Mid Project Report on the Study of

TECHNOLOGY APPLICATIONS FOR TACTICAL DATA SYSTEMS

15 October 1965

Prepared for

Advanced Warfare Systems Division
Naval Analysis Group
Office of Naval Research

under
Contract Nonr-4910(00)

by
Hobbs Associates, Inc.

TABLE OF CONTENTS

1. INTRODUCTION AND SUMMARY

This report presents the results at the mid point of a study of Technology Applications for Tactical Data Systems. The study is divided into two major phases. The first deals with the effect of new technologies on the maintainability of future tactical data systems and the ways in which maintainability considerations will influence the utilization of new technologies. The second covers the study and evaluation of new hardware technologies that will be used by systems planners in planning Navy and Marine tactical data systems for the 1970 to 1980 era. The study of hardware technology, which ~~includes~~ includes component and packaging techniques, memories, displays, and input/output equipment, is closely related to the MTACCS and ~~the~~ ANTACCS Phase I and Phase II studies by Informatics, Inc. Insert (1)

The over-all purpose of the study is to provide the necessary technical information and evaluations of new technologies to permit the systems planner to make proper decisions concerning the selection of hardware for implementing any necessary functions in 1970 to 1980 era systems. This study is intended to provide guidance for systems planners in both the selection of hardware to meet performance requirements and the proper utilization of new technologies to improve maintainability of future data systems operating in a tactical environment.

This report is preliminary in nature covering only the first half of the study. As a result, preliminary information, opinions, and conclusions are presented that may be altered by subsequent investigations and evaluations during the remainder of the study. This report is not intended to be complete in all areas. Greater detail is presented in some areas than in others depending upon the status of the work in particular areas and the information presented in previous reports.

The manner and extent to which technical information is presented is also influenced by the fact that part of this study is a follow-on to a previous study of hardware technology conducted last year in conjunction with Informatics as part of the ANTACCS study. The results of the investigations and evaluations of hardware technology last year are presented in great detail in Volume V of the ANTACCS Final Report. This is particularly true with respect to components and packaging techniques, memories, large screen displays, and conventional input/output equipment. Hence, in these areas this study has concentrated on the investigation and evaluation of newer research and development efforts and on monitoring, validating, and updating the status and expectations for the more important technologies that were covered in the ANTACCS Final Report.

Emphasis has been placed in the study this year on the relationship of new technologies and packaging techniques to maintainability and on new technologies for replacing conventional types of electromechanical input/output equipment. These topics are covered in greater detail in this Mid Project Report than are components, memories, and displays. In these latter three categories the material presented in this report primarily covers important conclusions, changes in a specific technology that have occurred since the end of 1964, and new technologies that were not adequately covered in the ANTACCS Final Report but which have subsequently shown greater importance or higher feasibility. The preliminary material presented in this Mid Project Report will be revised, updated, and expanded in the Final Report.

New electronic and magnetic technologies, particularly those based on batch-fabrication techniques, have advanced at a much faster rate than most of the industry had anticipated. Feasibility has already been proven for many new technologies and several of them have already been utilized in production equipment. However, the products available today employing these new technologies represent only the initial steps in a revolutionary change in electronic and magnetic equipments. For example, a single monolithic integrated circuit mounted in a flat pack, which represents a major advance over equivalent circuits fabricated from discrete components on a printed circuit board a year or two ago, will be replaced within the next few years by large interconnected multi-circuit arrays fabricated on a silicon chip. Each such chip may contain hundreds or thousands of interconnected circuits. Several multi-circuit arrays of this type can be interconnected by vacuum deposited wiring patterns on substrates and packaged as a single large unit. This will make it possible to fabricate and interconnect major portions of a computer in a single replaceable unit, but logic design and machine organization techniques must be developed to permit computers to be organized in large functional blocks to a much greater extent than at present. This will be necessary in order to minimize the interconnections between functional blocks and the number of leads that must be brought out from each functional unit.

The solid state electronic and magnetic portions of large digital systems are more amenable to batch fabrication and hence will benefit from new technologies to a much greater extent. This includes central processors, internal memories, solid-state on-line auxiliary memories, and the digital logic, control, and storage portions of displays and input/output equipment. The portions of displays, input/output equipments, and mass memories that will require high voltage, high power, photographic equipment, optical equipment, or electromechanical equipment will continue to present major problems with respect to cost, size, weight, maintainability, and reliability. Hence, a serious system imbalance will result unless solid-state electronic or magnetic replacements are developed for present types of displays (visual transducers), mass memories, and input/output equipments.

The impact of new technologies on Naval tactical systems by the early 1970's will be profound. Even if no performance or application requirements exist for the development of new systems, the significant improvements that new technologies will make possible in size, weight, reliability, and maintainability will justify the development of a new generation of tactical data systems.

The efficient utilization of batch-fabrication technologies will require a significant increase in the functional size and complexity of replaceable or throw-away units. Although the cost per component or per circuit will be only a fraction of present costs, the batch fabrication and interconnection of large arrays of circuits in a single package will probably cause an increase in the total cost of an individual package. If maximum advantage is to be taken of the capabilities of batch fabrication for small size, low cost, and high reliability, it will not be feasible to make repairs in a packaged unit on shipboard, and probably not at a state-side repair depot. Hence to realize the full potential of batch fabrication techniques will require increasing the functional size, complexity, and cost limits presently established for throw-away units. Any increase in the cost of the unit will be offset to a large extent by the increased reliability and hence lower failure rates.

Increasing the functional size and complexity of the throw-awy unit offers major advantages from the standpoint of maintainability. The training and skill levels required for maintenance technicians and the number of maintenance technicians required on shipboard will be reduced, supply and logistics problems will be reduced, fault isolation will be simplified, and down time will be minimized.

If the complete central processor is packaged in a total of 10 or 15 packages, maintenance will consist of locating the fault in one out of 10 or 15 units and replacing the unit. The fault location can be accomplished primarily by diagnostic programs. With significantly higher MTBF's, even this type of maintenance will be required very infrequently. It is reasonable to expect that some time during the 1970 to 1980 period a complete central processor will become a replaceable unit. A multi-computer system concept based on the use of identical small modular computers may facilitate this. In the 1975 to 1985 period such small modular computers may even become throw-away units.

To make these improvements in maintainability possible, changes in maintenance concepts and attitudes on the part of Navy systems planners, budgeters, and users will be necessary. A maintainability concept for future systems should be based on very large functional throw-away units and no shipboard repair except for any electro-mechanical equipment that may still be necessary.

By 1970 logical circuits are expected to be available in large inter-connected circuit arrays costing 3 to 5¢ per circuit and capable of providing speeds in the order of .5 to 10 nanoseconds propagation delays and 10 to 50 megacycle clock rates. Main internal memories are expected to be available costing between 1 to 3¢ per bit and providing read/write cycle times in the order of 0.5 to 2 microseconds with capacities in the order of 100,000 words. Large-screen dynamic displays that do not depend upon electromechanical, photographic, or optical projection systems will be feasible along with flat-panel console type displays that are completely compatible with batch-fabricated solid-state electronics.

New types of input/output equipment and solid state replacements for some conventional types of input/output equipment will be feasible, but input/output equipment and large capacity mass memories will represent the major problem areas in future tactical systems with respect to size, weight, cost, reliability, and maintainability. At present the best approach to overcoming these input/output problems seems to lie in developing system techniques that minimize the need for this type of equipment. Unless extensive additional research and development efforts are initiated in input/output equipment and large capacity mass memories, these devices will be the limiting factors in the capability and performance of future systems.

Major problem areas in 1970 to 1980 tactical data systems from the standpoint of hardware technology will be (in order of difficulty):

1. Input/output equipment
2. Very large capacity auxiliary storage
3. Large screen displays
4. Concepts and philosophies for maintenance of batch-fabricated equipment.

New hardware technologies discussed in this report will have a significant impact on future Naval tactical systems. This impact will be reflected not only in lower cost and increased performance capability, but also in reduced size and weight and increased reliability and maintainability. Reductions in the order of 25:1 in the size and weight of certain parts of the system, such as the central processor, are anticipated. For the over-all data handling and display portions of typical NTDS installations, new technologies feasible for use in 1970 will permit reductions of approximately 2/3 in the size, weight, and power requirements. Implications of these reductions, particularly for small ships, are clear. The accompanying reductions in system down time and maintenance personnel make it imperative that the Navy plan to take advantage of these new hardware technologies at the earliest possible time.

2. IMPACT OF NEW TECHNOLOGIES ON MAINTAINABILITY

2.1 GENERAL

One phase of this study deals with the effect of new technologies on tactical military systems and the ways in which these technologies can be utilized to improve maintainability. The term maintainability is used here in the broad sense to include all aspects of field maintenance - repair time and repair costs, parts usage, parts inventory, logistics, test equipment, replacement costs, personnel, training, etc. Training and maintenance personnel (salary, food, and other support costs on station, dependence allowances, etc.) represent the major maintenance costs. Hence, in the maintainability study, major emphasis has been placed on factors that reduce the time required for maintenance, the skill level required for the maintenance technician, and the number of maintenance technicians required.

New technologies providing solid state electronic and magnetic components fabricated and interconnected by batch fabrication techniques offer the potential for truly significant improvements in reliability and maintainability. Reliability and maintainability of electromechanical peripheral equipment, such as mass memories and input/output equipment, will improve but only in an evolutionary manner. The improvements that can be achieved economically in this type of equipment are limited. Hence, this study of maintainability has dealt primarily with improvements that can be obtained in those portions of the system that can utilize solid-state electronic and magnetic components.

From the maintainability standpoint, the major improvements that can be achieved in electromechanical peripheral equipment will be achieved by minimizing the need for this type of equipment and by finding solid-state electronic or magnetic replacements wherever possible. These questions are considered in greater detail in the memory, input/output, and display portions of the hardware technology part of this study.

It is in computers and central processors; digital logic, digital storage, and low level linear and video amplifiers in peripheral equipments; and solid-state on-line auxiliary storage that truly significant maintainability improvements can be achieved if new technologies that will be available by the early 1970's are properly utilized.

Maintainability considerations alone may justify the development of a new generation of tactical data systems. This study team believes the improved maintainability and reliability, coupled with reductions in size, weight, and power requirements which are discussed later, will necessitate the development of systems utilizing these new technologies even if performance requirements for new systems did not exist.

New concepts are needed to achieve the maximum improvement in maintainability commensurate with other system requirements such as performance, cost, size and weight, availability, etc. New attitudes and thought patterns are needed in considering equipment design and packaging, repair and inventory costs, and maintenance procedures and techniques.

Two specific examples of essential changes in attitudes and concepts illustrate this. One is the need for increasing the cost limit for throw-away units (presently in the order of $100) by a factor of several times (possibly over an order of magnitude). Another is the possible elimination of all shipboard repair for certain types of equipments. These changes in attitudes and concepts will be made possible by significant increases in reliability (i. e. reduced mean-time-between-failure) and significant reductions in the cost per element of the hardware involved.

A larger non-repairable unit is also required by the functional organization and interconnection and packaging techniques necessary to fully realize the reliability, cost, and size and weight potentials offered by new batch-fabrication technologies. Hence, some of the same changes in attitudes and concepts needed from the maintainability standpoint are also necessary to permit full realization of the advantages of batch fabrication.

Since cost, reliability, and maintainability considerations for batch fabricated units all favor a large functional throw-away unit, a difficult problem is raised with respect to flexibility. A particular large functional unit may be used in only one place in a computer. This creates a problem from both the manufacturing and spares standpoints.. If a throw-away unit is a single flipflop, as has been the case in the past, a large number of these can be manufactured and an individual one can be used in any one of a large number of places in the computer. However, if the throw-away unit is a complete parallel adder, only one may be used in the entire computer.

One possible approach that looks attractive is the use of a multi-computer system in which each individual computer is relatively small. This would permit a higher volume of production for each type of unit and would permit the possibility of carrying a spare computer to further facilitate easy and rapid maintenance. It may be desirable to design all types of shipboard systems, including data handling systems, weapons systems, and sensors, to utilize identical small computers with the number of these in each system being tailored to the requirements of the system. If the cost of logical components and storage drop as much as is anticipated, it may be relatively unimportant that one of these standard computers is less efficient in a particular system than a computer designed specifically for that system.

With the level of effort provided in this study, a maintainability investigation and analysis cannot be conducted in the depth of previous maintainability studies such as those of the Polaris program or other major Navy weapons programs, nor can this study delve as deeply into maintainability techniques, procedures, and data as the PACED program at NASL. Maintainability investigations of that magnitude require many tens, if not hundreds, of man years of effort. Fortunately, for the purposes of this study that level of effort and amount of detail are not necessary since a specific system and specific designs are not under consideration.

For a research study pointed toward the application of new technologies in 1970 to 1980 era tactical data systems, the important tasks are to determine relationships, guide lines, and criteria and to develop concepts for the utilization of these new technologies to achieve improvements in maintainability. The important results of this study will lie in the development of conceptual approaches to improved maintainability through the proper use of new technologies. It will call attention to and emphasize the need for new attitudes and thought patterns with respect to system design, packaging, and maintainability.

This study will develop criteria for determining the cost and functional size of throw-away units, will indicate the changes in maintainability concepts and attitudes necessary on the part of Navy personnel (systems planners, budgeters, and users), and will provide guidelines for Navy planners in utilizing new technologies to achieve improved maintainability.

2.2 STATUS TO DATE AND PLANS FOR REMAINDER OF STUDY

Batch-fabrication techniques suitable for the fabrication of central processors and storage are emphasized in the components and packaging and memory investigations in the hardware technology phase of this study. Since these fabrication techniques are essential to significant cost reductions and reliability improvements, they are also given major emphasis in this study of maintainability. In general, the higher the degree of batch fabrication, the lower the cost per function and the higher the reliability - hence, improved maintainability. Lower component costs will permit larger functional throw-away units which in turn will facilitate fault isolation and minimize repair time. Higher reliability will facilitate maintainability by reducing the number of failures and the number of repairs necessary and by permitting a further increase in the size of the throw-away unit.

Major consideration is being given to batch-fabrication techniques for:

- Logic circuits
- Low level amplifiers
- Memories
- Interconnections
- Packaging

Packaging techniques are directly related to the consideration of batch-fabrication techniques. Hence, detailed consideration is being given also to the criteria for selecting the size and configuration of throw-away units and the functional grouping within a throw-away unit. The effect of batch fabrication, reliability, redundancy, packaging techniques, and functional organization on the major elements of maintainability are being considered.

Present concepts, approaches, and problems in maintainability have been discussed with many Navy personnel. Attempts to obtain information on present maintenance costs have met with only partial success.

These investigations and analyses will be continued in the remainder of the study. Reliability will be considered from both the component and the system level. The effect of different levels of redundancy will be considered including:

No redundancy
Component level
Circuit level
Function level
Equipment level
System level

The relationships of packaging techniques and functional organization to diagnostic programming, fault isolation, and self test and the effects on tactical systems of improved maintainability that can result from new technologies will be considered. Changes in concepts and attitudes towards maintainability will be recommended where these are necessary to effectively utilize new technologies from the maintainability standpoint.

The effects of new technologies on maintainability are being investigated by discussions with technical experts working in these areas of technology and with ones working on maintainability problems, by a study of the applicable literature, and by evaluation of the information concerning the different technologies in relation to maintainability problems in future Naval tactical systems. This portion of the study is closely related to that dealing with new batch-fabrication technologies and is being closely coordinated with those investigations and evaluations.

2.3 TECHNICAL DISCUSSION

2.3.1 Elements of Maintainability

In considering the broad question of maintainability several different elements of the maintenance problem should be considered individually. These elements are not all affected in the same way by different approaches to maintainability or by changes in component or packaging technology. A technology change that may be advantageous with respect to one element of maintainability may be a disadvantage with respect to another.

The elements of maintainability include:

- Maintenance cost
  - Spares inventory costs
  - Logistics or supply costs
  - Replacement part costs
  - Repair costs
  - Personnel costs
- Reliability and failure rate
- Equipment down time
- System availability
- Fault location time
- Repair time
- Personnel training and skill levels
- Number of maintenance personnel
- Spares inventory quantity
- Personnel availability
- Spares availability
- Spares commonality
- Frequency of spare parts usage
- Test equipment requirements
- Diagnostic programming requirements

These elements are all inter-related and, unfortunately, sometimes affect one another adversely. For example, increasing the functional size of a throw-away unit may reduce fault isolation time, maintenance time, down time, and personnel training requirements; but it may, on the other hand, increase the spares inventory cost and reduce the commonality. Hence in considering the effects of new technologies on maintainability one must be careful not to achieve improvements in some of the elements in maintainability at the expense of excessive costs or severe disadvantages in other elements. This leads to the necessity for making a careful trade-off analysis when conflicting effects are created by a change in maintenance concepts or equipment technology.

Although the effects on different elements of maintainability have been considered at all phases of the study, they are discussed in this report only where a significant advantage or disadvantage exists. This is illustrated in subsequent parts of this section by the consideration given to the effects of batch fabrication and larger throw-away unit packages and the resulting trade-offs that must be evaluated.

2.3.2 New Technologies that will Influence Maintainability

In the technology sections of this report new technologies are analyzed and evaluated for components and packaging techniques, memories, displays, and input/output equipment. In the discussions of these different areas and individual technologies within each area, improvements in costs and reliability as well as performance are considered.

These new technologies will influence maintainability in two primary ways.

1. Increased reliability and reduced failure rates will reduce the maintenance effort required and will permit increases in the costs of throw-away units. If the failure rate becomes low enough it will reduce the number of technicians required and may eliminate requirements for stocking certain units as spares on shipboard.

2. Lower cost components and the lower costs of batch-fabricated interconnection techniques will permit a significant increase in the functional size of a throw-away unit. This will in turn facilitate fault isolation and reduce the training requirements and the number of maintenance personnel required. At the same time, efficient utilization of batch-fabrication techniques in interconnections and packaging will necessitate larger throw-away units. Hence the achievement of cost and performance potentials, as well as

maintainability improvements, depends upon significantly increasing the size of the throw-away unit. Fortunately, components and interconnection costs and improved reliability and reduced failure rates will permit such increases in the functional size of a throw-away unit.

The new technologies that will influence maintainability most significantly are those that are suitable for batch fabrication, that reduce the cost per component (or circuit) materially, and that significantly increase reliability. Such technologies that appear both promising and feasible include:

- Components and Packaging
  - Monolithic integrated circuits
  - Hybrid monolithic/thin-film integrated circuits
  - Metal-oxide-semiconductor (MOS) integrated circuits
- Memories
  - Integrated circuit arrays
  - MOS arrays
  - Planar magnetic thin-film arrays
  - Plated wire arrays
  - Permalloy sheet toroid arrays
- Displays
  - Opto-magnetic displays
  - Crossed-grid electroluminescent displays with integrated storage
  - Injection electroluminescence matrix displays

Although not adaptable to batch fabrication techniques, photochromic displays, thermoplastic and photoplastic light valves, laser displays, and solid-state light valves offer promise for maintainability improvements from the standpoint of both cost and reliability.

Some reliability improvements in electromechanical input/output equipment and mass memories are anticipated, but the major hope for significant improvements in maintainability for peripheral equipment lies in minimizing the need for equipment of this type and in finding replacements for some of the conventional types of equipments. The replacement of punched paper tapes by incremental magnetic tapes discussed in the input/output technology section will improve maintainability by increasing reliability. Solid-state mass memories discussed in the memory technology section will improve the maintainability and reliability of the system by serving as replacements for electromechanical mass memories and for some of the "input/output" functions performed by magnetic tape units in present systems.

The major improvements in maintainability will occur in the central processor, internal memory, and solid-state on-line auxiliary memories. However, the technologies and batch-fabrication techniques used in central processors and internal memories will also be applicable to portions of other equipment where similar functions are required and similar techniques are applicable. This includes the logic, control, and storage functions in display consoles and input/output equipments such as magnetic tape units. By 1970 low-level linear circuits, such as deflection amplifiers and video amplifiers in CRT displays, can be implemented with integrated circuit techniques. High power or high voltage circuits, such as the final stages of the deflection drivers in CRT displays, are more questionable but not completely hopeless within the time frame covered by this study. Communication equipments are not within the scope of this study, but power amplifiers in transmitters will probably represent a problem area.

In computer and data handling systems, the major areas where significant improvements in maintainability do not appear likely are in very large capacity auxiliary storage and input/output equipment. The best approach in these areas from the systems standpoint is to minimize the need for equipments of this type. There is also some question as to whether significant improvements in maintainability can be achieved in the viewing portions (i. e., the visual transducer) of displays - particularly large-screen displays. However, several potential display technologies, such as opto-magnetic panels and injection electroluminescence matrices, may permit significant improvements in maintainability for console displays, and possibly for large-screen displays.

2.3.3 Effect of Batch Fabrication on Packaging Concepts and Techniques

The importance of batch fabrication in future systems design has been emphasized in both the maintainability and technology portions of this study. Batch fabrication is the key to lower costs, higher reliability, and reduced size and weight. However, effective utilization of batch fabrication technologies will require major changes in packaging concepts and techniques.

2.3.3.1 Batch Fabrication and Interconnection Considerations

The packaging section of the ANTACCS Final Report discussed eight levels of packaging and interconnections in systems using integrated circuits:

1. Packaging and interconnection of the elements of each integrated circuit on a silicon chip.

2. Interconnection of separate circuits fabricated on the same silicon chip.

3. Interconnection between circuits on separate silicon chips that are packaged in the same module.

4. Interconnections between the silicon chips and the external leads of the package.

5. Interconnections between modules on a replaceable unit such as a printed circuit board.

6. Interconnections between replaceable packages in a modular subunit or a small equipment.

7. Interconnections between modular subunits in a unit of equipment.

8. Interconnections between separate pieces of equipment in a system.

The first and second level of interconnections are made in the initial processing of the silicon chip, although they may be made with separate masks and in separate vacuum deposition operations. To achieve the potential for improvements in both cost and reliability offered by batch fabrication, it will be necessary to continually strive to fabricate larger and larger arrays of interconnected circuits on the same silicon chip. Hence, emphasis will be placed on increasing interconnections at the second level and minimizing interconnections at higher levels - particularly at the fifth, sixth, and seventh levels which represent major elements of cost and lesser reliability. In fact, it is hoped that eventually a sufficiently large functional throw-away unit can be used that the fifth and seventh levels can be completely eliminated. In that case, the throw-away unit would consist of large arrays of integrated circuits on a limited number of silicon chips (first and second levels) that are interconnected by a wiring pattern on a substrate (third level) which also provides termination points for connecting to the external leads of the package (fourth level). Packages of this type would be either plugged or wired into the equipment containing the interconnections between the sockets or connectors (sixth level). These equipments would then be interconnected by cables to form the system (eighth level).

As semiconductor and batch fabrication techniques advance, the major limitation on the size of the functional unit (other than cost) will be the number of external leads that can be provided on a package. Although packages with larger numbers of leads (in the order of 40 to 100) are being developed, additional research in machine organization is urgently needed to develop functional organizational concepts that will maximize the interconnections within a replaceable package and minimize the interconnections between packages. The way in which the computer is divided into functional modules can greatly increase or decrease the number of connections needed between such modules.

It will be necessary to use different criteria for design efficiency in batch fabricated systems. In the past, minimizing the number of logical elements has been a major goal of most logical design efforts. In future systems, it may be necessary to utilize logical elements inefficiently in order to minimize the number of interconnections needed between functional modules. For example, frequently in previous computers a given gate or flip-flop has supplied inputs to a number of logical elements in different parts of the machine; while in future systems the logical gate or flip-flop may be duplicated many times in different parts of the system to avoid the necessity for transferring the signal from one module to another. Emphasis must be placed on reducing the number of packages and the number of interconnections between packages - even at the expense of increasing the logical complexity of each package significantly.

From the standpoint of cost and maintainability future systems should use large integrated circuit arrays (either monolithic or MOS) on single chips of silicon with these chips then interconnected by a vacuum deposited thin-film interconnect pattern on a substrate (e.g. the NAFI thin-film circuit techniques). Thin-film resistors and capacitors can be fabricated on the interconnection substrate where high precision or large values are needed. This unit would then become the replaceable or throw-away unit. The marriage of silicon integrated circuit techniques with thin-film fabrication techniques will combine the best advantages of both while maximizing the interconnections that can be made internally in the package. The importance of additional research efforts in computer design and machine organization to provide more highly functional organizations that will minimize interconnections between functional modules must be emphasized in order to take advantage of the potential offered by the combination of integrated circuit and thin-film connection technologies.

2.3.3.2 Factors Influencing the Determination of Throw-Away Unit Size

In establishing packaging trade-off criteria it is necessary to consider the effect on the initial cost of the system and on the major elements of maintainability. All of these factors except spares inventory cost, replacement part cost, and spares commonality favor a very large throw-away unit (large in the sense of complexity, not size) with shipboard and field repairs limited to the replacement of these large units. When replaced these units would usually be thrown away, but in certain special cases they might be returned to a state-side depot for repair.

The failure rate and the inventory cost of these large throw-away units will be sufficiently small, relative to present day failure rates and costs, to justify a quite large throw-away unit in preference to smaller ones. Although it is emotionally difficult to accept the idea of throwing away a $2000 subunit in which only one component has failed, this can be justified if such failures occur infrequently (e.g. less than once per year) and if the use of throw-away units of this size can eliminate the need for one or more technicians on shipboard.

In batch-fabrication technologies the selection of a throw-away unit size involves many inter-related factors, but in general the larger the throw-away unit size (in terms of complexity) the higher the reliability, the smaller the size, and the lower the cost of the function accomplished by the throw-away unit. Anything that is done in a large functional unit to make components, circuits, or subfunctions within the unit replaceable will tend to decrease the reliability, increase the size, and increase the over-all cost. Although there will undoubtedly be one or more intermediate steps before this is achieved, it is believed that a complete central processor with the capability of a USQ20B will likely become a replaceable unit without repair capability on shipboard, and possibly even a throw-away unit. However, it is too early to predict whether the cost and the mean-time-between-failure will be sufficiently low to permit discarding the unit or whether state-side repair will be required.

The need for a larger throw-away unit can be shown by listing some of the considerations that favor large throw-away units and some that favor small ones.

Considerations favoring large throw-away units:

1. With proper functional organization of the machine, large throw-away units minimize the number of interconnections required from package to package in the system. These interconnections (external to the package) are not as amenable to batch fabrication as those within the package and hence tend to be more expensive and less reliable. Since batch-fabricated interconnections can be more closely controlled and can be made very cheaply, a larger functional unit tends to improve reliability and reduce cost.

2. Making more of the interconnections within the package permits a smaller size and shorter lead lengths between circuits in a given logical function. This tends to permit higher speeds - particularly where a large multi-circuit array is fabricated in a single chip with interconnections deposited on the chip.

3. Although large throw-away units may increase the number of different types of spares carried in inventory, they will significantly reduce the total number of items carried in spares.

4. Since packaging costs are a significant part of the cost of completed circuits, the larger the number of circuits in a single package the lower the initial cost.. Continuing improvements in integrated circuitry technology will permit larger and larger arrays of circuits to be fabricated and interconnected in a single silicon chip. Interconnection of a number of these chips by printed or deposited wiring on a substrate will permit an even larger interconnected logical function in a single package.

5. Up to a certain point, the limit in putting more circuits in a package is imposed by the number of leads that can be brought out of the package. The ratio of external leads required to the number of circuits in the package is relatively high for smaller package sizes because of the connections that must be made to other packages. However, if the throw-away unit size is increased to the point that complete major logical functions can be contained in a single package, the total number of external connections in the system and the ratio of leads from the package to the number of circuits in the package are significantly reduced. For example, if a complete binary adder with associated registers is packaged in a single unit, the number of external leads required in relation to the number of circuits in the package would be quite small. A striking example of this is the use of several (e.g. 16 or 32) one word registers interconnected and addressed in a matrix fashion in a single unit compared to the packaging of individual one word registers with external interconnections to each.

6. The larger the throw-away unit the easier it is to isolate faults to a particular unit. For example, if the computer or central processor is a throw-away unit in the extreme case, it would be

relatively easy for a technician with minimum training to determine that the fault is in the computer with the aid of a simple diagnostic program. It is progressively more difficult for the maintenance technician to determine that the fault is in the arithmetic unit, in a particular register, in a particular flip-flop circuit, or in a particular diode or transistor on the other extreme. This is extremely important because it affects the training and skill level required of the technician, the repair time, the number of technicians required, and, perhaps even more important, the down time and availability of the system.

7. Easier fault isolation also reduces the length and complexity of the diagnostic programs required in the computer for automatic fault isolation. A diagnostic program to determine that the fault is in the arithmetic unit is considerable shorter than one required to indicate that the fault is in the third bit position of the adder.

8. Easier fault isolation and minimization of repairs made on shipboard as a result of large throw-away units tend to eliminate the need for special test equipment and check-out equipment. For example, if a throw-away unit is a printed circuit board containing a single flip-flop or a few gates, it is usually necessary to have a board tester capable of determining whether a replaced board is in fact malfunctioning. It should be noted also that this tends to encourage a sloppy form of maintenance which has unfortunate results on maintainability - the indiscriminate replacing of boards until one is found that starts the system working again. If a replaced board is to be repaired on shipboard, the test equipment must be even more complex.

Considerations favoring small throw-away units:

1. The smaller the size of the throw-away unit, the greater the commonality and the ability to utilize one spare unit to replace any one of a large number of units in the system. A printed circuit card containing a single flip-flop is a good example of a small unit with high commonality.

2. The higher commonality for small units also reduces the cost of spares inventory. This is certainly true if the cost per circuit is the same in a large functional unit as in a small one. However, it may not be true if a larger throw-away unit permits a significant reduction in the cost of a circuit (e. g. a flip-flop) compared to the cost of that same circuit as a single throw-away unit. If a complete computer using large throw-away units costs as much as an equivalent computer using small throw-away units, the cost of spares inventory required for the one using small units will be considerably less. On the other hand, since batch fabrication of large throw-away units should significantly reduce the total cost of the computer, the cost of the spares inventory may be less than for an equivalent system utilizing small throw-away units.

3. With manufacturing and fabrication techniques used to date, a small throw-away unit offers manufacturing economies - again due to commonality. A much larger production run of flip-flop boards can be made if the same flip-flop is used in a large number of places in each computer. On the other hand, if each replaceable or throw-away unit in a system is unique, the production volume of each unit would be limited to the number of computers. However, for some of the newer batch fabrication technologies being developed, this may not be a significant factor. This is illustrated by the possibility of making variable interconnect masks under computer control.

4. If replaceable units are to be repairable instead of throw-away, small units permit greater standardization. This facilitates the technicians ability to repair the units.

5. The lower cost of the small throw-away unit is a significant factor if the usage rate is high - i. e., if the reliability is low and the failure rate high. However, the low failure rates anticipated for batch-fabricated circuits minimize the importance of the cost of the unit in relation to other considerations.

6. A small throw-away unit gives greater flexibility in the organization and layout of the logic of the system. Additional research in machine organization for batch-fabricated systems is needed to overcome this disadvantage of large throw-away units.

Large non-repairable throw-away units(large in the sense of function or complexity rather than physical size and cost) containing complete major functional parts of the computer will improve reliability, simplify fault isolation, reduce down time, reduce the number of technicians required and their training and skill levels, permit higher speed operation, reduce logistics and repair costs, and improve the performance and availability of the system. On the negative side these larger units may increase the number of different types of spares required, the parts cost of replacing a failed unit, and perhaps the total inventory costs. The initial procurement cost of a system using a large throw-away unit will be less if adequate fabrication techniques (e. g., the fabrication of interconnection masks under computer control) for specialized units are developed.

2. 3. 4 Throw-Away Unit Cost and Maintenance Personnel Cost Trade-Offs in Future Systems

In a new procurement initiated recently, the next AN/USQ-20B computers purchased will cost approximately $125,000 per computer. By the early 1970s integrated circuit and other batch fabrication technologies will reduce the cost of computers with equivalent capability to $25,000 or less. This cost reduction will be accompanied by a significant reduction in size and increase in reliability. However, these improvements in cost, size, and reliability cannot be fully realized without changing maintainability concepts and attitudes to permit much larger functional throw-away units. For example, the $25,000 central processor predicted above might be packaged in 10 to 15 non-repairable units each costing between $1500 and $3000. The reliability of electronics is expected to improve by two orders of magnitude with the rapid development of integrated circuit technologies. Hence, this increase in the cost of the throw-away unit could probably be justified on the basis of reduced usage resulting from higher reliability. Logistics costs would be reduced also as a result of reducing the number of items handled through the logistics system. The higher cost of the larger throw-away unit can certainly be justified in terms of fewer technicians required on station and reductions in their required training and skill levels. The elimination of one technician alone would pay for the cost of the complete computer, and hence a complete set of spare units, in one year.

On an NTDS ship visited by the study team, it was estimated that 10 of the 33 technicians in the NTDS section were devoted to the maintenance of the computers, their internal memories, and the limited amount of input/output equipment in the system. It is reasonable to believe that reducing the repair task to that of locating and replacing one of ten or fifteen major units comprising the computer would eliminate at least one technician. In fact, assuming that half of these ten technicians are required by the peripheral equipment and half by the computers and internal memories, as many as four of the five technicians concerned with the computers and memories might be eliminated. With very significant reductions in failure rates and fault isolation time and with repairs reduced to merely replacing one of fifteen units, a single technician could easily maintain four computers including the central processors and internal memories.

The predictions and extrapolations from present technology made above may seem far out and perhaps unrealistic. However, based on the investigations and analyses of this study and lengthy discussions with integrated circuit, semiconductor, and batch-fabrication memory experts, these prognostications are believed to be conservative. In the early 1970's the three USQ20B computers and their internal memories, two magnetic tape units (four tape transports), punched paper tape reader, teletype printer and punch, and several large banks of mechanical interconnection switches in a typical NTDS installation can be replaced with three small batch fabricated computers and internal memories including internal electronic switching and gating, a large capacity solid-state random access mass memory, one magnetic tape unit (two tape transports), and a keyboard-printer unit with an associated incremental magnetic tape recorder. The keyboard printer unit may be a non-mechanical keyboard and non-impact printer with no moving parts except for paper feed. At the most, three maintenance technicians would be required for this complete computer system compared to approximately ten at present. The savings from elimination of seven technicians would exceed the cost of the computer system in two years.

From the maintenance standpoint, the NTDS system on the ship visited by the study team was divided into three major areas - the computer system, the display/input consoles, and the communications terminals. The discussion above has dealt exclusively with the computer system where the greatest gains in maintainability can be achieved through the use of new technologies. However, the same considerations and reasonings apply to portions of the display/input consoles and the communications terminals. For example, the analyses presented above are equally applicable to the digital control logic and storage in the display/input consoles. Hence, the proper utilization of new technologies will permit maintainability improvements in these other two areas also but to a lesser extent than in the computer system since major portions of the equipments in these areas are not as readily amenable to batch fabrication technologies in the near future.

It is important to point out that these discussions of improved maintainability are valid only if we assume the design of a new-generation system utilizing these new technologies. The fact that these capabilities and improvements will be possible in the early 1970's does not assure that they will be achieved. This depends on factors such as the willingness to obsolete and replace present equipment and the willingness of Navy systems planners, budgeters, and users to adopt the radically different attitudes toward maintenance procedures and costs called for by the maintainability concept advocated here. This maintainability concept is based on very large functional throw-away units and no shipboard repair, except for any electromechanical equipment that may still be necessary.

3. HARDWARE TECHNOLOGIES

3.1 CRITERIA FOR SELECTING TECHNOLOGIES TO BE INVESTIGATED

Potential uses and advantages in future Naval tactical systems are the major criteria used in selecting technologies to be investigated in this study. Investigation is not considered justified merely because a technology is interesting or different. It must fill some need or offer some potential advantage to Navy systems planners for future tactical data systems.

The needs of the systems planner are influenced by both system requirements and systems design. The systems requirements determine functions that must be implemented, and the systems design determines the way in which these functions are implemented. Both affect the usefulness of a particular technology. Conversely, the characteristics of one type of technology compared to those of another type can influence the way in which the function is implemented. In fact, the availability of a new technology at a low cost and high reliability can make it feasible to implement functions that were not previously justifiable on a cost-effectiveness basis, thus changing the analysis of systems requirements.

After a requirements analysis and systems design based on those requirements have been completed, it is relatively easy to limit the scope of an investigation of technologies for implementing the system. However, since requirements analysis and preliminary systems design for future Navy and Marine Corps tactical systems are still underway, a good deal of judgement is necessary in determining which technologies are to be investigated. It is better to investigate a technology that may not be used than to overlook one that might offer significant advantages to planners of future systems, but it is necessary to limit the number of technologies to be considered in order to concentrate on those that offer the greatest potential for future tactical data systems. In order to accomplish this, four specific criteria have been applied in selecting technologies for investigation:

1. Is the technology useful for implementing functions existing in the present Naval Tactical Data System or Marine Tactical Data System?

2. Is there some known Navy or Marine Corps operational task for which the technology offers potential advantages, even though the task may not presently be mechanized or may be implemented in a completely different manner?

3. Does the technology represent a sufficiently significant advance in the state-of-the art that systems planners will find a worthwhile use for the technology even though no requirement is known at present?

4. Does the technology offer important potential advantages over existing alternative technologies without suffering from any decided or overriding disadvantages within the context of a tactical operating environment?

<u>Is the technology useful for implementing functions existing in the present NTDS or MTDS?</u>

Since the present operational systems have been designed on the basis of earlier analyses of requirements for tactical data systems, future systems will probably require the same types of hardware functions, although alternative technologies may be used where they offer advantages. For example, console displays are an integral part of the present NTDS system; hence, it is very likely that technologies for implementing console displays will be required in future tactical data systems. This type of justification also implies the need for most types of components and devices used in conventional computer systems. For example, implementing a computer or data processing system in accordance with known and foreseeable computer design concepts requires logical circuitry and internal storage.

The four major categories of technologies to be investigated - components and packaging techniques, memories, displays, and input/output - were selected on this basis. This has also served as the first criteria in selecting specific technologies to be investigated in each of these categories including:

- Components and packaging techniques
  - Logical circuits for implementing logic in the central processor and in peripheral equipment
  - Linear circuits (e.g memory sense amplifiers)
  - Interconnection techniques
  - Packaging techniques
- Memories
  - Registers and high-speed control memories
  - Main internal memories
  - On-line auxiliary storage
  - Off-line auxiliary storage
- Displays
  - Console displays
- Input/output equipment
  - High speed block serial input
  - Low speed incremental serial input
  - Keyboard input
  - Character printers

Insert

<u>Is there some known Navy or Marine Corps operational task for which the new technology offers potential advantages?</u>

Some technologies not used in the present NTDS or MTDS may offer advantages in implementing specific functions in future tactical systems. If functions or tasks in Navy and Marine Corps tactical systems can be identified for which a technology offers potential advantages, this is considered sufficient justification for investigation of that technology. Systems planners may or may not decide to use the technology in a future tactical data system, but the technology must be evaluated in order to provide technical information the system planner will need in order to make that decision.

For example, associative memories that permit addressing stored information by content rather than by physical location offer some advantages in track while scan and threat evaluation and weapon assignment operations. A system planner must have information about associative memories in order to decide whether those advantages justify the cost of an associative memory in contrast to alternate approaches such as programming a memory search in a conventional high-speed random access memory.

Hence, if a use for a technology can be identified in which it offers potential advantages to a systems planner, that technology will be investigated in this study.

The systems planner will then have the necessary information to properly evaluate the use of alternate approaches in the design of a future system. Examples of such technologies and brief reasons for including them in the investigations in this study are:

Associative memories - potentially useful in several functional tasks including track while scan and threat evaluation and weapon assignment.

Read only memories - potentially useful for microprogrammed (stored logic) machine organizations, fixed program storage, and storage of data that is changed relatively infrequently (e.g. screen patterns in multi-ship ASW operations).

Large screen displays - potentially useful for Flag presentations and CIC plots.

Character recognition equipment - potentially useful for reading data initially entering the system in printed form.

Voice recognition and voice output equipment - potentially useful for direct communication with the computer without the need for manual operations such as keypunching.

Graphic input equipment - potentially useful for directly entering graphical information such as flight paths and formation and maneuver patterns.

The selection of technologies in this category assumes that the role of future tactical systems will expand beyond that of anti-air operations (the major function of the present NTDS and MTDS systems) and envisions the possibility of closer integration of tactical data systems with weapons systems and sensor systems in the future and the inclusion of functions such as intelligence data processing. Only by understanding the full range of technologies available can a systems planner adequately determine the capabilities that can be implemented in a future tactical system and the alternative methods of accomplishing this.

Does the technology represent a significant advance in the state-of-the-art that will cause it to be used for functions not presently anticipated?

Some new technologies may be developed that advance the state of the computer art in a major way. If this occurs, it is very likely that designers of future systems will see ways of utilizing the new technology to achieve results that are not possible with present kinds of equipment. If such technologies appear, they should be investigated whether a specific requirement can be foreseen or not. However, none of the technologies investigated so far fall in this category.

Does the technology offer important potential advantages over existing alternative technologies without suffering from any decided or overriding disadvantages within the context of a tactical operating environment?

This criteria is superimposed on the first three. Regardless of whether a use exists or is anticipated for a new technology, there is no point in considering it unless there is reason to believe that it may be better than existing well established technologies. For example, evaluating a new storage technology would be a waste of time unless it has some potential advantages over magnetic core memories.

Many technologies have been eliminated from consideration in this study because they did not offer sufficient advantages over better established approaches. Hence, a good deal of judgement has been exercised in limiting the study to those technologies that are useful, applicable to tactical environments, and worthwhile. No attempt has been made to evaluate in detail every different technique or approach.

3.2 COMPONENTS AND PACKAGING

3.2.1 General

For the past five to seven years discrete component semiconductor circuits have dominated the computer data processing field as logic components. A number of alternatives to transistor and diode electronic circuitry have been proposed but none of these have proven superior for the majority of applications. These alternatives include cryogenic logic, fluid logic, all magnetic logic, and optical logic. Cryogenic and optical logic are yet to be proven feasible. Fluid and magnetic logic offer some advantages in slow speed applications, such as the implementation of control functions in input/output equipment. However, semiconductor integrated circuits will be dominant for the foreseeable future - probably for the next ten to fifteen years at least.

Closely related to basic integrated circuit technology are the associated technologies for batch fabrication of interconnections. The two major techniques are vacuum deposition of metallic interconnect patterns through masks and printing of metallic interconnect patterns by processes similar to silk screening in the graphic arts. Batch fabrication is the key to low cost high reliability components and interconnections for both logical circuitry and internal memories. Major improvements in cost and reliability can be achieved by fabricating large arrays of circuits on a single silicon chip and interconnecting these on the chip. In order to minimize the number of interconnections brought from the chip it will be necessary to develop logical design and machine organization techniques that facilitate the organization of the machine into large functional units with a minimum number of interconnections required between these functional units. For example, either an adder or perhaps an entire arithmetic unit may be fabricated on a single large chip with external connections required only for input/output and control signals. Another approach is to fabricate the unit on several large chips which are then interconnected by wiring deposited on a substrate and packaged as a single unit. This is directly related to the subject of throw-away unit size and maintainability discussed in Section 2.

The remainder of this section will present the status and future plans for the components and packaging portion of this study and then briefly summarize technical developments of importance to future tactical data systems. Most of the component and packaging techniques applicable to future systems were discussed in detail in Volume V of the ANTACCS Final Report. A separate report on component and packaging technology is being prepared that will revise and update the material in Volume V of the ANTACCS Report which is about nine months old at this time. Since that report will discuss these technologies in depth, only changes in the technology or in the anticipated progress of the technology (since the material prepared for the ANTACCS Report) will be presented briefly in the technical discussion in this section. The Final Report will contain material from the special report mentioned above and will present in greater detail the latest developments in this area.

3.2.2 Status to Date and Plans for the Remainder of the Study

Particular attention is being given during this study to those component technologies for 1970 era systems that appeared most promising during the 1964 ANTACCS study including:

- Monolithic integrated circuits
- Hybrid monolithic/thin-film integrated circuits
- Active thin-film integrated circuits
- MOS integrated circuits

Consideration will also be given to other component technologies whose feasibility or applicability appeared questionable during 1964 if subsequent developments indicate that the status appears to be changing. This category will include:

- Optical logic
- All magnetic logic
- Fluid logic

However, no such changes have been detected to date.

The following levels of packaging and specific packaging techniques are being investigated:

- Multi-circuit chips
  - Cellular logic
  - Multi-function logic
  - Variable interconnections
  - Fixed interconnections
- Multi-chip substrates
- Mother board and back board techniques
  - Printed circuit boards
  - Multi-layer printed circuit boards
  - Multi-layer deposited (or printed) wiring
  - Connectors

Bonding techniques are also being investigated including:

- Flip-chips
- Welding
- Soldering

These technologies are being investigated by discussions with technical experts working in these fields, by studying the applicable literature, and by evaluating information concerning the different technologies in relation to the requirements that will be imposed by future Naval tactical systems. This portion of the study is closely related to the part of the study dealing with the effect of new technologies on maintainability. In the evaluation of new technologies, the effect on reliability and maintainability is given major weight. A separate interim report is being prepared that updates the material presented in Volume V of the ANTACCS Report concerning components and packaging technology. That interim report will be further updated at the end of the study for inclusion in the Final Report.

3.2.3 Technical Discussion

The investigations during the first half of this study have tended to confirm and support the evaluations, conclusions, and recommendations made during the ANTACCS study in 1964. The belief that future computers will utilize large arrays of interconnected logical circuits performing major logical functions has been greatly strengthened by discussions with semiconductor specialists and by published information. Although there was some controversy about this last year, the major questions now seem to be when this will be feasible (rather than if) and how large the arrays will be. Many technical experts were optimistically predicting these large interconnected arrays last year, but now even the managements of major semiconductor companies are publicly announcing that these will be available. For example, recently Dr. Robert N. Noyce, Group Vice President of Fairchild Camera and Instrument Corporation, addressing the San Diego Council of WEMA stated,

> "However, from a point on the complexity scale now where 50 components in the cheapest level for an integrated circuit, I expect to move to 1000 by 1970.... At the same time there will be new problems where it takes only 10 chips to make a computer and almost every circuit made will be different."

The major controversy now appears to be whether these large arrays will be fabricated primarily with monolithic silicon circuits (using bipolar transistors) or with metal-oxide-semiconductors (MOS). One interesting development since the investigation last year has been the rapid progress of MOS devices. Some in the semiconductor industry believe MOS technology will prove dominant where large arrays are required because of the somewhat simpler processing required. The smaller number of processing steps tends to make more feasible the high yield necessary for large arrays. However, in monolithic circuits is is necessary to control the thickness of the diffusion layer in the semiconductor, while in the MOS it is necessary to control the thickness of the oxide layer. Hence, the problem of process control is transferred from the body of the semiconductor to the surface. Many feel that surface effects will be a more difficult factor to control. Even if the large MOS arrays do prove easier to fabricate and hence cheaper, they will still suffer from one major disadvantage - speed. The MOS is a field-effect type device with more limited speed capability. Although progress in both technologies is expected, it appears likely that MOS devices will remain approximately one order of magnitude slower than monolithic integrated circuits. MOS devices may be utilized in applications where high speed is not required and in applications where very large standardized arrays can be used. Examples of the latter category are large integrated circuit storage arrays for main internal memory. Monolithic integrated circuit storage arrays will be faster, but slower speed MOS devices may be sufficiently cheaper to make their use in larger capacity memories more feasible.

At this time it is still believed that monolithic integrated circuits will be the dominant technology for logic circuits in the type of computers of interest for future tactical data systems. Hybrid monolithic/thin-film circuits will probably be used for linear amplifiers where high values or high tolerance resistors and capacitors are required. Examples of circuits of this type are memory sense amplifiers and video amplifiers in displays. The use of additional active elements in the monolithic circuit can permit compensation in some cases where high value or high tolerance resistors or capacitors would otherwise be required.

In considering large arrays, one is faced with two major problems:

The possible need for eliminating bad or substandard circuits from the array to achieve a reasonable yield.

The lack of flexibility resulting from large arrays which tends to make each array within a system unique.

There are three major approaches to the utilization of large interconnected arrays from the systems standpoint that are under consideration. The first is cellular logic in which large arrays of identical circuits are fabricated with a standard interconnection pattern (e. g. connecting each circuit only to its four adjacent neighbors) with the ability to modify the function of the circuit by changing something in the circuit subsequent to fabrication. For example, one approach of this type uses a circuit with four cut-points which can be cut in different combinations to alter the function of the circuit.

In the second approach, a large array of circuits is fabricated and each circuit is individually tested. The test results are put in a computer which is also storing logical equations of the function to be implemented. The computer then generates the proper interconnection pattern to interconnect available good elements (skipping the bad ones) to perform the required logical function. In this approach, a separate mask must be prepared for each array fabricated, hence, this is an expensive operation unless cheap methods can be developed for producing interconnection masks under computer control. Several such mask fabrication techniques are under development. On the other hand this approach offers a major advantage since it is easy to vary the function performed by the array by changing the logical equations supplied to the computer. If each interconnection mask for each array is generated individually, there is little incentive for rigidly standardized functions.

The third approach is advocated by those who believe that in the future it will be technically feasible to achieve high yields of large integrated circuit arrays in which all circuits are good. This would permit a standardized interconnect pattern to be used for each specific logical function. This has the advantage that only one mask need be made for a particular function. This mask can then be used to interconnect the circuits in many arrays of that type. On the other hand, it is more difficult to change the function to be performed by the interconnected circuit array since this requires making a different mask.

The implications of these approaches to maintainability are discussed in Section 2 of this report. The major types of integrated circuits presently under development with characteristics anticipated by 1970 and brief comments on the advantages or disadvantages of each are shown in Table 3.2-1.

The speeds shown in Table 3.2-1 for different types of circuits are chosen to be realistic, but many in the semiconductor industry will consider them overly conservative. Costs are expected to range between 3¢ and 5¢ per circuit in large interconnected circuit arrays. The cost will be somewhat higher for linear circuits requiring thin-film passive elements and somewhat lower for repetitive functions (e.g. storage arrays) using large MOS arrays. These figures are intended to indicate cost potentials that can be realized by semiconductor technology. However, these cost potentials can be achieved only by fabricating large arrays of interconnected circuits in a single package since packaging and interconnections are major factors in the cost of an integrated circuit. Hence, the ability to achieve these costs is dependent upon the computer industry's ability to develop logical design and machine organization techniques permitting and utilizing such large arrays. This raises many difficult and conflicting questions, such as packaging design, maintenance philosophy, flexibility, and functional logic segmentation. Some of these are discussed further in Section 2 of this report.

Technology	Performance Anticipated by 1970	Comments
Hybrid discrete/ thin-film circuits	1 to 10 ns propagation delay 5 to 20 mc clock rate	Useful where high ratio of passive to active components is required (e. g. linear circuits) and where higher power capability is required. Higher cost and probably lower reliability.
Monolithic circuits	0.5 to 10 ns propagation delay 10 to 50 mc clock rate	Low cost, high speed, and high reliability. High value and high tolerance passive components are very difficult, but the use of extra active elements can help compensate for this.
Hybrid monolithic/ thin-film circuits	1 to 10 ns propagation delay 5 to 20 mc clock rate	Compromise between the advantages and disadvantages of discrete components and monolithic circuits. More expensive than monolithic circuits but useful for linear circuits requiring higher tolerance passive components.
Metal-oxide-semiconductor (MOS) circuits	20 to 100 ns propagation delay 2 to 10 mc clock rate	Simpler to make and easier to fabricate large arrays of interconnected circuits. Lower power consumption. Speed approximately one order of magnitude slower than monolithic circuits.
Silicon-on-sapphire circuits	20 to 100 ns propagation delay 2 to 10 mc clock rate	Fabrication suitable for large arrays. Promising, but presently being pushed by only one company.
Active thin-film circuits	Too early to predict	Potentially cheaper and easier to fabricate very large arrays. Feasibility is not proven and utilization much farther away.

MAJOR TYPES OF INTEGRATED CIRCUITS

Table 3.2-1

3.3 MEMORIES

3.3.1 General

Several different techniques for batch fabricating solid-state electronic or magnetic storage devices are being developed that will provide improvements in internal storage costs and reliability compatible with those for integrated circuit logical components. Very large capacity auxiliary storage requiring electromechanical devices will probably continue to be a problem area.

For purposes of analysis and evaluation, storage requirements have been divided into four major categories based on their functional use:

- Registers and high-speed control memory
- Main internal memory
- On-line auxiliary storage
- Off-line auxiliary storage

Because of the wide difference in characteristics and cost, it is also helpful to differentiate between solid-state on-line auxiliary storage and electromechanical on-line auxiliary storage. A particular type of storage technology may be useful in more than one of these categories but the trade-offs between capacity, speed, and cost will vary with the category.

As with components, batch fabrication is the key to low cost high reliability memories. In fact, the integrated circuit techniques discussed in the component and packaging section of this report will be directly applicable to the electronic portions of future memories. In future memories monolithic circuits will be used for the straight digital portions of the memories (e.g. addressing, etc.) and hybrid monolithic/thin-film circuits will be used in other portions of the memory where linear circuits are required, e.g. the sense amplifier.

Integrated circuit array memories, either monolithic or MOS, in which integrated circuit elements rather than magnetic elements are used for the storage function will be a factor in future systems also. This will probably be the first use of very large arrays of interconnected circuits on a single silicon chip. Packaging techniques to permit easy maintenance will be important in the design of memories using these batch fabrication technologies.

The remainder of this section will present the status and future plans for the memory portion of this study and then briefly summarize technical developments of importance to future tactical systems. Most of the memory techniques applicable to future techniques were discussed in detail in Volume V of the ANTACCS report. A separate report on memory technology is being prepared that will revise and update the material in Volume V of the ANTACCS report which is about nine months old at this time. Since that report will discuss these technologies in depth, only changes in the technology or anticipated progress of the technology (since the material prepared for the ANTACCS report) will be presented briefly in the technical discussion in this section. The Final Report will contain material from the special report mentioned above and will present in greater detail the latest memory developments

3.3.2 Status to Date and Plans for the Remainder of the Study

In any system configuration for tactical data systems in the 1970-1980 period, requirements will exist for:

- Registers and high-speed control memories
- Main high-speed (random-access) internal memories
- On-line auxiliary storage (large capacity)
- Off-line auxiliary storage

Depending upon system design and system requirements, requirements may also exist for:

- Associative memories
- Read-only memories
  - Permanent
  - Mechanically alterable
  - Electrically alterable
  - Read mostly
- High speed serial memories

In this study emphasis is placed on the memory technologies in the first category above. Those in the second category will also be investigated where a possible Naval application has been identified. This is the case for both associative memories and read only memories. Although possible uses for high speed serial memories can be hypothesized, no specific Naval application of sufficient importance to justify their consideration has been specified to date. One possible use for high speed serial memories is in a very small, light weight, portable computer for Marine Corps field use.

Particular attention is being given during this study to those memory technologies for 1970 era systems that appeared most promising during the 1964 ANTACCS study including:

- Integrated circuit arrays
- MOS
- Planar thin-films
- Cylindrical thin-films (plated wires)
- Magnetic cores

Consideration will also be given to other memory technologies whose feasibility or applicability appeared questionable during 1964 if subsequent developments indicate that this status appears to be changing. This category includes:

Permalloy sheet toroid
Laminated ferrite
Cryogenic

Particular consideration is being given to technologies for large capacity low cost memories that may provide solid state replacements for electromechanical magnetic tape units and disc files. This includes the ferroacoustic type storage and other BORAM techniques.

Consideration will also be given to associative memories, read only memories, and high speed serial memories but the extent of this consideration will be determined by information that can be obtained about system requirements from the ANTACCS and MTACCS studies.

These memory technologies are being investigated by discussions with technical experts working in these fields, by studying the applicable literature, and by evaluating information concerning the different technologies in relation to the requirements that will be imposed by future Naval tactical systems. The criteria for selecting memory technologies to be investigated are discussed in Section 3.1 of this report. The effect of new technologies on reliability and maintainability is given major weight in their evaluation. A separate interim report is being prepared that updates the material presented in Volume V of the ANTACCS report concerning memory technology. That interim report will be further updated at the end of the study for inclusion in the Final Report.

3.3.3 Technical Discussion

As in the case of component technology discussed previously, the investigations during the first half of this study have tended to confirm and support the evaluations, conclusions, and recommendations made during the ANTACCS study in 1964. The importance and feasibility of batch fabricated memory arrays have been emphasized by further discussions with memory specialists and by published information. The importance of developing batch fabrication techniques for connecting the storage arrays to the associated electronics is appreciated by those working in the field. In fact, the ability to easily connect the storage arrays with the associated electronics is a major factor in the evaluation of particular storage techniques.

One significant development during the past six to nine months has been the relative down grading of expectations for batch fabricated ferrite memories. It is understood that work on the Flute memory has been discontinued. The laminated ferrite memory is still being pursued, and it is now commercially available in small capacity arrays. However, there has been little public discussion or published information recently on laminated ferrite memories for large capacity applications. Emphasis now seems to be placed more on their use in relatively small capacity high speed applications. Although this is a controversial question with many in the memory field having a different view, it is the belief of this study team that the laminated ferrite memory and other batch fabricated ferrite memories will not compete successfully with plated wire and planar thin-film memories in the long run.

Another interesting and very significant development during the past few months has been the increasing emphasis on memories fabricated with semiconductor integrated circuit arrays. This is true both for

MOS storage arrays and for monolithic integrated circuit storage arrays. Many of those in the semiconductor field with whom this has been discussed feel that both will be feasible; however, only a few go so far as to say that either will replace magnetic storage techniques for main internal storage. Most seem to feel that their applicability is limited to relatively small memories of a few thousand words or less, except perhaps in unusual environments such as space applications where power is a major consideration. MOS arrays offer a potential for extremely low power consumption in the quiescent state. In general, monolithic silicon arrays are believed to be more applicable for very high speed small capacity applications (e. g. high speed control memories) while MOS devices are more applicable for larger capacity slower applications (e. g. small main internal memories).

The cost of magnetic core memories is continuing to decrease as production techniques are improved and automated, and speed is continuing to increase as cores are made smaller and smaller. One core memory planned for a future high speed, large scale, commercial, scientific computer is expected to have a read write cycle time of 0. 5 us using a 12 mil o. d. and 7 mil i. d. (or smaller) core. Hence, improvements in the well established magnetic core technology continue to provide a fast moving target for the newer technologies. Some in the memory field believe that automation of magnetic core production and array fabrication will reduce the cost of core memories below that which will be achieved by batch fabricated memories. However, it is the belief of this study team that these production improvements will perhaps extend the time during which the core memory will remain dominant but that batch fabricated memories will inevitably replace discrete core memories at some point in the future. It is further the belief of this study team that this point will occur by the early 1970's.

Plated wire memories are still considered the most promising with planar thin-film and integrated circuit arrays following closely. There is a strong likelihood that integrated circuit arrays will quickly dominate the register and high speed control memory area.

The characteristics anticipated for solid-state storage devices in 1970 are shown in Table 3. 3-1 and those for electromechanical auxiliary storage devices are shown in Table 3. 3-2. Solid-state electronic and magnetic devices are applicable to registers and high-speed control memories, main internal memories, and on-line auxiliary storage while electromechanical storage devices are applicable primarily to large capacity on-line auxiliary storage and off-line auxiliary storage. Some off-line auxiliary storage devices, such as magnetic tape units, are also considered input/output equipment. In fact, the distinction between off-line auxiliary storage and input/output equipment is somewhat gray, based largely upon whether it is used to store information generated by the processor for its later use or whether it is used to enter data initially into the system from the outside world or to transfer data from the system to the outside world.

The costs of storage will vary with speed and capacity and the particular technique employed. Typical costs anticipated by 1970 for given categories of storage, including the storage media and all mechanical and electronic components necessary to provide an operating memory, are:

Registers and high-speed control memory - 2 to 5¢ per bit.

Main internal memory - 1 to 3¢ per bit.

Solid-state random access on-line auxiliary storage - 0. 2 to 1¢ per bit.

Electromechanical on-line auxiliary storage - 0. 001 to 0. 01¢ per bit.

Photographic on-line auxiliary storage - 0. 005 to 0.0005¢ per bit.

Type of Storage	Registers & High Speed Control Memories: Typical Capacity (Words)	Registers & High Speed Control Memories: R/W Cycle Time	Main High-Speed Internal Memories: Typical Capacity (Words)	Main High-Speed Internal Memories: R/W Cycle Time	Solid-State On-Line Auxiliary Storage Devices: Typical Capacity (Words)	Solid-State On-Line Auxiliary Storage Devices: R/W Cycle Time	Comments
Integrated Ckt. Arrays	256	50 ns 0	0.01×10^6	0.2 us			Most promising for very high speed registers and control memories.
MOS Arrays	512	250 ns	0.02×10^6	0.7 us			Promising for low cost intermediate capacities; Volatility is disadvantage.
Planar Thin-Film	512	100 ns	0.1×10^6	0.5 us	2×10^6	1 us	Promising for fast control memories, possibly for on-line aux storage; Questionable for main internal mem.
Laminated Ferrite	512	150 ns	0.1×10^6	2 us			Reasonable yields not proven for capacities over a few hundred words; Actively pushed by only one company.
Plated wire	512	250 ns	0.2×10^6	0.5 us	4×10^6	1 us	Very promising in all categories.
Magnetic Core Matrix	512	350 ns	0.1×10^6	0.7 us	2×10^6	3 us	Well established and will be dominant for several years; Will be replaced eventually by batch-fab techniques.
Permalloy-Sheet Toroid			0.2×10^6	20 us	4×10^6	100 us	Potential for very low cost but feasibility and yield are unproven; Actively pushed by only one company.
Continuous-Sheet Cryogenic			2.0×10^6	2 us	20×10^6	5 us	Feasibility still unproven; Not economic for capacities below appx. 10^8 bits because of refrigerant cost.
Ferro-Acoustic					20×10^6	(serial)	In early research stages; Concept promising for low cost block-oriented aux storage, but feasibility not proven.

STORAGE DEVICE CHARACTERISTICS ANTICIPATED IN 1970

Table 3.3-1

Type of Device	Capacity Per Unit In Char.	Average Access Time	Data Transfer Rate Ch/Sec	On-Line or Off-Line Storage	Comments
Magnetic Drums	250×10^6	80 ms	500,000	On-Line	Large physical volume; Well proven by field use for years.
Fixed-Head Disc Files	100×10^6	20 ms	800,000	On-Line	Fastest access time but highest cost; Relatively new with little field experience.
Moving-Head Disc Files	$1,000 \times 10^6$	80 ms	800,000	On-Line	Most field experience of on-line devices; Best cost, capacity, and access time compromise.
Removable Disc Files	50×10^6	100 ms	500,000	Either	Relatively new but widely accepted; Offers advantage of both on-line and off-line capability.
Magnetic Tape Loop	20×10^6	80 ms	200,000	Either	New and relatively unproven in the field; Made by only one company at present.
Magnetic Tape Reel	50×10^6	(serial)	400,000	Off-Line	Well established and proven for many years; Lowest cost per character off line; Serial access.
Magnetic Card Files	$1,000 \times 10^6$	200 ms	300,000	Either	Available several years, but not as well established as discs. Lower cost per char. for large capacity.
Optical Discs	150×10^9	Seconds	500,000	Either	New and unproven by field use; Offered by only one company; Read-only; Largest capacity and low cost per character; Very slow access.

ELECTROMECHANICAL AUXILIARY MEMORY CHARACTERISTICS ANTICIPATED IN 1970

Table 3.3-2

The concept of storage hierarchies is very important in considering the use and capabilities of storage devices. There is no one ideal type of storage that fulfills all requirements while providing the maximum speed and capacity for the minimum cost.

It will be necessary to use a combination of storage devices utilizing the best characteristics of each to effect a better over-all storage system. This is true not only within the processor itself and between the internal and external storage but also with respect to different levels of external storage. One important aspect in the efficient use of hierarchial storage that should be emphasized is the need for development of machine organization and software techniques that make the entire internal and on-line auxiliary storage appear as a single uniform storage to the user.

In the past few years, relatively large development efforts have been expended on associative memories that can address stored information on the basis of a portion of its contents rather than a unique numeric address. Data is located by association rather than by physical location. Basically, an associative memory involves sufficient logical capability to permit all memory locations to be searched essentially simultaneously - i.e. within some specified memory cycle time. The search may be made on the basis of the entire contents of each location or upon the basis of selected bit positions of each location. Searches may be made on the basis of equality, greater-than-or-equal-to, between limits, less-than-or-equal-to, and in some cases more complex criteria.

Associative memories developed to date are significantly more expensive than random access memories having comparable capacity and cycle time. In some types of applications the ability to address the memory by content may offer overall systems economies or speed improvements that justify the cost of this type of memory. However, most of these advantages can usually be obtained by using a relatively small associative memory in conjunction with a large capacity random access memory. Hence, it is not likely that a central processor will utilize a large associative memory as the main internal memory unless some unforeseen breakthrough in associative memory technology is achieved. On the other hand, small associative memories used in conjunction with large random access memories may offer advantages in tactical data systems that will justify their cost. Such uses might include track while scan and threat evaluation and weapon assignment applications.

3.4 DISPLAYS

3.4.1 General

The possibility of a higher degree of compatibility with integrated circuit and other batch fabrication technologies is an important criterion in considering technologies for future displays. This requires display technologies that can operate with low voltage and low power. A flat panel type display is also desirable in order to provide smaller volume displays

Although batch fabrication is a goal in searching for better display technologies, the prospects are not as promising as in the case of logical circuits and memories. However, the integrated circuit techniques discussed in the component and packaging section of this report will be directly applicable to most of the electronic portions of future displays. Monolithic circuits will be used for the straight digital portions (e.g. control logic) and hybrid monolithic/thin-film circuits will be used for other portions (e.g. video amplifiers) in which linear circuits are required. Batch-fabricated memories will provide the necessary buffering and local storage capability in displays.

In the display technology portion of the ANTACCS study last year, primary emphasis was placed on large screen displays because of the lack of an adequate existing technology in that area and because of the acceptability of existing cathode-ray-tube console displays. Investigation of large screen display technologies is continuing, but an added emphasis is being placed on consideration of technologies that offer a potential for reducing the size, weight, volume, and power requirements of console type displays for future tactical data systems.

Reducing the size of console displays would significantly reduce the space on shipboard required for a tactical data system. A major portion of the total space required for the present NTDS is occupied by

Consideration will also be given to other promising display technologies whose feasibility appeared questionable during 1964 if subsequent developments indicate that their status is becoming more favorable. This category will include:

- Solid-state light valves
- Opto-magnetic displays
- Electro-chemical displays
- Laser/luminescent (or electroluminescent) displays
- Injection electroluminescence matrix displays

Of this latter group, opto-magnetic and injection electroluminescence displays are of special interest because of their compatibility with semiconductor integrated circuits and their suitability to batch fabrication.

With respect to console displays, consideration is being given to the availability of brighter screen cathode-ray tubes to permit use of display consoles under normal ambient light. However, it must be noted that the major problems and difficulties with console displays have not been with the basic display technology but rather with the equipment design, system operational concepts, and functional design. That is, the major questions with respect to console displays are not questions of hardware technology but rather of systems design and user requirements. Flat panel display techniques for consoles are also being emphasized because of the advantage of space reductions in Naval tactical systems.

Display technologies are being investigated by discussions with technical experts working in these fields, by studying the applicable literature, and by evaluating information concerning the different technologies in relation to the requirements that will be imposed by future Naval tactical systems. The criteria used in selecting display technologies to be investigated are discussed in Section 3.1 of this report. The effect of new technologies on reliability and maintainability consoles. Although the cathode-ray tube is expected to remain dominant at least until 1970, it is hoped that flat panel displays will become available for console applications in the early 197 0's.

The remainder of this section will present the status and future plans for the display technology portion of this study and then briefly summarize technical developments of importance to future tactical data systems. Most of the display technologies applicable to future systems were discussed in detail in Volume V of the ANTACCS Final Report. Hence, only changes in the technology or anticipated progress of the technology (since the material prepared for the ANTACCS report) will be presented briefly in the technical discussion in this section. The Final Report will present the latest display developments in greater detail.

3.4.2 Status to Date and Plans for the Remainder of the Study

Both large screen and console type displays are being investigated. Particular attention is being given to those display technologies for 1970 era systems that appeared most promising during the 1964 ANTACCS study including:

- Photochromic displays with cathode-ray tube or laser image generation
- Thermoplastic and photoplastic light valves with cathode-ray tube or laser image generation
- Crossed-grid electroluminescent displays with integrated storage
- Laser inscribing systems
- Cathode-ray-tube displays

and their compatibility with integrated circuits and new memory technologies are given major weight in their evaluation. Information presented in this report will be expanded and updated at the end of the study for inclusion in the Final Report.

3.4.3 Technical Discussion

There has been little change in the status or expectations for most of the types of large screen display technologies invsstigated during the ANTACCS study in 1964. However, photochromic/CRT displays that were considered promising do not appear to have been receiving the level of development effort that had been anticipated. It is not certain at this time whether this is because of technical problems or because of the interest and goals of the companies involved. During the remainder of this study this question will be investigated further to determine whether photochromic displays should still be considered a promising technology.

With the exception of photochromic/CRT displays, the conclusions and recommendations concerning large screen displays presented in Volume V of the ANTACCS Final Report remain valid. Thermoplastic and photoplastic light valves, electroluminescent displays, and laser inscribing systems still appear to be the best prospects for large screen displays by the early 1970's, with solid-state light valves, opto-magnetic displays, laser/luminescent displays, and injection electroluminescence matrix displays offering promise if feasibility is proven.

Unfortunately, display technology, as well as that in other input/output areas, has not kept pace with advances in digital electronics and magnetics technologies. The term "display technology" in the sense used here refers to the presentation or generation of the actual visual display (i. e. the visual transducer) rather than to the many digital logic, storage, and control circuits used in display equipment. Integrated circuits are being used now to implement these latter digital functions in newer display equipments.

Integrated circuit techniques are most effective for the implementation of low voltage, low power, low precision components which are ideally suited to the fabrication of bi-valued computer logic and storage elements. These techniques are very poorly suited to the requirements of most of the approaches to the implementation of visual transducers is use today.

Although most of the technologies for large screen displays cited in Volume V of the ANTACCS Final Report do not meet the criteria for compatibility with integrated circuits and other batch fabricated electronic and magnetic components, there is no certainty at this time that any other large screen display technologies capable of meeting these criteria will be available by the early 1970's. For console displays there appears to be some hope of achieving reasonable compatibility with batch fabricated electronic and magnetic components by replacing the cathode-ray tube with a flat panel, low voltage, low power visual transducer.

The cathode-ray tube represents a well established technology that will probably be dominant for consoles through the early 1970's. The cathode-ray tube is adequate and satisfactory from most standpoints, but it has some disadvantages. While these are not critical, they will justify the utilization of other display technologies when these have proven feasible. The major disadvantages of cathode-ray tubes are associated with their incompatibility with new solid-state batch-fabrication technologies. These disadvantages include physical volume, lesser reliability, high power requirements, and a need for high voltage circuits. In some applications involving high ambient light conditions, the brightness and contrast offered by cathode-ray tubes may also be considered limitations.

Criteria for compatibility with batch-fabricated computers include low voltage, low power, small volume, digital selection, high reliability and long life, low cost, adaptability to batch fabrication, and feasibility. It is fairly obvious that the development of large-screen displays meeting these criteria is unlikely in the near ~~foreseeable~~ future. However, there are several visual transducers in research or development stages at this time that offer promise for console displays meeting these criteria. Some of these will later be adaptable to large-screen displays. Table 3.4-1 compares several existing and proposed visual transducer technologies for console displays against the criteria for compatibility with batch-fabricated computers. Most of these technologies do not meet the required criteria at this time, but the comparisons in Table 3.4-1 are based on capabilities anticipated in 1970 if the particular techniques is proven feasible and development efforts are successfully carried to completion.

Preferred display systems are those compatible with solid-state electronic component technology and those employing such components. On this basis, of the technologies presently in the research and development stage, the more promising include crossed-grid electroluminescent panels with integrated storage, matrix controlled opto-magnetic panels, and injection electroluminescence matrices. If they prove feasible, the latter two offer the greatest promise with respect to meeting the compatibility criteria set out above. Digitally deflected laser/luminescent systems may be less compatible but offer promise for large-screen displays. Electroluminescent panels and laser deflection presently require high voltages that may limit their use if other techniques more compatible with the voltage capabilities of integrated circuits prove feasible and economical.

	Low Voltage	Low Power	Small Volume	Digital Selection	Reliability & Life	Low Cost	Adaptability to Batch Fabrication	Feasibility
Cathode-Ray Tube	Poor	Poor	Poor	No	Good	Fair	Poor	Readily available
Electro-luminescent	Poor	Fair	Good	Yes	Fair	Good	Good	By 1970 if ever
Opto-Magnetic	Good	Good	Good	Yes	Good	Good	Good	Unknown at this time
Laser-Luminescent	Fair	Fair	Fair	Yes	Unknown	Fair	Poor	Promising
Injection Electro-luminescence Matrix	~~Excellent~~ Good	Good	Good	Yes	Unknown	Good	Good	Unknown at this time

ANTICIPATED COMPATIBILITY OF VISUAL TRANSDUCER TECHNOLOGIES WITH BATCH-FABRICATED COMPUTERS

Table 3.4-1

It is, of course, very likely that presently unforeseen developments will permit additional display approaches during the 1970's, but those listed above are the most promising of the presently known technologies for providing compatibility with low-cost, high-performance, batch-fabricated computers of the early 1970's.

3.5 INPUT/OUTPUT

3.5.1 General

There are three major approaches to improving the performance of future systems with respect to input/output capability. These are:

Improvements in the performance of present types of input/output equipment.

Development of new types of input/output equipment that are not in wide spread use at present.

Approaches to system organization that minimize the need for conventional input/output equipment.

Each of these approaches will play a part in performance improvements in future systems. However, unless much greater effort is placed upon the development of non-mechanical input/output equipment, the best hope for future systems lies in developing system techniques that minimize the need for input/output equipment.

This section will present the status and future plans in the input/output equipment portion of the study and then discuss technical developments affecting each of the three approaches to improving input/output performance outlined above.

Several types of equipment in the first two categories will be discussed in greater depth in this report than other areas of hardware technology that were discussed in greater detail in Volume V of the ANTACCS Final Report. However, the information presented here concerning input/output equipment is preliminary. It will be revised and expanded in the Final Report based on the results of the remainder of this study.

3.5.2 Status to Date and Plans for the Remainder of the Study

Work to date has centered about the investigation of new techniques of input/output equipment that offer promise for performance improvements in future systems. These investigations have included:

Character recognition and print readers

Voice recognition and voice output

Non-mechanical keyboards

Solid state replacements for magnetic tape equipment

New devices and techniques, both in the research stage and currently under development, to allow direct entry of data are being investigated and evaluated. The investigation and follow-up of particularly interesting techniques and approaches that were examined during the initial ANTACCS study contract is being continued. These techniques were examined briefly in the ANTACCS study but were not pursued in depth due to lack of adequate time to cover all research and development projects of interest.

Improvements in conventional types of input/output equipment are also under investigation. The most promising of these examined so far is the replacement of perforated paper tape by incremental magnetic tape. This is a technique that seems particularly applicable in tactical data systems and which has seen considerable recent advance in the state-of-the-art.

Preliminary evaluations and conclusions are given in this Mid-Project Report concerning the future of character recognition, voice recognition and voice output, non-mechanical keyboards, non-impact printers, and incremental magnetic tape as a replacement for perforated tape. These are based on incomplete data and are presented to indicate the work done to date and as bench marks against which additional data will be evaluated.

The second half of the input/output study will be devoted to detailed technical comparisons and evaluations of technologies offering promise for improving the performance of future systems. Additional information that must be gathered to provide proper technology evaluations includes equipment reliability (mean time between failures), power requirements, and relative size, weight, and cost. This additional data will provide the basis for more detailed summaries and comparison tables to expand and update the technical information to be included in the Final Report.

In addition to continuing the investigations of new types of input/output equipment discussed above, new forms of graphic input equipment, new types of graphic output equipment, digital-to-analog and analog-to-digital conversion equipment, and trends toward the replacement of analog data generating equipment with digital data generating equipment will be examined. The investigation of character recognition will be expanded to include current research on handwritten input techniques.

3.5.3 Technical Discussion

3.5.3.1 Improvements in Conventional Types of Input/Output Equipment

Almost all present types of input/output equipment are electromechanical. This imposes limitations on the improvements that can be achieved and on the ability to utilize the benefits of batch-fabrication techniques in electronics and magnetics. Although these electromechanical input/output equipments will limit systems performance, the effect on systems cost and reliability is even more serious. The performance limitations could be overcome to some extent by using a lar ger numer of input/output units, but this further accentuates the cost and reliability imbalance with respect to the central processor and memory.

Performance characteristics anticipated by 1970 for some of the major types of conventional input/output equipment are shown in Table 3.5-1. Examination of these characteristics will indicate performance improvements of less than one order of magnitude and in most cases of less than two-to-one over equipment commercially available today. Punched paper tape is not included in Table 3.5-1 because it is believed that incremental magnetic tape readers and recorders will replace punched paper tape equipment for most high performance applications. Incremental magnetic tape equipment will be cheaper for high performance, will be more reliable, and will utilize tape records and formats that are completely compatible with high speed conventional magnetic tape units. Although block oriented magnetic tape units have been in use since the early days of the computer industry, the ability to economically read and record incrementally opens new applications for magnetic tape input/output. Incremental magnetic tape recorders and readers and their advantages as replacements for punched paper tape equipment will be discussed in detail in the remainder of this sub-section.

INCREMENTAL MAGNETIC TAPE AS A REPLACEMENT FOR PERFORATED PAPER TAPE

Small letters 1st Letter Caps

Perforated tape equipment was originally developed for use in connection with land line data transmission and the performance characteristics of the devices available were closely linked with the speeds of the lines on which they transmit and receive. With the advent of high speed digital computers, perforated tape reading equipment has been developed with the capability of reading several thousand characters per second. However, as the punching process is essentially mechanical in nature involving making physical holes in the tape, the best speeds attainable have been in the order of 300 characters per second (slightly less information capacity than is available on a 2400 bit per second line.

Magnetic tape units	300,000-400,000 char/sec read write rate	2000-3000 char/inch density
Incremental magnetic tape		
Recorders	800-1000 char/sec record rate	800 char/inch density
Readers	500-600 char/sec read rate	556 char/inch density
Punched cards		
Punches	300-500 cards/min punch rate	
Readers	2000-3000 cards/min read rate	
Line printers		
Impact type (multiple copy)	1500-2000 lines/min	64 character types 132 char/line
Non-impact type (single copy)	3000-5000 lines/min	64 character types 132 char/line

INPUT/OUTPUT EQUIPMENT CHARACTERISTICS

ANTICIPATED BY 1970

Table 3.5-1

Although paper tape units with MTBF's in excess of 1000 hours are more reliable than some other militarized peripheral equipment available, they still require extensive operator attention. A 300 character per second perforator consumes one 1200 foot reel of tape in slightly over seven and one-half minutes; therefore, constant operator attention must be provided in order to change reels.

The use of high speed tape perforators also entails a serious supply problem since a tape perforator operating at full speed consumes non-reusable tape at the rate of 13.6 pounds per hour at a typical cost of 60¢ per pound. Further, the tape itself is subject to deterioration through aging.

In contrast, an equivalent size reel of magnetic tape contains 2400 feet. When incrementally recorded at a density of 556 characters per inch, the reel of magnetic tape is equivalent to 80 reels of perforated tape. Thus it allows much longer periods of operation without operator intervention. Since the magnetic tape is reusable and has a life in excess of 20,000 passes, the supply problem is drastically reduced.

Present tape punching equipment has achieved reliability on the order of 1000 hours MTBF; however, the equipment is essentially a highly stressed, high wear item that requires one time use tape. Two intermediate approaches can be taken to overcome limitations of present tape punching equipment. Where human readability is necessary, the perforated tape can be eliminated entirely as an intermediate machine language and replaced by an alphanumeric printout captured directly from the transmission line or another machine via a printer. This printout may later be used as machine input by using character recognition equipment. Advantages are gained in replacing the punching mechanism by alphanumeric printing mechanisms which can operate at higher speed and in allowing direct operator reading rather than tape interpretation by "reading the holes." Since the printing can be produced and read without mechanical action, highly stressed moving parts can be substantially reduced. Non-impact printing and character recognition are discussed in greater detail elsewhere.

Where no direct operator cognizance of data is required, perforated paper tape systems may readily be replaced with incremental magnetic tape systems in which data is recorded character by character on a reusable magnetic tape in much the same manner that it would have been on a paper tape. Since no electromechanical punching mechanism is required, total system wear is substantially reduced which should substantially increase input rates. The magnetic tape can be written in the same language and format that is used on block read magnetic tapes. Hence, this tape may be read directly into a computer system at speeds much higher than are attainable with perforated tape equipment.

Incremental magnetic tape recorders offer an improved technique for the recording of synchronous and asynchronous, bit serial or character serial, information. They will be of primary value to the Navy in communication and data collection applications.

Since incremental magnetic tape equipment records at a higher density than perforated tape equipment (556 characters per inch as opposed to 10 characters per inch), the recorded data is much more transportable and much smaller quantities of media are required. The reusable nature of the magnetic tape as opposed to the expendable nature of the perforated paper tape offers a further reduction in the supply and storage problems.

1st Letters Caps Only

INCREMENTAL MAGNETIC TAPE RECORDERS

Existing commercial incremental magnetic tape recorders typically use standard 2400 foot rolls of 1-1/2mil thick oxide coated Mylar computer tape and are capable of recording data in IBM format at densities of 200 to 556 characters per inch. Recording is accomplished while the tape is stopped under the recording head. Non return to zero (NRZI) recording is used since it requires only one incremental tape advance per character recorded.[1] Also, NRZI recording is necessary in order to provide IBM tape compatibility.

After a character has been recorded the tape is advanced one 1/200 or 1/556 of an inch to the position where the next character will be written. This tape advance is usually accomplished by driving the tape capstan with an incremental motor.

Since little energy is required for the tape drive, total power requirements of the recorder are low. The slow tape speeds do not cause rapid wear of the mechanism and therefore do not require high levels of maintenance. The unit is relatively inexpensive (about $5,000 with electronics) and the magnetic tape is reusable and can store very large amounts of data (approximately 12×10^6 characters per reel).

Since incremental magnetic recorders are useful in the same functional applications as perforated paper tape punches, the two are compared in Tables 3.5-2 and 3.5-3.

[1]Conversation with C. Kennedy, President, Kennedy Company.

	Incremental Tape		Paper Tape System (Current State of Art)		
	Current State of Art	Anticipated Future State of Art	High Performance	Medium Performance	Low Performance
Approx. Cost (No Control Elect.)	\$3,000	\$3,000	\$10,000	\$1,000	\$500
Speed in Char/Sec	500	800	300	60	20
Density in Char/In.	556 (on 1/2" tape)	800 (on 1/2" tape)	10 (on 2/3" to 1" tape)	10 (on 2/3" to 1" tape)	10 (on 2/3" to 1" tape)
Cost of Tape per Char.	.0003¢	.0002¢	.0008¢	.0008¢	.0008¢
Is Tape Reusable	Yes	Yes	No	No	No
Max. Char/Reel with 1000 Char. Records	9.6×10^6	14.4×10^6	0.12×10^6	0.12×10^6	0.12×10^6

COMPARISON OF INCREMENTAL TAPE RECORDERS
AND PERFORATED TAPE PUNCHES

Table 3.5-2

ADVANTAGES OF INCREMENTAL MAGNETIC TAPE RECORDERS	ADVANTAGES OF PERFORATED TAPE RECORDERS
Lower cost for high performance unit.	Lower cost for low performance systems.
High recording speeds obtainable.	Provides permanent recording.
Reusable recording medium, e.g. lesser supply problem, lower cost per bit recorded, less operator intervention to change tape.	Produces tape that can be used by typewriters and other paper tape equipment.
Produces tape that can be used directly by computer tape transports.	Visual inspection of output is possible.

ADVANTAGES OF INCREMENTAL MAGNETIC TAPE RECORDERS
AND PERFORATED TAPE RECORDERS

Table 3.5-3

The low power requirements, long MTBF, and long recording time per reel of tape makes incremental magnetic recorders suitable for use in remote data collection systems in which perforated tape would not be suitable.

The high recording speeds which incremental magnetic tape systems can obtain, coupled with the long recording time available from a reel of magnetic tape, make them able to serve high speed communication lines much more effectively than paper tape. The two areas where perforated tape presently has an advantage over magnetic tape are in low-cost, low-performance systems and in systems hwhere perforated tape is required for compatibility with other existing equipment.

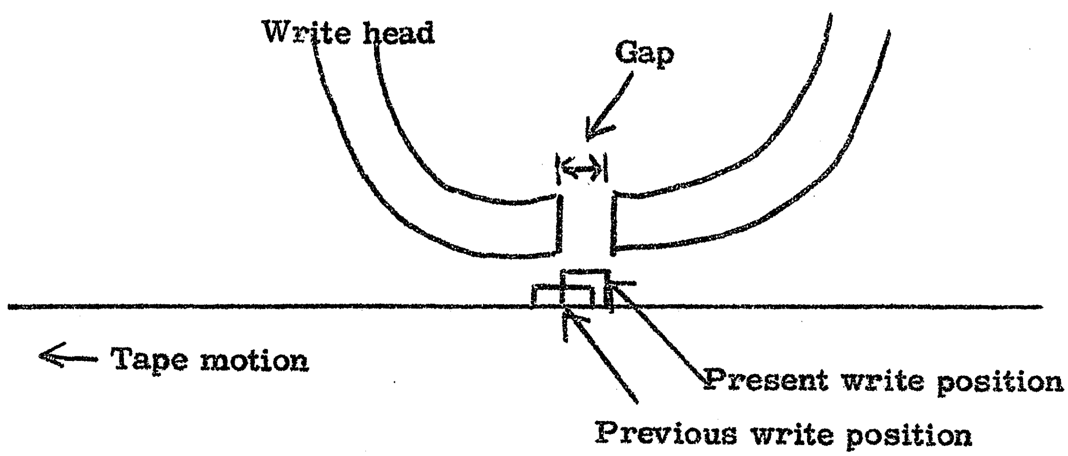
In order to obtain high density recordings with reasonable size head gaps, bit positions are overlapped during the recording process. See Figure 3.5-1. This also allows the recording head to operate at more than one tape density.

Recording speed is dependent upon the ability of the tape advance mechanism to discretely advance the tape in increments of 1/200 of 1/556 of an inch and maintain a tolerance of $\pm$ 10% required for IBM compatible tape.

Current state-of-the-art is about 500 steps per second. This may be extended to 800 steps per second in the next several years, but advances beyond this are not predictable.[2]

[2] Ibid.

OVERLAPPED RECORDING



Tape advances .005" for 200 bpi recording density

Tape advances .0018" for 556 bpi recording density

Figure 3.5-1

Maximum recording density is determined by tape standards that are based on limitations of tape reading techniques. Present techniques require an average space between bits of 1/200, 1/556, or 1/800 of an inch for IBM NRZI recording. They also require regular spacing of bits (± 10% tolerance for IBM compatible tape).

Current reading techniques can read NRZI recorded data up to 800 bits per inch, however, current incremental magnetic tape recorders are only able to maintain satisfactory bit-to-bit accuracy up to densities of 556 bits per inch because of limitations in incremental tape advance techniques. In several years, improvements in incremental motors will allow recording of densities of 800 bits per inch or more with the result that present NRZI reading techniques will become the limiting factor in increasing bit density.

1st Letters Caps Only

INCREMENTAL MAGNETIC TAPE READERS

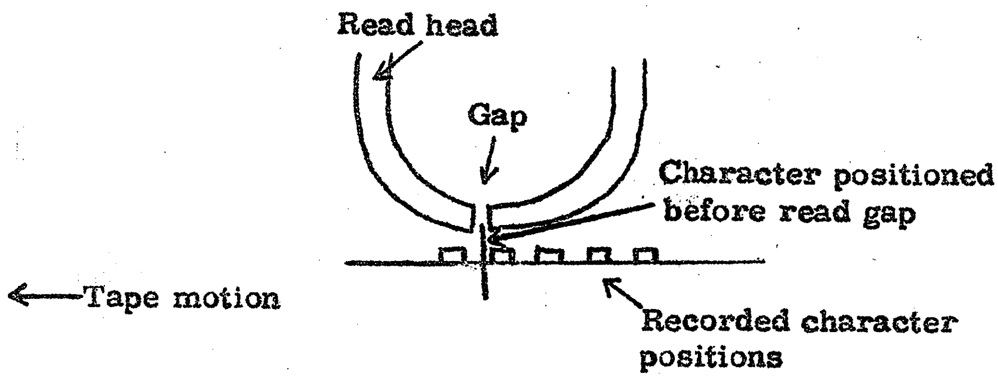
Incremental magnetic tape readers are similar in construction and application to incremental magnetic tape recorders and frequently use the same drive mechanism. However, their principles of operation are different and their performance is limited by somewhat different parameters.

In most readers, magnetic tape is read by detecting a change in flux as the tape is moved across the gap of the read head. Thus, the tape must be in motion when it is read. In order to supply this motion and yet allow synchronous access to each character, the tape is first accurately positioned in front of a recorded character and then driven into the character position to generate a detectable flux change. The tape is stopped while the character is still under the head so that it can then be prepositioned for the reading of the next character (see Figure 3. 5-2). Incremental reading creates two problems that do not occur during incremental recording. Two tape movements are required to read each character; hence, incremental reading is not as fast as incremental recording (actually about 6/10 as fast since the two movements can be synchronous with each other).

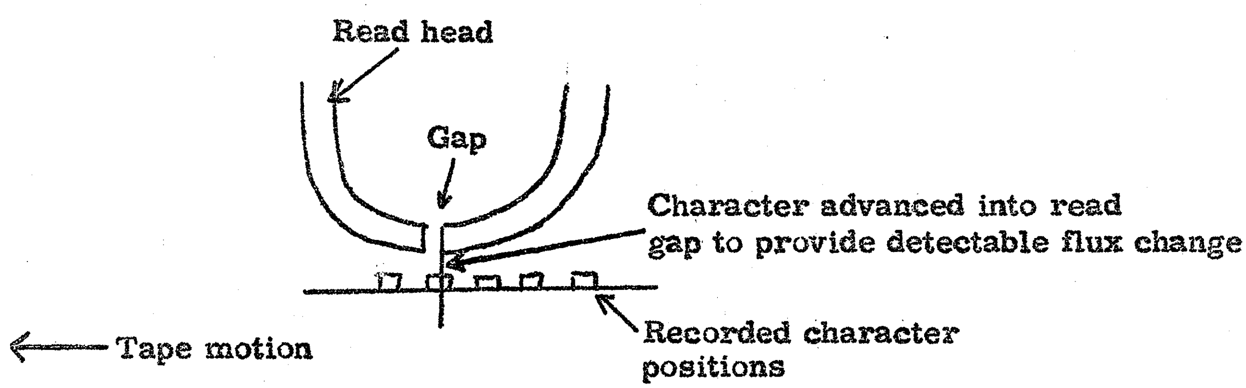
Since two movements are required to read each recorded character, it is not practical to incrementally read tape at as high bit densities or as high speed as it can be incrementally recorded. Current state-of-the-art for reading is 300 characters per second at 200 bits per inch. This may be improved to 500 characters per second at 556 bits per inch during the same time period that incremental recording is expected to be improved to 800 characters per second at 800 bits per inch. Since incremental magnetic tape readers are useful in similar functional applications as perforated tape readers, the two are compared in Tables 3. 5-4 and 3. 5-5.

Table 5 indicates that tape readers do not offer all of the advantages over perforated tape readers that incremental magnetic tape recorders offer over paper tape punches.

Militarized versions of the incremental magnetic tape recorders and readers that use a 300 foot cartridge of magnetic tape are currently available. Data is recorded in 200 bpi IBM format at up to 500 characters per second and read at up to 150 characters per second. These units are capable of meeting MIL-E-16400. The small tape cartridge and low recording density limits recording time to about six hours. This is far less than is obtainable by current state-of-the-art but far in excess of that which is practical with perforated tape.



Step 1. Position of tape pre-positioned for reading but before read step.



Step 2. Position of tape after read step.

TAPE MOVEMENT REQUIRED
FOR INCREMENTAL READING

Figure 3. 5-2

COMPARISON OF INCREMENTAL MAGNETIC TAPE READERS AND PERFORATED PAPER TAPE READERS

	INCREMENTAL TAPE		PAPER TAPE SYSTEM (Current State of Art)		
	Current State of Art	Anticipated Future State of Art	High Perf.	Med. Perf.	Low Perf.
Appx. Cost	$5000	$5000	$6000*	$4500*	$650*
Speed in Char/Sec (Asynchronous)	300	500	1000	400	60
Density in Char/In.	200	556	10	10	10
Max. Char/Reel with 1000 Char. Record	5×10^6	11×10^6	0.12×10^6	0.12×10^6	0.12×10^6

* Commercial reader and tape handler combination

Table 3.5-4

ADVANTAGES OF INCREMENTAL MAGNETIC TAPE READERS	ADVANTAGES OF PAPER TAPE READERS
Can read computer generated tape. (The computer can generate magnetic tape on line at 90 KC or more compared to 0. 3 KC or less for paper tape.)	Available in a wide variety of cost and performance levels.
Can be readily combined with incremental recorder to provide dual purpose unit.	Higher reading speeds possible.
Tape is reusable.	Can read short piece of tape.
Can accomodate large amount of data due to high density of recording.	Can read output of existing perforated tape equipment.

ADVANTAGES OF INCREMENTAL MAGNETIC TAPE READERS
AND PAPER TAPE READERS

Table 3. 5-5

All incremental tape reading equipment presently available uses 200 bpi, 1/2 inch tape with IBM compatible format; however, current technology is suitable for the development of a cartridge-loaded incremental tape unit to read or record 1 inch wide, 450 bpi tape, compatible with the militarized digital magnetic tape transport model MT-451 developed by Sylvania under contract NObsr 87543.[3]

1st Letters Caps Only

NON-IMPACT PRINTERS

High speed electromechanical printers are normally used to provide printed output on computing systems designed by most computer manufacturers. They are an outgrowth of the punched-card tabulator and were designed for use in business applications where a number of carbon copies are required. Their speed, cost, and availability have also caused their adaptation as peripheral equipment on scientific and military computers.

Electromechanical line printers are presently capable of printing line lengths of 20 to 160 characters with type fonts of 64 characters at 1500 lines per minute. In the future, speeds may be pushed up to 2000 lines per minute. Detailed discussions of various types of electromechanical line printers, their operation and functional limitations, are contained in Volume V, Section 2 of the ANTACCS report. Although suitable for commercial and scientific applications, these printers suffer several disadvantages when used in a military environment including:

- High maintenance requirements
- Large power requirements
- Large physical size
- Heavy weight
- Noisy

[3]Peripheral Device Design Characteristics, Sylvania Electronic System Contract NObsr 87543. Evolution of Digital Magnetic Tape Systems for Use in Military Environments; Tyrrell, Morrison & Staller; Proceedings 1963 Fall Joint Computer Conference, pp. 577-590.

In military applications where multiple copies are not required, the non-impact printer can be used to overcome these five disadvantages of the electromechanical printer. Major techniques for non-impact printing include electro-optical, electrographic, and magnetic printing techniques.

The electro-optical technique utilizes an electronic-to-optical transducer such as a cathode-ray tube to form a character shaped optical output. This output is projected on a charged surface which is developed by dusting, spraying, or otherwise bringing the surface into intimate contact with a series of finely divided particles that are attracted to the surface in the charged areas. Unless a treated paper with high dielectric properties is used, it is then necessary to transfer this powder or "ink" to the final printing surface. In either case, the image is fixed in place by heating.

The electrographic printer makes use of a treated paper with high dielectric properties. As the treated paper is moved across a matrix of conducting wires, the paper picks up an electrostatic charge in the shape of the desired characters or symbols. The paper is developed by dusting, spraying, or otherwise bringing the surface into intimate contact with a series of finely divided particles which are attracted to the surface in the areas of the charge. This powder or "ink" is then transferred to the final printing surface and fixed by heating.

Magnetic printers utilize a shaped magnetic field formed by a magnetized type wheel, matrix, or stylus to form a character on a readily magnetizable surface. This surface is then used to transfer a finely divided magnetic material to the surface of the paper for heat development.

In addition to these three major categories discussed in detail in the ANTACCS Final Report, several other non-impact printing techniques are being investigated.

The electro-chemical printer uses a chemically treated paper which, when exposed to an electric field, reacts to form a localized blackening of the paper surface. Two versions of this technique are currently being investigated. In the first version, the heat generated by the electric charge is used to create a thermal reaction with the surface of the paper. Typical of this type of paper is that used in electrocardiograms and other hot stylus recorders. In the second version of electro-chemical printing, the voltage supplied by the print head is used to penetrate a dielectric separating two chemical compounds which react through the pinhole break in the dielectric to produce a visible output.

The photo-chemical electronic printer utilizes a photosensitive chemically treated paper much like a blue print paper. The chemicals used are slow reacting except in the presence of ultra violet light. The paper is subjected to a mild ultra violet exposure in the form of the desired characters produced by a fibre optic insert in the face of a cathode-ray tube utilizing an ultra violet phosphor. Invisible or latent images are produced on the paper which are then developed by further exposure to moderate ultra violet radiation.

From a technology standpoint, all non-impact printers utilize two subsystems of interest. These are the electrical to visual image transducer and the image developing technique.

The electrical to visual character transducer is usually a cathode-ray tube or a matrix of conducting wires. In current printer implementations the cathode-ray tube is the only means of obtaining a high quality image. Unfortunately, CRT devices require high voltage which is not amendable to use of batch-fabricated circuits and solid state technology. The same holds true for the wire matrix techniques as they depend upon a high voltage output either to generate a spark, heat, or an electrostatic charge. Switched beam laser technology which has been examined in the display section of the ANTACCS report offers an interesting candidate to replace the CRT or wire matrix, but relatively high voltages may still be required. Further investigation of the possibilities of this technique will be undertaken later in this study.

The image developing problem is one of major consequence in non-impact printers since most image developing techniques are not suitable for a militarized application.

With electrostatic developing techniques, a material is electrostatically attracted to the printing surface and then fused in place by heat or bonded with some other technique. The electrostatic techniques are probably the most suitable for military environments in that they add a material to the surface of the paper so that the paper can not be accidentally or intentionally altered by exposure to ultra violet light, chemicals, electromagnetic forces, etc.

The chemical developers utilize a chemically treated paper and either a gaseous development such as ammonia or a liquid developer. Development time is of considerable importance, fairly expensive equipment is required, chemicals must be frequently changed, and a supply problem is created. This type of development provides a fixed, unalterable, permanent copy, but it is bulky and cumbersome to use.

The self contained chemical reactants which are released by exposure to heat, ultra violet light, spark puncturing, etc. require a relatively expensive chemically treated paper and the copy can later be altered. Further exposure to heat, ultra violet light, etc. can permanently damage the copy to such an extent that it is useless. Further an aging problem exists in the use of such papers. This class of material is generally not suitable for military applications.

The balance of this study will concern itself with all techniques that appear promising for non-impact printing, but major emphasis will be placed on those that improve the electro-optical transducer (e.g. laser or cathode-ray tube) and on means of developing images with electrostatis techniques since these techniques seem most promising toward the production of a future non-impact printing system suitable for use in a Naval environment.

3.5.3.2 New Types of Input/Output Equipment

Several new types of input/output equipment are under development that offer promise for performance improvements in future systems. These include:

- Character recognition and print readers
- Voice input and voice output
- Non-mechanical keyboards
- Solid-state replacements for magnetic tape equipment

Some of these, such as optical character readers, are in limited use at present while others, such as voice recognition equipment, are probably ten years or more away.

The term character recognition is applied to a broad range of devices from relatively simple ones capable of reading controlled and highly stylized magnetic ink printing on bank checks to ones capable of reading fifteen or twenty different type fonts on pages of printed documents. By 1970 equipment capable of reading 2000 to 3000 characters per second from a printed page should be available.

Advances in integrated circuit logic components and memories discussed in Sections 3. 2 and 3. 3 will provide significant reductions in cost since the implementation of character recognition equipment involves complex logical functions.

Research into voice recognition and voice output techniques are being supported in a number of organizations at this time. Limited voice output equipment capable of outputting canned messages is available now and some equipment has been demonstrated that is capable of putting together recorded words or, in some cases, syllables to make up a message. However, equipment for truly synthesizing voice output from alphanumeric information and equipment for recognizing spoken messages as computer input are in fairly early stages of research. It is too early at this time to predict any cost and performance characteristics for devices of this type.

Keyboards have always played an important role as a man to machine-language transducer. This is true both of independent input devices (e. g. keypunches) and of input portions of consoles providing man-machine interaction. Present types of electromechanical keyboards have suffered from reliability problems and have required the user's fingers to operate in a basically flat rectangular area. New types of keyboards are being developed that do not involve mechanically moving parts and that may permit more design freedom from the human factors standpoint. These include pneumatic, optic, and piezo-electric techniques.

Solid state replacements for magnetic tape may improve the speed and reliability available for this type of input/output function, but cost competition with magnetic tapes is questionable. At least two different programs are underway to develop solid-state storage modules that could be plugged into read-write electronics in a manner somewhat equivalent to placing a reel of tape on a tape unit. If this proves feasible and economical, the input/output and off-line storage functions presently provided by magnetic tape could be provided by high-speed, high-reliability devices and media with no moving parts.

The goals for one development program of this type are 4 million characters per module, read-write rates in the order of 2 or 3 million characters per second, and costs of approximately 0.015¢ per character for off-line storage. A further advantage that would be offered by this particular device is random access (in 1 usec) to any block of data within a storage module on the read-write unit in comparison to the strictly serial access of magnetic tape. The read-write unit would have approximately 1/10 the power requirements and weight of a magnetic tape unit and about one half the size. If a device of this type provides random access to a block of data in the storage module, it could also be used as a replacement for electromechanical on-line mass memories such as magnetic discs, magnetic drums, and magnetic card files.

1st Letters Caps Only

CHARACTER RECOGNITION AND PRINT READERS

The use of character recognition equipment in a real time system would seem to be something of an anomaly since a real time system implies the direct transmission of data from its source to a central processor that is capable of interrupting its operation on a priority basis to process the data as received. Character recognition, on the other hand, implies the intermediate storage of data in printed form which is later to be read into the computer system by the character recognition equipment. However, real time systems may be frequently used in non-real time applications or certain parts of the application may be non-real time. Hence, it is worthwhile to examine those areas in which character recognition can effectively be used.

Character recognition can be used for entering data that was previously created for human use only (e.g. books, reports, etc.). In this type of application, character recognition equipment has frequently been considered as a data input source for computer operated language translation systems.

Character recognition equipment can be used also in applications where data has been created at a central point, distributed to a number of points for later human use, then returned for subsequent computer processing. When data is intended for human use it should be written in a human-readable language. When it is also required for later computer processing the use of character recognition will allow the reuse of the same data without intermediate keypunching or other transcription. There are a number of other means which could accomplish this purpose. These include magnetically recorded information on the back of a printed form such as is used on bank ledger cards; punched cards which carry both the punched holes and a printed interpretation of those holes as used in utility bills, bar coding schemes which include both a bar code suitable for easy machine reading and characters which are suitable for human reading. These are frequently used on oil company credit cards.

Character recognition equipment is also useful in applications where documents are created from a large number of widely dispersed locations for entry into a central data processing system. In this type of application the cost of installing equipment to provide machine coded data at each of the remote locations can become so high that it is more economical to install a small inexpensive printing device and rely on a centralized character recognition system to convert to computer input.

The types of applications discussed above are not found in the present NTDS but are likely to occur in more general tactical data systems - particularly if intelligence reports are involved. Marine Corps data systems may utilize this type of equipment for entering printed data originating with small remote field units.

Many attempts to develop character reading machines have relied on a wide diversity of technologies; however, recent work has centered around three general techniques. These techniques are mask matching, feature matching, and matrix matching. Each of these techniques has been incorporated into one or more pieces of usable character recognition equipment. Each has its own advantages and its own limitations and is, therefore, applicable under certain conditions. None has yet been developed to the point where it is completely satisfactory for reading a complete set of handwritten alphanumerics.

Mask matching consists of comparing the character as a total entity with a standardized version of the charact er in order to determine whether the two are or are not identical. Mask matching may be done either optically or electronically. In either case, it is done by comparing one shape with another to determine identity. In the typical optical system, the character to be identified is projected against a series of negative masks. Where there is no match of the character, light passes through the mask and can be seem by a photo multiplier. Where a match exists, the dark area of the character obscures the light area of the mask causing a minimum light transmission which is detected by the photo multiplier and is used to identify the character. Since some large characters can completely obscure a small character (e.g. an L could obscure a period) both a positive and negative mask are usually used.

When there is a coincidence of maximum light and minimum light between two masks that identify a character, that character is considered to have been read. In order to compensate for variations in skew and alignment, the projected character is usually optically rotated and vibrated up and down during the time that it is matched against the mask.

This same technique is used electronically by matching an electrical mask of the character against the characters electrical signal as stored in the reader.

Optical mask matching in theory is an attractive means of character recognition since the masks can be built quite inexpensively - all logic is optical, and only the recognition circuits are electronic in nature. Unfortunately, a large number of masks are required for any appreciable type font size, e.g. a 64 character type font would require 128 masks. Further each variation of a type font used must include its complete set of masks as the machine is recognizing a specific character including all its characteristics rather than selected characteristics that could be common to a group of characters from similar fonts.

If a reasonable reading speed is to be obtained, the character must be projected against all possible masks at the same time. This involves an elaborate and complex optical system with its resultant attenuation of light. The more characters that must be read the more extensive the optical system and the greater the light attenuation. This attenuation can only be overcome by a high intensity light source with the result that light reflection is usually not adequate and the printed source must be on film for projection. Hence, what started out to be a simple and inexpensive system frequently becomes a very complex, expensive system that will not work. The state of present technology for optical mask matching is such that it could be developed into a small system for reading a specified set of numeric characters, or perhaps alphanumerics, but it is not suitable for multiple font readers or the reading of any printed matter except that which has been prepared under a specially controlled condition.

Matrix matching is similar in theory to mask matching. However, it is dependent upon the point by point matching of a character against its match rather than matching the character in toto. The system operates by scanning a character point by point and storing the light value of each point in a recognition matrix. The size of the matrix varies with the refinement of the system, however, it usually consists of several hundred points. Each point is identified as to its color, e. g. black, dark grey, grey, light grey, or white. When the character has been completely entered into the recognition mask, it is moved horizontally and vertically into a standard position and rotated to match a base line.

In some systems, the character is then expanded or contracted in order to fit a given recognition area of the matrix. In other systems this is accomplished optically before entry of the data into the matrix. The recognition matrix is then matched against a series of character matrices in order to determine identity. Since no printed character is perfect in its composition, voids, fuzzy edges, and other variations will occur from one character to another. In the recognition matrix, the probability of a character occupying each area is determined by the relative grey factor that is included in the recognition matrix. Therefore, it is not necessary that the character be perfect, but rather that it come within some percentage match of the character matrix. A number of character recognition machines have been constructed using the matrix matching technique.

Matrix matching has proved to be a suitable and practical technique for reading both single and multiple type fonts. Closely related type fonts can be read using the same character masks and in many cases it is possible to allow a new font to be added by providing masks for only those characters that show substantial variation from one font to the other. Since this is essentially an improved mask matching technique, it is necessary to provide different character masks for each character of widely divergent fonts. Therefore, this type of system is not too practical where it is desirable to read a large number of widely different type fonts, hand printed characters, or constrained handwriting. The limiting factor on the number of characters that can effectively be read is the electrical attenuation that results from the number of masks that must be provided. The larger the number of masks, the greater the amount of power that must be used.

Feature matching is perhaps the most promising approach to a generalized character reader. Feature matching relies on scanning the character to detect certain pre-established features and matching these features against a series of truth tables representing each character.

The features that may be examined for character identity are determined by the particular design of the system. Features that have been used in the past have included determination of horizontal and vertical bars in the character, determination of line intersections and angles of line intersection, number and position of closed loops; number, position, and direction of opening of open loops; number and position of line ends, etc. The criteria used can be reduced or expanded as required by the number of type fonts that must be read. Since many characters from different type fonts have the same features in common, feature matching systems are readily upgraded for multi-font reading. They have also been used experimentally with some success to read constrained hand printed characters.

Feature matching offers the most probably candidate for future character recognition systems for hand printed characters. In September 1962, 100 students at Tufts College were given thirty minutes of instruction in hand printing numerals. They were then asked to produce copy for character recognition equipment utilizing feature matching. Of 56,000 numbers produced, only 120 were rejected as non-readable.[4]

1st Letter Caps Only

VOICE INPUT

Voice input to a computer system involves two major functions - speech recognition and word interpretation. Speech recognition is the analysis of the human voice in order to determine what word is spoken. Word interpretation is the differentiation of one spoken word from other similar spoken words and synthesis of its alphabetic rather than phonetic equivalent for use as computer input.

Most of the work in voice input has been concentrated in the areas of speech recognition. The problems involved in speech recognition are similar in nature to those encountered in character reading. In both cases it is necessary to analyze the input into a series of identifiers that are then compared with a set of standard criteria to establish input identity. In voice recognition systems, extensive variation in input occurs because of the variation of voices from individual to individual and because of the variations of the voice of a single individual over a period of time. Aging causes gradual long term variations in the frequency output of vocal cords; minor physical conditions (e. g. colds, sinus trouble, etc.) cause considerable variation of a speaker's voice from day to day; and the emotional state of the speaker varies from moment to moment with a resulting variation in

[4] Optical Scanning Machines That Read, Ken Gilmore, Electronics World, Vol. 72, No. 4, October 1964, p. 84.

emphasis on each word spoken which varies the relative frequency distribution and power distribution during the word.

While a character recognition system can be useful if it can read a font of 64 characters, a speech recognition system must be able to accept several thousand words to have any meaningful value. Speech recognition systems must deal with a group of variables in pitch and intensity that are occurring over the period of time while the word is being spoken; however, character recognition systems can evaluate all of the criteria for one character at a single moment in time. Since the length of words also varies greatly, it is necessary to determine both the beginning and ending of a word in order to provide its complete analysis.

Contextual interpretation seems to have been a generally ignored facet of the voice input problem. This is probably because the problem of speech recognition is so far from solution. However, if a satisfactory means of voice input to a computing system is to be achieved, this problem must also be solved.

Language translation problems that utilize character recognition are also faced with the problem of determining word meaning. The word "frank" could be a proper noun, an adjective, or a verb. For example:

> Frank sat in the chair.
> It was a frank discussion.
> I want to frank this letter.

In the case of proper nouns in character recognition systems, it is possible to distinguish on the basis of capitalization (providing that the capital noun does not have two distinct meanings), but in other cases it is necessary to differentiate on the basis of word context. Voice identification systems are faced with a similar problem of determining word meaning, but they must determine meaning not only for words of different meanings that are spelled alike, but also for words that sound alike but are not spelled alike. They must recognize syllables of words as a partial word rather than a whole word. For example:

I have four apples.

They are for you.

We played in a foursome.

The word is foreign to me.

In each of the previous examples, the word "for" sounds the same, yet they could not be treated in the same manner within a computer. Voice recognition equipment capable of recognizing the word "for" is still not a useful device until it is able to distinguish true identity - e.g. whether the input should be transmitted to the computer as a digit, a word composing part of a sentence, or a syllable comprising part of a word. Of course, part of this burden could be put on the computer itself. Word meaning is not an insurmountable problem, but it is one that will require considerable effort before a solution is available. At present little effort is being devoted to this area of voice recognition.

The investigation of voice recognition in this study is in the initial stages. The techniques being pursued both for voice recognition equipment and voice interpretation devices will be presented in greater detail in the Final Report.

1st Letters Caps Only

VOICE OUTPUT EQUIPMENT

Limited forms of voice output equipment are presently available for use with some commercial systems. Applications of voice output in the commercial market usually occur in forms of status reporting such as stock market quotations, insurance policy status, retail credit status, inventory status, etc. These applications usually take advantage of existing telephone communications systems to allow remote inquiry via the telephone dial, a remote output via voice generation, without requiring specialized remote input/output stations.

In a real-time system voice output can also be useful as a means of issueing instructions to an operator and as a means of sounding oral alarms. Voice output is particularly advantageous where the telephone system or other audio communication systems are already in existence since it allows the computer to communicate over this network without the installation of additional peripheral equipment. Unlike the traditional means of visual output from a computer, voice output is able to alert the operator under any circumstances including periods of time when his attention is elsewhere, when his back is turned, when he is in an adjacent room, or even when he is asleep.

Two types of voice output equipment are currently in use. One type of equipment is a peripheral device that stores recorded words or "canned messages" that may be called up as output under computer control. Words are recorded in analog fashion usually one to a track on a drum or tape-loop system. They are switched into the output circuit of the voice system as the computer selectively activates the magnetic read heads. Such systems are limited in output capacity by the number of tracks of audio storage which are available. One such system that is commercially available has a maximum capacity of 128 words.

The other type of system utilizes conventional digital storage techniques to store digitalized versions of each word. These are called up as required and passed through a series of filters with suitable energizers. An audio output is obtained by the combination of the output of these filters which are energized by a pattern of input data. In such systems, coded voice can be stored in the same type devices as computer data including disc, drum, card, magnetic tape, or punched paper tape. In one commercially available system of this type, fifteen filters are used to cover the voice frequency range of 200 to 3700 cycles per second. Approximately 2400 bits of storage are required for each second of voice output or 800 bits per word at an average speaking rate of 180 words per minute. The number of words that can be stored in this type of system is limited only by the availability of computer memory and on line auxiliary storage that is accessible within the time delay permissible in creating the output message.

In both types of equipment the output message is at least partially preconceived and recorded as a series of numbers representing the addresses of the words to be selected. In some equipments the output selected is based upon the input of a request to the system. For example, the user requesting a stock quotation provides an input of the symbol of the stock in which he is interested. This symbol in turn is used to provide an address at which the last stock transaction is stored. This is then used to select the audio equivalent of numbers representing the value of the last transaction.

Should voice output be desirable in an advanced tactical data system, there is no reason that a militarized version of present commercial equipment could not be implemented Since the versatility of current techniques are dependent largely upon the storage available, voice output in the future will be more a storage problem than an input/output problem.

1st Letters Caps Only

NON-MECHANICAL KEYBOARDS

The keyboard has been the major means of man-to-machine communication since the introduction of data processing equipment, but little has been done to improve keyboard mechanisms. There are many technologies which can be applied to the creation of a non-mechanical keyboard as a replacement for a mechanically encoded keyboard. In commercial applications there is little incentive to develop such keyboards as contact closures have proven to be sufficiently reliable in normal office atmospheres. However, in highly corrosive atmospheres, explosive atmospheres, and areas of environmental extremes, improved keyboard techniques are needed. Non-mechanical keyboards offer definite reliability and maintainability advantages under the type of conditions in which the Navy system must operate.

Computer input keyboards are essentially mechanical to electrical transducers coupled with some form of encoding device. Presently, the encoding is either mechanical or electronic. Most existing keyboards depend on some form of mechanical contact closure for the mechanical to electrical transducer and utilize one of the following forms of encoding:

- Direct contact (or uncoded)
- Direct code generating
- Matrix coded
- Serial coded

Direct contact or uncoded keyboards utilize key depression to cause a contact closure. Output is an open or closed circuit which may be used directly or used in conjunction with a code generator to provide output. These keyboards require at least one contact for every switch or key, and at least one wire connected to each contact plus a ground wire.

Directly encoding keyboards are linked to a mechanism that allows a number of contact closures to occur at the same time. The group of contact closures allowed varies with the key that is depressed and results in the direct generation of an output code. Although mechanically more complex than uncoded keyboards, the number of contact closures can be substantially reduced as can the number of data transmission lines. One contact closure and one line plus a ground is required for each encoded bit generated.

Matrix encoded keyboards are, in effect, crossbar switches. The depression of a key closes a contact representing the row in which the key is located, and another contact representing the column in which the key is located. Matrix encoded keyboards require one switch and output wire to each row and each column position.

Bit-serial coding can be generated from a key depression by using the motion to start an action (usually mechanical) that generates a series of timed pulses which in turn can be identified as the coded output of that key. This type of output is particularly advantageous in applications such as transmission over telephone or teletype lines.

In military keyboards it is desirable to reduce mechanical actions and contact closures to a minimum. In the previously described devices it is possible to eliminate contact closures by replacing them with some non-contact form of mechanical to electrical transducer such as magnetic transducers, optical transducers, piezo-electric transducers, capacitive transducers, etc. This transducer is then used to generate a pulse that is either used directly or used to trigger a flip-flop that can act as the contact closure. Since the transducer technologies are all well known, only their application to keyboards will be discussed here.

There is no keyboard technology in the sense that there is a memory or circuit technology. Each keyboard is designed for some special application and the method of implementing the encoding or contact closure is usually left to the keyboard designer. The following examples illustrate how the previously mentioned technologies could be applied to providing solid state implementation of typical keyboard configurations.

A direct contact keyboard or uncoded keyboard could be implemented through the use of piezo-electric crystals by coupling these crystals directly to the key so that pressure applied to the key would create a pressure on the crystal resulting in a voltage output on a line. This pulse could be used directly or used to set a flip-flop providing the equivalent of a contact closure. No mechanical key movement is required.

A directly encoded keyboard could use piezo-electric crystals to generate a coded output for each key directly. This output could either be parallel or serial. Serial outputs would allow such techniques to be used on telephone or teletype lines. There are also a number of techniques that can be used for direct coding of output which eliminate contact closures but involve some minimal amount of mechanical motion. The first and most obvious of these is to replace the contact closure with a vein used to interrupt light beams directed at photocells with the particular beams interrupted to correspond to the coding. Keyboards of this type are commercially available now. Others involve the movement of a permeable material in a magnetic field to generate flux changes that can be sensed on one or more windings. Each winding can be used to represent the separate bit of the output code.

Pneumatic keyboards have been built in which the fingers cover openings through which air under slight pressure is normally escaping. The change in backpressure caused by placing a finger over one of the openings is sensed and can be used to actuate pneumatic logic devices.

These pneumatic logic devices can encode the information with the encoded information then being converted to electrical signals by suitable transducers. This approach can provide a high reliability keyboard since the fingers have replaced mechanically moving keys. The absence of mechanical linkages can also permit greater flexibility in the human factors design of the shape and "key" placement.

1st Letters caps only

SOLID-STATE REPLACEMENTS FOR MAGNETIC TAPE EQUIPMENT

In the present NTDS, magnetic tape is used primarily for the purpose of program storage. In this application, appropriate program tapes are kept on line with the computer to allow re-entry of a program in case of computer failure and to allow fast changes in computer functions via program changes.

Future applications of magnetic tape in NTDS type systems may also include:

Temporary storage of intermediate results where it is not economically practical to furnish sufficiently large main memory or auxiliary memory.

A media for transferring data from one system to another in the same or different physical locations.

Off-line storage of data not required for the immediate problem.

The wide range of applications for magnetic tape storage is large the result of the characteristics of the tape rather than the tape transport. These desirable tape characteristics include:

Low cost per character of storage.

High density of storage.

Light weight of the tape in terms of characters per pound.

No power required while data is in stored condition (i. e. not being read or written).

Read/write speeds commensurate with the input/output rates of computing systems.

Reusable over a prolonged period of time without wear or degradation.

In extreme military environments, present magnetic tapes require some environmental control both during shipment and while in operation. The typical operating environment required for magnetic tapes is 65-85°F. with 40-60% relative humidity. Storage requirements are normally 40-90°F. with 20-80% relative humidity. Most tapes will melt or burn and stored data will be lost completely if the tape is heated beyond the Curie point of the magnetic material. Shock or exposure to electrical, nuclear, or magnetic environments can also cause loss of data. The tape itself can be damaged by many chemical atmospheres and solvents. However, the Achilles heel of a militarized magnetic tape system is not the magnetic tape but the tape transport.

Presently available militarized magnetic tape units provide performance comparable to that of their commercial counterparts. Although some commercial equipment can provide much higher peak transfer rates, the overall performance of this equipment is still limited by the start stop times (on the order of 3 ms) that can be achieved with electromechanical equipment.

All present tape transports involve the physical movement of a very thin (approximately 1 mil) piece of plastic at high speeds (100-200 inches per second) across a highly sensitive read/write head. As the tape is usually coated with iron oxide, head wear and tape wear is inevitable. Head wear produces a widening of the read/write gap with a resultant decrease in frequency response of the head. Tape wear produces dust particles that can result in loss of data unless constant cleaning is provided to remove the dust. Good magnetic tape system performance is the result of fast start times, high tape speed, and small head gap sizes; however, these are the very items that produce wear and require frequent maintenance.

It is possible to completely eliminate the need for magnetic tape units through the use of large amounts of on-line mass storage and real time communication channels between all processors in a computing system. However, other present concepts allow a less costly system to achieve similar performance while increasing reliability.

The removeable disc storage system offers an attractive alternative as a possible intermediate step between the all-solid-state tape replacement for magnetic tape units and the present magnetic tape systems.

Prior to extensive development of magnetic tape replacements, the optimum data storage size for a tape system should be carefully determined. In many scientific applications, the first 400 feet of tape are used so much more frequently than the balance of the reel that some users follow the practice of cutting off the worn tape and using the balance of the tape until it has worn out. Size should be based both on present data requirements and anticipated future requirements categorized by different types of applications. It is only through such an analysis that the optimum tape length or size of data storage block can be determined. Since this is of vital importance in the determination of specifications for a future magnetic disc or solid state magnetic tape replacement it is recommended that such a study be undertaken.

Specifications for the Sylvania MT451 transport currently under Navy evaluation call for MTBF of 400 hours with 90% confidence. They further require 15 minutes per day of scheduled maintenance plus 6 hours of scheduled maintenance every 30 days. The deficiencies of even this ruggedized magnetic tape unit are evident when it is realized that these units are intended to be used with an NTDS computer such as the CP642 that provides MTBF in excess of 1800 hours with little or no scheduled maintenance required. The high maintenance requirements and low MTBF are a result of the electro-mechanical strains that must be placed on the system in order to achieve reasonable start-stop times and transfer rates. It is not possible to eliminate those strains in a conventional magnetic tape transport design without seriously degrading the performance of the system. Effective use of the transport required stopping and starting the tape in a few milliseconds. In the case of the Sylvania transport, tape is accelerated from a rest position to 100 inches per second in 3 milliseconds. This represents a total travel of the tape of 0.125 inches during its acceleration period.

Considering the large amounts of wear and stress that are placed on a magnetic tape, the reliability of current tape units is remarkable. However, when they must be depended upon in a real time combat situation, their performance, maintenance requirements, and MTBF are major problems.

Both high maintenance requirements and low MTBF could be overcome by developing a solid state auxiliary storage unit as a magnetic tape replacement. One approach is to provide a large on-line auxiliary mass storage system "partitioned" so that sections or "reels" are allocated to different computers or problems as required. However, to effectively replace magnetic tape units in many applications (particularly from a cost standpoint) it will be necessary to develop removable storage modules that can be transported and plugged into a set of read-write and control electronics much as a reel of tape is placed on a tape transport.

On line solid-state auxiliary mass storage units capable of fulfilling many of the requirements of a magnetic tape replacement are available now. However, they are expensive and are not removable or transportable. Memory technologies suitable for the development of this type of memory must provide large capacity storage at a low cost per bit including electronics, must be non-volatile, and must require little or no power in the quiescent state. Compactness of storage is also important since large amounts of such storage may be necessary.

Prior investigation of mass storage techniques reported in Volume V of the ANTACCS study covered the following technologies that may be available by 1970 for such applications.

- Plated wire storage
- Planar thin film storage
- Permalloy sheet toroid storage
- Continuous sheet cryogenic storage (requires power for refrigerator in order to maintain storage).
- Ferroacoustic storage

These are described and discussed in greater detail in the memory section of this report and in an interim report being prepared on memory technology.

For intermediate applications and applications where rotating equipment can be tolerated, large fixed head disc or drum systems can be used.

In applications where the solid state replacement for magnetic tape is to function only as a program store, read-only memories and slow write memories should also be considered. Read-only memories that can be considered for this type of application are the piggyback, twistor, capacitive sensing memories, photographic storage, and non-destrictive read versions of plated wire and planar thin-film memories.

The portable and off-line storage concepts of solid-state magnetic tape replacement require a storage media (in blocks of several million characters) that is compact, is easily and economically separable from its electronics, has a very low cost per bit for the media without electronics and controls, and can be packaged in a portable form that is relatively insensitive to shipping and environmental damage.

The ferroacoustic delay line is the best candidate of those listed above since it can be most easily separated from its drive and control electronics at low cost, but packing density may limit the practical size of such memories.

The functional replacement of magnetic tape transports with a "solid state" unit could offer many desirable features for military applications. Among these are:

Reduction in maintenance requirements.
Substantial improvements in MTBF.
Improved performance characteristics.

The greatest difficulty in application of solid state techniques to a magnetic tape replacement is their relatively high cost per bit of storage. The cost per bit of some techniques such as the ferroacoustic delay line can be less when used for a solid state magnetic tape unit replacement than they are when used as an on-line auxiliary memory because of the ability to store the media off-line without tieing up read-write electronics.

3.5.3.3 System Organization to Minimize Input/Output

In large systems the greatest improvement in the performance of input/output equipment can be achieved by avoiding input/output operations wherever possible. By keeping the data within the system and by capturing data at the source, much of the need for conventional types of input/output equipment can be reduced. For example, the need for voluminous printed reports can be reduced sharply if the user is operating on line with the processor through an efficient console. When any part of the data base within the system is rapidly available to the user upon request, he will have little need for large reports that are used for occasionally looking up printed results - particularly since these may be out of data by the time they are used. The present NTDS system provides a good example of this approach with input and output being handled directly on-line through the user consoles. The major use of conventional types of input/output equipment in NTDS has been reduced to that of loading and changing or programs.

Hardware developments such as the availability of low cost solid-state on-line auxiliary storage will be essential to this approach, but this solution is primarily a matter of systems design. Hence, this approach to solving the problem of imbalance between input/output equipment and central processor can only be recommended here. The development of this approach is outside the scope of this study but should be considered in related systems design studies. To achieve the improvements possible in this area will require a combined effort of users, programmers, hardware engineers, and systems planners and designers.

4. IMPACT OF NEW HARDWARE TECHNOLOGIES ON FUTURE NAVAL TACTICAL SYSTEMS

Any new tactical system developed in the future will undoubtedly represent increased scope and increased performance requirements. However, improvements in maintainability and reliability and reductions in size, weight, and power that can be achieved by the use of new technologies will be so great that they will justify the development of a new system--even if there were no requirements for increased performance or broader scope. Although this study does not include a cost effectiveness analysis, it is believed that increased system effectiveness resulting from increased availability coupled with reductions in the training level and the number of maintenance personnel required on shipboard will justify the cost of developing a new system. Equipment costs (aside from development) will be less and logistics costs will be decreased also. Significant savings in space and weight will be of particular importance on smaller ships.

Maintenance personnel savings were discussed in Section 2.3.4. To illustrate the savings in size, weight, and power requirements that will be possible with technological advances anticipated by 1970, each equipment in the present NTDS system (excluding communications) has been compared with estimates for equipment capable of providing the same performance but utilizing new technologies. These comparisons, shown in Table 4-1, also serve to illustrate the types of equipment in which significant improvements are anticipated and those in which only minor advances are expected. The estimates for equipment in 1970 are believed to be conservative for the digital electronic equipment but may be somewhat optimistic for some of the electromechanical peripheral equipment.

Equipment	No. in System	Present NTDS			Equivalent 1970 System			Total Reduction (No. X Difference)		
		Size Cu. Ft.	Weight Lbs.	Power Watts	Size Cu. Ft.	Weight Lbs.	Power Watts	Size Cu. Ft.	Weight Lbs.	Power Watts
AN/USQ20B Computer	3	51	2400	4500*	2	100	250	147	6900	6900
Magnetic Tape Unit	2	46	1400	2700	35	1100	2100	22	600	1200
Video Processor	2	46	1500	2100	4	200	400	84	2600	3400
Teletype & Adaptor	1	29	300	500	20	200	350	9	100	150
Paper Tape Unit	1	15	260	700	10	170	470	5	90	230
System Monitor Panel	1	14	400	240	7	200	150	7	200	90
Terminal Equip. Logic	1	32	1000	1400	3	100	200	29	900	1200
Keyset Central	1	32	960	1400	3	100	200	29	860	1200
Keyset Universal	8	3	100	200	2	70	120	8	240	640
MG Set	3	14	1000	1000**	5	300	150	27	2100	2550**
MG Control	3	11	320	----**	2	120	---**	27	600	----**
Interconnection Panel	8	14	250	----	0.5	20	---	108	1840	----
Central Pulse Amp	1	27	630	390	12	300	200	15	330	190
Symbol Generator	1	32	700	680	4	150	150	28	550	530
Display Console	12	32	1200	1400	16	500	600	192	8400	9600
Totals for Typical Systems		1113	38410	49810	376	12100	16080	737	26310	33730

* Includes 2000 Watts required to run the blowers

** Power input to MG Set and MG Controller in excess of that delivered to the computer

COMPARISON OF EQUIPMENTS OF TYPICAL NTDS SYSTEM

WITH EQUIVALENT PERFORMANCE EQUIPMENTS FEASIBLE IN 1970

Table 4-1

These comparisons indicate that significant advantages can accrue to the Navy in utilizing new technologies even without considering increased performance requirements. For a typical NTDS installation, the estimates for equipment feasible in 1970 represent reductions of approximately 67% in volume, weight, and power requirements. In addition to the advantages illustrated by these comparisons, improved maintainability and reliability improvements of greater than one order of magnitude for digital electronic equipments provide strong arguments for the utilization of these new technologies at the earliest possible time. The maintainability improvements will be reflected in reduced training required for maintenance personnel, reduced numbers of maintenance technicians required on shipboard, reduced supply and logistics requirements for spare parts, and reduced down-time and increased availability.

5. INFORMATION SOURCES

5.1 ORGANIZATIONS CONTACTED

Hardware technologies and maintainability have been discussed with personnel of a number of different companies and governmental agencies in the course of this study. The following list indicates the companies and governmental agencies and the topics discussed with each:

IBM Research Laboratories Yorktown Heights, N. Y.	Advance technologies in memories, circuits, and input/output equipment
NOTS China Lake, California	Modular exploratory computer (ARC) Display technology Incremental magnetic tape technology
Navy Special Projects Office Washington, D. C.	Modular integrated circuit subassembly standardization
RADC Rome, New York	Solid-state mass memory and associative memory technology Display technology
Naval Applied Science Laboratory Brooklyn, New York	Maintainability Packaging Concepts
Naval Electronics Laboratory La Jolla, California	Maintainability Integrated Combat System
General Dynamics Electronics San Diego, California	Display technology

ONR Washington, D. C.	Maintainability and Inventory problems
BuWeps Washington, D. C.	Maintainability and Reliability aspects of IHAS
BuShips Washington, D. C.	Maintainability Reliability Integrated circuits Microelectronics NTDS
The RAND Corp. Santa Monica, California	Future computer technology
Teledyne Corp. Los Angeles, California	Maintenance and packaging aspects of IHAS
Litton Industries Canoga Park, California	Display technologies
Librascope Group Glendale, California	Memory technology Display technology
Burroughs Corporation Pasadena, California	Character recognition Print readers
Kennedy Corporation Pasadena, California	Incremental magnetic tape
Univac Blue Bell, Pennsylvania	Memory technology Component and packaging technology Fluid logic technology

Informatics, Inc Van Nuys, California Bethesda, Maryland	ANTACCS Study MTACCS Study
EMC[2] Washington, D. C.	ANTACCS Study
Westinghouse Molecular Electronics Division Elkridge, Maryland	Integrated circuit research Packaging techniques
GE TEMPO Washington, D. C.	Maintainability
NAFI Indianapolis, Indiana	Thin-film circuits Automatic packaging techniques
WADC Dayton, Ohio	Reliability and maintainability Integrated circuit and packaging technology
USS Kitty Hawk San Diego, California	NTDS operation and maintenance

Discussions with personnel of these organizations provided a basis for much of the information presented in this report. In addition to discussing techniques and approaches that have not been adequately described in published literature, the opinions of experts in specific areas in these organizations were solicited concerning the advantages, disadvantages, limitations and future prospects for different technologies.

5.2 BIBLIOGRAPHY

A large number of references have been used in the course of this study. Many of these were listed in the Bibliography in the ANTACCS Final Report and are not repeated here. This Bibliography is not intended to reflect all of the published material reviewed in this study but to list the more important new references that have contributed to information in this report.

(Bibliography is presently being typed and will be added to this report before it is distributed.)

Pg 28 ✓ hyphen

29 ✓
43 ✓
65 ✓
66 ✓
70 ✓
75 ✓
80 ✓
86 ✓
92 ✓
95 ✓
97 ✓
100 ✓