characteristics, such as speed or cost. In this report, logical components will be classified in general categories by the basic technology involved:

1) Electronic
2) Magnetic
3) Optical
4) Cryogenic
5) Fluid.

Most of the discussion is devoted to electronic components classified by their method of fabrication. One method of fabrication is by the use of discrete components such as individual transistors, diodes, resistors, and capacitors. Several other methods of fabrication are classed under the general category of "integrated circuits".

Particular consideration is given to integrated semiconductor circuits which are further classified as:

1) Hybrid
2) Monolithic
3) Hybrid/monolithic
4) Active thin-film
5) Metal oxide semiconductor.

Hybrid circuits are those in which passive elements are deposited on a ceramic or glass substrate, and discrete (but unpackaged) active components are connected to printed or deposited interconnections on the same substrate. This combination is then packaged as a single unit. (One example of this method of fabrication used in a new commercial computer system is called SLT - Solid Logic Technology.)

Monolithic integrated circuits are circuits in which there are a number of active elements (e.g., transistors and diodes). These include associated passive elements and interconnections to perform a specific circuit function (or set of circuit functions). They are fabricated by a series of vacuum deposition, etching, and diffusion processes in a single silicon chip. Both active and passive elements are the result of diffusion in the silicon chip.

Hybrid monolithic/thin-film circuits are those in which active elements, and possibly certain passive elements, are diffused into a silicon chip. Additional thin-film passive elements are fabricated on top of the same silicon chip by vacuum deposition processes.

Active thin-film circuits are those in which the active components and the passive components are fabricated by vacuum deposition of thin-film elements on a substrate such as glass or ceramic. This approach at present appears to offer more promise for field-effect devices then for bipolar transistor devices.

Metal-oxide-semiconductors (MOS) are also field-effect devices. However, in fabrication a semiconductor (usually silicon) substrate is used and a single diffusion process is required.

Integrated circuits can also be classified by the type of logical configuration. The major types are:

1) Direct coupled transistor logic (DCTL)
2) Diode transistor logic (DTL)
3) Resistor transistor logic (RTL)
4) Resistor capacitor transistor logic (RCTL)
5) Transistor coupled transistor logic (TTL)
6) Emitter coupled transistor logic (ECTL) also referred to as current mode logic (CML or MECL)

The choice between these different types of logical circuits depends both upon the function for which the circuit is chosen and the method of fabrication of the integrated circuit itself. The relative importance of speed, cost, power, size, and reliability will vary with different applications and different circuit fabrication techniques.

5.2.2 Functional Uses

Although it is anticipated that monolithic integrated circuits will comprise the majority of logical circuitry in a 1970 digital system the requirements of some functions may be such that all magnetic logic or other techniques may be more advantageous for specific functions. In any event, the type of integrated circuit, the type of logical configuration, the cost/performance trade offs, and the packaging and interconnection considerations may differ depending upon the function for which the circuitry is used. The following list illustrates the functional uses of logical circuitry that may be required in a 1970 era ACDS.

In Central Processors:

1) Internal control logic
2) Input/output control and synchronizing logic
3) Arithmetic logic
4) Timing and synchronizing circuitry
5) Parallel memory selection and addressing logic
6) Serial memory selection and addressing logic.

In Peripheral and Auxiliary Equipment:

1) Control and synchronizing logic
2) Selection and addressing logic
3) Timing and sequencing circuitry
4) Electromechanical interface circuitry
5) Communications control and driving circuitry
6) Analog-to-digital and digital-to-analog converters.

The same type of circuitry might conceivably serve most of these functional uses, but it is unlikely that a single type of circuitry will be optimum for all of the functions. For example, the internal control logic in the central processor will require higher speed circuitry than will the control functions in the peripheral equipment. Arithmetic logic tends to be highly repetitive, while the control logic tends to be more unique and non-repetitive. This has direct implications on the type of integrated circuitry used and, particularly, on the packaging and interconnections for these circuits. For example, it is possible to package an entire shift register or several stages of a parallel adder in a single module because of the repetitive nature of these circuits. On the other hand, most of the control logic is unique rather than repetitive; hence, many fewer logical functions can be packaged in a single module without adversely affecting the flexibility of the module and the frequency of its usage.

In other cases, the type of logical circuitry used may be dependent upon the choice or selection of other components or devices. For example, the choice of a type of memory will certainly affect the choice of memory selection and addressing logic circuits. The same is true for the logical circuitry for buffering and synchronizing input/output equipment.

The use of at least two different sets of logical circuitry with significantly different operating speeds may be justified. Much of the internal logic of the machine should be mechanized by high-speed logical circuitry, while circuits with an order of magnitude less speed capability will be adequate for much of the peripheral equipment. The slower circuits may also be used in central processor input/output control and buffering functions. The trade-off between the cost saving for the lower speed circuitry and the increased maintenance and logistics problems imposed by having two different sets of circuitry will influence the decision as to whether different types of circuitry should be used. The extent to which logical circuitry is grouped functionally to reduce interconnections and minimize packaging problems will also influence this decision. If functional grouping of circuits into modules is employed to a large extent, the circuits used in internal logic would not be interchangeable with those used in the peripheral equipment in any event; and hence, basically different circuits might be used to achieve a cost advantage. For naval tactical systems, spares and logistics considerations may override questions of cost and lead to a decision in favor of a single set of circuit types.

Although this section on components and packaging is limited primarily to components for logical functions, many of the considerations are also applicable to other types of circuits in the data system. Primary among these are the memory addressing, selecting, driving and sensing circuits discussed in the memory section of this report. Integrated circuit technqiues will be used for memory electronics, but this is somewhat more difficult than for the digital circuits discussed in this section. Other applications of integrated circuit techniques will be found in linear and analog type circuits used in other areas of shipboard electronics such as radar or fire control systems.

5.3 REQUIREMENTS FOR COMPONENT AND PACKAGING TECHNOLOGY IN A 1970 ACDS

Requirements for component and packaging technology in a 1970 ACDS will exist in the central processor, displays, and auxiliary and peripheral equipment. The component and packaging requirements associated with the memory are discussed in the report on memory technology. Aside from the memory electronics, all of the requirements for components and packaging technologies within the central processor will be for relatively low power logic circuits that can be realized easily with integrated circuit technology. The displays and peripheral equipment will require logic circuits in addition to some relatively low-voltage, low-power linear circuits that can be mechanized by integrated circuit technology similar to that emphasized for the central processor. However, in the displays and peripheral equipment, requirements will also exist for linear integrated circuits providing either high precision, high power, or high voltage. High precision linear circuits will be required in analog and digital conversion equipment and in the display equipment; high power circuits will be required in the control of electromechanical equipment and in some types of displays; high voltage circuits will be required in cathode-ray tube consoles and possibly other display applications. High precision is difficult, high power very difficult, and high voltage all but impossible with present integrated circuit technology.

For the logical components in the central processor and peripheral equipment, no requirement is anticipated for either high power or extremely high speeds. Power dissipation should not exceed 25 milliwatts per gate. Propagation delays in the order of 20 nanoseconds per gate and flip-flop cycle times in the order of 100 to 200 nanoseconds should be adequate. However, to a very large extent, the basic circuit speeds required are a function of the machine organization and logical design techniques used. As an extreme example, much higher basic speeds will be required for a serial computer than for a parallel computer for equivalent system operational speed. The estimated requirements cited above are based on the assumption of a parallel machine organization.

With respect to components and packaging technology, the greatest need for improvement for a 1970 ACDS is in packaging and interconnection techniques. Improvements in speed, as well as in size, weight, power, and cost, are desirable and will be achieved without difficulty. However, improvements in reliability and maintainability are mandatory if the design of a new system is to be justified.

Present methods of interconnecting discrete semiconductor circuits and packaging these in computers and other types of digital equipment will not permit full realization of the advantages offered by integrated circuits. Interconnections, including wiring, solder joints, and connectors, represent major sources of failures and malfunctions in present systems. This will be even more true when the basic component and circuit reliability afforded by integrated circuits is realized in a system. Therefore, in the design of a new naval tactical system for the 1970 era, the development of improved packaging and interconnection concepts is a most important requirement. These concepts should:

1) Permit the interconnecting of a number of circuits in an array on a single silicon chip in a single package;

2) Reduce the number of interconnections external to the package;

3) Give proper consideration to the trade-off between the cost and the failure rate of throw-away packages;

4) Give proper consideration to the trace-off between package size and spares requirements;

5) Base the maintainability requirements (particularly with respect to personnel and training) by techniques such as functional grouping of logical circuitry in a package to aid fault location and diagnostic programming.

5.4 COMPARISON OF COMPONENT TECHNOLOGIES

In evaluating and comparing different component and packaging technologies, a relatively large number of characteristics and parameters should be considered. However, a few of these are of primary importance in selecting technologies for use in a 1970 ACDS. For example, any technology under consideration should meet certain minimum specifications (e.g., environment) for tactical applications.

The component technologies recommended are applicable to all types of naval tactical applications including shipboard, airborne, and mobile ground based systems. However, the systems planner may give greater weight to some characteristics for certain types of applications. For example, the power requirements for a particular type of component or circuit is a more important consideration for airborne systems than for shipboard systems. As another example, for mobile ground based systems for the Marine Corps, the need for portability and rapid setup may require a higher degree of modularity and hence different packaging techniques between sub-modules. In selecting particular component and packaging techniques, the systems planner must consider the advantages and disadvantages and the detailed characteristics of different technologies in relation to the specific requirements of his application.

The major parameters and characteristics of concern to systems planners in selecting components and packaging approaches for use in 1970 ACDS are:

1) Type of active and passive elements
2) Type of fabrication (particularly whether batch-fabrication)
3) Number of active and passive elements per circuit package
4) Approximate cost per package and per circuit function
5) Feasibility
6) Availability
7) Reliability
8) Propagation delay and other speed criteria
9) Power dissipation and requirements
10) Susceptibility to nuclear radiation effects and electromagnetic interference
11) Generation of electromagnetic interference
12) Ability to withstand environmental conditions (e.g. shock, vibration, humidity, temperature)
13) Special requirements (e.g., cooling or refrigeration)

The first four criteria are largely reflected in cost insofar as their importance to the system planner is concerned. Since all techniques must meet minimum requirements for tactical environmental and operational conditions, the choice between acceptable alternatives must be made largely on the basis of cost, feasibility, availability, reliability, and speed.

Some of the criteria in the list will rule out certain types of components without the necessity for detailed comparisons. Applicable components should be compared and evaluated on the basis of those characteristics that directly affect the relative value or importance of competitive components. For example, components will not be compared on the basis of their susceptibility to nuclear radiation effects, but this will be cited as an advantage of specific techniques where applicable. Numerical comparisons are difficult when comparing widely differing component technologies, but considering the major advantages and disadvantages of different categories of components quickly leads to the clear selection of semiconductor integrated circuits as the major candidate for a 1970 system.

For a given technology, such as semiconductor integrated circuits, the choice of a particular type of logic (e.g., RCTL, T^2L, DTL, etc.) is made largely on the basis of:

1) Permissible levels of logic
2) Fan-in and fan-out ratios
3) Noise sensitivity
4) Isolation
5) Power
6) Load distribution
7) Tolerances permitted

Any final selection will be made on the basis of comparisons and evaluations of components and packaging techniques, but it must also be made within the context of some known or assumed machine organization and overall systems design. Although one type of integrated circuit might be superior to another in terms of cost and performance alone, considerations such as redundancy, logical design techniques, machine organization, spares and maintenance requirements, etc., may reverse the choice between the two types of circuitry. An example of this is the fact that the use of field-effect transistors in integrated circuit form is much more attractive in a highly repetitive logical configuration that permits relatively large arrays of components to be fabricated on a single silicon chip. Hence, the final evaluation and selection of components and packaging techniques should be made in close cooperation with the study and evaluation of machine organization and system design approaches since they are closely interrelated. This report presents the descriptions and characteristics that are necessary in making such a selection and the advantages and disadvantages of different technologies.

The major types of components that can be considered for a 1970 era system are compared in Table 5-1. This comparison and the technical discussions in the appendix indicate the superiority of monolithic integrated circuits, hybrid monolithic/thin-film integrated circuits, and metal-oxide-semiconductor arrays for the implementation of logical functions in future systems.

The logical components investigated during this study include:

1) Cryogenic logic
2) Fluid logic
3) Optical logic
4) Semiconductor logic using special elements (e.g., tunnel diodes)
5) All-magnetic logic
6) Semiconductor integrated circuits

These techniques are discussed in detail in the appendix. However, most of the investigation has been devoted to semiconductor integrated circuit techniques for digital equipment since they emerged early as clearly the best approach for a 1970 era naval tactical system. All of the types of components listed above are discussed briefly, but the major part of the discussion is devoted to integrated circuits. In analyzing components and packaging techniques for a 1970 system, primary consideration should be given to their adaptability to batch-fabrication techniques. Microelectronics and batch-fabrication techniques are frequently associated and discussed as though they were synonymous. However, there is a distinction in that the term "microelectronics" places emphasis on miniaturization and small size; whereas the term "batch-fabrication" places emphasis on methods of fabrication - methods that permit relatively large numbers of elements to be fabricated in a "batch" without the necessity for individual handling of discrete elements.

A number of microelectronic techniques are not adaptable to batch-fabrication. On the other hand, techniques necessary to achieve batch-fabrication processes tend to lead to small sizes of individual elements and hence to microelectronics.

A comparison made by Webster is shown in Table 5-1. It confirms and gives further details of the different semiconductor integrated circuit techniques.[1]*

Table 5-1. Components and Packaging Technology

	Circuits Per Dollar		Versatility		Feasibility of Large Scale Arrays		Speed	
	Now	Later	Now	Later	Now	Later	Now	Later
Discrete/Thin-Film Hybrid	10	10	~1	~1	1	1	1	1
Monolithic Silicon	10	10^2	10^{-1}	~1	1	10	10^{-1}	1
MOS	N/A	$>10^2$	10^{-2}	10^{-1}	N/A	10^2	10^{-1}	1/3
All Thin Film	N/A	$>10^3$	N/A	~1	N/A	10^3	1/50	1/20

Note: N/A = Not Available for Present Use

* References to this section are given in section 10.7.

In the table above pure monolithic and hybrid monolithic/thin-film circuits are considered together in the "monolithic" category. The numbers in each of the "later" columns are normalized to the present versatility, e.g. applicability of a type of component to a wide variety of circuity; feasibility of large-scale arrays, e.g. ability to develop large circuit packages without mechanical interconnections; and speed of components as used in typical digital circuits. This is done to show relative present and future performance of present or future techniques. In considering integrated circuits for logical components, it is also necessary to consider the type of logical configuration to be used. The major types are:

1) Direct coupled transistor logic (DCTL)
2) Diode transistor logic (DTL)
3) Resistor transistor logic (RTL)
4) Resistor capacitor transistor logic (RCTL)
5) Transistor coupled transistor logic (T^2L)
6) Emitter coupled transistor logic (ECTL), also referred to as current mode logic (CML, or MECL).

The choice between these different types of logical circuit depends upon the function for which the circuit is chosen and the method of fabrication of the integrated circuit itself. The relative importance of speed, cost, power, size, and reliability will vary with different applications and different circuit fabrication techniques. The major advantages and disadvantages of each type are shown in the following list:

Logic Circuits	Advantages	Disadvantages
DCTL	Low power Simplicity	Poor load distribution Noise sensitive Low fan-out
RTL	Simplicity Better load	Noise sensitivity Slower speed than DCTL
RCTL	Good load distribution Good noise rejection High fan-out Low power	Slower speed

T^2L	High speed Simplicity Low power	Low fan-out Poor noise sensitivity
DTL	Good noise immunity Good isolation Good fan-in capability Low power	Two power supplies required Slower speed Low fan-out
ECTL	Simplicity Good load distribution High speed operation	More critical circuit parameter More components Two power supplies Noise sensitivity

Table 5-2 shows a comparison of component technologies for 1970.

Table 5-2. Comparison of Component Technologies for 1970

Technology	Advantages	Disadvantages	Comments
Cryogenic	Low cost in large quantities.	High "overhead costs." Feasibility and availability questionable. Present cryotron approaches are relatively slow.	Applications probably limited to use in large cryogenic memories and associative memories or associative processors.
Fluid	Less affected by temperature, electromagnetic fields and nuclear radiation. Easy interface with mechanical equipment. Perhaps low cost in batch-fabricated form. High reliability and long shelf life.	Very slow. Size and weight large relative to semiconductor integrated circuits. Unsatisfactory cost/speed ratio. Batch-fabrication techniques not well developed.	May be applicable to functions such as weapon direction and ships control, but not competitive with semiconductor integrated circuits for central processor and most peripheral equipment applications in tactical data systems.
Magnetic	High reliability. Radiation resistance. High-temperature operation. Low stand-by power.	Slow speed. No steady state output indication. Batch-fabrication techniques not developed. Logical circuits more complex and multiphase clock usually required.	Not competitive with semiconductor integrated circuits except perhaps in peripheral equipment and other shipboard equipment such as weapon direction systems and ships control.
Optical	High frequencies possible. Fiber optics can conduct light around curved path. High density possible. Can provide complete isolation from electrical circuits.	Feasibility is far into the future. Digital technology and fabrication techniques not well developed.	Will be used in memories and displays before successful use as logic components. Not feasible for use as logic components in a 1970 system.

Table 5-2. Comparison of Component Technologies for 1970 (Continued)

Technology	Advantages	Disadvantages	Comments
Tunnel Diode	High speed. Low impedance.	High cost. Two terminal device. Not readily amenable to batch fabrication.	Not competitive with semiconductor integrated circuits since high speed is not required in 1970 ACDS.
Hybrid Discrete/ Thin-Film Integrated Circuits	Inherent isolation. Cheap passive elements. High precision and large value resistors and capacitors easier to fabricate. Versatility and flexibility. Low temperature coefficient. Less tooling costs for small runs.	Expensive discrete active elements. Only partial batch fabrication. Ultimate reliability probably less than monolithic integrated circuits. Higher cost in large volumes.	Useful where a high ratio of passive to active components is required.
Monolithic Integrated Circuits	Low cost. High reliability. Arrays of circuits can be batch fabricated on a single silicon chip.	Isolation of the pn junction is not good enough. Passive components are not good (poor tolerances). Passive components take up too much space on the chip. Difficult to fabricate large capacitors.	Expected to be the major type of circuit used to mechanize logic functions in computers of the 1970 era.
Hybrid Monolithic/ Thin-Film Integrated Circuits	Combines some of the advantages of Hybrid Discrete/ Thin-Film with some of the advantages of Monolithic. Can be used in linear or high frequency circuits where isolation, good tolerances or large value R and C are required.	More expensive than Monolithic for digital circuits. Only partial batch-fabrication.	Expected to be used in 1970 system to supplement Monolithic circuits where required characteristics can be obtained more easily.

Table 5-2. Comparison of Component Technologies for 1970 (Continued)

Technology	Advantages	Disadvantages	Comments
Active Thin-Film Integrated Circuits	May be very cheap ultimately. Substrate size not limited to size of a single silicon chip. When technology is developed to point of feasibility, large arrays can be fabricated easily.	Slow speed (FET types). Only FET types look promising at this time. Difficult to make reproducibly. Stability problems. Feasibility and availability questionable.	Feasibility for 1970 system is questionable but they offer promise for long range future.
Metal-Oxide-Semiconductor (MOS) Integrated Circuits	Simpler to make. Inherently isolated. No passive elements (essentially). Large arrays are feasible. Low noise. Possibly better radiation resistance.	Electrical stability problems to date. Slow speed. Technology not as well established as that for bipolar transistor type devices.	High impedance levels are considered a disadvantage by some and an advantage by others. Very attractive for large arrays such as matrix storage arrays.

The state-of-the-art in logic circuits today is illustrated by the summary of one manufacturer's standard "off-the-shelf" line of integrated circuits shown in the following listing:

Category	Type Logic	Power (milliwatts)	Speed	No. of Circuit Types
Low Power Low Speed	RCTL	2-4	300 kc	15
	RTL	3-10	1 mc	7
Medium Speed	Modified DTL (pnp input)	5-30	8 mc	11
	DTL	20	800 kc	8
	DTL	---	5 mc	10
Higher Speed	T^2L	10-20	10 mc	8
	DTL	15-25	6 mc	4

The advanced state-of-the-art is represented by very high speed circuits with propagation delays in the order of 1 to 3 nanoseconds per state. These are usually custom circuits using ECL type logic.

Semiconductor integrated circuit costs are expected to drop sharply before 1970 as the number of circuits per chip and per package increase. Monolithic and monolithic/thin-film integrated circuits will be significantly cheaper than other technologies with equivalent performance except for the possibility of metal oxide semiconductor devices in larger arrays such as matrix storages. The reliability of semiconductor integrated circuits is expected to be about 0.0001% failures per 1000 hours by 1970. These integrated circuits are capable of meeting all of the environmental requirements for naval tactical systems. Even with today's technology, propagation delays per gate in the order of two to five nanoseconds are available. This is in excess of any requirements anticipated for this type of system in 1970. Based on the advantages and disadvantages discussed above and cost, reliability, and environmental considerations, semiconductor integrated circuits are clearly the first choice for mechanization of the logical functions in a 1970 era ACDS.

5.5 ANTICIPATED CAPABILITIES VS. REQUIREMENTS

Semiconductor integrated circuit technologies will be able to meet all of the requirements for mechanization of the logic functions in the central processor, displays, and auxiliary and peripheral equipment of 1970 era naval tactical systems from the standpoint of both performance and operational requirements. Based on preliminary estimates of response characteristics for logic circuits for a combat direction type of application the following parameters were developed. Power dissipation of 25 millowatts per gate flip-flop cycle time of 100 nanoseconds, and costs of a few dollars per flip-flop can be equalled or bettered, while meeting the environmental specifications of MIL 19500. Very high reliabilities in the order of 0.0001% per 1,000 hours will be realized on a per-package basis for the integrated circuits.

The question mark concerning component technology is in the area of non-digital circuits -- linear circuits, high-power circuits, and high-voltage circuits. The requirements for circuits of these types will come primarily in the displays and peripheral equipment rather than in the central processor. Some requirements for linear circuits and relatively high-power circuits will occur in the memory area of the central processor, but these have been discussed in the report on memories and it is believed that they will be available in integrated circuit form for use in a 1970 system.

The relatively low-voltage, low-power linear circuits with high precision can be realized readily by means of hybrid monolithic/thin-film integrated circuits in which high precision and large value resistors and capacitors are fabricated by thin-film technology on the silicon chip containing the active elements and the remainder of the passive elements in monolithic integrated circuit form. It may prove more desirable to fabricate these thin-film components on a passive substrate that also contains the printed or deposited interconnections to which a number of monolithic integrated circuits are attached by methods similar to the "flip-chip" technique. In either case, the requirements for this type of circuit will be well within the state-of-the-art in 1970.

The high-voltage and high-power circuits required in the displays and some of the electromechanical peripheral equipment present difficult problems for integrated circuit technology. These will most likely be fabricated from discrete semiconductor components similar to those used in today's systems. This is expected to account for approximately 10% of the total electronics in the system.

Monolithic and hybrid monolithic/thin-film integrated circuits will account for approximately 90% of the electronics in a 1970 era ACDS, unless metal-oxide semiconductor devices find large-scale use because of their simplicity and ease of interconnection in large circuit arrays. There appears to be no reason at this time to consider any of the component technologies other than these three for logic functions or for linear circuits not requiring high voltage or high power. All-magnetic or hybrid discrete/thin-film integrated circuits may be used to meet some of the requirements for high-power and high-voltage circuitry in auxiliary and peripheral equipment rather than continuing the use of discrete component circuits similar to those in today's systems.

The major requirements for improvements where solutions are not obvious at this time are in the areas of interconnection and packaging concepts and techniques. Techniques in these areas capable of meeting the requirements for an ACDS are being developed and will be available for use in a 1970 system. However, unless additional emphasis and developmental effort is put on these areas, they will limit the even greater improvements that would otherwise result from semiconductor integrated circuit technology in terms of cost, reliability, and maintainability. Present integrated circuit technology exceeds foreseeable interconnection and packaging technology to the extent that the latter will be the limiting factors in 1970 naval tactical systems.

It should be emphasized that this is not a matter of achieving improvements or meeting minimum requirements since this will be accomplished by integrated circuit technology in any event. It is rather a question of whether the full potential offered by integrated circuit and batch-fabrication technologies will be realized or whether this potential will be limited by the interconnection and packaging problem.

5.6 PACKAGING

A major factor in the optimum use of integrated circuits in future computers will be the packaging and interconnection techniques employed. It is necessary to consider packaging and interconnections at several different levels.

The first level is the packaging and interconnection of the elements of the integrated circuit on the silicon chip. With several circuit elements diffused into a single silicon chip, it is necessary to provide adequate isolation between the components so that they do not interact excessively through the silicon. In most integrated circuits, to date, this has been accomplished by diffusing back-biased junctions between the elements to minimize interaction. However, this has permitted excessive leakage currents and junction capacitancies. These effects have been reduced in some circuits by depositing some resistor and capacitor elements in the form of thin-films on top of the silicon chip rather than fabricating them as diffused elements within the silicon itself. This is a more expensive process and in any event does not overcome the possible interaction between active elements (transistors and diodes) in the silicon chip. A more recent approach investigated by several companies has been isolation by use of dielectric layers.[27] An appropriate combination of diffusion, deposition, and etching steps are used to create integrated circuits with dielectric isolation between components (refer to Figure 1 in Appendix A). In either approach, interconnections between elements of the circuit may be made by vacuum deposition of compatible metals.

The second level is the interconnection of separate circuits fabricated in the same silicon chip. This can also be accomplished by the deposition of thin-film conductors. This level will become more significant as the use of large arrays of interconnected circuits on a multi-circuit chip increases.

The third level involves interconnections between circuits on separate silicon chips that are to go into the same module. This can be accomplished in several ways.

1) The chips can be imbedded in a potting compound with the face exposed and thin-film interconnections deposited with the potting compound acting as a substrate.

2) Interconnections can be printed, deposited or otherwise fabricated on a substrate with tabs on the integrated circuit chips connected by soldering or welding techniques to the printed or deposited interconnection areas (refer to Figure 5-1). The circuits produced by the semi-automated thin-film production system at the Naval Avionics Facility in Indianapolis is an example of this approach in which passive components as well as interconnections are deposited.[69]

3) An interconnection matrix can be printed or deposited on a glass or ceramic substrate with the chips mounted by a "flip-chip" technique.[70] In this approach, small bumps on each external connection point of a chip are mated to printed or deposited interconnection areas on the substrate by turning the chip upside down (refer to Figure 5-2). Ultrasonic soldering can be used to make the bond. This approach is similar to that used in connecting discrete transistors and diodes to the ceramic substrate in the commercial SLT modules. Some of the passive components can also be printed or deposited on the interconnection substrate.

The fourth level is the connections between the chip (or chips) and the external leads of the package. (In some techniques, the third and fourth levels may be accomplished similarly and in the same operation.) This type of connection now represents one of the major sources of failure in integrated circuits - frequently due to the use of dissimilar metals (e.g., aluminum and gold) or to mechanical misalignments and stresses. The most common technique at present is the use of gold ball bonding in which the gold wire is fed through a tube with a slightly larger inside diameter causing a small ball to be formed when the wire is melted by a torch. Pressing this ball against the contact area deforms the ball making a good bond between the wire and the deposited contact area on the chip. The properties of aluminum are ideal for interconnections on the wafer but problems (the so-called "purple-plague") sometime result when gold leads are bonded to the aluminum interconnections on the chip. To avoid this, one manufacturer has recently developed a proprietary interconnection technique that uses a three layer process where the top layer is gold. The three layers of different metals with gold on top achieve the desirable properties of aluminum yet provide gold-to-gold contact bonds.

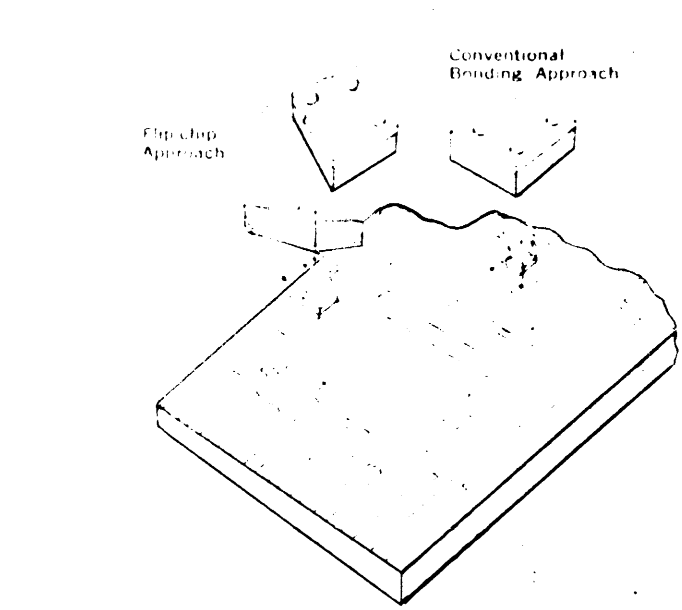


Figure 5-1. Discrete Devices Being Placed into Position on a Substrate by Conventional and Flip-Chip Methods

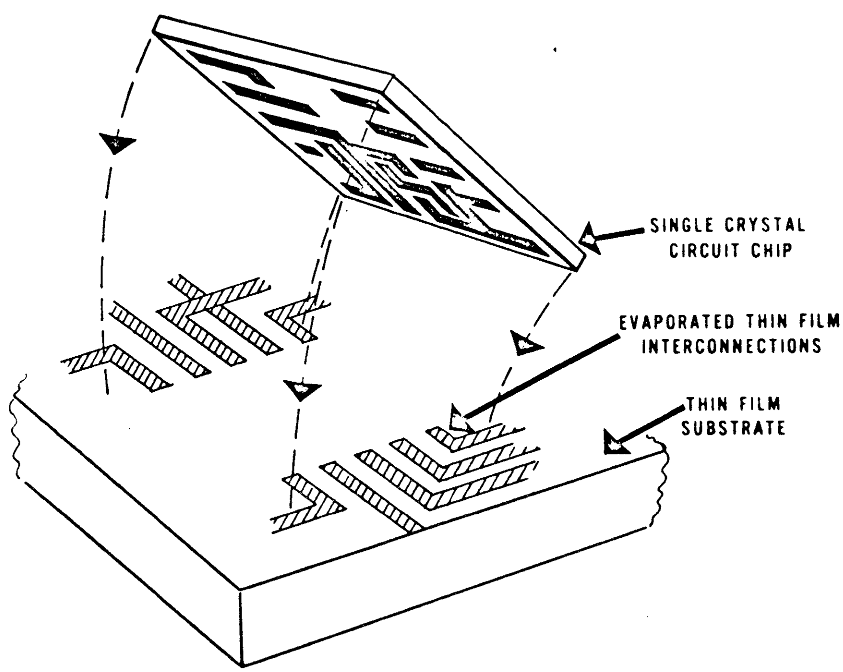


Figure 5-2. Flip-Chip Technique

The fifth level is the interconnection of integrated circuit packages by means of a printed circuit board, welded matrix, micro-module, or printed or deposited substrates similar to those discussed under the third level.[71,72] The most common interconnection technique at this level in use today is the multi-layer printed circuit board.[73] This is generally the level of the plug-in package. Packages at this level are usually fabricated in such a way that they can be plugged into some type of connector to permit easy removal for trouble-shooting and repair. This is also the desirable level for the throw-away package although cost considerations may force the preceding level (the integrated circuit package) to be the maximum throw-away unit despite the fact that its replacement requires soldering or welding operations. The technique chosen for this level depends to a large extent on whether this is considered a throw-away package or whether it will be necessary to be able to repair packages at this level by removing previous level circuit packages.

The sixth level is the interconnection of packages (of the preceding level; e.g., printed circuit boards, etc.) into an equipment or modular subsystem. Since the preceding level is usually a plug-in unit, the interconnections at the sixth level commonly consist of connections between sockets or connectors. This has been done in the past by manual or machine wiring. However, the use of printed circuit "back-board" wiring using larger multi-layer printed circuit boards is becoming more common for reasons of size, cost and reliability. If the package from the preceding level is not a plug-in unit, the sixth level may use another connection technique such as soldering, wire wrapping, or welding to the leads of the package.

The seventh level is the connection of modular subunits into a unit of equipment. This is usually accomplished by means of cables or a wiring harness. Normally, a connector is used to make the modular subunit removable, but this is not always necessary and depends upon the application and the maintenance techniques. The modular subunits can be soldered to the cable or interconnection harness rather than connected by means of sockets or cable connectors. This level may be essentially non-existant in small pieces of equipment.

The eighth and final level is the interconnection of separate pieces of equipment into a system. For reasons of mobility, maintenance, shipping, and manufacture, this level is almost always handled by means of cables and cable connectors.

In a sense, communications systems could be considered a ninth level of interconnection since they connect physically remote and isolated equipment or systems by means of data transmission. However, this is outside the scope of this discussion and is mentioned here only to show the extent to which the interconnection concept can be carried. In systems of the more distant furture, it is conceivable that interconnections between packages or modules within a piece of equipment (and possibly even between circuits) can be accomplished by local communication system-like techniques, such as low level electromagnetic coupling, optoelectronic techniques (light signals), etc., rather than by hard wiring.

From the standpoint of fabrication techniques, the first four levels of interconnection are part of integrated circuit technology and, as such, have been discussed in previous portions of this section. However, from a conceptual standpoint, these levels are also of importance in packaging considerations such as placing larger and larger circuit arrays on a single chip, placing more and more chips on a single substrate, and making trade-offs between cost of throw-away unit, maintainability, and spares. Hence, this discussion of techniques is concerned primarily with the fifth and sixth levels, but the consideration of packaging concepts is broader. The seventh and eighth levels are not considered since they are outside the scope of this discussion.

There are many important considerations of interconnection and packaging techniques from the standpoint of fabrication and manufacture that are not considered here. These have been discussed in a number of published articles.[74, 75, 76, 77, 78] This discussion is concerned primarily with those aspects of interconnection and packaging that directly affect the Navy user -- cost, reliability, maintainability, and logistics (spares). The effects on performance requirements and the ability to meet environmental conditions are no longer major problems for a shipboard data system from the standpoint of interconnection and packaging techniques. Cost, of course, is a significant factor. However, any one of several batch-fabrication techniques under investigation can provide fabrication cost improvements that are sufficiently close to one another that differences in operating and maintenance costs outweigh differences in fabrication costs. Hence, the major concern is the effect of interconnection and packaging techniques on reliability, maintainability, and spares requirements.

One reason for the increased reliability of integrated circuits is that groups of elements can be interconnected by vacuum deposition processes rather than be soldering, welding, or crimping wires and leads.[5,53,77] The use of vacuum deposition techniques can lead to the formation of molecular junctions at the points of interconnections rather than the interfaces that result from other methods. The vacuum deposition of interconnections also removes much of the human element. This advantage has been described by McKenzie as follows:

> "Whereas welding or soldering constitute a weakening of reliability, owing to possible carelessness or ineptitude of a technicain, the thin-film applied through a fixed mask would necessarily provide automatic and uniform interconnection.
>
> Present interconnection practice involves many methods of making joints and the connecting leads themselves are of materials chosen as best suited for joining. Hand soldering may always be used for a number of larger joints or touch-up work, but as the size of units decreases the uncertainty as well as the damage sometimes caused will continue to curtail use of hand soldering.
>
> Automatic dip soldering and flow soldering involve certain hazards such as overheating, corrosion from flux, and particles of excess solder. The joints are good only to the melting point of the solder used. Special techniques such as the use of solder preforms and hot air, are continually under investigation but the limitations of the soft-solder joints are understood and efforts are directed to better methods of joining.
>
> Welded circuits can be successfully made and the joints hold up to temperatures of about 1,500°F. Initial problems of obtaining satisfactory welds with tinned copper, brass and nickel-iron alloy wires have been largely eliminated through the use of nickel, nickel-clad copper and stainless-clad copper.

> Improvements in welding techniques have produced successful joints even with formerly difficult materials. Data are still lacking on the definite improvement in reliability of the welded over the soldered joint but it may be as high as 20 to 1."[77]

The interconnection of integrated circuits is another possible application for lasers. Many of the problems of soldering and welding interconnections can possibly be overcome by using a laser microwelding technique.[79] The use of a laser for welding does not require high vacuum equipment as does electron beam welding equipment, no foreign materials are introduced into the joint as in soldering, and heating of the elements is not necessary. No pressure is applied to the joint, and the laser beam can reach places that are inaccessible to other welding techniques. The use of the high energy beam from the laser for welding purposes has been demonstrated and is being further investigated.

Another problem in the assembly of groups of integrated circuits, as in any other type of electronics, is that of cooling. One interesting approach to this problem is to provide a completely controlled atmosphere by immersing all the components in a liquid such as Freon. The Freon can be maintained at a constant temperature by external water cooling to permit close control of the temperature around the individual components. It also keeps foreign substances such as dust and humidity away from the components. The ability to control the temperature and environment in which the components are working simplifies this basic circuit design and permits higher performance circuitry by removing the necessity for working over a large temperature range.

An example of an advanced interconnection and packaging technique that offers great promise is the automated thin-film fabrication facility at the Naval Avionics Facility in Indianapolis, Indiana.[69] Although a number of published accounts of this approach discuss it in terms of a hybrid discrete/thin-film competitor to monolithic integrated circuits, the techniques and concepts are equally adaptable to fabrication and interconnection of hybrid monolithic/thin-film circuits. In this application of the technique, monolithic integrated circuits can be used to the greatest extent possible because of their cost advantages, but the NAFI thin-film circuit panel technique can be used to interconnect the monolithic integrated circuits and to provide thin-film resistors and capacitors where high precision or large values are needed. It is believed that this marrying of silicon integrated circuit techniques with thin-film fabrication techniques offers promise of an ideal solution to the shortcomings of monolithic integrated circuits, the shortcomings of thin-film circuits, and the interconnection problem. The NAFI semi-automated thin-film deposition production system is basically an in-line four-chamber vacuum deposition unit. It holds 24 substrates that are magazine-fed. "All passive components, insulation, and interconnection paths are applied to the glass substrates by vacuum deposition. Two runs through the four chambers are required to complete the passive circuit structures, employing up to eight successive film depositions. Transistor chips are soldered on later to complete the network."[69] In the future, integrated circuits could be soldered on rather than discrete transistors.

Another interesting interconnection and packaging technique using printed circuit boards has been described by Rice.[79] His article presents an excellent analysis of the interconnection and packaging problem including a discussion of different levels of interconnections and the relationship between integrated circuit package philosophy (form factor, orientation, number of pins, etc.) and printed circuit or plug-in package philosophy. Two tables that he presented are reproduced as Table 5-3 and Table 5-4. The first summarizes packaging techniques for connecting individual integrated circuits to the next level. The second summarizes techniques for interconnecting functional packages consisting of several circuits to the next level (assuming a throw-away functional package). He believes that this packaging scheme will permit an integrated circuit computer with the capability of an IBM 7090 central processor to be packaged on 10 printed circuit boards each 1 x 1 inch square; and that by 1970 it will be possible to package the same central processor on a single 1 x 1 inch square board using the same packaging approaches and concepts but with more circuits per module resulting from higher yields and advances in internal interconnection techniques. The advantages of this packaging approach results from the following listing.

Table 5-3. Summary Circuit Packages

Pack-age	Mounting	Leads and Form Factor	Subsystem Intra-connection	System Intra-connection	Cooling	Remarks
TO-5	Flat	Pins Perpendicular Circle	--	P.C. board	Air	+Auto. soldering (batch) -Close drilling tolerances -Difficult insertion -Intraconnection interference
TO-5	Flat Lead Arranger	Pins Perpendicular Inline	--	P.C. board	Air	+Auto. soldering +Simple insertion +Minimum intraconnection interference -Special lead bending
Flat pack	Flat	Flat One plane Two rows	--	P.C. board (multilayer)	Heat sink (air?)	-Individual contact attach-ment -Intraconnection interference -Requires multilayer p.c. board
Flat pack	Flat (Raised)	Pins Perpendicular Rectangle	--	P.C. board	Air	+Auto. soldering -Close drilling tolerances +Easy insertion -Intraconnection interference
Flat pack	Perpendicular Heat sink and holding fixt.	Flat Perpendicular Inline?	--	P.C. board	Heat sink (built in)	+Auto soldering -Flimsy leads (holding fixture) -Intraconnection interference -Close drilling tolerances
Flat pack	Perpendicular Long vertical pins	Flat Multiplane	--	Special package system	Air?	+Auto. soldering; hand solder or wire wrap (weld?) -Flimsy leads (holding fixture) Very long leads

Prepared by
R. Rice

Table 5-4. Summary Subsystem Packages

Prepared by R. Rice

Package	Mounting	Leads and Form Factor	Subsystem Intra-connection	System Intra-connection	Cooling	Remarks
Flat pack stack	Flat-stack Potted	Pins Perpendicular Two rows	Special welded riser assembly	P.C. board	Heat sink to air?	+Auto. soldering -Close drilling tolerances +Easy insertion -Intraconnection interference -Pin limited logic -Requires high volume -Expensive throwaways
Vertical assembly flat pack	Special holder and assembly	Pins Perpendicular Rectangle	6-12 layers p.c. intra-connection Special parts and assembly Cover	P.C. board	Heat sink to air?	+Auto. soldering -Close tolerance drilling +Easy insertion -Intraconnection interference -Requires high volume -Expensive throwaway
Multi-chip flat pack	Flat	Flat One plane Two rows	Films on substrate	P.C. board (multilayer)	Heat sink (air?)	+More terminals available -Individual contact attachment ?Flimsy leads?? -Intraconnection interference -Requires multilayer board -Requires high volume -Expensive throwaway
Multi-chip flat pack	Perpendicular	Pins Perpendicular Inline	Films on substrate	P.C. board	Air	-Could be pin limited +Auto. soldering +Simple insertion +Min.intraconn.inter-ference -Requires high volume Expensive throwaway

1) A functional grouping of logical circuitry

2) Use of a replaceable but functional unit

3) Use of an in-line package permitting better standardization and component density

4) Use of a larger printed circuit board to minimize connections between boards, and

5) Elimination of one level of plug-in package by the use of functional groupings within a module and a large printed circuit board.

Ultimately, the successful widespread use of integrated circuits in computers and information processing systems will depend upon the industry's ability to find new and more effective ways of utilizing larger arrays of individual circuits. Although significant improvements can be achieved by replacing the discrete semiconductor circuits with integrated circuits in present types of logical configurations and machine organization, new approaches will be required to realize the ultimate potential of integrated circuits. It will be necessary to fabricate groups of circuits in "functional electronic blocks" or in some kind of generalized "cellular logic" array.[72, 80] The cost advantages of placing larger arrays of interconnected circuits on a single silicon chip have been discussed previously. The interconnection and packaging incentives are tremendous. An ultimate goal is the fabrication of major segments of a computer on a single silicon wafer - the "computer on a slice" concept.[81]

The use of larger functional electronic blocks depends upon techniques for making major segments of a machine more repetitive, so that a relatively large number of similar blocks can be used. This is possible now in some arithmetic parts of a parallel machine where successive stages of registers and adder circuitry are repetitive. However, it is very difficult at this time in the control parts of a machine where there is little tendency for repetitiveness. Cellular logic provides an approach to logical arrays that permits batch-fabrication of large numbers of circuits in a single set of processing operations. A major problem with such arrays is the interconnection and the problems of eliminating bad circuits to permit an acceptable yield. In one approach, each cell (logical circuit) communicates only with its four adjacent neighbors.[80] The connection from cell to cell along the horizontal row is a direct wire connection with no logic. The connection between adjacent cells in a vertical column involves a logical function. The direct horizontal connection from cell to cell permits eliminating columns which contain bad elements. Four specific connections in each circuit can be selectively cut to alter the logical function performed by the circuit.

In present military systems, using discrete component transistorized circuits, a small printed circuit plug-in package costing in the neighborhood of $20 is considered a throw-away unit. Maintenance procedures consist of isolating the fault to a specific circuit plug-in board and then replacing this package with a spare. The individual packages are relatively small in terms of function and cost, and considerable efforts have been made to reduce the number of types of individual packages. As a result, the ratio of total number of packages to number of types of packages is relatively high. This permits a limited number of boards to be carried as spares for replacing malfunctioning boards during maintenance. Obviously, if a much larger number of different types of boards were used, the number of spares that must be carried would be increased, even though the total number of boards in the machine were decreased. The spares required are more directly influenced by the number of types of packages than by the total number of packages. This is one of the major problems facing computer designers in attempting to efficiently use integrated circuits in military systems.

The full advantages of integrated circuits cannot be realized if they are packaged and interconnected in the same manner as present discrete component circuits. Since a number of components making up a complete circuit (and possibly several complete circuits) are packaged in a single integrated circuit flat-pack, interconnections can be significantly reduced. This in turn can permit many more circuits or functions to be packaged on a single plug-in module. As the number of circuits or functions packaged on a single plug-in module is increased, the interconnections are decreased and the total number of packages is reduced. However, the relative cost of each plug-in package is increased, the number of different types of packages is increased, and the ratio of total number of packages to number of types of packages is decreased. Hence, the large scale use of integrated circuits for military computers and digital systems imposes severe restrictions on the trade-offs between easy maintenance, cost of throw-away modules, spares and logistics requirements, and efficient packaging and interconnection concepts. It is also necessary to closely relate those considerations to component and equipment redundancy, systems design, and diagnostic programming for fault location.

5.7 FACTORS AFFECTING COST AND YIELD

The cost advantage of integrated circuits over discrete components is not primarily in the processing of the silicon wafer. The cost advantage results largely from two factors:

1) Large quantities of components are packaged and tested together.

2) The interconnection of components into circuits is accomplished during the processing of the silicon wafer; part of the "assembly" cost is eliminated by the "fabrication" operation.

The former accounts for the lower cost per component and the latter for the additional decrease in cost per circuit. The emphasis on placing arrays of circuits on a multi-circuit chip in order to further decrease the interconnections between packages and increase the reliability is discussed under packaging considerations. However, this same goal of placing more circuits on a chip in a single package is also important from the circuit cost standpoint. Moore has estimated that, in the past few years, the number of transistors per integrated circuit chip (for a given surface area) has been increasing in a binary progression in about 1 year intervals - from 1 transistor to 4 to 8 to 16 to 32.[38] Sixty-four transistors are anticipated in the near future for the same surface area. This should be increased to several hundred by 1970. These estimates are for bipolar devices. This figure will be higher for MOS devices.

Four major factors in the production cost of an integrated circuit are:

1) The cost of processing the silicon wafer

2) The cost of testing the circuits

3) The cost of packaging the circuits

4) The yield

The cost of the processed silicon wafer increases very little with circuit complexity, except to the extent that the area occupied by a more complex circuit may be greater. In any event, the cost of the processed silicon wafer prior to testing is a small percentage of the total cost of the ultimate integrated circuit. The cost of testing is a function of circuit complexity, but the cost of testing an interconnected circuit array is less than the total cost of testing the circuits individually. In other words, the per chip or per package cost is higher but the per circuit cost and the total cost are lower. The packaging cost, which is significant, is a function of the size of the chip to be packaged and, more importantly, of the number of external leads required. Again, the number of leads and the packaging costs will be increased for a more complex interconnected circuit array, but will be less than the total if the circuits were packaged individually. Circuit complexity has little effect on yield unless it adds additional processing operations or increases the physical area required for each circuit function. Integrated circuit yield is highly area dependent. If there is a bad component in a particular area of the silicon wafer, there is a high probability of additional bad components in close proximity to it; or conversely, it is unlikely that a single bad component will be found in an isolated area. Hence, the yield is not affected as much by the complexity of the circuit as by the physical size. In general, the larger the physical size of the diced chip, the lower the yield will be unless provision is made for varying the interconnecting of elements and circuits to permit the elimination of bad components and bad circuits on the chip.

The effect of the cost of the processed silicon wafer is essentially neutral, the effect of the testing and packaging costs argue strongly in favor of multi-circuit arrays, but the yield is adversely affected by the larger arrays if they require an increase in the physical area of the chip. Hence, there is some optimum point to which the size of the circuit function (e.g. the number of interconnected gates) should be increased before the physical size begins to adversely affect yield sufficiently to off-set the gains in testing and packaging costs. As integrated circuit fabrication and processing techniques are improved and experience is gained, this circuit array size will move upward. As a result of these considerations, there is a significant cost incentive in attempting to put more and more on a single chip by interconnecting multiple circuits into a logic array or logic function on a single chip.

An example of multi-circuit chips that also uses functional grouping of the circuits is a special two package circuit recently developed by a manufacturer to provide complete counting and decoding from a bit serial pulse train to a binary-coded-decimal nixie tube driver. One package will contain the logic for bit serial counting and conversion to BCD. The other package will contain the BCD to decimal decoding and the Nixie tube voltage driver.

Another example of efforts to place more components on a chip with the ability to vary the interconnection pattern is the "master slice" approach currently used by one manufacturer. In this technique, a common master slice is made for a given family of circuits. Each circuit chip on this master slice has an identical layout of components-- resistors, diodes, transistors, etc. A different interconnection pattern mask is used for each type of circuit in the family to interconnect the components required to make that particular type. The advantages are:

1) All of the processing is identical up to the point of depositing the interconnection pattern.

2) Slices can be fabricated and stored in inventory without committing them to a particular circuit type.

The disadvantages are:

1) For any given circuit type, a number of the components on the chip are not used.

2) The chip is larger than for a similar circuit not using the master slice approach.

New circuit configurations that can be fabricated from the components on a master slice can be prepared within three weeks for an initial cost of about $1,500.00 for the interconnection mask. Custom design circuits on the other hand require three to four months and $10,000.00 to $15,000.00 design and tooling costs.

The same company is working actively on the fabrication of multiple gates on a single chip. Some of their standard circuits provide four 2-input gates on a single chip. They now have a contract calling for the delivery of circuits with 25 interconnected gates in each package by the end of 1964, and 120 by mid-1965. A 120 to 150 gate chip will contain between 2,000 and 3,000 components. Approximately four such chips can be fabricated from a single silicon slice. They expect to be able to fabricate 400 to 500 gates per chip in the future.

These large chips containing many gates require the ability to eliminate bad circuits from the interconnected array in order to obtain reasonable yields. After the individual gates have been fabricated on the silicon slice, they are tested individually. Information concerning the location of defective gates is put into a computer that has also received data concerning the desired logical funtion or array. A computer program has been prepared that generates the proper interconnection pattern to connect the good gates to generate the desired logical function based on the inputs concerning the location of defective components and the desired logical function. This permits the use of chips that have a limited number of defective gates, but it can also permit the fabrication of different logical functions. Since a separate interconnection mask is made for each chip, this interconnection pattern can be varied on the basis of both the input data concerning good and defective gates and the input data concerning the desired logical function.

In simple integrated circuits, advantages are gained at the component level through standardization and the fact that individual components within a circuit do not have to meet a "worst case" design criteria. In circuit arrays where large numbers of gates are interconnected on a single chip, these same advantages are obtained at the circuit level. For example, a single gate in an individual package would have to be tested to meet specifications for a particular fan-in and fan-out capability based on the "worst case" use of that gate in the system. However, in an interconnected gate array on a single chip, an individual gate must meet a fan-in or fan-out specification only for its specific use in the array. Hence, if the initial tests indicate that a given gate is good in all respects except that it cannot handle the maximum fan-out requirement, the computer program could take this into account and interconnect this gate in a particular part of the logical function where its fan-out capability is sufficient.

It is anticipated that a package containing four gates will cost approximately 1.2 times as much as a one-gate package, and that a package containing 50 gates will cost approximately 7.5 times as much as a one-gate package. Hence, the cost per gate for a four-gate package will be 30% of that for a one-gate package; and for a 50 gate package, approximately 15% of that for a one-gate package. Larger packages containing around 100 gates may cost ten times more than a single gate package (or ten times less on a per gate basis).

A good indication of the importance of increasing the number of components and circuits per packaged chip is presented in Table 5-5 developed by Noyce showing a hypothetical cost comparison for transistors and integrated circuits of comparable specifications.[39]

Table 5-5

HYPOTHETICAL COST COMPARISON
FOR TRANSISTORS AND INTEGRATED CIRCUITS OF
COMPARABLE SPECIFICATIONS
(Presented by R. N. Noyce)

Transistors		Integrated Circuits		
		3 Transistors	10 Transistors	30 Transistors
Wafer Cost	$15.00	$20.00	$20.00	$20.00
Units/Wafer	2,000	1,000	500	200
Yield	75%	60%	50%	30%
Cost-Die	$ .01	$ .033	$ .08	$ .33
Package Material	$ .03	$ .05	$ .06	$ .07
Assembly & Test	$ .15	$ .19	$ .20	$ .25
Factory Cost	$ .19	$ .273	$ .34	$ .65
Cost/Transistor	$ .19	$ .091	$ .034	$ .022

Aside from the cost per element or cost per circuit from the production standpoint, there are system considerations as to the effect on efficiency and flexibility. The larger the circuit array, the more difficult it is to use it efficiently from the standpoint of logical design and machine organization. The decrease in flexibility resulting from the use of a larger array rather than individual circuits is directly related to design questions such as:

1) Can machine organization be made more highly repetitive so that large circuit arrays can be used repetitively?

2) Can functional blocks be used in which a package may provide a complex logic function?

3) Can the logic function be varied or changed easily by changing the interconnection of the circuits in the array?

In planning and designing systems using batch-fabricated components, it is necessary to change our traditional way of looking at computer design. The criteria of efficiency and desirability are different. The criteria is no longer the number of gates of flip-flops used and not used, but rather, the number of packages and interconnections.

The ability to easily vary the logic function mechanized on the chip overcomes the problem of flexibility in the design and fabrication of the system, but it raises serious questions of maintainability, spares, and logistics requirements for use in a Navy shipboard system. In the future, it may be easy and economic to design and fabricate a system with significant portions of the logic of the machine interconnected on a single silicon chip in a single package, but this will be achieved at the expense of making each of these packages unique. In this case, the total number of packages will decrease, but the number of types of packages will increase. In any specific case, this question should be decided on the basis of comparing the increase in the cost of the throw-away package and the cost of carrying a larger number of spares,against the simpler debugging and maintenance, the lower machine cost, and the high reliability resulting from the reduction in external interconnections.

The costs of integrated circuits are also highly volume dependent. As volume use of integrated circuits increases, the cost will decrease further. This is also a strong argument for standardizing circuit types unless automatic techniques can be developed for varying the interconnection patterns. Actual yields being realized are closely guarded secrets that most companies are not willing to discuss. However, a 10% yield seems to be typical of the integrated circuit industry today (yield based on the final number of good packages compared to the potential circuits from a silicon wafer after epitaxial growth.) By 1970, 80% yield on this basis may be possible.

Approximately 40% of the cost of integrated circuits is in the tested circuit on the silicon wafer prior to dicing and 60% of the cost is incurred after the circuit is tested on the wafer--dicing, packaging, testing, etc. Hence, the elimination of defective circuits prior to packaging significantly reduces the overall costs. The earlier in the fabrication process that a defective circuit can be rejected, the less the economic effect of yield. When discussing yield, it is important to identify the point in the fabrication process at which the yield is quoted. For example, if defective circuits can be identified and rejected on the silicon slab prior to dicing, the effect on cost will be much less than if these same circuits are rejected at the final testing step prior to packaging, which in turn, will be much less costly than if they are rejected after packaging.

According to Moore, the circuit yield for integrated circuits is now approaching the device yield for discrete components.[38] Eventually, yield should be essentially independent of the circuit complexity since yield is highly area correlated. In internal quality control and test runs, one manufacturer has reported that integrated circuits appear even more reliable than single discrete transistors.

5.8 REDUNDANCY TECHNIQUES

Consideration of majority logic in the above sense leads to the general question of redundancy in digital systems.[47] Reliability of digital systems can be improved by using better and more reliable components, but, for any given level of component reliability, the system or equipment reliability can be further improved through the use of redundancy. Of course, this may be neither necessary nor desirable if the basic component reliability is sufficiently high. Also, redundancy must be used carefully to assure that the actual overall reliability is increased rather than decreased and to assure that the increase in reliability is commensurate with the increase in components and hardware.

Redundancy is usually used to permit equipment or system operation with a limited number of component failures - or at least to permit the detection of errors resulting from such failures. A common example is the use of a parity check or error detecting code in most commercial computer systems. A very early example of a different type of redundancy was the duplication of the complete arithmetic unit in the UNIVAC I.

Although redundancy can provide higher reliability and permit system operation in the event of component failures, a consequent disadvantage is the increase in the number of components required resulting in increased cost, size, weight, and power consumption. A further disadvantage is the possibility of actually reducing rather than increasing reliability if the redundancy techniques are not carefully chosen. A straight-forward statistical reliability analysis indicates a decrease in reliability with an arbitrary increase in the number of components. Hence, the type of redundancy used must be carefully chosen so that the reliability increase achieved through redundancy is not offset by the reliability decrease resulting from the greater number of components. This type of danger is illustrated by a redundancy system in which a logical function is triplicated but in which the majority logic element taking the "best-two-out-of-three" vote is no more reliable than the basic logic elements used to mechanize the function itself. Majority logic elements, that is elements that permit voting, were investigated as part of this study. A more detailed description of their characteristics, advantages and limitations are given in the appendix (10.7). Included in the appendix is a discussion of the use of voting circuits with triplicated elements.

Redundancy can be used at any level in the system including redundancy of basic components, logical functions, units or sub-equipment, equipment, subsystems, and complete systems.[48,49] Theoretically, the lower the level of redundancy, the higher the improvement in reliability. This is illustrated by the fact that in a system using redundancy at the component level a large number of individual components can fail in different parts of the system without affecting the operation of the overall system. At the other extreme, if redundancy is used at the system level by triplicating the system, a single component failure in each of the three systems might put the overall system out of operation completely. By the same line of reasoning, it can be shown that component level redundancy is more reliable than circuit redundancy, that circuit redundancy is more reliable than function redundancy, etc.

On the other hand, the higher levels of redundancy have an advantage of flexibility. For example, if triple redundancy is used at the system level, the three systems could be used independently in applications where reliability is not as important or for temporary peak loads. Also, in the event of a catastrophic failure in one system, the other two systems could continue to operate with the malfunctioning system cut out of the operation. Another interesting possibility with system level redundancy is the physically remote distribution of the three redundant systems so that if one system were destroyed by enemy action, the other two systems could continue to function. Hence, in general, the lower the level of redundancy, the greater the increase in reliability and the less the flexibility and the adaptability; the higher the level of redundancy, the greater the flexibility and adaptability but the less the improvement in reliability. Developments in integrated circuit techniques may also make low level redundancy the cheapest type to achieve in terms of both cost and weight.[50] Redundant components or circuits can be fabricated on the same chip without significantly increasing the cost of the chip and without increasing the number of external (to the chip) interconnections required.

Several types and levels of redundancy used by one company in different aerospace systems were described by Bird recently at an informal conference.[51] Possible forms of redundancy include the following:

1) Simplex - no redundancy.

2) Duplex redundancy at the system level.

3) Triple modular redundancy at the system level.

4) Duplex redundancy at the subsystem or circuit level. (below the system level)

5) Triple modular redundancy at the subsystem or circuit level.

6) Quadruple-multiple-component redundancy.

Other combinations of types and levels are, of course, possible. The advantages and disadvantages of four different types of redundancy are summarized in the following listings:

<u>Quadruple-Multiple-Component Redundancy</u>

Advantages	Disadvantages
1. Best practical method of achieving ultra-reliability.	1. Requires more than four times the hardware.
2. Machine interrupts not required.	2. Operational speed of the machine is slower.
3. Lower power requirements than for triple modular redundancy (1/2 to 1/3)	3. Difficulty in designing wide tolerance circuits to permit component failures.
4. No special fault isolation techniques required.	4. Lack of assurance that failures are truly independent.
5. No voting circuits required.	5. Component failure modes must be known.
	6. Test ability limited.

Duplex Redundancy

Advantages	Disadvantages
1. Greatest reliability and MTF improvement at a given level.	1. Additional hardware required for detection, isolation, and switching.
2. Least weight and power increase (2 to 3)	2. Test processes and operational time required for fault detection and switching.

Triple Modular Redundancy

Advantages	Disadvantages
1. Error voted out without interrupting machine operation.	1. Hardware increase required. (3 to 4 times)
2. Moderate weight and power increase (3 to 4 times)	2. Test ability limited unless additional hardware is instrumented.
3. Significant reliability and MTF improvements.	3. Voting circuits capable of isolating failure are required.
4. Operational speed capability retained.	4. Component failure modes must be known.

In summary, the following points are significant in considering redundancy:

1) Redundancy can be used to improve reliability at the cost of additional hardware.

2) It is necessary to carefully choose the correct type of redundancy for specific applications, reliability requirements, cost limits, and basic component reliabilities.

3) Lower level redundancy gives better reliability improvement; higher level redundancy gives better flexibility, adaptability, and survivability.

4) Component and circuit level redundancy give the greatest improvement in reliability but require the greatest number of components. However, integrated circuit techniques may also make these types of redundancy the cheapest by packaging redundant components or circuits on the same chip thus minimizing external interconnections. Since failures in integrated circuits may be highly area correlated, this type of redundancy may not result in the theoretically possible increase in reliability unless redundant components can be widely separated on a relatively large chip.

5.9 RELIABILITY

Previous discussions have shown that, for a given level of component reliability, equipment and system reliability can be improved through the use of redundancy techniques. However, this reliability is obtained at the expense of:

1) A significant increase in the number of components. (typically two to four times)

2) Some dangers in choosing the proper type of redundancy for the specific application.

3) A possibility of greater difficulty in maintenance and fault isolation since it is necessary to locate a faulty component or circuit even though the outputs of the redundant system are correct.

Theoretical reliability improvements through the use of redundancy may not be achievable since a cause of failure in one component may also affect other components, hence the assumption of independence is violated. That failures in integrated circuits may be highly area correlated is an example of this shortcoming of redundancy techniques.

Hence, the proper place to seek improved reliability is at the component level. In fact, Bird has cited estimates of reliability for the Orbiting Astronomical Observatory for one year's successful operation showing that a simplex system with a factor of 10 improvement in the reliability of individual components is significantly better than redundancy using four parallel systems and almost as good as a quadruple-multiple-component redundant system.[51] The probability of successful operation for one year for a simplex system and three different approaches to improved reliability that he cited are summarized below:

1)	Simplex System	0.01
2)	Four Parallel Systems	0.04
3)	Simplex System but with a factor of 10 improvement in the reliability of individual components.	0.63
4)	Quadruple-multiple-component redundant system.	0.76

If a higher reliability is required than can be achieved from available or realizable components, then the system designer must fall back on redundancy techniques to achieve his reliability goals; but the system designer is much better off if components with basically higher reliability can be obtained. Fortunately, semiconductor integrated circuits offer this opportunity. Integrated circuit reliability figures have been achieved to date in actual experience that provide significant improvements in system reliability. Anticipated further gains in integrated circuit reliability will enhance equipment and system reliability to the point that consideration of redundancy techniques may be unnecessary. This decision has already been made in the case of the computer for the Apollo Moon landing where no provision is made for redundancy or for in-flight repairs--

> "Once you get integrated circuits that are good, they will keep on working fine; the only trouble is in getting perfect integrated circuits for the instrument in the first place."[52]

Integrated circuit reliability will increase to the point that most failures in the computer will result from interconnections and packaging problems. Reliability workers concerned with the Apollo computer have reported finding no inherent failure modes, but a large number of failure modes have been found that result from fabrication flaws, human errors, and poor quality control. All failure modes that have been discovered are said to be "the result of poor process control or the vendor's lack of complete technical knowledge of his process. Most problems are quality control problems. There is no substitute for good, tight inspection on the line."[52] As a result, a number of government agencies and companies have put particular emphasis on "analysis of physics of failure".[53,54,55,56] The fact that failures are largely the result of poor quality and process control was dramatically illustrated by a table comparing the test results and failure rates for three different vendors manufacturing the same integrated circuit type for the Apollo program.

The following listing was presented by Partridge at the ONR sponsored conference on Micro-electronics and Large Systems.[56]

Vendor	Pre-Qualification % Failures	Total	Screen & Burn-in % Failures 2nd & 3rd Electrical	Failure Rates At Use Conditions 90% Confidence
A	5	1.8	0.3	0.005%/10^3 Hrs. (0 failures)
B	26	3.8	1.7	0.3%/10^3 Hrs. (2 failures)
C	58	5.0	2.5	1.8%/10^3 Hrs. (26 failures)

The relative position of the three vendors was maintained at all four steps in the evaluation. A recent report from the Apollo project indicates that 50,000,000 component hours of operational life test have been experienced on the integrated circuits provided by one manufacturer with no failures.[63]

Since most monolithic semiconductor integrated circuits are fabricated in the same manner and with the same processes as the silicon planar transistor, most workers in the field expect the failure rate of an integrated circuit to approximate that of a single discrete transistor of comparable die size.[57,58,59] In fact, Platzek and Goodman state:

> "Because these circuits are fabricated in exactly the same manner as the silicon, planar, passivated transistor, it is reasonable to exploit the test data acquired from the Minuteman high reliability component program. ...Recent published data supports the position that semiconductor integrated circuits will have failure rates closely approximating those of individual discrete transistors."[59,60]

Moore has reported that in internal quality control test runs at his company, some integrated circuits appear even more reliable than single discrete transistors -- probably because the tests were watched more closely and the processes were better controlled.[38]

Integrated circuit technology is building on the established base of experience, know how, and processing techniques developed in transistor technology during the past fifteen years. In this sense, it is an extension of an established technology rather than a new technology.

On this basis then, it is fair to refer to the reliability improvement in transistors for an estimate of integrated circuit reliability. A curve showing the reliability improvement in transistors for the past ten years presented by Narud is reproduced as Figure 5-3.[58] (The vertical axis on this curve is "Failure Rate (1/hours)", hence it is necessary to multiply by 10^5 to convert this to "percent per 1,000 hours" used in other parts of this discussion.) This indicates a failure rate for transistors of 0.0004% per 1,000 hours, which closely approximates predicted failure rates for integrated circuits discussed later. The fact that integrated circuit reliability is largely a "per package" rather than a "per component" function is also a strong factor in favor of more complex packages containing an interconnected array of circuits on a single chip.

Since semiconductor integrated circuits using current design and processing technology have been available for a relatively short time, many of the reliability estimates are based on accelerated life tests,frequently using temperature step stress tests or long-term elevated temperature tests which are then converted to estimated room temperature failure rates by multiplying by a conversion factor. Referring to tests of this type by one manufacturer, Platzek and Goodman state:

> "Achieved failures rate of 0.01 to 0.5% per 1,000 hours at elevated temperature support the expectation that failure rates of 0.0002 to 0.001% per 1000 hours will be achieved under Minuteman operating conditions, and the potential exists for improving these failure rates by factors from 2 to 10." [59]

These results were based on extrapolations from long-term reliability tests at elevated temperatures rather than step stress testing. The step stress tests provide a good method for isolating failures modes but are not too satisfactory as a base for extrapolating failure rates to those expected in normal operation. Extrapolation of the results of step stress tests to normal conditions appears to give estimates of failure rate higher than those actually experienced under normal conditions. Longer term elevated temperature tests such as those reported above by Goodman and Platzek are probably more meaningful.

Prepared by J. Narud

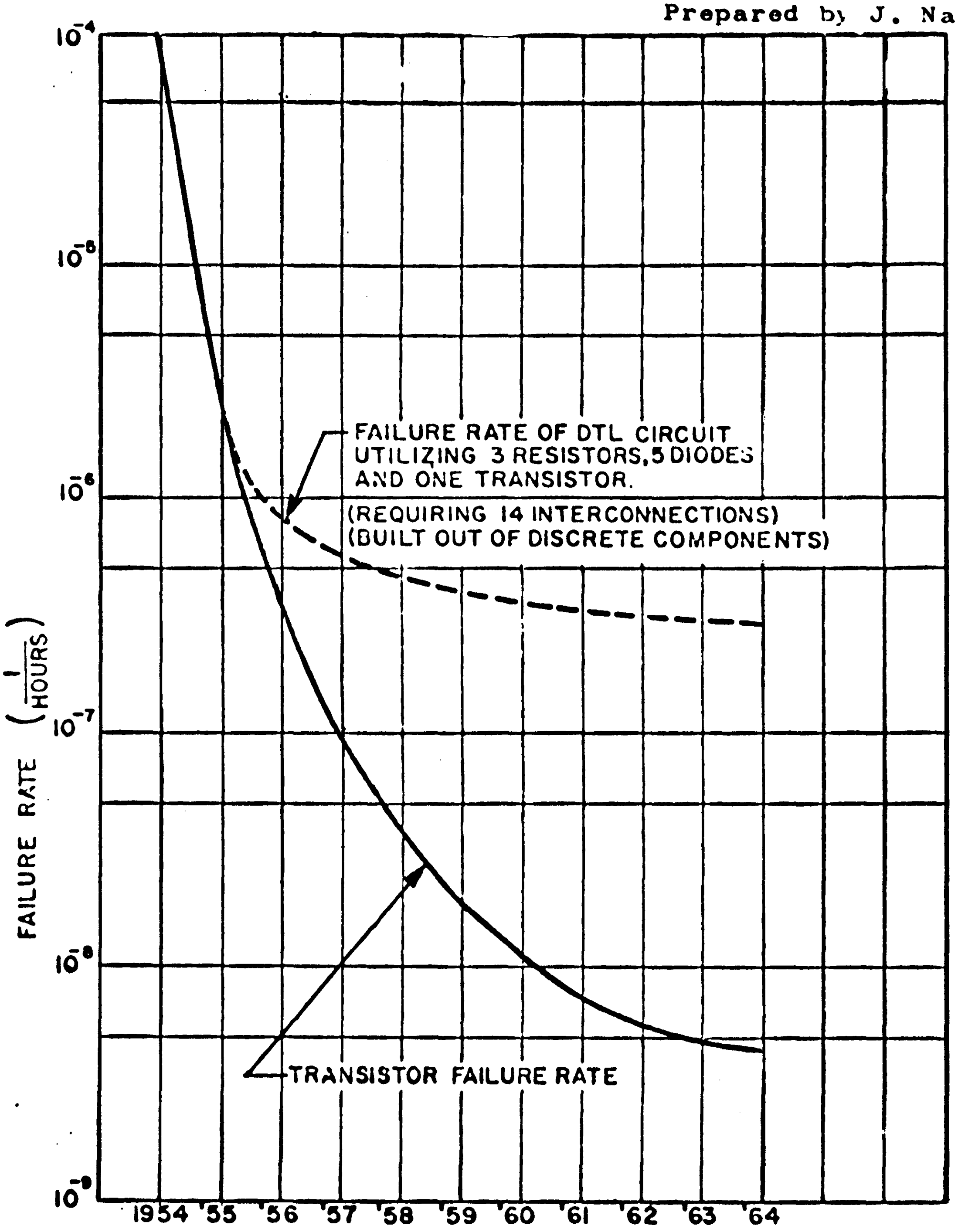


Figure 5-3. Reliability Improvement in Transistors for the Past Ten Years

Bridges (of the Department of Defense) states that "a semiconductor integral circuit containing the equivalent of some 20 parts displays the same failure rate as a single conventional transistor", and he predicts failure rates of approximately 0.0001% per 1,000 hours.[61] A number of estimates place the ultimate reliability of monolithic integrated circuits in the order of 0.0001% failures per 1,000 hours.[59,61,62] Dr. Noyce of Fairchild Semiconductor has described the actual reliability experienced on two specific aerospace computers as follows:

> "We have data on two operating medium-sized computers that use integrated circuits. The first is the Apollo guidance computer, designed by MIT and built by Raytheon. It has accumulated 19 million operating hours on its integrated circuits, in which time two failures have occurred -- an initial failure, and the other a failure, external to the package, that was caused by moving the computer. The second system, the MAGIC 1, an airborne computer built by the AC Spark Plug Computer Division, has accumulated 15 1/4 million hours with two failures. Fairchild's in-house life-test program, with 33 million total operating hours, has had a total of eight failures; of these, five accumulated during the first 6 2/3 million hours and only three occurred on more recent units during the last 26,334,982 hours. These data are not extrapolated from accelerated tests, but are actual, observed operational failure rates, and include early production units in some cases. Considering the complexity of the function performed by these circuits, the integrated circuit equipment today is ten times more reliable than its discrete component counterpart."[62]

This statement was published in June 1964. Since then approximately six months additional experience has been obtained on these machines without failures. It is extremely interesting and significant to note that actual failure rates that can be quoted now are limited, not by failures, but by the time the machine has been in operation. The reliability figures are improving with each hour of operation.

The higher reliability of integrated circuits results from the facts that there are fewer individual components, circuits are of smaller size, there are fewer connections of dissimilar metals, most connections are made by vacuum deposition, and there is less handling of components. Integrated circuit failure rates at present are primarily on a per package basis and are essentially independent of the number of components in a package (within a reasonable range and for a given die size). If failure rates for integrated circuits are comparable to those for discrete transistors as discussed above, then an integrated circuit will have a significantly better reliability than a similar circuit fabricated from 10 to 20 discrete components. On the charts showing reliability improvements in transistors prepared by Narud (Figure 5-3), he has also shown a curve of the failure rate of a discrete component DTL circuit utilizing three resistors, five diodes, one transistor, and 14 interconnections. If the failure rate of an equivalent integrated circuit approximates that of a discrete transistor, then the failure rate of the integrated circuit will be better than that of the discrete component circuit by approximately two orders of magnitude.

Keonjian and Danner have presented a table showing failure rates of typical circuits at different points in time which is reproduced in Table 5-6.[57]

Table 5-6

FAILURE RATES OF TYPICAL CIRCUITS

	FAILURE PER MILLION HOURS			
	1960 Tube Circuit	1964 Std. Solidstate Circuit	1965 Electronic Circuit	1970 Micro-Electronic Circuit
Flip Flop	51.57	5.87	0.08	0.04
Binary Element	42.57	4.65	0.08	0.04
Half Shift Register	43.99	5.59	0.08	0.04
Nand Gate	44.76	4.84	0.04	0.02

(This table shows "Failures Per Million Hours" which must be multiplied by 10^{-1} to convert to "percent per 1,000 hours" to be consistent with other figures in this section.)

They estimate that these failure rates for a typical 1965 integrated circuit are at least one order of magnitude better than a similar circuit made up of 10 to 20 individual parts.

Grant has stated, "I would say integrated circuits are two hundred to five hundred times more reliable than a circuit with the same number of components arranged separately on a circuit board."[64]

Hence, based on extrapolations from planar epitaxial transistor experience, extrapolations from accelerated life test data, and actual field experience, integrated circuit failure rates are from one to two orders of magnitude better than those for equivalent circuits fabricated from discrete components. Alberts has reported a ten to one improvement in system reliability in the first demonstration model integrated circuit computer built in 1961.[18] Based on the above considerations of increased circuit reliability, an increase of one to two orders of magnitude in system reliability of those portions of the system using integrated circuits is a reasonable expectation. This refers, of course, primarily to the logical (e.g. control and arithmetic) portions of the computer and peripheral equipment. Memory reliability will depend upon memory batch-fabrication techniques described elsewhere. The improvement in reliability of the central processor is also a function of the interconnection and packaging techniques as well as the circuit reliability. This is discussed elsewhere, but it is believed that interconnection and packaging techniques can be developed having reliability compatible with (but not equal to) that of the integrated circuit. Since batch-fabricated internal memories with integrated circuit electronics for reading, writing, and addressing are anticipated, a reliability improvement in the central processor of one to two orders of magnitude is achievable for a 1970 ACDS. Overall system reliability will be seriously limited by the electromechanical input/output equipment.

5.10 MAINTAINABILITY

The maintainability of shipboard digital equipment is a function of reliability (failure rate), interconnection and packaging techniques, machine organization, and system design. The interconnection and packaging aspects are described later, but circuit reliability achieved through the use of semiconductor integrated circuits will, in itself, have a significant effect on maintainability by reducing the number of failures. The lower failure rate will permit a larger functional throw-away unit (i.e. a unit that is discarded rather than repaired when it fails) since the throw-away unit can be more expensive if it is to be replaced significantly less often. At the same time, cost reductions anticipated through the use of integrated circuits either will further reduce the cost of the throw-away unit or will permit a further increase in the functional size of the throw-away package. A larger functional throw-away package, in turn, will permit easier debugging since the area to which the maintenance man must isolate the fault is larger. It will also provide higher reliability by permitting larger circuit arrays to be fabricated on a single chip and by reducing the number of external interconnections.

Possible adverse effects of redundancy on maintainability have been pointed out previously as one of the **arguments** against the use of redundancy and in favor of basically higher component reliability. The goal of easier maintainability also provides a strong argument in favor of greater modularity or functional packaging of logical arrays. However, larger throw-away packages and functional modules have to be examined and weighed carefully in the planning of a new shipboard system because of the possible adverse effect on the total number of spares that the ship must carry. Easy maintenance and simplified logistics must be properly balanced, but a decrease in failure rate of one to two orders of magnitude should permit an increase of two to five times in the cost of the throw-away unit. Permitting such cost increases in throw-away units coupled with the concurrent decrease in cost per circuit resulting from the use of integrated circuits and batch-fabrication techniques, will lead to significant increases in the functional size of the throw-away package. Such an increase will simplify the interconnection and packaging problem, simplify maintenance procedures and training requirements for maintenance personnel, and further reduce machine down-time. Some increase in the total costs of spares inventory (but a decrease in the total cost of spares usage) should be tolerated to achieve these advantages.

O'Connell and Brauer have pointed out that total annual support costs for military systems run approximately 1.5 times the total initial price of equipment.[22] Their breakdown of average price and annual support costs for today's conventional discrete component equipment, today's integrated circuit equipment, and 1970 integrated circuit equipment is summarized below.

	Average Price	Annual Support Cost
Today's Discrete Components	40¢	60¢
Today's Integrated Circuits	28¢	21¢
1970 Integrated Circuits	12¢	12¢

These figures emphasize the improvement that can be expected in maintainability in a 1970 military system through the use of integrated circuits. The effect of integrated circuits on maintainability and maintenance costs has been discussed by Lowell, who said:

> "Cost in military electronics in the past five years has seen a spiral unequaled in any other weapons area of America's defense system. ...This problem can be called 'cost of ownership associated with the maintenance of the design performance'. The cost spiral and maintenance deterioration has led to a philosophy of cost effectiveness which attempts to evaluate both the performance impact and military effectiveness in relation to the total cost. ...It is in the area of maintenance and reliability that micro-electronics offers the immediate solution. In the long-range solution, an order of magnitude reduction of procurement and design costs is possible with extensive use of micro-electronics. The impact of micro-electronics in this area will now make it possible to return to standards of maintenance ratios that existed with 1950 equipment, which has only 10% of the complexity and sophistication of today's electronics. This will have a multifold impact, for not only will

down-time decrease, but cost of training technicians, cost of maintaining skills, cost of space, cost of test equipment, and cost of maintenance areas will all decrease at the same ratio or greater." [65]

5.11 CONCLUSIONS AND RECOMMENDATIONS

Components for all logic functions and approximately 90% of the total electronics in a 1970 ACDS can be manufactured by semiconductor integrated circuit technology. The majority of interconnection and packaging requirements can be manufactured by batch-fabrication techniques. Hence, approximately 80 to 90% of the electronics and interconnections in a 1970 tactical data system can and should be manufactured by batch-fabrication techniques. Such techniques will be feasible, economic, reliable, highly developed, and in widespread use by 1970.

Monolithic silicon integrated circuits should be the major component technology used in a 1970 ACDS. Essentially all of the digital logic functions should be mechanized with this type of component. Low-level linear and analog circuits should be mechanized with hybrid monolithic/thin-film components that are closely related to the first type above but that use thin-film fabrication techniques for resistor and capacitor elements requiring either high precision or large values. Because of inherent fabrication simplicity, metal-oxide-semiconductor (MOS) techniques may be used for functions that are amenable to organization in large interconnected arrays. However, they will have more limited speed capabilities than the monolithic and hybrid integrated circuits. MOS technology is particularly attractive for small memory arrays.

Circuits requiring high-power handling or high-voltage capability present the most difficult problems with respect to the use of integrated circuit technology. Requirements for circuits of this type, which are found primarily in displays and electro-mechanical peripheral equipment, will probably be handled by either discrete component circuits similar to those in use today, or by hybrid discrete/thin-film technology. In the latter technique, discrete active components and thin-film passive components are interconnected on a substrate -- with discrete passive components, such as large high-power resistors, used where required.

Interconnection and packaging techniques represent major areas of improvement from the standpoint of cost, reliability, and maintainability. There will be significant improvements in these areas over today's technology, but it will be difficult to achieve improvements equal to those that will be realized in the components themselves. Interconnections will represent the major source of failures in the central processor unless improved methods of batch-fabricated interconnections are developed and larger replaceable units are used. In addition to basic reliability improvements, larger throw-away packages offer a major opportunity for improved maintainability. Lower component costs and significant reductions in failure rates should permit functionally larger throw-away packages that will reduce the number of "pluggable" interconnections and simplify maintenance procedures. A larger number of different types of replaceable modules may increase spares inventory costs somewhat, but this may be offset by reductions in component costs through batch-fabrication. In any event, the spares usage costs will be sharply reduced as a result of lower failure rates and lower component costs.

The two most promising packaging and interconnection approaches are the use of multi-layer printed circuit boards and the use of automated thin-film interconnection substrates similar to those developed for the the Naval Avionics Facility in Indianapolis. This latter approach, combining monolithic silicon integrated circuits, thin-film resistors and capacitors (for high precision and large values), and thin-film interconnections in a semi-automated production process is extremely promising. The thin-film interconnections and passive components could be deposited on the substrate in the same set of semi-automated operations with the monolithic integrated circuits attached by a "flip-chip" technique.

If printed circuit boards are used, a new integrated circuit packaging format or form factor is desirable. This should permit upright and in-line mounting of the integrated circuits. It should also provide more pins to permit larger packages containing more circuits and logical functions. A similar approach can be used for mounting the thin-film substrates discussed above to the next level of interconnections which could be a multi-layer printed circuit board. Hence, a packaging concept for future systems can utilize the advantages of "flip-chip" monolithic integrated circuits, thin-film passive components, thin-film interconnections, and multi-layer printed circuit boards.

More complex integrated circuit configurations in a single package, and preferably on a single chip, are highly desirable to reduce costs and minimize interconnections external to the basic circuit package. Full utilization of the technological capabilities in this regard will require further development of cellular logic, repetitive logic, or variable interconnection techniques. Variable interconnections are very attractive if low cost computer controlled methods can be developed for adapting the interconnection pattern to the desired logical function and the availability of good components on the chip.

Integrated circuit technology will result in reduced cost and increased reliability while meeting required environmental conditions and providing increased performance capability. Costs of a few cents per transistor and possibly less than $1.00 per gate, propagation delays of a few nanoseconds per gate, and reliability in the order of 0.0001% failures per 1,000 hours are anticipated for components meeting shipboard environmental specifications. Maintainability and logistics requirements will also be improved but to a lesser extent.

Interconnection and packaging techniques present the major problems with respect to cost, reliability, maintainability, and logistics requirements. The latter two are the more serious and require additional emphasis and investigation.

A higher cost basic throw-away package is recommended as a result of sharply reduced failure rates. This, coupled with anticipated reductions in component costs, will permit a much larger functional throw-away package in terms of logical capability. The larger functional throw-away package will reduce external interconnections, increase reliability, and facilitate fault location. These will provide needed improvements in maintainability from the standpoint of time to repair and of personnel and training requirements. Although reduced cost and enhanced capability are of importance, the greatest advantages to the Navy will accrue from improved reliability and easier maintainability.

The development of improved packaging and interconnection concepts are recommended. These should:

1) Permit the interconnecting of a number of circuits in an array on a single silicon chip in a single package.

2) Reduce the number of interconnections external to the package.

3) Ease the maintainability requirements (particularly with respect to personnel and training) by techniques such as functional grouping of logical circuitry in a package to aid fault location and diagnostic programming.

Proper consideration should be given to questions such as the trade-off between the cost and the failure rate of throw-away packages and the trade-off between package size and spares requirements. Improved concepts of machine organization (e.g. repetitive arrays or cellular logic) to permit functional groupings of components (and/or repetitively used logical functions) to aid in fault isolation through diagnostic programming techniques should be developed.

Section 6
MEMORY TECHNOLOGY

6.1 INTRODUCTION

Some types of memories, such as registers, main high-speed internal storage, and on-line auxiliary storage, will be required in any future Advanced Command Data System. Whether other types of "special memories", such as read-only or associative memories, are used, is a decision that will have to be made during the design of the system. The specific selection of individual types of memories to be used in the system will depend upon the eventual machine organization and systems design as well as upon the state of the art of memory devices at that time. During this study, all categories of memories that may be applicable to the design of a future Advanced Command Data System have been considered, but emphasis has been placed upon the major categories that are certain to be required.

The feasibility of batch fabrication is a major criteria in evaluating and selecting memory technologies for a 1970 system. The components and packaging section of this report discussed the impact that integrated circuits will have on the logical elements of future computers. Integrated circuits will also play an important role in the electronics associated with the memory array--the addressing, selection, driving and sensing circuitry. However, batch fabrication of the storage elements themselves will be an equally important factor. Magnetic cores will continue to dominate the internal storage areas for the next few years; but, by 1970, they will be giving way to storage elements, such as thin films or plated wires, that can be fabricated in batches rather than as discrete elements. Batch fabrication of logical and memory circuitry and of arrays of storage elements will be the key factor making possible more capable and sophisticated computers with greater reliability, lower cost, and smaller size, weight, and power requirements.

In the remainder of this section, the classification and functional uses of memory devices and requirements for different types of memories in future naval tactical systems are discussed. The characteristics of different types of memories applicable to each of the major categories are compared and related to Navy requirements. Technical descriptions of the major types of memories anticipated for 1970 are given, conclusions are drawn, and recommendations for memory development projects are made.

6.2 CLASSIFICATION AND FUNCTIONAL USES OF MEMORY DEVICES

Memories can be classified in four major categories based upon the techniques of mechanization and their use in the system:

1) Registers, high-speed control, and scratch-pad memories
2) Main-high-speed internal memories
3) On-line auxiliary storage
4) Off-line auxiliary storage

Each of these categories requires different combinations of speed, capacity, cost, and other characteristics. Although a specific memory technology may overlap two or more categories, the relative importance of different characteristics and, to some extent, the design approaches and criteria vary from one category to another.

In addition to these four major categories, certain types of memories can be classed in a fifth category -- "special memories". This category would include:

1) Read-only memories
2) Read-mostly memories
3) Associative memories
4) Analog memories

These types of special memories are not compared in the same detail as those in the four major categories, but discussions are presented indicating their functions and ranges of anticipated characteristics. Some of these special memories may be mechanized with completely different techniques than those in the other categories (e.g. photographic read only memory); others may be mechanized with essentially the same basic techniques but with additional control and logical functions or, in some cases, with certain hardware omitted (e.g. thin-film read only memory).

Buffer storage could be considered another category since the capacities for this type of storage are in the same order as those for registers and high-speed control memories while the speeds are usually in the same order as those for main high-speed internal memories. However, there is not sufficient difference in the characteristics and mechanization to justify considering buffers as a separate category since they are very commonly mechanized by the same techniques as main high-speed internal memories but with significantly smaller capacities.

In analyzing memory characteristics for a future system, it is necessary to consider the functional uses of memory devices and techniques. The following functional uses for memory elements may exist in a future ACDS.

In Central Processors:

1) Discrete single bit storage for logical functions
2) Individual one word or partial word registers for mechanizing control registers, index registers, and arithmetic registers
3) Fast multiple-word addressable storage of limited capacity for control memory and scratch-pad purposes
4) Read-mostly storage for micro-programmed systems
5) Large-capacity high-speed internal data storage
6) Large-capacity high-speed internal program storage
7) Buffers and speed-matching registers

Auxiliary Storage:

1) On-line semi-random-access auxiliary data storage
2) On-line semi-random-access auxiliary program storage
3) Off-line auxiliary data storage
4) Off-line auxiliary program storage

In Peripheral and Auxiliary Equipment:

1) Discrete single bit storage for logical functions

2) Individual one word or partial word registers for mechanizing control registers, counters, synchronizers, etc

3) Multiple word addressable storage of limited capacity for control memory and buffering purposes

4) Read-mostly storage for programmed control of certain types of peripheral equipment

Peripheral and auxiliary equipment that will require some storage capabilities include input/output equipment, displays, and communications terminal equipment.

Registers and high-speed control memories are classed in the same category since they usually serve the same function in the system. However, the actual mechanization or memory technology involved may be quite different. For example, individual registers may be mechanized with integrated circuit flip-flops while high-speed control memories may be mechanized with magnetic-thin-films. In general, a high-speed control memory represents an optional way of mechanizing some of the functional registers in the machine. For example, if 16 one-word registers are required for a certain function, these can be mechanized as 16 specific address locations in a high-speed control memory rather than as discrete one-word registers, if simultaneous access is not required. There is sufficient overlap in the functional use to classify these in the same category even though the mechanization may be quite different.

The high-speed control memory and the high-speed internal memory are normally considered an integral part of the computer or central processor, while the on-line auxiliary storage, and the equipment for reading and writing the off-line auxiliary storage, may be considered external peripheral devices. However, the techniques used in mechanizing registers and high-speed memory in the central processor are also used for control and buffering functions in peripheral devices. This is illustrated by the use of magnetic core memories as a small capacity high-speed control memory, as a large capacity high-speed main internal memory, as a very large capacity slow-speed on-line auxiliary storage, or as a small capacity slow-speed buffer in a display unit or a communication terminal equipment. Although a magnetic core memory may be used in each of the above applications, the combination of characteristics designed into the core memory are quite different for each of these applications.

The auxiliary storage category represents very large capacity bulk storage that is addressed by the computer in large blocks rather than by individual words. It usually has an average access time several orders of magnitude slower than that of the high-speed internal memory. The on-line auxiliary storage is directly available to the computer under computer control without manual intervention. The off-line auxiliary storage normally requires a manual operation to place the storage medium on the read/write device (e.g. a magnetic tape unit) that is controllable by the computer. In this sense, a magnetic tape unit can be considered an on-line auxiliary storage if a particular reel of tape is written, left on the tape unit, and later read back by the computer. However, if a tape reel is written by the computer, taken off the tape unit, stored on the shelf, and later put back on a tape unit to be read into the computer again, it is considered off-line auxiliary storage.

Most off-line storage equipments such as magnetic tape units, punched paper tape equipment, and punched card equipment are commonly classed as input/output equipment since they act as input/output devices to the central processor. Unfortunately, this tends to obscure the fact that these devices are actually serving an off-line auxiliary storage function in the overall system rather than an input/output function. They should not be confused with "true input" and "true output" devices such as keyboards, printers, analog-to-digital converters, and digital-to-analog converters. In this report, these types of off-line storage devices are listed in their conventional category as input/output equipments and have been discussed in the Input/Output Section.

Some equipment, such as magnetic card memories and magnetic disc files with removable disc stacks, are on-line auxiliary storage devices with respect to the cards or discs actually on the device at a given time. However, they act as read/write and access mechanisms for off-line storage with respect to cartridges of magnetic cards or stacks of removable discs on a shelf if these have been written by the device previously and will be read by the device subsequently. In this report, these devices are discussed in the category of on-line auxiliary storage. Those that can act as read/write mechanisms for off-line storage are identified.

In selecting the proper storage elements or devices for a future ACDS, it will be necessary to determine the functional uses of storage and then consider the characteristics of individual storage devices that effect their applicability to the particular functions. The desirable combination of characteristics will vary from one functional use to another.

6.3 MEMORY TECHNOLOGY IN A 1970 ADVANCED COMMAND DATA SYSTEM

The major requirements for storage in 1970 naval tactical systems will be for registers and high-speed control (or scratch-pad) memories, buffers, main high-speed internal memories, on-line auxiliary storage, and off-line auxiliary storage. Whether any of the special types of memories, such as read-only memories or associative memories, are required will depend upon the eventual machine organization and system design. Functional uses of storage devices in a 1970 ACDS will include most of those listed in Sub-section 6.2, but some of those will be optional for the system designer.

Although the speeds and capacities may differ, essentially the same techniques will be used for mechanizing storage requirements in peripheral and auxiliary equipment as in the central processor. For example, control flip-flops or buffers used in a display console may be slower speed and smaller capacity but will probably use the same basic technology as those in the central processor.

Although a computer used in a 1970 era naval tactical system is expected to be faster and have a greater capability than present shipboard computers, no real requirement is seen for speeds and capacities that are significantly beyond today's state-of-the-art. Requirements for registers and high-speed control memories with capacities of a few hundred words or less and cycle times in the order of 100 nanoseconds are anticipated. Main high-speed internal memories with capacities between 64,000 and 256,000 words and cycle times between one-half microsecond and one microsecond will be required. Both are within the state-of-the-art today and these performance requirements can be readily achieved by a number of techniques in 1970. However, significant improvements are required in cost and reliability. These improvements will be realized through batch fabrication. Improvements in size, weight, and power consumption are also desirable and are anticipated.

The categories of storage in which significant improvements in performance are required over existing techniques are on-line auxiliary storage and off-line auxiliary storage. Present electromechanical approaches to these categories of memory are unsatisfactory from the standpoint of reliability, environmental specifications, size, weight, and power. Although the data transfer rate of these devices is probably satisfactory, significant improvements in access times are desirable. Non-mechanical, solid-state on-line auxiliary storage devices with capacities between 1,000,000 and 10,000,000 words and access times in the order of two to ten microseconds will greatly increase the performance of future naval tactical systems. These will be feasible and can be available for use in a 1970 system, but some support of development efforts and some cost premium will probably be required.

6.4 COMPARISON OF MEMORY TECHNOLOGIES

In evaluating and comparing different types of memories, a relatively large number of characteristics and parameters should be considered. However, the actual selection of a specific type of memory for use in a particular function in a 1970 Advanced Command Data System can usually be made on the basis of detailed comparisons of only a few of these since all of the devices under consideration should meet certain specifications (e.g. environmental) in common, if they are to be used on shipboard. The major parameters and characteristics of concern to Navy planners in selecting the proper storage devices for use in 1970 naval tactical systems are:

1) Type of storage
2) Storage capacity
3) Type of access
4) Access time
5) Read/write cycle time
6) Read/write rate
7) Volatile or non-volatile
8) Availability
9) Batch fabrication techniques
10) Feasibility
11) Relative cost

Any storage device for use in tactical systems must possess the following characteristics. Some of these characteristics can be eased by special packaging, system, or facility techniques:

1) Erasable and reuseable media;

2) High reliability;

3) Low susceptibility to electromagnetic interference;

4) No generation of electromagnetic interference;

5) Military environmental specifications for

   a) temperature,
   b) shock and vibration,
   c) humidity,
   d) easy maintainability, and
   e) simplified logistics requirements.

Additional factors that could influence a final choice between acceptable alternatives include:

1) Storage density;

2) Static or dynamic;

3) Nondestructive read-out;

4) Size and weight;

5) Susceptibility to nuclear radiation effects;

6) Minimum power requirements.

For certain types of memories and applications, other special characteriscs may require consideration, including:

1) Read-only or read-mostly capability;

2) Non-destructive read-out;

3) Associative or other special addressing features;

4) Special requirements, such as cooling or refrigeration.

The characteristics in the first group of parameters above have been compared in Tables 6-2, 6-3, and 6-4 for the storage techniques that are considered to be the major contenders for consideration for use in an ACDS. All of those compared meet the necessary requirements with respect to characteristics in the second set of parameters. Storage devices that do not meet all of these requirements (e.g. electromechanical mass memories with respect to reliability and maintainability) are not included in Tables 6-2, 6-3, and 6-4 since alternatives are expected to be available by 1970 that meet these requirements. If the final selection between the acceptable alternatives is not clear cut, it may be necessary to further compare some of the characteristics in the third category. However, with respect to these characteristics, there are no differences apparent at this time between the acceptable types of memories that are sufficiently significant to dictate the use of one type of storage over another shown in the three tables.

The following types of memories have been investigated during the study:

1) Integrated circuit memories;
2) Tunnel diode memories;
3) Planar magnetic thin-film memories;
4) Cylindrical magnetic thin-film (plated wire) memories;
5) The permalloy sheet toroid memory;
6) The laminated ferrite memory;
7) The flute memory;
8) Magnetic core memories;
9) Delay line memories;
10) The woven screen memory;
11) Continuous-sheet cryogenic memories;
12) Ferro-acoustic memories;
13) Magnetic surface storage (e.g. tapes, drums, discs, cards);
14) Associative memories;
15) Read-only memories.

Each of these memory techniques is discussed in the appendix. Some that are not considered of sufficient realizability for ACDS have not been inestigated in detail and are not described or discussed in depth. In a few cases, only a brief statement is given of the reasons that a particular device or technique is not considered suitable.

Table 6-1 shows the characteristics available in 1965 for storage devices that are typical of the major categories. This provides a basis for comparing present technology with that anticipated for 1970. The cost per bit shown in Table 6-1 includes memory electronics (e.g., read, write, selection, etc.). For a serial off-line storage, such as magnetic tape, access time is not a meaningful characteristic; and capacity and cost per bit depend upon the number of reels of tape stored off line. Hence, values for these three characteristics are not included in Table 6-1 for magnetic tape.

Table 6-2 compares 1970 estimates of the characteristics of registers and high-speed control memories; Table 6-3 the characteristics of main high-speed internal memories, and Table 6-4 the characteristics of all-electronic/magnetic on-line auxiliary storage devices. Table 6-5 compares the characteristics of available electromechanical on-line auxiliary storage devices. Off-line auxiliary storage techniques are not compared here since they have been considered elsewhere in the discussion of input/output technology. With the possible exception of removable disc-pack type disc files and removable card-cartridge type magnetic card files, off-line storage is provided primarily by computer input/output devices such as magnetic tape, punched paper tape and punched cards.

Although all-electronic/magnetic on-line auxiliary storage devices are anticipated by 1970, there is no strong indication that an all-electronic/magnetic off-line auxiliary storage device will be available by 1970. Electromechanical devices, such as magnetic tape units, punched paper tape equipment, and punched card equipment, will most likely still be used for input/output and, possibly, off-line storage applications.

All-electronic/magnetic storage devices are available for high-speed registers and control memories and main high-speed internal memories. Extensive work is underway on all-electronic/magnetic on-line storage devices such as those shown in Table 6-4. But with the possible exception of 10^7 to 10^8 bit magnetic core memories, none of these are available at this time.

Table 6-1. Characteristics Available in 1965 for Storage Devices Typical of Major Categories

Category	Primary Technologies	Type of Access	Cycle or Access Time	Read/ Write Rate	Capacity In Bits	Cost Per Bit
Discrete Bit Storage and Registers	Integrated Circuit Flip-Flops	Random	50 nanosec to 500 nanosec	2 mc to 20 mc	1 to 1,000	\$10 to \$50
High speed Control and Scratch Pad Memories	Magnetic Thin-Film	Random	140 nanosec to 500 nanosec	2 mc to 7 mc	2,500 to 200,000	\$0.50 to \$2.00
Main High-Speed Internal Memories	Magnetic Core	Random	1 microsec to 4 microsec	250 kc to 1 mc	10,000 to 2,000,000	5 cents to twenty-five cents
On-line Auxiliary Storage (Solid State)	Magnetic Core	Random	3 microsec to 12 microsec	83 kc to 333 kc	1×10^6 to 100×10^6	1.5 cents to 3.5 cents
On-line Auxiliary Storage (Electro-Mechanical)	Magnetic Disc & Card Files	Semi-Random	20 millisec to 250 millisec	50 kc to 400 kc	20×10^6 to $2{,}000 \times 10^6$	0.02 cents to 0.2 cents
Off-line Auxiliary Storage	Magnetic Tape	Serial	----	20 kc to 200 kc	----	----

Table 6-2. Estimate of Characteristics of Registers and High-Speed Control Memories in 1970

Type of Storage	Typical Capacity (Words)	Type Access	R/W Cycle Time	R/W Rate	Vola-tile	Possible Date of 1st Prod.	Batch Fab Tech	Feasi-bility Ranking	Est. Cost Ranking
Tunnel Diode	256	Random	10 ns	100 mc	Yes	1965	None	5	9
Integrated Ckt. FF Registers	25	Random	25 ns	40 mc	Yes	1966	Diffusion and Vacuum Deposition	4	8
Integrated Ckt. Arrays	256	Random	50 ns	20 mc	Yes	1968	Diffusion and Vacuum Deposition	9	7
MOS Arrays	512	Random	250 ns	4 mc	Yes	1967	Diffusion and Vacuum Deposition	8	4
Planar Thin-Film	512	Random	100 ns	10 mc	No	1965	Multi-Layer Vacuum Deposition	3	2
Cylindrical Thin-Film	512	Random	250 ns	4 mc	No	1965	Plating	2	1
Flute	512	Random	250 ns	4 mc	No	1966	Ferrite Molding	7	6
Laminated Ferrite	512	Random	100 ns	10 mc	No	1966	Silk Screening "Doctor-Blading" Lamination	6	5
Magnetic Core Matrix	512	Random	350 ns	3 mc	No	1966	None for the cores, but wiring may be printed	1	3

Table 6-3. Estimate of Characteristics of Main High-Speed Internal Memories in 1970

Type Storage	Typical Capacity (Words)	Type Access	Access Time	R/W Cycle Time	R/W Rate	Volatile	Possible Date of 1st Prod.	Batch Fab. Tech.	Feasibility Ranking	Est. Cost Ranking
Continuous-Sheet Cryogenic	2×10^6	Random	---	2.0 us	0.5 mc	No	1969	Multi-layer Vacuum Deposition	9	3
Permalloy-Sheet Toroid	0.2×10^6	Random	---	20.0 us	0.05 mc	No	1967	Silk-screening, Etching, Plating	8	4
Plated Wire	0.2×10^6	Random	---	1.0 us	1 mc	No	1967	Plating	4	1
Planar Thin-Film	0.1×10^6	Random	---	0.5 us	2 mc	No	1967	Vacuum Deposition	3	2
Woven-Screen	0.1×10^6	Random	---	2.0 us	0.5 mc	No	1967	Weaving, Plating	5	7
Laminated Ferrite	0.1×10^6	Random	---	2.0 us	0.5 mc	No	1968	Silk-screening, "Doctor-Blading", Laminating	7	5
Flute	0.1×10^6	Random	---	2.0 us	0.5 mc	No	1968	Ferrite Molding	6	6
Magnetic Core Matrix	0.1×10^6	Random	---	1.0 us	1 mc	No	1965	None for the cores, but wiring may be printed	1	8
Glass Delay Line	0.02×10^6	Serial/ Random	200 us	---	20 mc (Serial bit rate)	Yes	1965	Glass Plate or Rod	2	9

Table 6-4. Estimate of Characteristics of On-Line Auxiliary Storage Devices in 1970

Type of Storage	Typical Capacity (Words)	Type Access	Access Time	R/W Cycle Time	R/W Rate	Vola-tile	Possible Date of 1st Prod.	Batch Fab. Tech	Feasi-bility Ranking	Est. Cost Ranking
Continuous-Sheet Cryogenic	20×10^6	Random	--	5.0 us	0.2 mc	No	1970	Multi-Layer Vacuum Deposition	7	2
Woven-Screen	4×10^6	Random	--	10.0 us	0.1 mc	No	1968	Weaving, Plating	5	6
Permalloy-Sheet Toroids	4×10^6	Random	--	100.0 us	0.01 mc	No	1968	Silk-screening, Etching, Plating	4	4
Ferro-Acoustic	20×10^6	Serial/ Random	1 us (to block)	--	3 mc	No	1969	Plating, Acoustic Cylinder	6	1
Planar Thin-Film	2×10^6	Random	--	1 us	1 mc	No	1969	Multi-layer Vacuum Deposition	3	5
Plated Wire	4×10^6	Random	--	1 us	1 mc	No	1968	Plating	2	3
Magnetic Core	2×10^6	Random	--	3 us	0.33 mc	No	1965	None for the cores, but wiring may be printed	1	7

Table 6-5. Summary of Characteristics of Electromechanical Mass Memories Available in 1964

Type of Device	On-Line Capacity Per-Unit In Char.	Typical On-line Costs in Cents/Char.	Average Access Time In Millisec.	Data Transfer Rate In Ch/Sec.	Remarks
Large Fixed-Head Mag. Drums	0.2×10^6 to 5.0×10^6	2.0	15 mc	100,000 to 200,000	Limited Capacity for Special Applications
Moving-Head Magnetic Drums	4.0×10^6 to 130×10^6	0.2	100 ms	50,000 to 150,000	Large Physical Volume
Fixed-Head Magnetic Disc Files	10×10^6 to 40×10^6	0.5	20 ms	100,000 to 400,000	Offers Promise for Militarization
1 Dimension Moving-Head Mag. Disc.	10×10^6 to 250×10^6	0.2	100 ms	100,000 to 400,000	More Field Experience than other Devices in this Category
Magnetic Tape Loop (Removable Cartridge)	7×10^6	0.3 (on-line) 0.003 (off-line)	88 ms	86,000	New Device Not Yet Proven in Field Operation
Removable-Stack Disc Files	2.0×10^6 to 7.0×10^6	0.4 (on-line) 0.01 (off-line)	150 ms	160,000	Contract Has Been Awarded for Militarizing One Device of this Type
Magnetic Card File	5.5×10^6 to 340×10^6	0.1 (on-line) 0.001 (off-line)	225 ms	100,000	Off-line Storage Capability, Contract Has Been Awarded for Militarizing One Device of This Type

The comparisons given in Tables 6-1, 6-2, 6-3, 6-4, and 6-5 present characteristics that are typical of advanced usage of the specific memory technology, but they do not represent the extremes in either direction. The following explanations and comments should be kept in mind when considering the comparisons in these tables:

1) Typical Capacity - This assumes a word size in the order of 40 to 60 bits. In most cases, the typical capacity is determined more by the requirements of the systems' designers than by limits of the technology. For example, in comparing main high-speed internal memories, capacities of 100,000 words are shown for most of the storage types. Capacities of 200,000 words are shown for the permalloy-sheet and plated-wire memories since larger capacities may be somewhat easier to achieve with these technologies (not because the other technologies are incapable of providing that capacity). A capacity of 2,000,000 words is used for the continuous-sheet cryogenic memory to indicate that this technology is suitable primarily to larger capacity memories and is not economic for smaller memories.

2) Access Time - This is shown only for those devices which have a serial or semi-serial type access.

3) Read/Write Cycle Time and Read/Write Rate - The numbers shown in these columns represent the rates at which the devices are expected to operate in the particular category and type application. Frequently, faster rates will be possible for smaller capacities or higher costs.

4) Possible Date of First Production - This column requires careful interpretation. Based on the state of research and development in the individual technologies, it is believed that memories with the characteristics indicated could be put into production by the dates shown, if sufficient incentive exists for doing so. However, in a number of cases, these dates will not be met simply because a single company is working on the specific technology and that company does not choose to make a sufficient effort and expenditure to meet dates that are technically possible. The availability

of government support is also an important factor in determining whether these possible dates are met. Some of the dates, of course, may not be met because of technical problems that prove to be more difficult than now anticipated.

5) Feasibility Ranking and Estimated Cost Ranking - These two columns also require some interpretation. Since the differences in several technologies may be very slight, one rated 7 may in fact be quite close to one rated 3. These rankings represent the judgment of the investigator, based on information from technical articles, technical conferences, and discussions with those working on the specific technologies. Some of the technologies are ranked lower than would be indicated by the claims of their proponents where these claims are believed to be over optimistic. These rankings may vary for a particular technology in different categories. For example, the relative cost of thin film memories is more favorable in the high-speed control memory category than in the on-line auxiliary storage category. Any estimate of feasibility and cost in 1970 of technologies that are in the research stage today, is very risky, but these rankings give an approximation of the relative feasibility and cost.

Once memory technologies have been isolated that meet the performance and operational requirements of the application, reliability and cost ultimately become the deciding factors. These are both improved significantly by batch fabrication as is emphasized in several places in this report. When technical and manufacturing feasibility is proved, batch fabricated devices will prove superior with respect to cost and reliability to those fabricated from discrete components. The cost is primarily a function of three things:

1) The number and type of processing steps involved;

2) The number of bits of storage fabricated in a single set of processing steps;

3) The yield.

The latter is extremely important since there are several memory batch fabrication technologies that are feasible today but whose yield is too low to permit them to compete economically. To a large extent, the yield depends upon understanding the chemical and physical processes involved and developing techniques for adequately controlling the processing steps.

In memory technology, two types of batch fabrication must be considered:

1) Batch fabrication of the storage array, and

2) Batch fabrication of the reading, writing, and addressing electronics.

Most of the technical discussions in this section have dealt with array fabrication since that is peculiar to memories in most cases. The reading, writing, and addressing electronics will benefit from the rapid progress in integrated circuit technologies. To a certain extent, these techniques are similar for many of the memory technologies. Integrated sense amplifiers are already available, write drivers will be available within 12 to 18 months, and selection matrix segments are being developed.

For small memories, the electronics costs predominate, and for large memories, the storage array costs predominate. Hence, registers and high-speed control memories will benefit most from integrated circuit advances, while large capacity on-line auxiliary storage will benefit most from batch-fabricated array developments. For main high-speed internal memories, the two are more evenly balanced, and improvements in both are required if costs are to be reduced significantly.

Although established technologies, such as magnetic core memories, have a decided advantage in the short run, they will ultimately yield to batch fabrication technologies.

During the time from 1970 to 1980, continual improvements will be made in the characteristics of most of these memory types. Other types of memories not feasible for a 1970 system will probably be developed to a point that they can be included in an operational system by 1975 or 1980. There will undoubtedly be some radically new memory techniques developed during the 1970-80 period, but a large part of the improvement in memory characteristics and capabilities during that time period will result from continued improvements of memories now in use or under development.

This is particularly true with respect to improved batch-fabrication techniques. Although there is a possibility that some exotic new memory techniques, such as a high-speed random access read/write memory based on the use of lasers, will be developed during that time period, it is certain that new methods of fabricating magnetic memories will be developed that may have significant and dramatic effects on the cost, speed and capacity.

It is difficult to place ultimate limits on the cost, speed, and capacity of different memory types since the violation of basic physical laws has not been the limiting factor to date and probably will not be for the foreseeable future. The comparisons given in Tables 6-2, 6-3, and 6-4 indicate the characteristics anticipated for a 1970 system but these are not ultimate limitations in most cases. It is important to note that in considering the limitations, the set of characteristics must be taken as a whole. For example, for a particular type of memory, a certain combination of speed and cost may be anticipated for a 1970 system. However, if the capacity were decreased significantly, the speed could be increased; and if the speed were decreased, the capacity could be increased. Therefore, the characteristics shown in these tables should not be considered as limitations on any individual characteristic, but rather as a reasonable expectation for combinations of characteristics for 1970.

A number of memory experts have given consideration to ultimate limitations of memory technologies. One of these is Dr. J. A. Rajchman of RCA Laboratories who prepared the diagram shown in Figure 6-1. This diagram shows Dr. Rajchman's estimate of the limitations in terms of speed vs. capacity for different memory technologies. The difficulty of placing such limitations on a rapidly developing technology is indicated by the fact that the diagram shown in the figure is the latest of a number of similar diagrams prepared by Dr. Rajchman over the past two or three years, each being updated to reflect changes in the technology since the previous one.

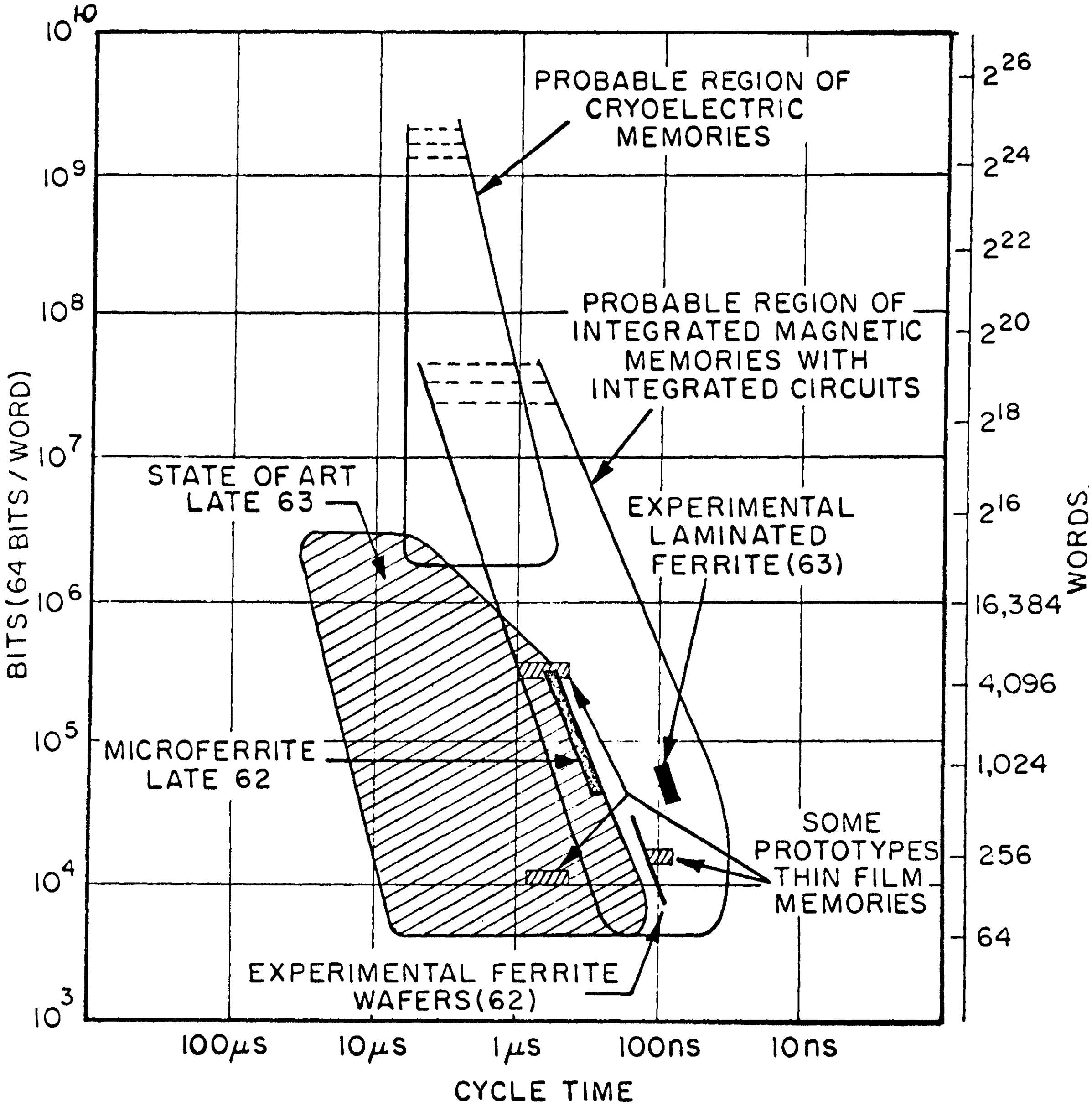


Figure 6-1. Storage Capacity and Cycle Time of Memories (After Rajchman)

6.5 ANTICIPATED CAPABILITIES VS NAVY REQUIREMENTS

The capabilities of the more promising memory technologies compared in Section 6.4 must be considered in terms of their ability to meet the Navy requirements discussed in Section 6.3.

The detailed characteristics required for memories in 1970 ACDS will depend upon the eventual system design. However, since it is certain that some types of registers and high-speed control memories, main high-speed internal memories, on-line auxiliary storage, and off-line auxiliary storage will all be required in future naval tactical systems, the applicability of different memory technologies to these application areas can be determined. The results of further studies of machine organization and the system implementation will indicate whether requirements exist for any special memories.

All of the more important and more feasible types of memories that might be applicable to either naval or Marine tactical systems in the 1970 era have been analyzed, evaluated, and compared. Memories meeting only commercial specifications and those for aerospace requirements have not been considered, but the memory technologies discussed cover the full range of requirements for shipboard and ground-based military environments. These same technologies are applicable for use in airborne systems also, but characteristics such as size, weight, and power are of greater importance. For airborne applications the more stringent requirements placed on these three characteristics may lead the system planner to select different memory technologies than those chosen for shipboard or ground environments.

Types of memories required for particular functions in a computer, or in other parts of a naval tactical system, can be selected based on the characteristics given in Tables 6-2, 6-3, and 6-4. Applications of memories in tactical data systems will include status registers; high-speed control memories; high-speed internal memories for program and data storage; on-line and off-line auxiliary memories for storage of multiple alternate programs; large data files and historical records; and control registers and buffers for input/output equipment, communication terminal equipments, and display equipment.

The particular categories in which different types of memories may be useful in 1970 naval tactical systems applications are summarized in Table 6-6. This table also shows a rating for each type of memory on the following basis:

1) Devices that will be feasible and that are recommended for serious consideration for use in 1970 naval tactical systems.

2) Devices that are being developed by only one manufacturer, but that will be feasible if sufficient emphasis is placed on them. Devices in this category are recommended for consideration for 1970 naval tactical systems if available.

3) Devices that will be feasible by 1970, but that are not recommended for use in naval tactical systems.

4) Devices that may be considered for use in naval tactical systems in the interim period but that will be obsoleted (for tactical use) by newer technologies by 1970.

The summary in Table 6-6 is based on data from Tables 6-2, 6-3, 6-4, and 6-5, and on the technical discussions in section 6-6 of this report. On the basis of the summary in Table 6-5, primary consideration should be given to the following technologies in selecting memory devices for a 1970 ACDS:

1) For registers and high-speed control memories:
   - Integrated circuit flip-flop registers;
   - Integrated circuit arrays;
   - Metal-oxide-semiconductor arrays;
   - Planar thin-films;
   - Cylindrical thin-films (plated wires);
   - Magnetic cores.

2) Main high-speed internal memories:
   - Planar thin-films;
   - Cylindrical thin-films (plated wires);
   - Magnetic cores.

3) On-line auxiliary storage:
   - Planar thin-films;
   - Cylindrical thin-films (plated wires);
   - Magnetic cores.

Table 6-6. Memory Systems

Type of Storage	High-Speed Registers & Cont. Mems.	Main H-S Internal Memories	On-Line Auxiliary Storage	Off-Line Auxiliary Storage	Rating
Tunnel Diode	X				3
Integrated Circuit FF Registers	X				1
Integrated Circuit Array	X				1
MOS Array	X				1
Planar Thin-Film	X	X	X		1
Cylindrical Thin-Film (Plated Wire)	X	X	X		1
Flute	X	X			2
Laminated Ferrite	X	X			2
Magnetic Core	X	X	X		1
Cryogenic		X	X		5
Woven Screen		X	X		2
Permalloy-Sheet Toroids		X	X		2
Ferro-Acoustic			X		5
Glass Delay Line		X			3
Magnetic Drum File			X		4
Magnetic Disc File			X	X	4
Magnetic Card File			X	X	4
Magnetic Tape Loop File			X	X	4

NOTE: Numbers in rating column have the following meaning:

1) Recommended for consideration for 1970 Advanced Command Data Systems.

2) Backed by only one copy at present, but recommended if proved feasible.

3) Feasible but not recommended for 1970 ACDS.

4) Will be obsoleted by other technologies for naval tactical systems type applications by 1970.

5) Feasibility by 1970 questionable, but should be considered if proved feasible.

6) Devices whose feasibility by 1970 is questionable at this time, but which should be considered for use in naval tactical systems if proved feasible.

Consideration should also be given to the use of the flute memory, the laminated ferrite memory, the woven-screen memory, the permalloy-sheet-toroid memory, cryogenic memories, and ferro-acoustic memories if subsequent developments indicate that they will in fact be feasible and available. However, techniques and approaches being developed by a single company are quite risky. Technologies, such as integrated circuit flip-flops, planar thin-films, cylindrical thin-films, and magnetic cores, on which a number of different companies are working, have a much higher probability of feasibility, performance, and low cost.

All of the memory technologies compared in Tables 6-2, 6-3, and 6-4 are capable of meeting environmental specifications for naval tactical equipment and all offer high reliability by today's standards. It can not be determined at this time whether any of them will eventually prove significantly more reliable than the others, but it is believed that all of them have essentially equivalent reliability potential. When the newer technologies are developed to the point of actual packaging, relative size, weight, and power requirements may lead to the final choice between different technologies offering equivalent costs and performance.

The comparison of characteristics in Tables 6-2, 6-3, and 6-4 indicate several technologies that will be able to meet the approximate requirements estimated previously for a 1970 era ACDS:

1) Registers and high-speed control memories with capacities of a few hundred words and cycle times in the order of 100 nanoseconds.

2) Main high-speed internal memories with capacities of 64,000 to 256,000 words and cycle times between 1/2 microsecond and 1 microsecond.

3) All-electronic/magnetic on-line auxiliary storage with capacities between 1,000,000 and 10,000,000 words and access times in the order of 2 to 10 microseconds.

The choices open to the systems planner may narrow if one or more of these technologies proves clearly superior to the others. If this occurs, development of the others may be slowed or dropped so that they will cease to be contenders that must be carefully evaluated.

6.6 CONCLUSIONS AND RECOMMENDATIONS

Memories in all categories (except off-line auxiliary storage) for use in a 1970 ACDS should and can be manufactured by various batch-fabrication techniques. Such techniques for fabricating large memory arrays as units rather than by the assembly of large numbers of discrete elements, are well along at this time and are receiving considerable attention from the industry. The memory function is particularly adaptable to batch-fabrication techniques since it consists of large numbers of similar elements or circuits and hence is highly repetitive. This is true on one extreme for small high-speed one word registers that might be fabricated as a single integrated circuit array, and on the other extreme for very large capacity on-line auxiliary memories such as a cryogenic memory, a thin-film memory, or a woven screen memory. It is certain that techniques of this type will be feasible, economic, highly developed and in wide-spread use by 1970.

However, it is not certain that large capacity on-line auxiliary memories of this type will be competitive with electromechanical memories (e.g. magnetic disc files and magnetic card memories) on a cost-per-bit basis by that time. It may be necessary either to use some electromechanical device for this mass memory function, or to recognize and accept a cost penalty for using an all-electronic/magnetic approach. This is particularly true for mass memories with capacities of 10^9 bits and above. Although these very large capacities can be achieved by using multiple banks of smaller memories, this will probably not be economically feasible. As a result, moving magnetic-media type electromechanical memories will likely be used if such capacities are required.

Associative memories will be feasible and available but their use will depend upon developments in machine organization and upon significant cost reductions. Relatively small capacity associative memories will probably be used in conjunction with the main high-speed random-access internal memory for functions such as indexing and perhaps some list processing. However, it is not likely that large capacity associative memories serving as the main internal memory will be economically justifiable or feasible by 1970.

Tables 6-2, 6-3 and 6-4 predict characteristics that are expected to be achievable by 1970. The most promising memory technologies for use in 1970 era naval tactical systems are:

1) For registers and high-speed control memories:

Integrated circuit flip-flop registers;

Integrated circuit arrays;

Metal-oxide-semiconductor arrays;

Planar thin-films;

Cylindrical thin-films (plated wires);

Magnetic cores.

2) For main high-speed internal memories:

Planar thin-films;

Cylindrical thin-films (plated wires);

Magnetic cores.

3) For on-line auxiliary storage:

Planar thin-films;

Cylindrical thin-films (plated wires);

Magnetic cores.

Magnetic cores will continue to dominate the internal storage areas for the next few years; but, by 1970, they will be giving way to storage elements, such as thin films or plated wires, that can be fabricated in batches rather than as discrete elements. Batch fabrication of logical and memory circuitry and of arrays of storage elements will be the key factor making possible more capable and sophisticated computers with greater reliability, lower cost, and smaller size, weight, and power requirements.

The categories of storage in which significant improvements in performance are required over existing techniques are on-line auxiliary storage and off-line auxiliary storage. Present electromechanical approaches to these categories of memory are unsatisfactory from the standpoint of reliability, environmental specifications, size, weight, and power. Although the data transfer rate of these devices is probably satisfactory, significant improvements in access times are desirable. Non-mechanical, solid-state on-line auxiliary storage devices with capacities between 1,000,000 and 10,000,000 words and access times in the order of 2 to 10 microseconds will greatly increase the performance of future naval tactical systems. These will be feasible and can be available for use in a 1970 system, but some support of development efforts and some cost premium will probably be required.

No support of development efforts is necessary to assure availability of internal memories meeting the needs of an ACDS in 1970 from a performance standpoint. However, development efforts will be required to assure there will be auxiliary memories capable of meeting the operational requirements for temperature, shock and vibration, electromagnetic interference requirements, humidity, size and weight, and reliability and maintainability. It is anticipated that the solid state electronic and magnetic memories will meet the requirements for reliability and maintainability, but if electromechanical memories such as magnetic drums, magnetic disc files, and magnetic card memories have not been completely replaced by all-electronic/magnetic memories by that time, additional development efforts will be required to further militarize these electromechanical devices. Some work in this direction is currently underway but additional work will be necessary to meet fully the requirements of 1970 naval tactical systems. This will be an interim effort since slectromechanical devices of this type will ultimately be replaced by all-electronic magnetic memories. However, at this time it is not safe to assume that this will be accomplished in all cases in time to satisfy all of the requirements of 1970 era systems. Hence, it will be necessary to improve further the environmental characteristics, reliability, and maintainability of present types of electromechanical memories (particularly disc files and magnetic card memories) for these systems.

By the same token, the most important area for Navy support of memory research and development efforts is that of all-electronic/magnetic (non-mechanical) on-line and off-line storage. Such developments must be supported if the systems potential offered by batch fabrication of the internal computer logic and memories is not to be nullified by auxiliary storage limitations.