MAN-MACHINE IMPACT OF TECHNOLOGY ON COAST GUARD MISSIONS AND SYSTEMS

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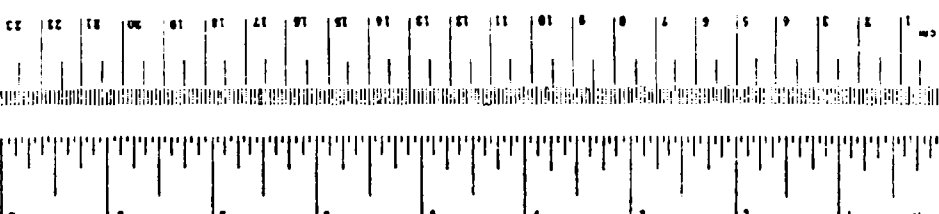### WASHINGTON, D.C. 20590

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16. Abstract

The purpose of this research is to forecast technological changes and their effects on Coast Guard man-machine systems. Impact projections are based on a literature review of developments in computers, infrared, lasers, and communications and on an analysis of Search and Rescue, Enforcement of Laws and Treaties, and Marine Environmental Protection missions. Advanced sensors and communications will permit highly effective search and surveillance by air. Remotely piloted vehicles (RPVs) offer a partial alternative to surface cutters. Computers at operational command centers will be able to process vast amounts of information to aid command decision making, automatic plan preparation, formatting and dissemination, and assume most administrative record keeping functions. Operational systems will become increasingly automated by microcomputers/microprocessors interposed between operator and system. Operator requirements will be reduced. Maintainer require-ments will vary, with some reductions and some increases. Practically all personnel will require at least familiarization with computer operation to perform their tasks efficiently. Increased marine farming, mining, and underwater recreation suggest that Coast Guard responsibilities will have to be extended to the subsurface environment. Recommendations are made for conduct of cost-effectiveness studies of RPVs and command computer systems.

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METRIC CONVERSION FACTORS

FIGURE 3. METRIC CONVERSION FACTORS

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INTRODUCTION AND PURPOSE

The work described in this report was conducted to (1) identify technological changes that will occur in the 1980-1990 time frame; and (2) determine the potential effect of these changes on the operations of Coast Guard man-machine systems (MMS).

The rationale for technological forecasting is the advantage such forecasts provide for planning the development or procurement of new systems and the adaptation of organizational (e.g., managerial) structures to accommodate these new systems. The introduction of a new technology may produce a new means of implementing an established system mission, or it may permit that mission to be performed in the same way but with greater efficiency. In the most extreme case, a new technology may suggest an entirely new mission. Also, technological changes may require that a new job structure be developed, as when a new device is required that demands additional personnel, different, and/or expanded training, or a new procedure for conducting the mission.

Technological change is defined as an improvement in hardware performance that manifests itself at the equipment/subsystem/system level. An improvement at the component level is of little interest to the Coast Guard unless that improvement is manifested in changes at a higher level. For example, the transistor was a significant improvement over the vacuum tube at the component level, largely in increased electronic reliability. Its primary impact on personnel, however, resulted from the advanced weapon, guidance, communication, and other operational systems that its use made possible. In this report, primary attention will be paid to technological change as it is reflected at the device level, although the basis of that change at the component level will be documented.

A technological change is not important for Coast Guard purposes unless it produces effects on the functioning of an MMS. Those effects can be categorized as follows:

1. Increase in performance capability (e.g., added sensitivity leading to increased range in a surveillance system).

2. Increased reliability and maintainability (e.g., increase mean-time-between-failure (MTBF), easier accessibility for maintenance, reduced corrective maintenance times).

3. Reduced cost.

4. Reduced packaging dimensions (i.e., reduced weight and size).

5. Increased capability to withstand environmental stressors. (As a result of technological change, the equipment configuration can function under more adverse or less optimal environmental conditions (e.g., higher or lower temperatures, increased vibration).)

6. Modified personnel requirements. This last effect can be described in terms of:

a. Change in the number of personnel required to operate and/or maintain the technologically modified equipment. (Note: The change need not necessarily be beneficial to the MMS. Although it is desirable that the technological change reduce the number of personnel required, the effect of a change may be minimal or may even act to increase the number of personnel.)

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b. Change in the qualifications required of personnel to utilize the equipment. (Note: Although it would be desirable for a technological change to reduce required personnel requirements, it is conceivable that increased technological sophistication would require a higher personnel performance level to utilize that sophistication.)

c. Change in the length and type of personnel training required.

d. Change in the manner in which equipment is utilized (i.e., changes in job design leading to changes in procedures).

This report will emphasize changes in personnel requirements and personnel utilization (the manner in which Coast Guard tasks are performed). The other change effects that may occur (e.g., increased performance capability and reliability) will be considered primarily in terms of how they impact on personnel and personnel utilization of the MMS. In considering these technological changes, special attention has been paid to the anticipation of potential future problems.

The organization of the report is described below.

1. The Methodology Section describes how this effort was accomplished.

2. The Technology Projection Section summarizes the conclusions derived from the analysis of the various technological areas. Because much of the material on which these projections are based is of interest only to a technology specialist, the supporting material has been placed in an Appendix.

3. The section entitled "Coast Guard Missions in the 1990-2000 Time Frame" takes the technological advances summarized in Section 2 and shows how they could be used in Coast Guard missions of the future.

4. A final section, "Personnel and Man-Machine Implications of Technological Advances," describes what effect the technological advances will have on personnel, the way they will have to operate and maintain Coast Guard systems, and implications for equipment design and training.

METHODOLOGY

General Approach

To accomplish the goals of the study, a four-stage strategy was adopted:

1. Select the technologies (e.g., computers, engines, aircraft) whose changes would be analyzed.

2. Select or devise a method of forecasting changes occurring in the selected technologies over the time span 1980-1990.

3. Analyze Coast Guard functions to determine where the selected technologies would apply (Coast Guard Missions in the 1990-2000 Time Frame).

4. Determine the anticipated effect of the forecasted technological changes on selected Coast Guard functions (Pesonnel and Man-Machine Implications of Technological Advances).

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The four steps above are roughly sequential although obviously it is possible to perform several steps concurrently. Each step in the approach will be discussed individually below.

Technology Selection

Technology selection can be accomplished in different ways:

1. Consider all possible technologies and select only those in which the greatest changes (expressed in terms of R&D activities) are occurring. (There might not be a very close match between technologies selected on this basis and the functions that are important to Coast Guard missions.)

2. Determine major Coast Guard functions, and then find those technologies that support those functions. For example, if communications are a significant Coast Guard function, one would then select communications as a technology for examination.

Since the limitations of these two approaches tend to cancel each other out, both were used in this study. Examination of the Coast Guard mission suggests that the most critical functions performed are: communication, navigation, surveillance, and information processing. Using the SAR mission as an example, information relative to a missing or sinking craft comes into Coast Guard headquarters, is analyzed (e.g., to determine the approximate area of the search, to determine what vessels and personnel are required); vessels navigate to the search area, and then perform surveillance in order to find the object of the search. In the enforcement of laws and treaties (ELT) and marine environmental protection (MEP) missions surveillance and navigation are critical functions.

The various technological areas were examined for their degree of R&D progress. This examination suggested that major R&D activity was occurring in computers and microprocessors, in infrared (IR) and laser surveillance systems, and in communications equipment. All of these technologies are significant to the four critical functions noted above, and were, therefore, selected for forecasting. Among the technology areas selected, computers and surveillance systems were found to be of greatest importance to Coast Guard operations and these have been emphasized both in the forecasting process and in the mission scenario descriptions.

Forecasting Method Selection

Although the number of generic forecasting methods is limited, there are a large number of individual variations (Figure 1). In order to understand which method was adopted for this project and why, it is necessary to review these methods.

The two general classes of forecasting methodology are Exploratory and Normative. Exploratory forecasting involves extrapolation from the past and present to the future. It assumes that technological attributes generally advance in some orderly manner over time. By choosing appropriate parameters and plotting these in a time series, one can extend the series into the future. The exploratory method generally assumes an S curve, with a slow start, exponential growth followed by leveling off as some limit is approached.

The normative method assumes that technology will be developed to satisfy a specified need. Normative forecasts identify some future objective and then work backwards to determine the technological developments needed to achieve the objective. The assumption is made that if the forecaster can project future needs, it is possible to

EXPLORATORY

Individual or "Genius"
Polls
Panels/Committees
Delphi
  Digitometer Exercise

Scenarios
Monitoring
Trend Extrapolation
  Straight Line and Fitted Curve Extrapolation
  Envelope Curve Extrapolation
  Trend Correlation
    Substitution Analysis
    Biological Growth (Pearl's Law)
    Hartman Model
    Economic Growth (Gompertz's Law)
    Bisexual Reproduction Analogy (Lenz)
    Acceleration Analogy (Adams)
    Seaman's Model
    Abt Model
    Fusfeld Model
  Precursive Indicators

Lontief Model
Lenz Learning Model

NORMATIVE

Morphological Analysis
  Network Construction
    Matrices
      Technological Scanning
      Contextual Mapping
        Functional Array
        Graphic Models
          Decision Trees
          Relevance Trees
            Perspective Trees
              (qualitative)
            Objectives Trees
              (qualitative)
            Objective Trees
              (quantitative)
    Cross-impact Matrix
Mission Networks and Functional Analysis
Systems Analysis
  Impact Studies

Figure 1. The technological forecasting jungle.
         (Excerpted from Lanford, 1972.)

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anticipate the factors driving technology. If a better mousetrap is desired, someone will design it.

Cutting across the two general methods is another and perhaps more important dichotomy, objective and subjective. Actually it is incorrect to talk about a dichotomy because the methods distribute themselves over a single continuum in which some methods are more subjective and others are less, but all are subjective to some extent. Among the less subjective methods are those emphasizing trend extrapolation and correlation, curve fitting, Gomperz curves, computer modeling, simulation, and gaming. The more subjective methods involve variations on the Delphi technique (Linstone & Turoff, 1975).

The forecasting approach taken in this study has focused on the exploratory method. This is because we assumed that, based on the analysis of Coast Guard operating programs for FY 81-90 (Department of Transportation, Coast Guard, FY 81-90 Operating Program Plan for the Search and Rescue Program, 1978; Department of Transportation, Coast Guard, Marine Environmental Protection FY 81-90 Operating Program Plan, 1978; and Department of Transportation, Coast Guard, Enforcement of Laws and Treaties FY 81-90 Operating Program Plan, 1978), those missions would be essentially the same in 1990 as they are now (with the possible exception of certain submarine functions related to deep sea mining, ranching, and farming). Since no new missions will be required of the Coast Guard in the 1990 time frame, we could not anticipate new technologies specifically designed to implement these new missions. As may be seen from the material in Figure 1, the methods available under the exploratory heading range from the highly subjective to the somewhat less subjective are more quantitative.

Whether one can make use of any particular forecasting method depends on satisfying a number of prerequisites:

1. Quantitative forecast methods (e.g., trend correlation, fitted curve extrapolations), require quantitative input data. Where input data are lacking, as is often the case, the quantitative methods cannot be used.

2. The input data required for forecasting must be at a level corresponding to the level at which one wishes to forecast. Much input data is either highly molecular, describing the components that make up a system (e.g., Charge Coupled Devices for lasers) rather than the systems themselves; or else the forecasts made are extremely general, describing for example the size of the market for a technology. For purposes of forecasting technology useful for Coast Guard missions, the level needed for prediction is the equipment/system level, because this is the level--rather than that of components--that impacts on mission performance. The information available should be able to predict how entire systems utilizing a technology would perform rather than how the components used in that system perform.

The strategy adopted for this research is summarized under the following headings:

Emphasis on System Applications of the New Technology. Technological impact is felt at the operational system level rather than at the system component level. Developments in Charge Coupled Devices (CCD), for example, are irrelevant for Coast Guard purposes unless CCDs lead to and are incorporated into improved laser, infrared, or other operational systems. Only then do they impact on system performance and personnel.

Review of the Available Literature. All available sources of data were explored (e.g., Defense Documentation Center (DDC) files and professional journals). As indicated

previously, this survey yielded a good deal of material indicating anticipated changes at the component level but little at the equipment/system level.

Consultation with Experts. Specialists at the Naval Ocean Systems Center (NOSC) and the Navy Personnel Research and Development Center (NAVPERSRANDCEN) in the areas of computers and sensor technology were consulted. Material was also secured from private companies researching and developing new technology in these areas.

Analysis of the Technology. The data gained from the sources listed above were analyzed to supply answers to the following questions:

1. What developments/advances are likely to occur in each technological area during the 1980-1990 time frame?

2. At what year will each change/development become available for incorporation into an operational equipment/system?

3. What would an equipment/system embodying the technological development probably be like in terms of:

    a. Capability (number of functions performed).
    b. Capacity (e.g., memory storage in computer).
    c. Speed of response.
    d. Range.
    e. Sensitivity (e.g., to certain light spectra).
    f. Physical size.
    g. Resolution.
    h. Weight.
    i. Cost.
    j. Power requirements (amount, type of electrical power needed).
    k. Reliability.

        (1) Mean time between failures (MTBF).
        (2) Anticipated availability (up time/total time).
        (3) Performance degradation tolerance (operation at partial levels).

    l. Maintainability.

        (1) Mean time to repair (MTTR).
        (2) Maintenance philosophy.

            (a) Remove-replace.
            (b) Repair aboard ship.
            (c) Depot maintenance only.
            (d) Maintained by operator.
            (e) Maintained by special maintenance technician.

        m. Resistance to environmental stressors (e.g., shock, vibration, temperature, humidity, electromagnetics, etc.).

Application of Technological Findings. The findings derived from analysis of the technology were then applied to the Coast Guard missions in the following ways:

1. Mission functions in three Coast Guard missions--Search and Rescue (SAR), Enforcement of Laws and Treaties (ELT), and Marine Environmental Protection (MEP)--were plotted in graphic (flow diagram) form.

2. An analysis was performed to determine which functions in the three missions were most critical. Criticality was determined by combining the following factors:

    a. Number of alternative ways to perform the function.

    b. Probability of personnel error in performing the function.

    c. Effect on satisfactory completion of the mission if the function were not performed or performed poorly.

3. Those functions that could be implemented or aided by advanced technology were identified on the mission flow diagram.

4. Each selected function was examined and described in terms of the alternative ways in which the function could be performed making use of the advanced technology.

TECHNOLOGICAL PROJECTIONS

Introduction

Advances, sometimes dramatic, are being made in all four of the technological areas selected for examination in this report. As was mentioned in the methodology section, technological developments are useful and meaningful for Coast Guard purposes only when they describe hardware at the equipment and system level (i.e., as characteristics and capabilities of operational devices and equipment). The reports of technological developments that were reviewed for this report were found to be heavily oriented toward the component rather than the system level of description.

It was therefore necessary to extrapolate system conclusions from the detailed component data gathered; these conclusions are presented in this section. Readers interested in the detailed forecasts from which these system conclusions were derived are referred to the Appendix.

Computer Technology

Advances in computers and computer technology will appear in three ways: (1) in computer systems (i.e., information storage, processing and retrieval systems), (2) in microprocessors and microcomputers as components of computerized or computer auto-mated systems, and (3) in adaptations of computer technology to other technologies (e.g., solid state sensors).

Computer capacity, speed, sophistication, and operational reliability in both hardware and software will continue to increase while dimensional size, weight, power require-ments, and functional cost will continue to decrease. Distinctions among categories of computers will continue to be vague as microcomputer capabilities encroach upon or surpass previous minicomputers, minicomputers move into the macrocomputer capability range, and macrocomputer capabilities will become even greater.

Advances in computer memory will permit relatively small computers to store and process vast amounts of data and information. Thus, it will become feasible for individual

Coast Guard bases and stations to employ "locally owned" computers for direct storage of many administrative, logistic and other records, information instructions, etc., as well as operational data and information needed for the planning and execution of the installation's functions. In addition, data telemetered from remote sensors, satellites, or other sources could be entered automatically into computer memory. All this information, as appropriate, will be instantaneously available for planning and executing command decisions. Data processing speeds will permit essentially real-time interaction with the computer.

Operator inputs to the computer will continue to be made by means of conventional electromechanical devices such as key pads, ball tabs, thumb wheels, light or touch pens, and "joysticks." In addition, inputs may be made by human voice using minimally restricted vocabulary.

Computer output to the user-operator will continue to employ conventional digital readouts, printed page or strip, and cathode ray tube (CRT). Large screen, flat, high resolution displays will also be used. The large screen will permit virtually photographic-quality imaging, split-screen presentation, magnification of all or portions of the display, presentation of maps, graphics, formats, and overlays.

Computational capabilities will provide practically instantaneous solutions to problems such as development of a SAR plan for command consideration and decision. Capabilities will also permit base station monitoring of plan execution by means of real time display of data/information transmitted or telemetered from on-site sources.

Computers will be available for installation aboard medium endurance cutters. Such machines probably would be oriented toward computerization of various administrative functions and computer monitoring and/or control of shipboard operational systems (e.g., propulsion, sensors, etc.).

Microprocessors and microcomputers will be embedded as components in a growing number and variety of operational systems. These computer components will perform the following functions: (1) analog-to-digital conversion and process control functions, (2) translation of operator commands into digital form for execution by the system proper, (3) control of system functioning in accordance with those translated commands, (4) monitoring and adjustment of system operating characteristics for optimum system performance, and (5) monitoring of system functioning and alerting of the operator to performance degradation and/or incipient failure. In sensor systems they will process incoming data for maximally meaningful display to the operator. Operators will control their equipment systems through mediating computers. Indeed, the embedded computers will permit operation of systems from centralized, consolidated, even distantly remote control centers.

Adapation of computer technology to other technologies will be discussed below under the sensor technologies.

Infrared Technology

While infrared (IR) technology is approximately 180 years old, it is only within the last three decades that the technology has produced practical operational devices and systems. This has been due to a variety of problems and limitations inherent in the technological field. Good progress is being made but no major breakthroughs are anticipated.

The family of Forward-Looking Infrared (FLIR) systems is currently the most advanced and successful of IR sensing systems. They are relatively large, heavy, costly, and the necessity for electronically "trimming" the separate amplifiers for each of the 100 or more detectors in the array imposes an undesirably heavy maintenance burden. FLIR systems are capable of an image resolution comparable to TV.

One of the major problems in the development of IR systems has been the need for cryogenic cooling of the detectors. The 1980s will see the emergence of a solid-state thermoelectric cooled focal plan array FLIR and possibly an uncooled IR imager. The extention of concept and construction of charge-coupled devices (CCDs) from computers into the IR field will be a major advance. The use of CCDs permits integration of signal processing with the detector array. This, in turn, will permit real-time operation of IR reconnaisance systems with direct linking of imagery to a remote command center.

A multispectral IR scanner (i.e., a single device operating in several IR frequency ranges), is unlikely in the foreseeable future. Within the 1980s, however, it will be entirely feasible to integrate several IR (and other) sensor systems to provide multi-spectral data for purposes of pollution detection, etc.

Laser Technology

Laser is an acronym for Light Amplification by Stimulated Emission of Radiation. Laser technology has advanced from a mere laboratory toy to an advanced technology in only about two decades. A laser device produces an extremely narrow, highly directional beam of light. This light beam tends to be scattered as it passes through the atmosphere. Certain light frequency bands are less subject to this scattering than others. Thus, developments in laser technology, like those in infrared, have been restricted to a relatively limited number of frequencies. Like IR also, many laser generating materials require cryogenic or thermoelectric cooling. Refinements and evolutionary developments can be expected in basic laser technology, but dramatic breakthroughs within the 1980s are unlikely. Advances will be primarily in the areas of laser applications.

A "ring laser gyroscope" (RLG) having an accuracy of about that of an inertial system, but at about half the cost and over 10 times the performance reliability, should be available by the mid-1980s. A "laser radar," functioning much like conventional radar but utilizing laser beams, may be available in the late 1980s. The technical feasibility of a scanning laser system for charting coastal water depths has been demonstrated. According to Optics and Laser Technology (August, 1978, p. 163), the system will also be tested for fluorosensing ability to detect and identify oil spills, pollutants, and algae. Such a system appears to have potential for a variety of Coast Guard applications. In addition to the above, advances utilizable by the Coast Guard can be expected from military research to develop laser systems for target detection, location, ranging, and tracking.

Laser and IR systems for reconnaissance share one functional restriction. They are limited to line-of-sight operation. Thus, the higher above ground or sea level they can be mounted, the greater their operational range. For Coast Guard purposes, they would best be used as airborne systems. Since they do not require immediate direct control and operation, the sensor or transceiver can be located at any distance from the operator. A remotely piloted vehicle (RPV) would be an ideal platform for Coast Guard deployment of these systems.

Another major area of application of laser technology is in the field of communications. This will be addressed in the following section.

Communications Technology

Electronic communications systems in the past have employed modulated sinusoidal carriers almost exclusively. Spectrum (1978, 15, p. 31) notes that general periodic wave carriers, usually as rectangular pulses, are attracting growing interest. This Pulse-Code Modulation (PCM) offers a variety of advantages. It immediately increases the capacity of the transmission medium. Standard telephone cables, for example, can carry twice the traffic with PCM than conventional. For long distance transmission, the signal can be regenerated virtually an unlimited number of times, but fewer repeaters are needed for PCM than conventional. It is also very tolerant of interference.

The higher the frequency of the transmitting beam the more information it can carry. Light beams can have frequencies millions of times higher than those of radio waves. Thus, conventional radio communications can be expected to give way to "digital radio;" increased development of communications systems utilizing light beams can be anticipated. Lasers probably will be the primary light source for these systems.

The limitations of lasers within the earth's atmosphere have already been mentioned (i.e., line-of-sight operation and the dispersion effect of clouds, mist, fog, pollution, etc.). These limitations would be minimal for systems operated at altitudes above atmospheric interference or at frequencies to which the interference is relatively transparent. It is important to note that laser communication does not require continuous transmission-reception. A "lasercom" system has already been demonstrated that is capable of a gigabit data rate (i.e., one billion pulses--the equivalent of the entire Encyclopedia Britannica--per second). Thus, only a brief "hole" in any interference condition would permit vast amounts of information to be transferred.

"Fiber optics" is the current "glamor boy" of communications technology. Optical fibers transmit light energy in much the same way that metallic wires transmit electrical energy and can be used in many applications where wire has been used. The inherent advantages of fiber optics, coupled with the rising cost and scarcity of wire metals, give grounds for expecting fiber optics generally to replace metallic wire wherever possible. The first conversion will probably be that of telephone lines. The combination of dramatically higher data transfer rate capability of light versus electrical frequencies and the employment of pulse-code modulation promises vastly increased telephonic communication capacity. Replacement of wire aboard ships and aircraft will probably follow.

Fiber optics require that the transmitter incorporate a light source and that the receiver incorporate a light sensor. Current transmitters employ solid-state light emitting diodes (LEDs) and injection lasers as light sources. Receivers depend on avalanche photodiodes (APDs) and PIN photodiodes. Neither of these embodies all of the desired characteristics of low noise, broad range sensitivity, low power requirements, temperature tolerance, and low cost. Further developmental progress is necessary.

The conversion to pulse-code modulation, fiber optics, digital radio, laser communications, etc., combines to offer the potential for unprecedented computerization, automation, and integration of many communication and operational control functions.

Functional Impacts

The four technological areas discussed were selected because of their potential impact upon the four critical Coast Guard functions of communication, navigation, surveillance, and information processing.

It seems likely that the technologies will have minimal effect on navigation. Laser gyroscopes may provide a better way of doing what inertial gyroscopes now do, but it is questionable at this time whether they will provide significantly more precise data. None of the technologies appear to offer potential for improved navigation over the precision now offered by LORAN C or possible navigation satellites. Use of either or both of these two navigational systems will, however, be enhanced by the projected advances in communications and computers.

Coast Guard surveillance capabilities will be greatly affected by improvements in infrared and laser sensor systems, especially if these systems are deployed in RPVs. Use of these sensors, with automatic telemetering of information to the shorebased command center, should result in dramatically improved and more effective surveillance/search and response operations.

These improvements will, in part, be a function of improved communications. The way in which an individual communicates (e.g., by telephone, radio, written notice, etc.), may not change. The way the systems transfer the content of such communications from originator to recipient will be very different and more reliable. Advanced communications systems will permit the automatic transfer of vast amounts of data and information, including such real time transfer of surveillance sensor data as mentioned above. This will give commanders unprecedented bases for their decisions and actions.

Large quantities of information can, of course, be more harmful than helpful if not appropriately presented. Communications systems will be fully capable of transferring far more information than a human can possibly handle in real time. Advanced computers will be able to process these data and present it in the manner most meaningful and useful to the system operator. The computer will also be able to acquire, process, and store much of the administrative information that now requires the attention and time of human processors. The communications and information processing functions are therefore likely to be most affected by the technologies surveyed for this report.

As was pointed out previously, IR and laser capabilities are line-of-sight limited. Consequently, their surveillance capabilities cannot be considered apart from the vehicles that will transport these systems to the area to be investigated. Two such candidate vehicles are the space satellite and the RPV.

It is outside the requirements of this effort to examine the space satellite and RPV as technological systems whose progress is to be forecast. The orbiting satellite used for military surveillance purposes has been state-of-the-art since the early 1960s. A series of such satellites can be orbited to maintain continuous surveillance over any area (limited only by the number of satellites needed to cover that area). Sensor resolution, although highly classified, is apparently good enough to identify types of vessels over 10 feet in length.

RPVs are largely experimental craft but their potential is enhanced by the ongoing development of long-range cruise missiles. In considering RPV capabilities, the authors have used anticipated cruise missile capabilities (e.g., variable altitude and speed) as the basis for projections of what will be possible with RPVs in the 1990-2000 time frame.

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COAST GUARD MISSIONS IN THE 1990-2000 TIME FRAME

Overview

This section describes three major Coast Guard missions (SAR, ELT, and MEP) as they might be performed with the use of advanced technology in 1990-2000. There is no reason to believe that these missions will be less necessary in the future than they are today. Conceivably the Coast Guard could be mandated with completely new missions at that time, but it is beyond the scope of this study to project these.

Although the Coast Guard will still continue to perform SAR, ELT, and MEP missions in 1990, these missions will change: (1) the environment in which these missions will be performed will be expanded, and (2) the manner in which they will be conducted will change if advanced technology is applied. The scenarios described below assume that the Coast Guard will take every possible advantage of technological change. Restrictions of finance and governmental authority may make impossible full development of Advanced Technology Systems.

These scenarios indicate the critical functions in which new technology could most profitably be employed and how they would be employed. In a later section, the implications of using that technology for personnel and man-machine interactions will be examined.

The new environment to which Coast Guard missions must be expanded is under the surface of the ocean. In an earlier study completed for the Coast Guard by Williams et al., (1978) it is stated that:

> ... we envision significant changes in underwater activities. Virtually all of these developments entail substantial implications for the Coast Guard.
>
> - Some major changes will occur in traditional concepts of marine military operations. The underwater arena will become proportionately more important. There will be substantial growth in the type and scale of military activities in the underwater environment.
>
> - Non-military operations concerned with the protection of property and life will also expand dramatically as a result of the: growing range of underwater activities; growth in antisocial technologies through which to disrupt marine activities; growing probabilities that such technologies can and will be used in extra-legal ways; growth in capabilities to predict natural catastrophies; and growing potential for accidents.
>
> - The marine environment will become much more involved with economic activities in all significant categories: energy, mining, marine agriculture, transportation, management of the injection of foreign elements, and recreation.
>
> - While we do not believe extensive underwater habitation will occur as a permanent alternative to land based

living, we do foresee some temporary human habitats to
serve functional or recreational purposes.

- Requirements for and technologies to achieve surveil-
  lance and monitoring will be a dynamic area.

- Scientific research will continue in a growing number of
  areas.

  - Regulations, standard setting, enforcement and
    inspection requirements will grow substantially
    and they will cover a number of new fields. (p.
    1-1)

It is quite possible that 1990 will see only the <u>introduction</u> of underwater farming,
fishing, ranching, and mining; but thereafter through the end of the century these
activities should increase rapidly. One can, therefore, anticipate some underwater
habitats (facilities in which to work and possibly even to live for extended periods of
time), an increased use of recreational, and even more importantly, commercial submarines,
much improved individual diving apparatus, and tools especially adapted to subsurface
operations.

Assuming the accuracy of this projection, it is probable that the only governmental
resource available to perform SAR and MEP underwater missions will be the Coast Guard.
It is hypothesized that the Navy will be fully occupied performing its military responsi-
bilities of safeguarding maritime security and will not be available for SAR and MEP
underwater missions. The Navy will be required to perform underwater ELT missions
(e.g., terrorists transitting in submarines, illegal underwater fishing), insofar as they
involve submersible craft and overlap so much with the Navy's antisubmarine mission.
Table 1 presents a detailed list of Coast Guard missions in 1990.

The Search and Rescue Mission

Introduction

In 1990 the Coast Guard will still be required to perform its SAR mission because
ships and aircraft will still become lost and/or sink. The volume of SAR will increase
because of increased use of recreational vessels. The recreational and commercial
civilian submersible with sizes ranging from one man boats to large, multi-man cargo
carriers will see increasing use. Since submersible craft function in a more complex
environment than do surface craft, one would anticipate a disproportionate increase in
percent of submersibles requiring SAR. (In addition, such craft will require inspection and
certification; users will have to be licensed to operate them. This could be an additional
Coast Guard responsibility under ELT because the Navy would have no authority over
civilians.) Rescue of sick or injured personnel aboard offshore oil rigs will also be
necessary. Personnel living or working in the subsurface habitats may become sick or
injured and need Coast Guard assistance.

Of the six SAR missions listed in Table 1, only two involve submersibles or subsurface
environments and the frequency of subsurface SAR missions is not expected to be great.
When these do occur, they will present substantial challenges to the Coast Guard. The
technology involved changes markedly for both surveillance and rescue functions. Some
of the sensor technology useful for surface operations (e.g., IR and radar) cannot be used
in the subsurface environment and attention must now be directed toward acoustic (sonar)

imagery. The rescue technology for the subsurface environment must involve submersibles of various sorts: submarines, diving bells, hard hat, and scuba diving apparatus with underwater communications.

Table 1

Coast Guard Functions Performed in 1990

Functions		Problems
A.	Search and Rescue:	1. Lost or sinking recreational and commercial vessels
		2. Lost or sinking commercial and recreational submersibles
		3. Lost or downed aircraft
		4. Personnel aboard oil rigs in need of assistance
		5. Personnel missing or injured in subsurface habitats (e.g., farms, mines)
		6. Transportation of injured or sick aboard surface ships
B.	Enforcement of Laws and Treaties:	1. Protection of offshore oil rigs against criminal elements (e.g., terrorists). (Navy may handle subsurface protection.)
		2. Inspection of offshore surface and subsurface habitats for conformance to safety regulations
		3. Inspection of all surface and submersible vessels for conformance to legal and safety requirements
		4. Licensing of personnel to function in subsurface jobs (e.g., mining, ranching, etc.)
		5. Prevention of illegal surface activities within the 200-mile limit. (Navy may handle subsurface prevention.)
		6. Monitoring of surface vessels to ensure conformance to treaty provisions for fishing, waste disposal, etc.
C.	Marine Environmental Protection:	1. Surveillance of surface and subsurface areas to detect and track pollution
		2. Clean-up of pollution (e.g., oil leaks, chemical and radiological pollution, unacceptable waste disposal)
		3. Inspection of surface and subsurface habitats and vessels for conformance to environmental standards

Performance of the search and rescue mission for lost or sunken submersibles may require these vessels to carry something equivalent to an acoustic EPIRB (i.e., emergency position indicating radio beacon), automatic signalling apparatus that would be activated by the submarine's crew as soon as an emergency arose. This would largely obviate the need to make sonar searches to locate the submersible. Nevertheless, the Coast Guard would have to have a sonar capability for those hopefully rare situations when the location of the submersible is unknown. Fixed underwater habitats (e.g., mines, farms) would also require an acoustic EPIRB although their location would be quite precise. Personnel hoping to work in such habitats would have to have special training and licensing before the Coast Guard could permit them to work underwater.

The advanced technology available for 1990 missions will be needed infrequently. To the extent that missions involve only simple situations (e.g., a motor yacht out of fuel and drifting) present Coast Guard technology will probably suffice as well as anyting more sophisticated. The advanced technology will exist to be used when required by complex situations, but it is unlikely to be in constant demand.

Description of Search and Rescue (Surface) Functions

1. **Receive distress message from**

   a. Radio
   b. Telephone
   c. Radio/telephone
   d. Transponder aboard vessel (e.g., EPIRB)

It is assumed that in the 1990 time frame most distress messages will be received as they are now, via radio, telephone, or radio/telephone. In the event that the vessel possesses a transponder (e.g., EPIRB) its activation will automatically alert the Coast Guard station to the distress situation. EPIRB-type signals as presently utilized do not automatically localize the vessel's position (this must be done by triangulation from bearings received by at least two separate receiving stations).

2. **Collect information about distressed vessel**

   a. Position (geographic coordinates)
   b. Vessel condition (e.g., speed, direction of movement, vessel drift)
   c. Weather
   d. Sea state

Once a distress call has been received, the most important questions to be answered are: where is the vessel located; what is the vessel's condition; and what are the climatic and sea conditions at the vessel's location? Should precise vessel location not be available the Coast Guard should have two resources available to it: (1) satellites orbiting the earth in such position as to command continuous surveillance of the coast line and offshore areas, and (2) Remotely Piloted Vehicles (RPVs) similar to present drone aircraft, capable of being launched from a Coast Guard station, flying predetermined or manually controlled search patterns, telemetering sensor information and geographic coordinates to a computer and returning to the Coast Guard station. Satellite surveillance will provide continuous monitoring of all vessels (at least 10 feet or longer). The satellites will also have the capability to pick up EPIRB type signals and relay them to the Coast Guard station. Since at least two satellites will be required to provide continuous coverage, each in a somewhat different position relative to the EPIRB signal, they can be used for triangulating that signal. RPVs will provide periodic or emergency surveillance with

somewhat finer detail than can be provided by satellite. (Consideration of cost factors is not provided here. It is recognized that the development of resources such as these would be expensive and it is anticipated that the Coast Guard would perform cost effectiveness studies before adopting any new technology.)

The orbiting satellites (multiple to provide 24 hour coverage) will be provided with photographic/television and IR capabilities with a sensitivity equal to or greater than current spy satellite resolution (this resolution is highly classified and cannot be reported here). Sensor information from the satellite will be telemetered back to the Coast Guard station where it will be processed by computer.

Although the satellite provides 24 hour data, its output need not be monitored by the Coast Guard on a continuous basis (although it may wish to do so as a matter of policy). The computer operator may interrogate the computer at any time, when he does so, he will be able to select from a "menu" any one or more of a number of functions, e.g.:

a. Sensor type (photo/TV/IR)

b. Total area coverage

c. Selected subarea coverage (according to coordinates specified by the operator)

d. Selected time periods

e. Selected vessel sizes

f. Selected vessel travel directions (e.g., south southwest)

g. Position of all vessels at any specified time period

h. Time-compression presentation of all vessel tracks over a specified time period

i. Hard copy printout or microfiche reproduction of data

j. Weather information (fed in not from the satellite but from a central meteorological station)

k. Sailing data for all vessels filing this information

l. Alternative search patterns with computer probabilities of search success

m. Resource availability information (e.g., availability of cutters, aircraft, etc.)

n. Composition and transmission of required Coast Guard reports to head-quarters

o. Transmission of selected search pattern coordinates to RPV

p. Reception and processing of RPV telemetered data

Selection of command input or data request might be on a verbal basis. A keyword representing the program for a category of information would be spoken to the

computer, which would then call up the appropriate program. (Verbal inputs to computers consisting of one or two words from a limited vocabulary are presently standard and will be much increased by 1990.) If the operator did not recall all possible categories he could then ask the computer to either display or even to speak the list. The information supplied by computer would be presented on a large screen display tied to the computer. The display would have the capability of magnifying any desired screen area or of being split into subsections with each subsection presenting a different type of information.

Since the satellite is telemetering information continuously, it would rapidly overwhelm computer core storage; hence, the computer is programmed to make a mass "dump" of its data once every 24 (or other period) hours to magnetic tapes that can store the information indefinitely.

The computer would be used to attempt to determine vessel location only when other information (e.g., from EPIRB) was not available. This determination would be based on deduction from partial cues such as the vessel's size and speed and other information such as any travel plans filed. The computer operator wishing to determine the coordinates of the distressed vessel might, for example, indicate to the computer the last known location of the vessel, its relative size, and direction of travel. The computer would then output all coordinates for vessels in the area specified that have the desired size and travel direction. This output would permit the computer operator to select the best SAR plan available to him.

3. Develop SAR plan

    a. Determine that available information is sufficient to develop (or utilize an already available) SAR plan without computer-aiding.

    b. Develop/select SAR plan.

    c. Determine which SAR units are available.

    d. Select appropriate SAR units.

    e. Dispatch SAR units.

In the great majority of cases the vessel location is known relatively precisely or is within a short distance of the land, so that the SAR plan is either obvious or can be developed without computer assistance. In that event the sequence of steps listed above are obvious and require no special technology. If the number of SAR units available to the dispatcher is sizable, the computer can be used in its bookkeeping mode to list those units immediately available. Where the vessel location is unknown and the emergency situation is so complex and serious that an already available SAR plan cannot be used (duty officer's judgment), the officer on duty will command the computer to develop the SAR plan.

Among the computer facilities available to the Coast Guard officer is a software program dedicated to planning. This program can be activated by inputting a keyword (identifier) either verbally or by typing it on the computer keyboard. The computer will respond by asking for the incident number assigned to the emergency. The program will immediately incorporate all available information in its memory banks about the target vessel and will procede to output the following:

- Area to be searched (geographical coordinates plus pictorial map display)
- Search patterns to be followed (pictorial)

- SAR units required and available
- Time period in which search is to be conducted
- Weather predictions for search area
- Estimated success probability of the search

The computer will provide alternative search scenarios if the officer indicates that he rejects the first scenario presented, or if he adds or changes an item of information about the emergency. After the officer has decided on the SAR plan he will accept, he requests a hard copy printout of the material that has been displayed (for station files). Concurrently, a copy of that scenario is automatically transmitted by the computer over telephone lines to Coast Guard headquarters.

(At this point it might be desirable to point out that all computers of this time period can be used to compose and transmit to any other Coast Guard station documentation reports and other messages. Report formats will be pre-structured so that it will be necessary merely to indicate the item number in the report and the information it should contain; the computer will format that report and transmit it after receiving authorization. It will be possible to compose reports verbally.)

4. Conduct search

The present method of locating a missing vessel or one in distress whose coordinates are imprecise, is to launch an air or sea search. The restricted speed and range of helicopters and cutters make it difficult for these units to cover large areas quickly. In the 1990 time frame, electro-optical surveillance capabilities will be such that only a method of placing these capabilities into position will be needed to make use of them. The method of delivering the surveillance will be the Remotely Piloted Vehicle (RPV), which will be launched from the Coast Guard station.

(The Coast Guard has been investigating the launching of RPVs at sea from the deck of cutters. This procedure, which would be very difficult because of the unstable platform resulting from sea motion, is unnecessary because the range of the RPV in 1990 will probably be somewhere between 500 and 1000 miles. This will make it entirely feasible to base the RPV on land.)

The RPV will be launched from a special launching platform located external to the station, in much the same way that a small missile is presently launched, after a number of checks of its operational readiness. The search pattern the RPV will fly has been output as part of the SAR plan. Should the duty officer decide to make use of an RPV for search purposes he does the following:

a. Orders the computer to transmit search plan coordinates to the RPV, which has both terrain following (coast line) and inertial guidance (open sea) capabilities.

b. Orders the RPV operator to select one or more of the sensor capabilities the RPV possesses: photographic, TV, or IR (for night time or foggy conditions).

Prior to the start of an RPV mission, the RPV operator located in the control room (which contains the RPV console, associated display equipment, closed circuit TV, and the computer referred to previously) runs through a pre-start checkout from his console. Once an OK has been received from the automatic checkout instrumentation in the console, and upon command of the duty officer, he launches the RPV. Activation of the search pattern in the RPV also automatically outputs a cathode ray tube (CRT) map display that pictures RPV position in relation to map coordinates and also to the proposed search pattern, which is overlaid on the electronic map.

The RPV is programmed to follow the search plan as developed by the SAR computer. During its flight, it automatically transmits signals representing the imagery its sensors pick up. Upon order from the the RPV control console, this imagery is presented on the large screen display associated with the computer. Thus, the duty officer and RPV operator can view in real time what the RPV is viewing.

The search plan specifies an altitude at which the RPV is to fly, depending on weather conditions. The RPV operator can override the search plan instructions and assume manual control based on a TV presentation of what the RPV is seeing. To fly the RPV manually, he has a 6 degree of freedom joystick that enables him to change bearings and increase or decrease altitude. He may require the RPV to orbit any object for which longer surveillance is desired. When a target is spotted, the operator may require the RPV to fly lower and circle the target until the operator determines that the craft is in no danger. For this purpose, the operator may activate the zoom feature of the TV instrumentation.

All signals received from the RPV are stored in the computer for 24 hours and then transferred to magnetic tapes. Accompanying the sensor imagery are the geographic coordinates at which the imagery was received. These coordinates will be used to direct SAR surface units to the distressed vessel.

When the distressed vessel is located, the RPV is ordered to orbit the vessel and provide continuing TV coverage until the SAR surface units reach the scene. The duration of this orbit depends, of course, on the amount of fuel available. The RPV operator monitors displays on his console that indicate the amount of fuel remaining. When returned to the Coast Guard station, the RPV is retrieved.

5. Perform on-scene rescue activities

As indicated in the previous section, surface and/or air SAR units have been proceeding to the location of the target vessel. The actual rescue function requires ships and/or aircraft because the RPV, being small, cannot be used for such functions as dropping life rafts, life vests, extinguishers, etc., and actually picking up and transporting rescued personnel. Surface rescue efforts will be performed in 1990 essentially as they are today. Consequently, no extended discussion of this function is needed.

Description of Search and Rescue (Subsurface) Functions

1. Receive distress call from

a. Emergency signal
b. Report of overdue submersible

If a civilian submersible encounters a difficulty, it will signal by activating an EPIRB type signal that will be reported to the Coast Guard station. Alternatively, information received from the Navy or other civilian sources about an overdue submersible will initiate emergency activity. Emergencies could also be signaled by subsurface habitats, which activate an emergency signal. Presumably the habitat would have some routine means of communicating with the surface.

2. Collect information about submersibles

a. Position
b. Condition of submersible (e.g., depth, damage)

  c. Weather

  d. Sea state

    Collecting information about a submersible in trouble presents the Coast Guard with problems somewhat greater than those presented by surface ships in distress because of subsurface operation. Military submarines presently possess radio devices comparable to the EPIRB. The submarine surfaces a buoy on the end of a cable and the buoy contains a radio apparatus that automatically emits a distress signal. The signal does not localize the submarine's position, but can be calculated by triangulation from receiving aircraft or ships. Depth information is not included in the distress signal, however, once the submarine's position is fixed, charts of the sea bottom will indicate the sub's depth.

    Civilian submersibles should be required by law to possess the locator equipment described in the previous paragraph. Triangulation can then be achieved using two or more satellites with very sensitive receiving apparatus in orbit over the coastal area. Satellite data will then be transmitted automatically to the Coast Guard station computer; a special software program receiving and processing such distress signals will automatically alert the Coast Guard duty officer to the occurrence of a downed submersible.

    The state of technology in 1990 will make available distress signalling apparatus, which can monitor critical parameters and transmit simple messages describing the depth of the submarine and the condition of the boat and crew. This information would, of course, be of tremendous value to the Coast Guard for both search and rescue and post incident investigation. Radio alerting apparatus data can be computer displayed on a large screen. Depth of the submarine could be ascertained from a chart of the sea bottom. Weather information would be derived from the computer's continuously updated files of radio weather reports for various continental shelf areas. Sea state information might also be available.

3. Develop SAR plan

    No SAR plan would be required if the sub's position were localized as described in 2. If no distress reports were made and the submarine were overdue, however, it would be necessary to mount a search. Under these circumstances the computer would be asked to prepare a set of search plans based on whatever information about the sub (e.g., its projected sailing plan, size, speed, etc.) the duty officer could input to the computer. The computer would output alternative search plans as described in the section on surface search.

4. Conduct search

    Assuming that the location of the submarine is only approximate, it is expected that search for it would be accomplished primarily by sonar and underwater television. Initial search might be conducted by a helocopter using "dipping" sonar or by a cutter with high precision sonar to locate the wreck. Once the submarine has been located, primary emphasis would be placed on securing information about the submarine and crew condition.

    The technology presently exists (e.g., the Navy's Mine Neutralization Vehicle (MNV)) to dispatch a tethered unmanned vehicle with short range sonar and photographic capabilities to swim to the site of a downed vessel and report back precisely where it is. In the MNV mission the vehicle is launched from the surface at a point several hundred yards from the mine, finds the mine by means of sonar and when it reaches the immediate

vicinity of the mine the operator (on the surface) switches to photographic display. Such a system could be used to locate and inspect a downed submarine or the entrance to an underwater habitat. A subsurface vehicle might be required to reach the site of an underwater emergency. The vehicle will either be a submarine specifically designed for rescue purposes, to clamp to a distressed vessel with provisions for entering that vessel; or a diving bell. Subsurface SAR missions may also require personal equipment such as diving suits. In any event, the technology to permit such rescue activities is either presently available or will be available by 1990.

Enforcement of Laws and Treaties

Introduction

The types of threats to be countered in the 1990-2000 time frame are roughly the same as those presently encountered. Smuggling, illegal immigration, and hijacking will almost certainly continue and there will be increased emphasis on maintaining surveillance over fishing ships from other nations. To the extent that the terrorist threat continues to escalate, much more attention will have to be paid to this quasi-military activity. The mode in which these criminal activities are carried on may change. An increasing number of terrorists may make use of submersibles. Hijacking raids on subsurface mining operations and terrorist raids on offshore oil rigs are quite possible. The detection and apprehension of subsurface malefactors will be a particularly difficult problem for the Coast Guard.

ELT missions have two aspects. The Coast Guard expends considerable resources in patrolling coastal and offshore waters to detect lawbreakers, or at least to deter potential lawbreakers, by "showing the flag." In the course of these patrols, an actual or potential lawbreaker may be detected and then action is taken to arrest the craft involved. In the 1990-2000 time frame at least some of the patrol/surveillance activity required by this mission could be taken over by satellite and RPV surveillance. The phrase "some" is used because there is apparently no substitute for the physical presence of a patrol cutter or aircraft to stimulate suspicious behavior on the part of an illicit vessel (e.g., turning to another course to avoid meeting a cutter) and to physically arrest that vessel's crew. The role of the cutter in ELT will not be significantly reduced, but satellite and RPV surveillance should add significantly to the effectiveness of ELT.

It will be recalled that we postulated a series of continuously orbiting satellites to be used for SAR. The same satellites can provide surveillance for ELT purposes. Data from those satellites will be received by the ground station computer, processed, and displayed on large screen displays. These displays will present the tracks of all vessels within the area being surveyed by satellite. Photographic, TV, and IR resolution should be sufficient at the very least to identify the vessel class. The Coast Guard will know the location of every vessel in a given area. More detailed surveillance can be provided by RPV.

Tracks provided by satellite data will provide the "big picture." This information will be especially useful in monitoring compliance of foreign vessels with fishery treaty limits. Such vessels will, of course, know that they are under satellite observation, which may cause them to be more restrained in any illegal activity. In addition, vessel activity in areas of high crime potential (e.g., approaches to Florida) could be identified. The cues used to cause the Coast Guard to suspect a specific vessel are so subjective that it is unlikely that satellite surveillance data will pinpoint a particular vessel for boarding.

The Coast Guard will continue to rely on informant tips and sightings by civilian vessels. It should have the capability of monitoring individual surface craft remotely by

flying a surveillance RPV to the vicinity of a suspected vessel and performing visual reconnaissance. The patrol cutter will still be required to board vessels, but the effectiveness of patrolling will be significantly increased by the RPV.

The Coast Guard officer at a ground station may require, on the basis of satellite data, that vessels in a particular area should be more closely inspected. An RPV will then be flown to the area in question. RPV transit to a general area can be performed automatically using satellite geographic coordinates processed by computer. Upon arrival at the general area of suspect traffic, the RPV operator will assume direct manual control of the vehicle and fly it to each vessel in turn. TV, photographic, or IR imagery of the individual vessel can be received and processed in real time. The RPV can be made to orbit at an altitude high enough to avoid gun fire (or follow a vessel if it endeavors to escape) until a cutter receiving coordinates from the RPV can arrive on the scene.

Description of Enforcement of Laws and Treaties (Surface) Functions

1. Receive information about suspicious activity

    a. Shore station

        (1) Informant tip
        (2) Citizen complaint
        (3) Satellite displayed information

    b. At sea

        (1) Cutter
        (2) RPV observation

2. Initiate surveillance of suspected craft

    a. On shore

        (1) Order surface unit already at sea to intercept.
        (2) Dispatch surface and/or air unit.
        (3) Launch RPV.

    b. At sea

        (1) Order craft to stop for inspection.

3. Dispatch air and/or surface units

    This would be performed as at present. Cutters should be capable of receiving RPV imagery and coordinates.

4. Board and inspect vessel

    Performed as at present. RPV would leave the area as soon as Coast Guard cutters reach the vicinity of the suspected vessel.

5. Return RPV

    The RPV will be landed under control of the RPV operator.

Description of Enforcement of Laws and Treaties (Subsurface) Functions

The Coast Guard will encounter a much more difficult problem in ELT relating to subsurface activities. Assuming subsurface habitats associated with subsurface farming, ranching, and mining, it is highly probable that the Coast Guard will be given the responsibility for inspecting these facilities for conformance to safety regulations (an activity parallel to one it has presently for surface vessels). It will also probably be given responsibility for inspecting non-military submersibles used either for recreational purposes or as part of the mining, ranching, and farming enterprises mentioned previously.

In order to perform such inspections, it will be necessary for the Coast Guard to possess a number of specially designed submersibles or other diving equipment that can reach the subsurface habitat. This requirement will have implications for Coast Guard research and development in the submarine area because off-the-shelf submersibles are not adaptable to the Coast Guard mission.

In view of the fact that illegal submarine activity by civilian craft will bring them into the Navy sphere of responsibility to protect national security, it is unclear whether the Coast Guard should have ELT responsibility for apprehending illegal activities by non-military submersibles. Any Coast Guard monitoring of submarine activity would inevitably overlap with the Navy's already existent monitoring activity. The Navy may retain responsibility for dealing with illegal activities of non-military submersibles. This will not, however, in any way affect the Coast Guard's SAR responsibility for submersibles and subsurface habitats.

Marine Environmental Protection

Introduction

The major impact of new technology on the MEP mission is to automate the surveillance of possible pollution areas and the sensing of actual pollution when it occurs. Once a polluted area is discovered and located, cleanup functions will be performed in much the same way as they are now, although undoubtedly containment devices, anti-pollutants, etc. will be much improved by 1990.

The principal mechanisms for automating surveillance of possible pollutants will be as in the case of the SAR mission in the RPV. The RPV could carry a laser spectrometer that transmits a beam of light in the IR spectrum, which is reflected from the ocean surface to an IR receiver in the RPV. Most serious oil spills will be detected by on-the-spot personnel (as in the case of tanker collisions), but the introduction of subsurface mining may produce subsurface pollutants that rise to the surface and drift. Another possible subsurface source may be pollutants resulting from subsurface seismic disturbances. Such pollutants might not be easily discovered. Under these circumstances, routine search of potential pollutant areas would probably be instituted. The frequency of such searches would have to be determined on the basis of cost-effectiveness tradeoffs between the cost of instituting the search and the probability of discovering pollution.

The RPV launched for such a search would probably be identical with that launched for SAR missions except for the instrumentation package that would contain the laser spectrometer rather than the photo/TV/IR package. Identical RPV vehicles could be used for both types of missions merely by replacing the instrumentation module as necessary.

The stages of the MEP mission are:

1. Receive spill information.
2. Determine spill location.
3. Determine MEP operational requirements.
4. Alert MEP units.
5. Transit MEP units to spill location.
6. Deploy equipment, contain spill, and perform cleanup.

Description of Marine Environmental Protection (Surface) Functions

These stages are described below:

1. Receive spill information

    This information may be received in a number of ways:

    a. SAR or ELT cutter patrol report.

    b. Telephone or radio/telephone report from non-Coast Guard source (e.g., fisherman).

    c. Message from stationary remote sensing source (e.g., environmental buoy).

    d. Data from RPV routine patrol surveillance.

2. Alert MEP units

    Performed by telephone or radio/telephone.

3. Transit MEP units to spill location

    Performed by sea or air in conventional manner.

4. Deploy equipment, contain spill, and perform cleanup

    These functions may involve advances in technology but not in the technological areas studied in this report.

Description of Marine Environmental Protection (Subsurface) Function

It was pointed out previously that when subsurface mining and drilling are initiated, some pollution may result from these activities. Information about such pollution might be received through any of a number of ways: a subsurface m 'er might notice the pollution and report it; the subsurface pollution might rise to the surface and be noted by a surface vessel; or on a periodic MEP patrol in a Coast Guard submersible the crew might note the pollution.

The MEP subsurface mission is considered a Coast Guard responsibility parallel to its MEP surface responsibilities. It is possible that the MEP subsurface mission may also include the requirement to conduct subsurface cleanup operations. There will clearly be a requirement for underwater inspection of mines to determine actual or potential sources of pollution. The submarine technology described in the SAR mission will be needed in the MEP mission with all of the personnel and man-machine implications that technology would have for the Coast Guard.

The phases of subsurface MEP would therefore be:

1. Receive information about possible subsurface pollution

   a. Surface observation
   b. Subsurface observation

      (1) Worker
      (2) MEP subsurface patrol

As indicated previously, there are a number of ways a subsurface leakage or pollution could be suspected.

2. Develop search plan

   a. Knowledge of subsurface mine locations and topography
   b. Computer-developed plan

It is axiomatic that the Coast Guard will know the location of all underwater mining and farming as well as the detailed topography of the sea bottom. Based on this knowledge, the duty officer may well develop his own search plan. Alternatively he could input to the computer all relevant data and ask it to draw the most effective subsurface search plan. The general operations by which such search plans are developed by computer have been described in the section on the SAR mission.

3. Conduct search

   a. Transit 1-2 man submersible to vicinity of possible pollution source.
   b. Conduct subsurface visual observation.
   c. Identify pollutant source.
   d. Call Coast Guard station for cleanup unit.

It is assumed that a 1-2 man submarine will conduct the search using visual observation aided by intense spot lighting. When the source of the pollution has been found, the submarine will request cleanup assistance.

4. Transit cleanup units

   These will be sent to the underwater site.

5. Perform subsurface cleanup

   Very advanced technology will be required, including bionic devices (remote manipulators).

6. Return MEP units to station

   As performed presently.

Summary

It is possible at this point to integrate the preceding mission analyses to summarize exactly how the technological advances described impact on the SAR, ELT, and MEP missions. To do so we have developed the diagram shown in Figure 2.

Figure 2 Summary of Technological Impact on Mission Phases

Each mission has two subsets, surface, and subsurface (any activity involving distressed aircraft is included by implication in the surface subset). Each mission has been categorized into seven phases: emergency alert, collect information, develop plan, conduct search, transit units, on-scene activities, and return units.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations in this section of the report are divided between those describing personnel numbers, skill, knowledge and training requirements, and those describing man-machine interactions.

Personnel Implications

Introduction

The recognition of personnel requirements imposed by new high technology hardware systems is critical for adequate implementation of such advanced systems. The initial operational effectiveness of a new system may be severely degraded until its manpower requirements can be met. System ownership can involve an unexpectedly high personnel cost element. A general rule-of-thumb estimate in Navy planning circles is that direct personnel and training costs will account for approximately 50 percent to 55 percent of total system life cycle costs.

Personnel implications are likely to become even more critical in the future. It is general knowledge that the size of the entry-level labor pool will be reduced for at least the next decade due to lowered birth rates in the recent past. The academic achievement of high school students has declined over the past decade and no significant improvement is anticipated for the immediate future. There will be increased competition among virtually all employers, including the Coast Guard, for qualified personnel from this pool. The acquisition of advanced technology systems could conceivably depend not on the Coast Guard's need or ability to pay for them, but on whether adequate numbers of qualified personnel can be recruited and trained to operate and maintain them.

Tradeoffs among the various factors affecting the manpower needed to utilize new systems make predictions very tentative. For example, the projected introduction of RPVs might reduce the number of cutters now needed for SAR patrols. Thus, the number of personnel required to operate and maintain the reduced number of cutters could be reduced. Increases in the number of recreational vessels sailing coastal waters might increase the number of distress calls for Coast Guard services and thus require additional smaller boats.

Personnel implications of technology may take one or more of several forms.

1. Eliminate personnel tasks entirely through automation.

2. Simplify or restructure personnel tasks to require (desirably) lower personnel skill levels.

3. Modify traditional tasks by providing mechanisms for performing the modified tasks that require new (and hopefully lower) skill levels.

4. Impose added and/or entirely new tasks/functions on personnel.

These changes may affect either the operation of a system or its maintenance, or both. It is not unusual for "savings" in operating personnel to be lost by increased requirements for maintenance personnel. Specific personnel implications of technological developments are dependent on the detailed characteristics of the individual equipments introduced. Several major trends have emerged from the technological and mission projections made in this report.

Personnel Implications of Computer Technology

Developments in computer technology continue to drive down costs and increase reliability and computational capability, especially in microcomputer and microprocessor applications. Computerization of functions is not merely cost-effective but cost-essential. It is possible that virtually any and every function that can be computerized will be computerized and automated. Automation of functions can be expected to lead to integration of functions.

As an extreme, computerized, automated integration of engine control, steering, navigation, sensors, communications, etc., could permit even a large cutter to be "operated" by essentially one or two persons. Manning would then be dictated by auxiliary requirements for administration and onboard maintenance, lookout and line handling, survivor rescue, boarding and inspection parties, etc. Administrative paperwork, a perennial burden in all services, could be eliminated by computerizing records--with those not essential for day-to-day onboard needs transferred, perhaps daily, to a shore-based computer for permanent storage.

Computer technology will have a beneficial effect on maintenance. Non-repairable--at least onboard ship--solid state components will reduce a large portion of electronic maintenance to remove-and-replace operations. Computer aided trouble shooting will be incorporated into many future systems. Electronic and sensor maintenance will involve fiber optic and laser technology, and maintenance personnel will have to be trained in the skills and knowledges relevant to those technologies.

Computer monitoring of heat, pressure, fluid flow, and other sensors embedded in operating systems will warn of impending or developing failure and cause automatic shut-down in case of sudden failure, thereby tending to reduce corrective, and possibly preventive, maintenance requirements. It is to be expected that the minaturization of computer capability and packaging will permit even small cutters to have their own minicomputers. The growing use of computers will clearly make orientation in computer (i.e., microcomputer and microprocessor) operation, and elementary programming, as essential as any "basic seamanship" subject.

Technological personnel implications for shore installations will probably be similar to those described above. Shore facilities will employ larger computers than cutters, with relatively large computers residing at each of the District Headquarters and smaller computers at subordinate bases and stations. These should be capable of storing operational, administrative, logistic, personnel, and other record files appropriate for the level of command, thereby minimizing the paperwork burden. They should also be capable of major data processing and analysis, and simulation, in order to aid command decision making by providing options. The shore-based computer should be able to present a real-time display of the evolution of a SAR or ELT case, process and display information telemetered from remote sensors. Automation and integration of the many functions performed by the Coast Guard should permit their accomplishment by a minimum number of personnel.

System operation will depend on highly sophisticated computer programs, which will require knowledgeable programmers. Despite manufacturers' glowing claims, computers continue to go off-line at inconvenient times. Highly skilled computer maintainers will be essential for each shore installation having a computer in order to ensure reliable system operation.

Personnel Implications of the Subsurface Environment

A variety of personnel implications are inherent in the projected expansion of Coast Guard missions to include the subsurface environment. The significance of these implications will depend upon the additional work load that environment will impose upon the Coast Guard. Whether the expansion to subsurface operations will require additional numbers of personnel cannot be determined. Personnel performing subsurface tasks will have to meet significantly more stringent physical and mental standards than required by surface tasks. The Coast Guard will be required to examine its recruiting, selection, assignment, training and test criteria, and procedures to accommodate these increased demands.

Undersea operations will probably involve both scuba and "hard hat" diving; the operation of "wet" and "dry" submersibles; the operation of underwater sensor, navigation, and communications devices; the transfer of personnel to a submerged Coast Guard recovery vehicle and/or surface vessel; and the attachment of devices for the retrieval of sunken submersibles.

New tasks will include the operation of shipborne underwater sensing systems, possibly in conjunction with airborne sensing systems, to locate a distress site precisely; the launching, operation, and recovery of remotely controlled underwater search vehicles; launch and recovery of personnel escape devices; operation of decompression chambers; and launch and recovery of submarine retrieval devices. Tests and inspections of underwater habitats, mining, and farming operations, will probably become a Coast Guard responsibility.

Certain of these functions (e.g., inspection and testing) are already performed by the Coast Guard for surface vessels and it is logical to hypothesize that these responsibilities will be extended to submersibles. These functions, when applied to submersibles, have skill and knowledge requirements that are relatively new for the Coast Guard. The Navy has had extensive experience in subsurface operations and it would, therefore, be logical to suggest that training of Coast Guard personnel for subsurface missions should most efficiently be accomplished through use of Navy training facilities.

The expansion of the Coast Guard MEP program to encompass underwater mining and farming will probably have some of the same personnel implications of the expanded SAR program. New MEP functions will be similar to those of the SAR and may involve the same personnel and equipment. For example, on-site inspection of underwater mining and farming operations will probably be required to ensure compliance with anti-pollution standards. This will probably involve both direct observation and the use of sensing and/or sampling devices. Pollution from underwater operations could pose significant problems in determining the specific source. The ability to identify the nature of the pollution by spectral analysis or IR, laser or other "signature" methods might provide a clue to the location of the source. But actually locating the source could be another matter if undersea currents and surface drift moved the detected pollutants far from the source. Actual determination may require the deployment of manned or unmanned underwater search vehicles and the employment of a variety of sensors to trace the pollution back to its beginning. These vehicles and personnel could be the same used for underwater SAR operations.

Personnel Effects of Satellite Technology

The employment of satellites for surveillance, navigation, and communications does not appear to have many or significant implications for enlisted personnel. The satellite is essentially an information source and makes little functional difference to an earth-bound operator. There are major implications for officers, especially at shore based command centers. Satellites along with computers, as information recorders and processors, will provide decision makers with a dramatically increased amount of data and information upon which to base their decisions. The data and information may be so great as to threaten to overwhelm the decision maker if not pre-screened and processed. Training of officers will probably be required to make effective use of computers as decision aids, the extent of the training being dependent upon the command decision hierarchy and the sophistication of the satellite supported computer system.

Personnel Implications of Remotely Piloted Vehicles

The employment of remotely piloted vehicles equipped with sophisticated, advanced sensor systems for search and surveillance functions has significant personnel implications. The most obvious and immediate implication would seem to be a reduction in the numbers of personnel needed to pilot, maintain, and repair aircraft and to man and maintain surface craft replaced by the RPVs. These reductions must be weighed against the numbers of personnel necessary to operate and maintain the RPVs and the sophisticated sensor, data processing, and telemetering systems installed in them. With maximum computerized automation, the operation of an RPV might be accomplished by two persons: one to monitor and remotely control the sensors, and one to manually over-ride the otherwise computer-controlled automatic pilot. Control of the RPV will require skill levels approaching those of conventional aircraft pilots. (It would be speculation to suggest that the RPV controller should be an aviation officer.) With lower levels of automation, the sensors would require greater numbers of personnel, with potentially dramatically higher levels of skill and technical knowledge, to operate the sensors and analyze and interpret the data telemetered back to the command center. Maintenance implications will depend on the number of RPVs to be maintained and the characteristics of the vehicle and its installed systems.

Requirements for maintenance and repair of the vehicle and its propulsion, control surfaces, and linkages are not expected to be significantly different from those for conventional aircraft. The servo mechanisms and telemetry equipment needed for remote control may add significant personnel qualification requirements onto those already required. Maintenance and repair of the sensors and onboard data processors is expected to require a high level of personnel proficiency. Certain characteristics of technologically advanced systems may tend to reduce needed proficiency levels. Application of solid state integration to IR receivers could eliminate the tedious, time-consuming need for precise alignment of the elements of the sensor array. Solid state technology may reduce or eliminate the problems inherent in maintaining the mechanically rotating mirrors in various laser devices.

Summary of Personnel Implications

In general, the technology and mission projections presented here tend to hold promise for potential reductions in numbers of personnel, both officer and enlisted. There may also be a tendency toward dichotomization of enlisted operator proficiency requirements (i.e., low or high rather than a continuum from low to high). Maintenance requirements are likely to be higher both in terms of numbers of personnel and their qualification requirements. The impact on officer personnel will not be especially great,

except that the need for pilots and commanders of smaller cutters will be reduced as a result of the introduction. Advanced technology will impose a broad spectrum of training requirements in order to qualify both officer and enlisted personnel for their operation and maintenance tasks.

Man-Machine Implications

Introduction

The previous discussion on personnel implications focused on technological implications for Coast Guard personnel. This section will address technological implications of the relationships between personnel and advanced systems. Specific man-machine interactions will depend on individual equipment features but certain general relationships can be anticipated.

The growing utilization of computers will probably have a dramatic, revoluntionary, impact on the way in which Coast Guard personnel accomplish their assigned functions. These impacts can be grouped into two general categories, those deriving from (1) the increased employment of computers for decision-making, information storage, and processing, and (2) from the use of microprocessors and microcomputers as mediators between the operator and the machines or systems operated in computerized systems.

Man-Machine Implications of Computers for Information Processing

The increase in data/information handling capabilities of computers will almost certainly have a major impact on the way in which Coast Guard command decisions are made. The computer will be able to provide the decision maker with an increased amount of information upon which to base his decisions.

The computer will also permit the presentation of options and alternatives for command consideration and will permit the decision maker to determine the costs and benefits of tentative decisions before selecting one for execution. The computer could present alternative search and rescue (SAR) search plans together with the units required as a function of search duration and probability of success.

The computer can automatically prepare and disseminate documentation necessary for the execution of daily Coast Guard business. The computer will have available standard report formats with blanks for the insertion of appropriate information. The operator will command the computer to insert that information (assuming it is within its memory banks) and the computer will then display the completed report and request permission to transmit.

A command-type computer, whether sited ashore or onboard ship, will utilize data from stored programs and data files, automatic inputs telemetered from remote sensors, inputs from operational systems, and data or directions from the computer operator. Computer operator controls will consist of the currently conventional ones (i.e., alphanumeric keyboard, switches, buttons, light pen, movable cursors, or symbol designators). The operator may also make direct voice inputs to the computer. The computer may be operated by a separate computer operator specialist or it may be operated by the command decision maker directly. In either case, the computer will contain a number of features to assist the user: (1) automatic error identification and correction software routines, (2) lists of options available to the user, and (3) routines to answer questions the user may have and to train him to employ more difficult branching networks. In particular, the automatic error identification/correction feature should do much to reduce the probability of input error, which often plagues systems using manual data entry.

The Command computer will probably make major use of one or more sophisticated CRT or flat screen displays for presentation of information to the user. The computer will permit on-line viewing as in "flying" an RPV as well as presentation of time-compressed events. A command computer center may also include a large, flat screen display for group viewing. Both types of displays will have very high resolution of a quality of at least equal to current television receivers (525 lines) to permit information to be presented in virtually any format desired. Among the display options available will be: tabular and graphic formats, split screen, display element magnification, several types and levels of coding, and map overlays. Supplementary displays, such as di al alphanumeric readouts, lights, or lighted pressure switch plates will be available for specialized types of information presentation. Controls and displays will be engineered, of course, to minimize man-machine interface problems.

Man-Machine Implications of System Computerization

The computerization of operational systems will tend to have two types of impact on man-machine relationships. One trend will probably be toward converting the operator into an administrator and monitor of the system, rather than its active controller. The other trend will be toward providing the operator with more, new, and better information with which to perform required tasks.

The first type of impact will result from the interposition of a computer as an active interface between the operator and the functioning system. The computer will receive commands from the operator, execute those orders for control of the system, monitor the behavior of the system, initiate any necessary corrections or adjustments, and report system performance to the operator (cybernetic loop).

The computer will control the functional system and will display system status or progress toward mission accomplishment to the operator. Once having activated a system, the operator would have little to do other than to monitor system feedback displays--and initiate any needed corrections, adjustments or revised, or new instructions. Direct operator voice input will be possible as well as conventional thumbwheels and keyboards. Displays will be conventional (i.e., digital readouts, CRTs, or flat screen).

The control of remotely piloted vehicles will present a special case of system computerization. Control of the vehicle during transit to target site and during the execution of a search or surveillance pattern will probably be fully computer-automated. Launch and recovery of vehicles at the ground station may also be fully computer controlled. It is probable that "manual" override will be necessary at some stage of an RPV's mission (e.g., when a target is tentatively identified and it is necessary to maneuver the vehicle for more positive identification). Controls for manual operations will probably consist of a six degree of freedom joystick to control bearing and altitude and a throttle for increasing/decreasing speed. The operator will not be directly controlling the vehicle but will be instructing the mediating computer which in fact controls the vehicle.

The second type of man-machine impact results from the increasing ability of advanced systems, primarily sensor and communication systems, to provide data and information to system operators.

Refinements in sensor and communications technologies have resulted in expansion of the data acquisition rate. This improvement can be helpful unless the operator is confronted by more data then he can handle in real time. Data pre-processing and "screening" by the computer will then become a necessity. This screening might take several forms (e.g., passing through only signals with certain characteristics, or

comparison with stored data to eliminate transitory or random "noise" signals). (The computer could also help ensure that system operational parameters (e.g., bias, gain, etc.), are properly set for optimum system performance.) Such computerization would tend to simplify the operator's task and eliminate a great deal of the "art" traditionally associated with the operation of sonar, radar, photo, and infrared interpretation. Computerization would, instead, require the system operator to become a computer operator in order to operate the sensor system most effectively. A multi-mode multi-functional console could result in a single operator serving selectively as a radar, sonar, IR, laser, etc., operator who would interact with the various sensor systems through the controls and displays of the single console. Such a console would also be used to perform pollution identification functions. Thus, the operator would select the spectral analysis mode and the console CRT (or large flatscreen) would display the existence and components of the pollution as detected by deployed laser or other sensors.

So far, everything that has been said relates to equipment operation. It is possible that the greatest technological impact of computers will be on maintenance functions involving computerized systems (where the computer is an integral part of that system). The computer of the 1990-2000 time frame will have an automatic self-checking capability that will immediately identify the existence of a potential malfunction source. This information will be immediately displayed to the equipment operator who will summon a technician (if he is not himself that technician). In this way equipment down time will be minimized, since the malfunction identification process that is the largest component of that down time will be eliminated. The ground station computer will, of course, automatically perform all functional checks of the RPV. Actual removal-replacement of components will still require human intervention.

Summary of Man-Machine Implications

The outstanding man-machine implication to be drawn from the above is that the Coast Guard personnel of 1990-2000 will tend to become more like computer operators than equipment operators. Many of the non-decision making functions they perform today will be taken over by the computer. Within the information processing, decision-making areas the computer will provide Coast Guard personnel with additional information and additional options. To the extent that a computer is incorporated into operational systems as an integral subsystem, it will relieve the maintenance technician of much of the troubleshooting effort presently required.

RECOMMENDATIONS

Technological developments will make satellites and RPVs feasible for Coast Guard use in search and surveillance missions. The Coast Guard should conduct cost-effectiveness and trade-off studies of missions involving satellites and RPVs to determine their utility, either as an addition to or as a partial replacement for, aircraft and cutters.

Extension of the Coast Guard Search and Rescue mission to include the underwater environment will entail a wide variety of problems and requirements not present in current operations. The Coast Guard should conduct a detailed, indepth analysis of subsurface operations to identify equipment, system and vehicle requirements, environmental dangers and problems, and personnel and training requirements. The analysis should also identify areas where responsibility and authority for types of action must be legally established or clarified.

Developments in advanced computers will make it feasible for the Coast Guard to make greater use of computers and micro-processors for decision analysis, planning,

record keeping, logistics, and operational functions. The Coast Guard should conduct a thorough cost-effectiveness examination of system and mission functions that can be computerized and a detailed comparison of advantages and disadvantages of centralized, distributed and combination, or hybrid computer systems to satisfy the requirements of those functions.

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APPENDIX

TECHNOLOGICAL PROJECTIONS

TECHNOLOGICAL PROJECTIONS

The technology surveys and projections presented in this section rely on relatively few source documents. While literally thousands of potential citations were reviewed--summarily to in-depth--only those reviewed here were found to be useful for the purposes of this human implications oriented study. These references do provide an acceptable basis for the projections of potential Coast Guard systems and their impacts on Coast Guard personnel as presented in this report.

In addition to technical future forecasts, the following technological discussions also provide historical development perspectives. The discussion of computer technology, especially, includes portions of previous forecasts. In some cases developments projected for the early to mid 1980s are already accomplished fact--and occasionally even superceded. Some sections therefore, may seem somewhat dated. The purpose in presenting such "dated" information is to develop a framework within which other current trend projections may be evaluated by the reader.

Computer Technology

The vacuum tube was the basis of electro-technology through the 1940s. Historically, solid state electronics started in 1947 with the invention of the transistor at Bell Telephone Laboratories. During the 1950s, transistors replaced the vacuum tube in a variety of applications. The 1960s saw the batch fabrication of integrated circuits and the refinement of their technology. The microcomputer/microprocessor emerged as the dominant device of the 1970s and, perhaps, beyond (Spectrum, Institute of Electrical and Electronic Engineering Journal, 1976, 7(1), 42).

In 1977, Adler et al., noted (p. 35) that:

> Integrated electronics has been evolving for more than ten years. New techniques and device structures have been developed but no radical and fundamental discoveries have occurred to change the development of the technology. Since radical, new developments can only be conjectured, but cannot be forecast, the assumption of continued technological evolution is made. Non-electronic discoveries appear unlikely to alter the developments of electronics . . .

Also in 1977, the IEEE Journal, Spectrum, in its annual technology review issue noted only incremental progress in the computer field, with microprocessors entering the consumer market and finding roles in mini and large computers and with the use of two or more processors in large computers gaining favor. There were also incremental advances made toward larger, lower cost-per-bit, semiconductor chips for computer memory.

The 1978 technology review issue of Spectrum commented on the fact that the slowing and maturing of computer technology in 1976 was even more pronounced in 1977. There were continued improvements made in memory core, tapes, and discs. Bubble memories and charge-coupled devices were under development. Integrated circuits were taking their place in peripheral devices and as a medium for standardized software capabilities. Some IC chips were becoming even more complex than microprocessors. A typical microprocessor contained approximately 7,000 transistors while a single-chip CRT, communications, or floppy-disc controller might contain as many as 22,000 transistors. The basic objectives of solid-state technology appeared to be increased speed, improved heat dissipation, and increased functional complexity. Metal-oxide-silicon (MOS) circuit design and fabrication techniques had quadrupled storage capacities every two years for

about a decade, with each generation having a simpler memory cell requiring about half the area of its predecessor. But the 16-kb dynamic MOS RAM was seen as essentially exhausting the potential for further simplification of the memory cell. The fundamental physical limits of large scale integration (LSI) technology were being approached. Still, in 1977 (Spectrum, 1978) the Japanese were reported to be working on very large scale integration (VLSI) MOS circuits, which would provide order-of-magnitude greater densities than then current. They anticipated putting an entire computer on one wafer within two years (i.e., by 1979).

By 1978, VLSI technology appeared to provide real promise for a quantum jump in processor capabilities; for example, a 16-bit microcomputer-on-a-chip. The Department of Defense also initiated a program to develop VLSI circuits to increase computational speeds by a factor of 100.

In 1977, Adler (p. 38) assumed that the development of computer technology would continue in an evolutionary manner with no revoluntionary developments to change its form abruptly and that new, but known, technologies such as x-ray lithography and laser applications would develop to permit the continued evolution of computer electronics. These assumptions appear substantiated.

The general pattern presented above is that of a maturing, yet far from "middle aged," technology.

There have been three persistent goals driving developments in computer technology: lower costs, greater speeds, and increased performance. The drive to lower costs has generally focused on reducing device size and simplifying circuit design and the fabrication process in order to pack more functions on a chip while obtaining higher yields (Adler, 1977, p. 6). Figure A-1 shows the ability to pack electronic components on a single chip (die) while maintaining acceptable yields. The number of components has been doubling every year and in the near term is expected to continue doubling about every two years. At the same time, the cost per function (in this case, per bit of memory) has been declining rapidly. It is this combination of increased functional complexity and decreased functional cost that is causing the rapid proliferation of electronics into many formerly non-electronic areas (Adler, 1977, p. 8).

The Adler (1977) report included a series of cost projection curves at too minute a level of detail to be especially meaningful for purposes of this study. The report authors, however, summarized (pp. 49-50) those projections as follows:

> The cost per 10K square mils of processed, packaged silicon is expected to decline slowly from 44 cents (1975) to 28 cents in 1990. As was the case from 1965 to 1975, the most dramatic reductions in cost per function [sic] will come from increased functional density and larger chip size. The use of merged device structures and an emphasis on basic charge transport in the silicon crystal will increase throughout the next decade. This trend will continue to reduce gate size through changes in device structure, with factors 20-30 percent per year in increased gate density through 1982, and about half subsequently from this source. New modes of submicron device operation may well continue the evolution in device structure into the mid 80s and 90s.

But they also anticipate that the basic physical limits of gate size, and thus, the density of packing on a chip, will be approached by the late 1980s (p. 51). Most
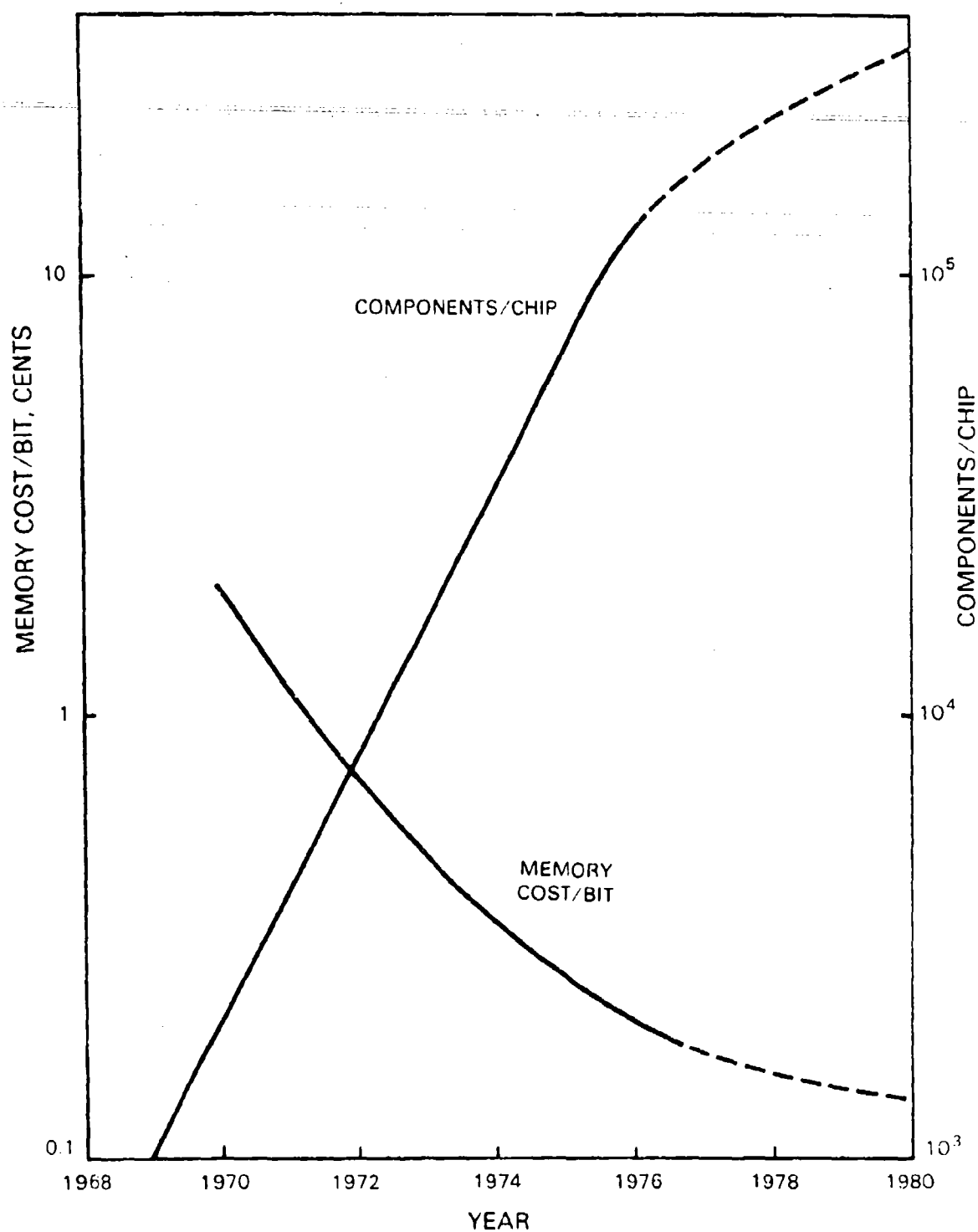
Figure A-1. Trends in Electronics Component Densities (From Adler, 1977)

projections, including those above, are based on the assumption that the binary gate will continue to be the foundation of the technology, and they caution (pp. 51-52) that:

> The focus on the binary gate as the basic circuit building block may not be appropriate after the early 80s. Charge transfer devices are now handling analog signals with very low loss and dispersion, and the use of non-binary logic or discrete-analog signal processing is not out of the question by the mid 1980s. There are diverse opinions on this in the industry now, but at least one company is nearing production on four-level logic structures. In a large machine, this could result in a significant improvement in effective gate density. By the mid 80s such improvements due to higher radix (non-binary) structures are expected.

They sum up by saying (p. 52): "Certainly, the problem of what to put on the chip will soon be more significant in most cases than how to do it."

Discussion of computer costs per-bit, per-gate, per-instruction, etc., are not, in themselves, especially meaningful for our purposes, especially since they are, in part, a function of the size of the chip and the amount and complexity of the circuitry on it. The discussion is, however, meaningful as an indication of the increasing computational capability a given dollar will buy. Whereas once integrated circuits (chips) were components of a computer, now a "computer" can be placed upon a single chip. The Adler (1977, p. 64) report summarizes the trends expected in computer-on-a-chip technology:

> Most first- and second-generator [sic] microprocessors are in the 30K to 40K square mil range in chip area. Third generation designs, containing significant amounts of memory on-chip (e.g., micro-computers with 8K bits of ROM and 1K bits of RAM) are expected in the 1977-78 time frame with chip sizes in the range of 50K to 60K square mils. Given at least three years in production so that mask limited yields are approached and by 1980 such microcomputers should exhibit a high volume price of less than four dollars. By 1985, with an improved plastic package, the same processor in high volume (excluding marketing and distribution costs) should be near two dollars. [Figure A-2] summarizes the objective cost of such a third-generation microcomputer versus time. The time duration of these curves reflects an expected production life of about ten years for these microcomputers. It is clear that the low cost of these elements can have enormous impact, particularly in entirely new areas (e.g., performance computers, automation of maintenance, etc.). The cost of a packaged electronic system will increasingly reside in the chasis, I/O connectors, and those portions of the system which do not use high-volume digital components. Although the packaged system cost may continue to exceed the LSI DIP cost by one to two orders of magnitude, the system cost will nonetheless drop significantly by virtue of reduced chassis size.

Microprocessors and microcomputers will likely find major use as components of other types of systems or of larger computers, as controllers and data processors rather than as computers per se. In addition to such applications, computers will be deployed as computers in air-, sea-, and ground-based configurations. Alder et al. (p. 65) projects the costs (in 1975 dollars) of various components of airborne and ground-based computer systems (Tables A-1 and A-2). These projections assume a constant computational
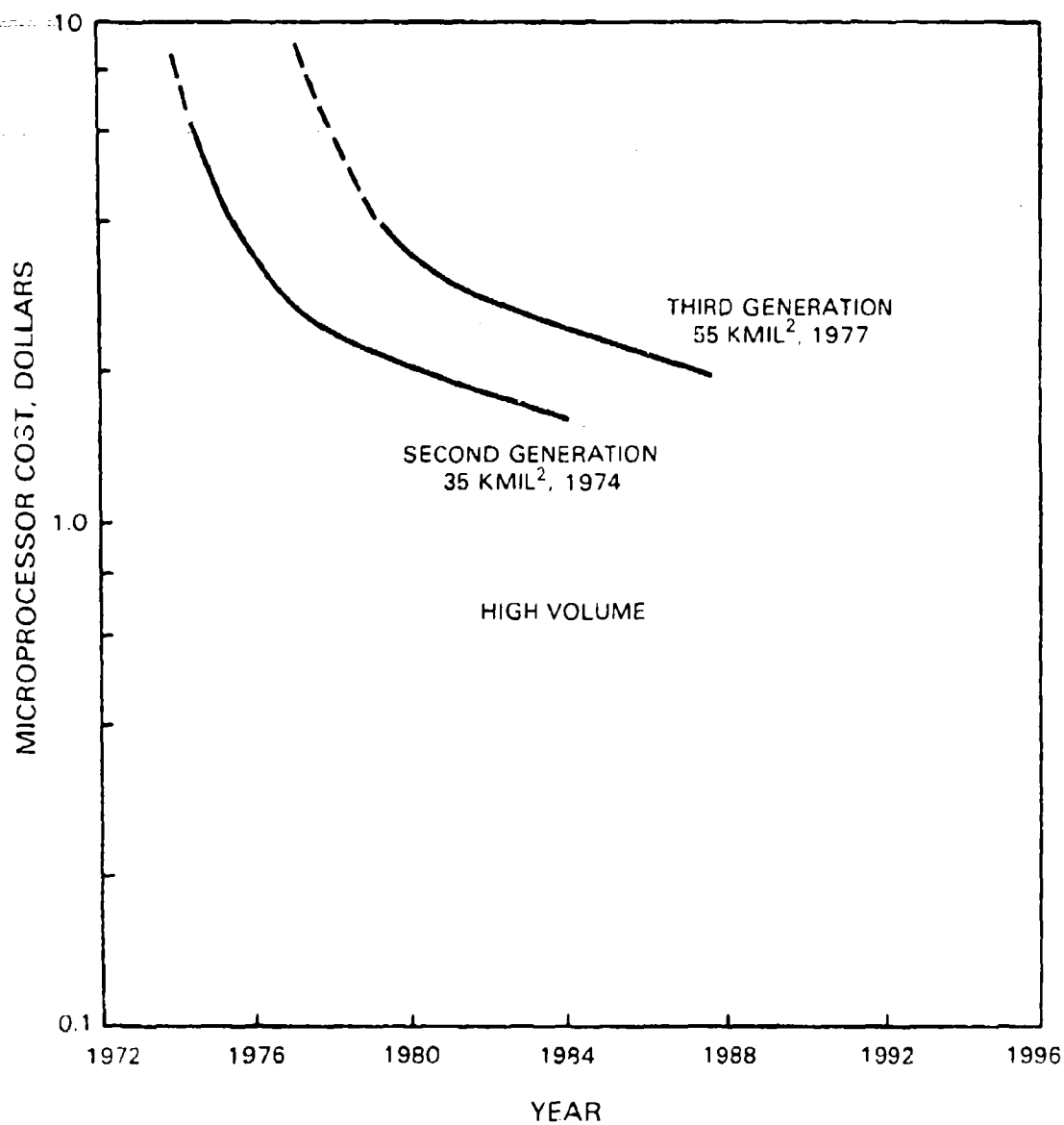
Figure A-2. Forecast of Cost of Third-Generation Microcomputer (From Adler, 1977)

capability. The cost figures are therefore, in a sense, unrealistic. The actual year 2000 system will likely cost a great deal more than the indicated $396 and $974.

Table A-1

Airborne System Component Cost Forecast vs. Time
(From Adler, 1977)

Component	Cost				
	1975	1980	1985	1990	2000
Microcomputer	$ 150	$ 51	$ 36	$ 28	$ 21
Interface Electronics	190	75	35	30	25
Bulk Memory	500	400	200	150	120
Display Memory	393	104	40	20	10
Display	110	85	75	65	50
Sensors	60	40	20	15	15
PC Boards	60	45	35	30	20
Power Supply	325	280	150	120	100
Chassis	75	60	40	35	35
Total Components	$1,863	$1,140	$631	$493	$396

Table A-2

Ground Based System Cost Forecast vs. Time
(From Adler, 1977)

Item	Cost				
	1975	1980	1985	1990	2000
CPU cost/chip	$ 20	$ 10	$ 5	$ 5	$ 5
CPU component cost	2000	200	70	50	40
Memory cost/bit (cents)	0.3	0.08	0.02	0.008	0.002
Memory cost	96K	25.6K	6.4K	2560	640
# PC boards	7+267	2+67	1+17	1+9	1+5
# IC packages	100+8K	20+2K	14+500	10+250	8+125
Cost of PC boards (incl. AW&T)	6028	1725	540	330	210
AW&T of IC packages	2025	606	180	104	54
Chassis cost	570	234	93	53	30
Total Cost	$106,623	$28,365	$7,283	$3,097	$ 974

Throughout the history of computer technology, projections of costs have shown a persistant downward curve. Taken at face value, these curves would seem to indicate that inevitably and inexorably computer costs will eventually reduce to zero, or close to it. But, as Amdahl (1978, pp. 18 and 20) states, such a conclusion is:

> Wrong. And even if the cost went to zero, the price wouldn't. Semiconductor components that are subject to high levels of integration and volume production are indeed rapidly getting cheaper. But these components do not comprise the entire system. Further, as price reduces, we tend to opt for more function--more processing power, more memory, better peripherals.

Thus, actual out-year computer systems costs will likely be considerably higher than those shown in Tables A-1 and A-2 (Adler, 1977, pp. 167 and 187) but their capabilities will likely also be dramatically greater.

Figures A-3, A-4, and A-5 present projections of microcomputer memory developments through the year 2000 made by Adler et al., (1977, pp. 77, 79, and 81). Figure A-3 for example, anticipates that by 1990, technology will be approaching one million bit RAM (random access memory) chips. Semiconductor RAMs are "volatile," however. They lose stored data if cells are not "refreshed" periodically or if power is lost. They are, therefore, not appropriate for long-term storage of programs. These require "permanent" memory currently provided by Read Only Memories (ROMs) or elecronically-alterable ROMs. With 8K bit alterable ROMs already available for microcomputers in 1977, Adler expected ROM developments to parallel those of RAM but with densities two to four times greater and costs one-half to one-fourth those of RAMs (p. 80).

Adler (p. 85) addressed bulk storage devices, particularly magnetic bubble memories, charge-coupled devices (CCDs) and electron-beam addressed memory systems (EBAMS). In 1977 chip capacities of 100K for bubbles exceeded those for CCDs by a factor of two but were an order of magnitude slower. Magnetic bubble devices were expected to replace disc memories for data processing applications but were not expected to be employed in systems requiring storage capacities of less than one megabit. Electron-beam addressed memory systems were expected to be limited to applications requiring memories of more than 10 megabits. Thus, none of these three was expected to affect microprocessors (or microcomputers), which was the primary focus of the Adler study.

In 1975, 4K-bit RAMs cost about $5.00, or 1 cent to 15 cents per bit, rivaling core memory prices. Digital IC RAMs of 8K-bit or 16K-bit capacity were expected in 1976 or 1977. And CCD memories for bulk storage became commercially available in 1975 (Spectrum, 1976, pp. 50-51). Mass storage systems, allowing on-line access to from 30 to 236 billions of bytes of data made their commercial appearance in 1975 also (Spectrum, 1976, p. 49).

Semiconductor RAMs were the choice for large (e.g., 16K 16-bit word) memories in 1976. Most manufacturers offered 16K-bit RAM chips whose cost was expected to drop 5 to cents per bit by 1978-79. Some 16K-bit CCD and bubble memories were available, and electron-beam accessed memories (EBAMS) with 10^8 bits of storage (at 1 cent per bit cost) came onto the open market in 1976 (Spectrum, 1977, p. 41).

By 1977, a 65K-bit CCD memory was available to fill the gap between high-speed semiconductor RAMs and slower-speed serial access magnetic memories. A 92K-bit bubble memory was available, intended primarily for microcomputers rather than mini- or larger computers (Spectrum, 1978, p. 88). Also in 1977, the U.S. Air Force initiated
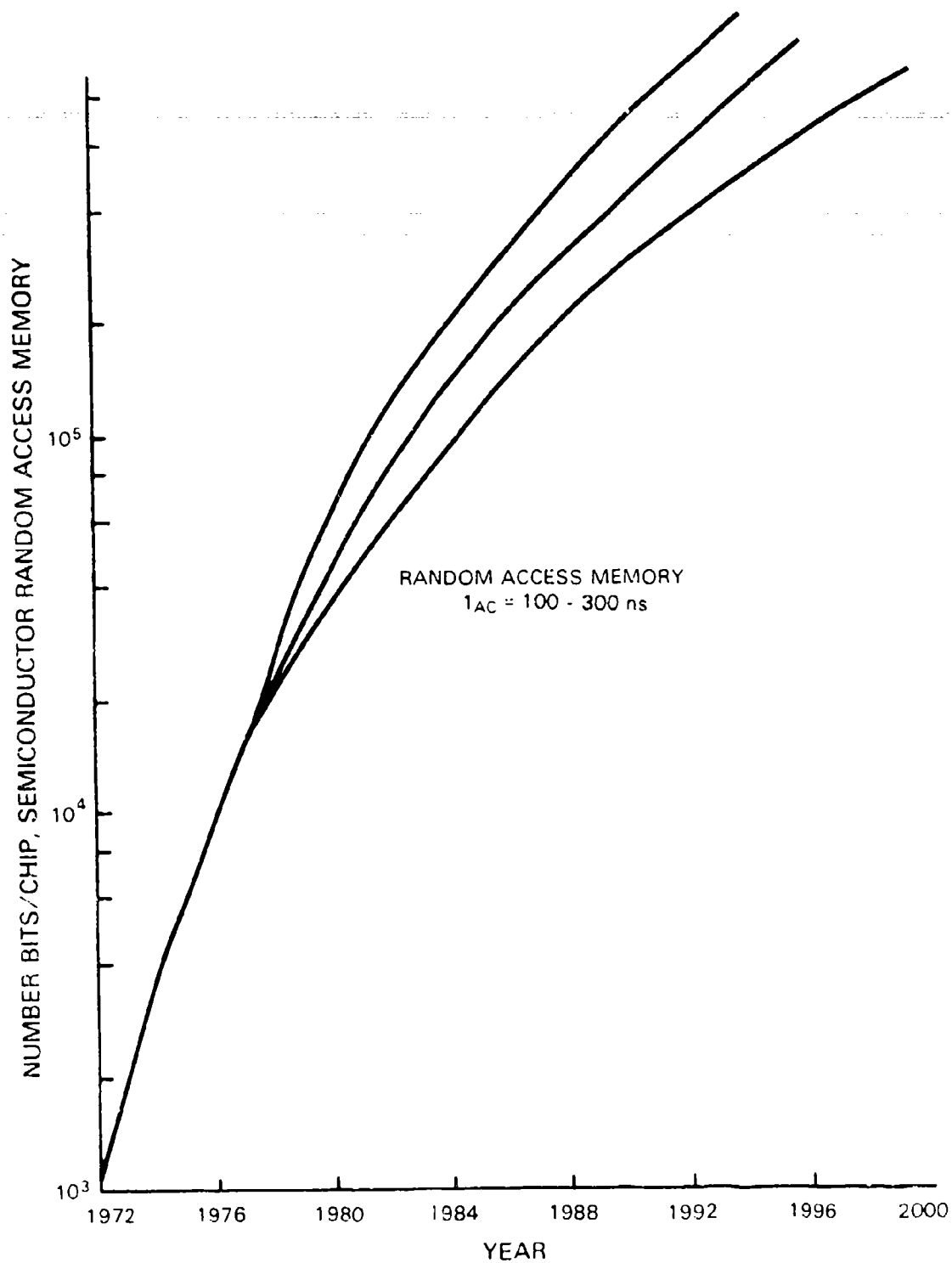
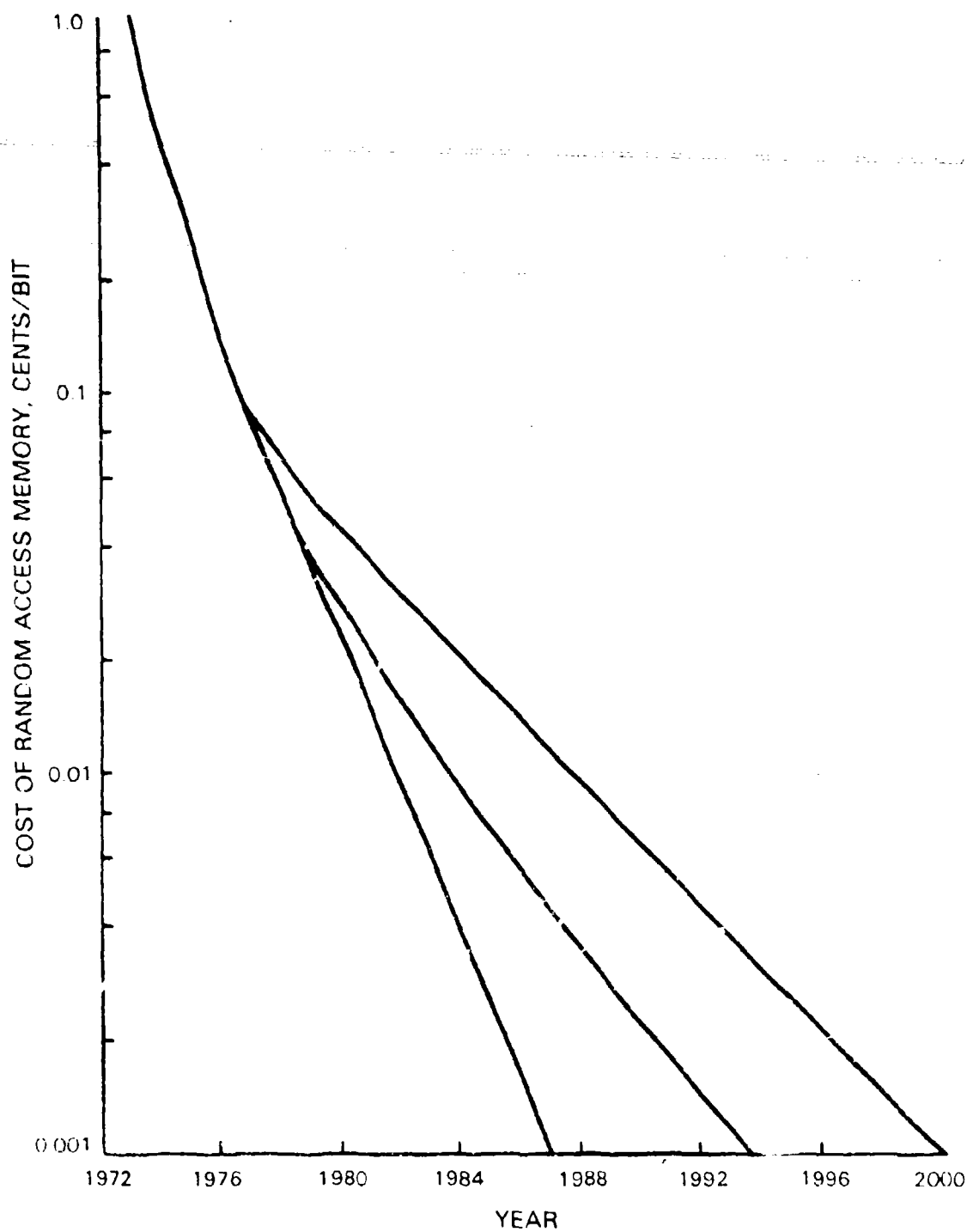Figure A-3 Forecast of Random Access Memory Density (From Adler, 1977)

Figure A-4. Forecast Cost of Random Access Memory (From Adler, 1977)
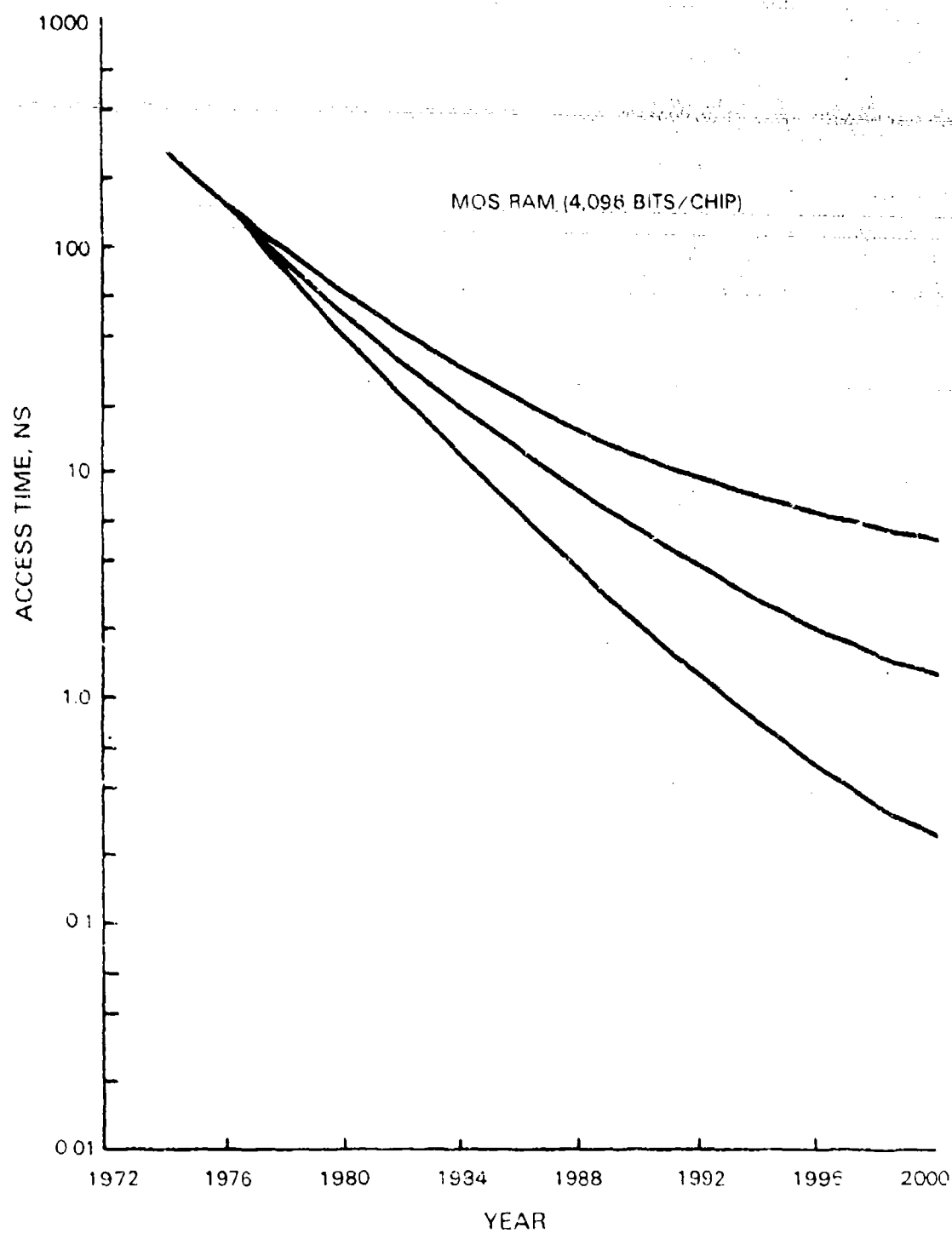
Figure A-5   Forecast Speed of Memory Access (From Adler, 1977)

advanced development of a 16-megabit bubble memory system, weighing under 60 pounds and taking up less than a cubic foot of space, for use as a substitute for disc and drum systems in airborne applications (Spectrum, 1978, p. 165).

Despite advances in other memory systems, magnetic core memories were still popular in 1978 for minicomputer real-time controllers. Cores of 64K-bytes on a single PC unit and of 128K-bytes on a single card were available for minicomputer systems. Tape memory was still unsurpassed for very large sequential files or for interchange of data between computers. Capacity was at 6250 bits/in and expected to double during the year. Progress was being made toward goals of 650Mb per spindle and a billion bytes per disc (Spectrum, 1979, p. 30). By 1979 attention was also being given to holographic recordings as permanent mass memories. Although more expensive than drum or disc magnetic memories, holograms were cost-effective compared with any technology offering comparable capacity and random ccess time (Amed, 1979, p. 475).

With the continuing increase in memory capacity noted above, memory, as such, clearly will not be a limiting factor in future computers and computerized systems. Whatever memory capacity is needed will be available. The limiting factor seemingly will be memory access time. The speed-capacity trade-off among memory technologies appears to be a continuing problem. It is, however, a relative one in that access times for all types of memories obviously are being steadily improved.

Basically, a computer computes by acquiring a datum from memory, operating on that datum in some way and outputting the result into memory. The computational speed is, therefore, a combination of both access speed and processing speed. If performed in strict sequence, the processor would be idle during the accession operations and the memory would be idle during the processing operations. Clearly, the faster the datum can be acquired and the faster it can be processed the less idle time both components will have. Since the data processing generally requires more time than data acquisition because of the number of operations involved, emphasis has been on designing faster processor circuits. Faster circuits are, however, mor costly. Cost-performance trade-off considerations, therefore, enter into system design decisions. Kosy projected (1974, p. 94) that:

> The cost of computing power is expected to continue to decrease exponentially although ... at a lesser rate than in the past. The projection of cost per MIPS is shown in [Figure A-6] These data apply mainly to high-performance processors as one must acquire very high MIPS capability to achieve low MIPS cost. Though the cost per MIPS for lower-speed processors is higher, their total cost is also decreasing because of declining component costs.

Memory speeds and costs are expected to show parallel improvements. But Kosy goes on to observe (p. 94) that:

> The speed and cost ratios between processors, main memories, and various levels of secondary memory are expected to remain constant in the future, however, or even widen. The same speed disparities between processor logic and memory access, and the same cost trade-offs between high-speed and low-speed memory, will still be with us in the 1980s.

The strict single path sequence mentioned above is, of course, inherently inefficient for most purposes. This inefficiency has been attacked from two directions: by keeping
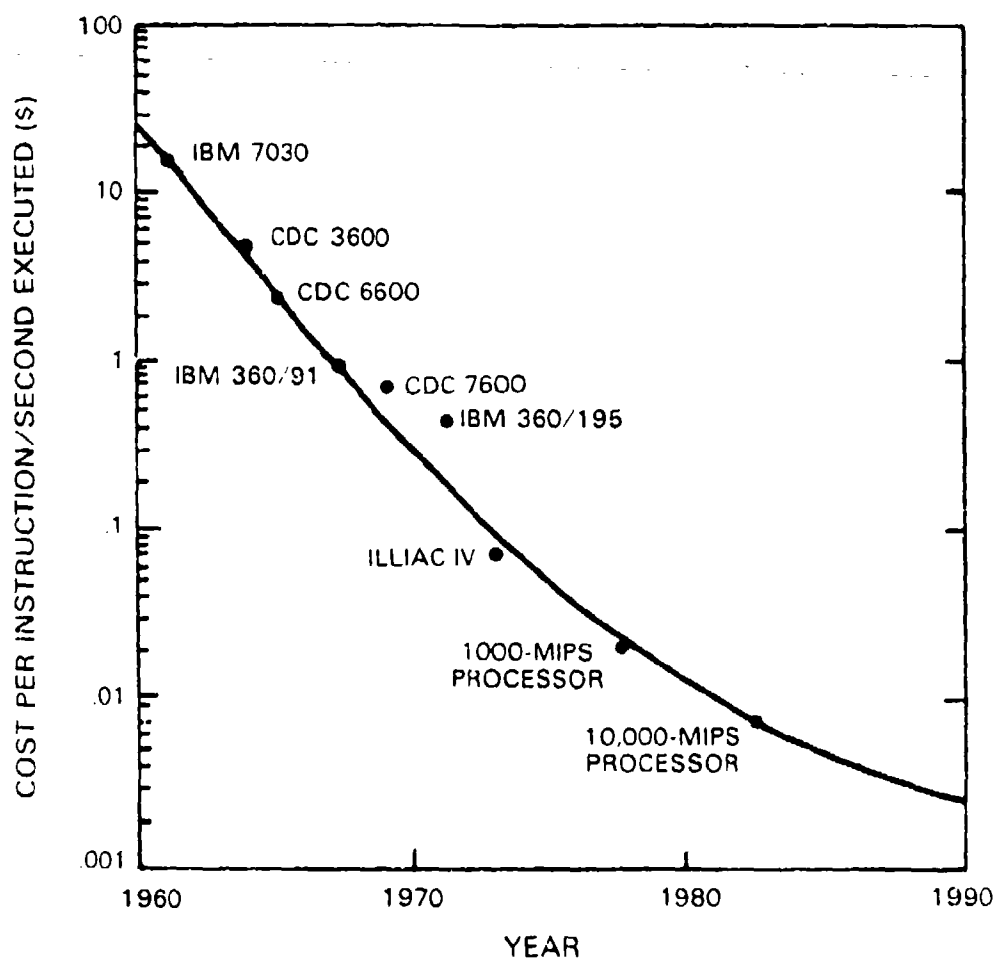
Figure A-6 Cost of High Performance General Purpose Computers 1960-1990 (proj.) (From Kosy, 1974; adapted from TURN, 1972)

the memory active on other tasks while the processor is processing and by "anticipating" data requirements so that the processor need not wait while a memory is searched. These goals can be accomplished by hardware, software, or a combination of the two. Kosy (1974, p. 94) comments:

> In the past, designers have incorporated memory interleaving (over-lapped data access) and simultaneous processing and I/O (by means of the data channel) in hardware to reduce the effect of these mis-matches. More parallelism can be expected in the futur :imilarly, software has been developed to use main memory more efficiently through overlay techniques and the use of virtual storage concepts, to buffer the difference between I/O rate and proressing rate, and to raise CPU utilization by causing it to work on several programs at once (multi-programming). Efficienc hardware utilization should continue to be a key goal of software design in the future. Although the cost of computing power has decreased significantly, nearly three orders of magnitude since 1955, interest persists in using it efficient-ly.

In addition, Kosy anticipates that future systems will employ multiprocessor designs with special processors dedicated to special functions, microprogrammed control and integral stand-by spares for both system reliability and "fail-soft" degradation. The effect, however, will be faster effective computation and greater computational power.

Figure A-7 shows system speeds projected for both single processor and alternate structures and commercial and military computers. Turn assumes that military computers--specifically airborne, shipborne, and missile borne--will be slower than ground-based commercial computers because of military requirements for light weight, ruggedness, and low power, which can be had only at the cost of somewhat slower speeds. Comparative speeds are, however, only relative since all can be expected to increase.

Five years after the initial 1972 Turn report, Adler et al., (1977, p. 66) projected an instruction cycle time for bi-polar processors of under 100 nanoseconds by 1980 and 20 nanoseconds or less by 1985. This appears wholly consistent with the Turn forecast and advertised characteristics of commercial devices.

A strong trend was noted in 1975 for military computer designs to employ multiple processors. A navigation computer was expected to incorporate 10 dedicated micropro-cessors, each performing a separate part of the total navigation computation. Not only did the design make highly efficient use of the hardware capabilities but loss of one of the microprocessors did not disable the whole computer (Spectrum, 1976, p. 45).

By 1976, separate microprocessors were being routinely used in microcomputers to perform input-output, data processing, program management, etc., rather than having everything done in the CPU. In addition, microprocessors were being designed into memory hierarchies to facilitate storage, shift, and retrieval of memory information (Spectrum, 1977, p. 38).

It appears, therefore, that system designers will continue to seek and create means of capitalizing on the increasing speed and capabilities of t..e circuitry being incorporated on LSI and VLSI chips and advanced memory chips.

Figures A-8 through A-11 present Adler's et al., (1977, pp. 161, 163, 184, and 185) projections of trends in computer size and weight. Their report notes that system size is
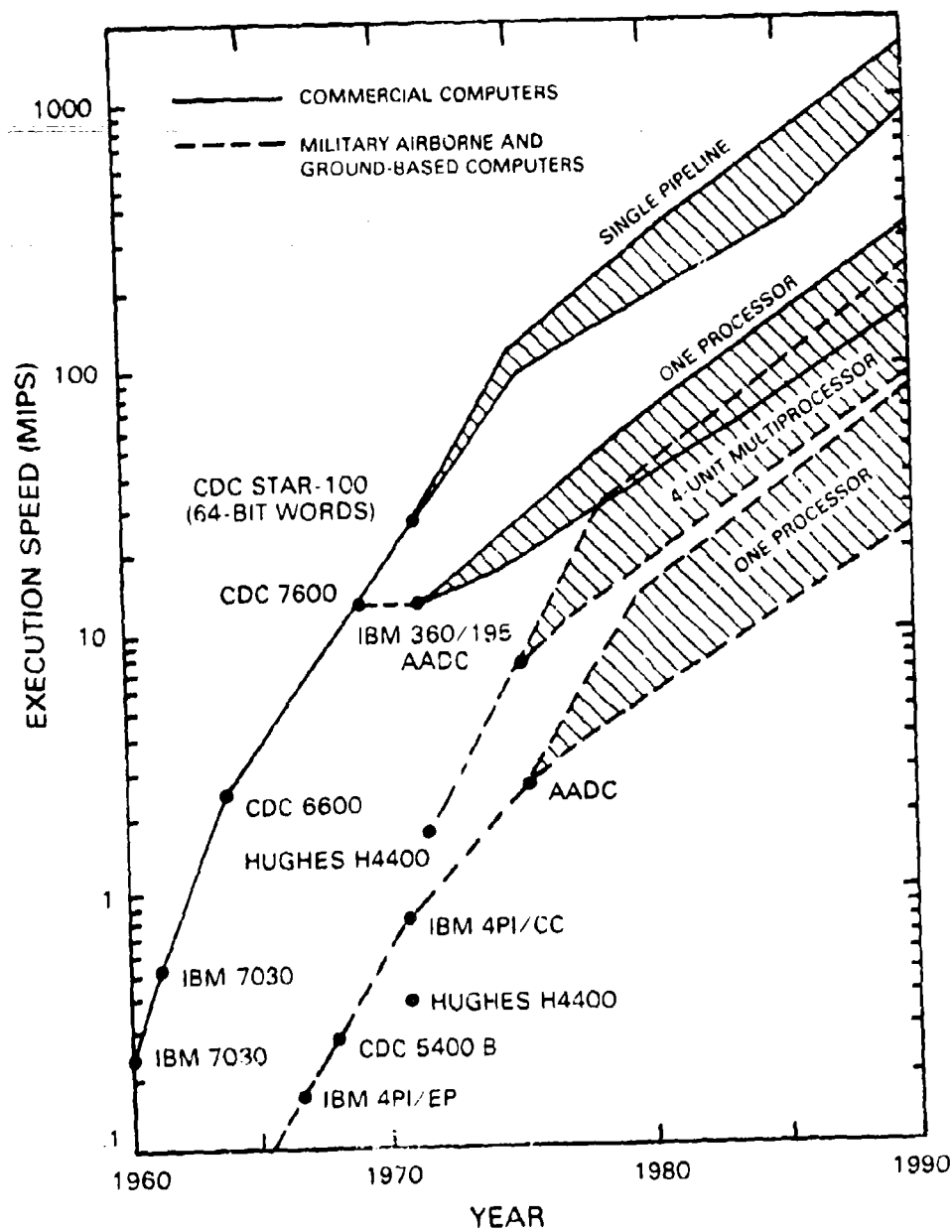
Figure A-7. Commercial and Military Computing Speeds, 1960-1990 (Proj.)
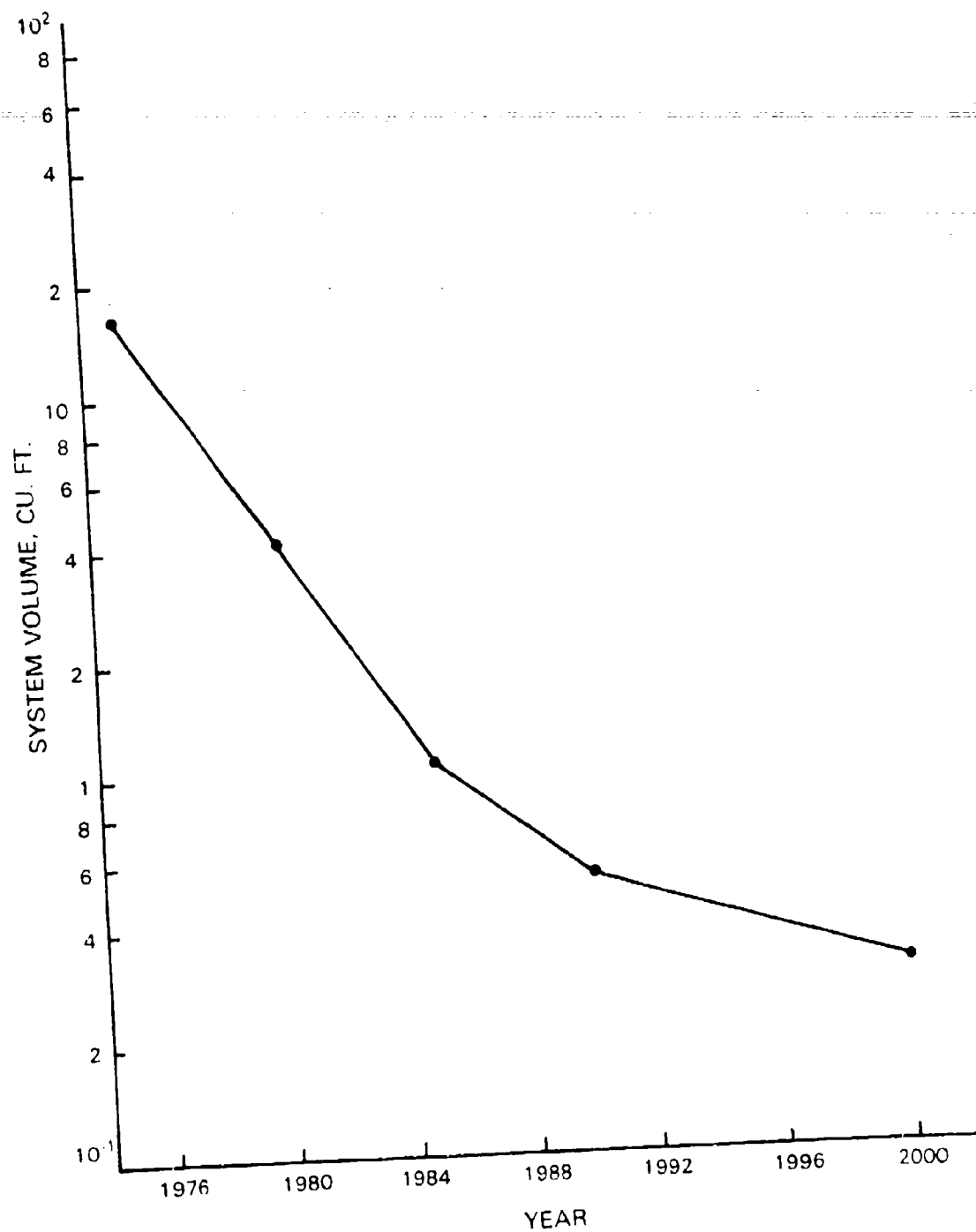(From Kosy, 1974; adapted from TURN, 1972)
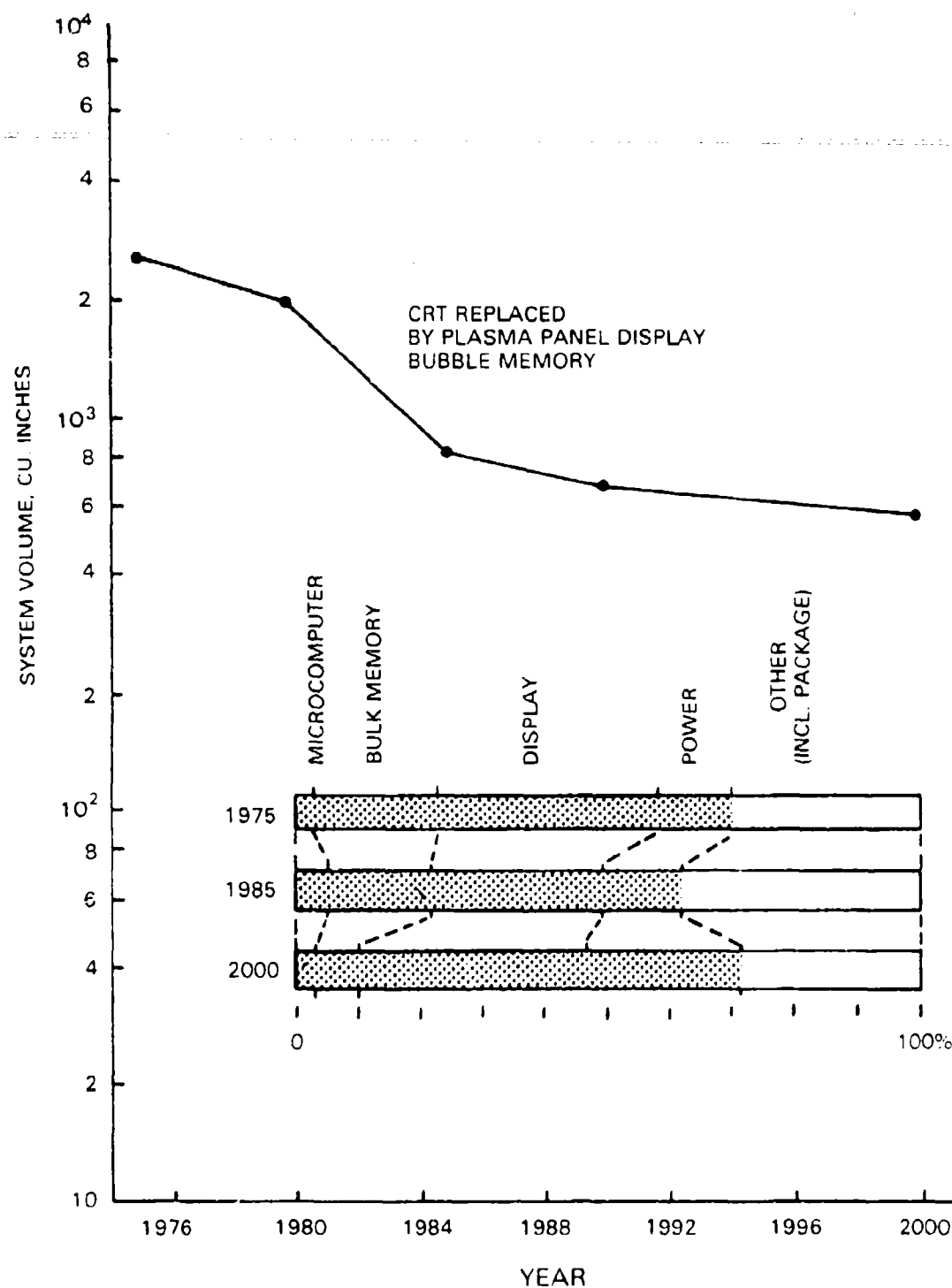
Figure A-8   System Size (From Adler, 1977)

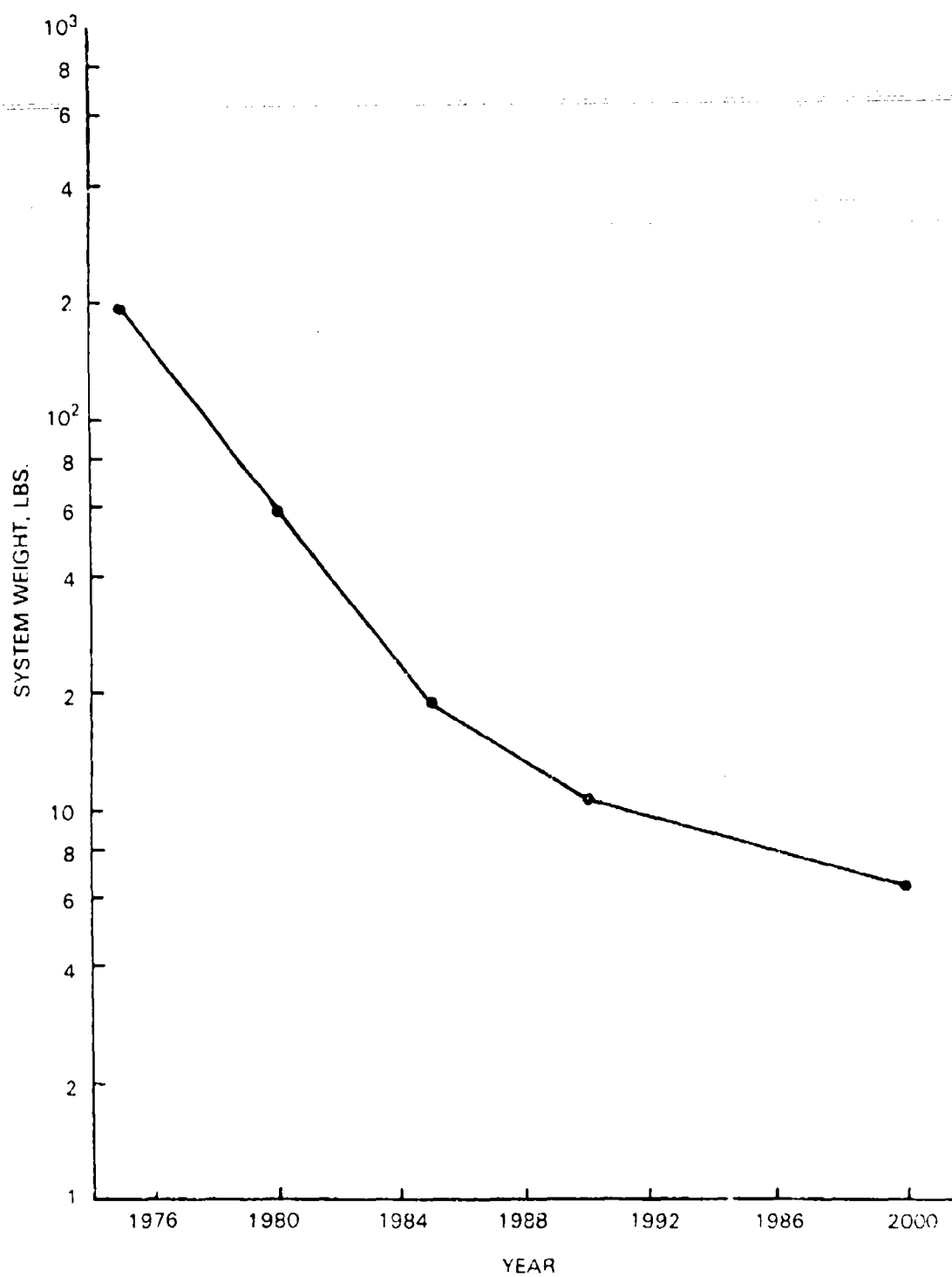Figure A-9. System Volume (From Adler, 1977)

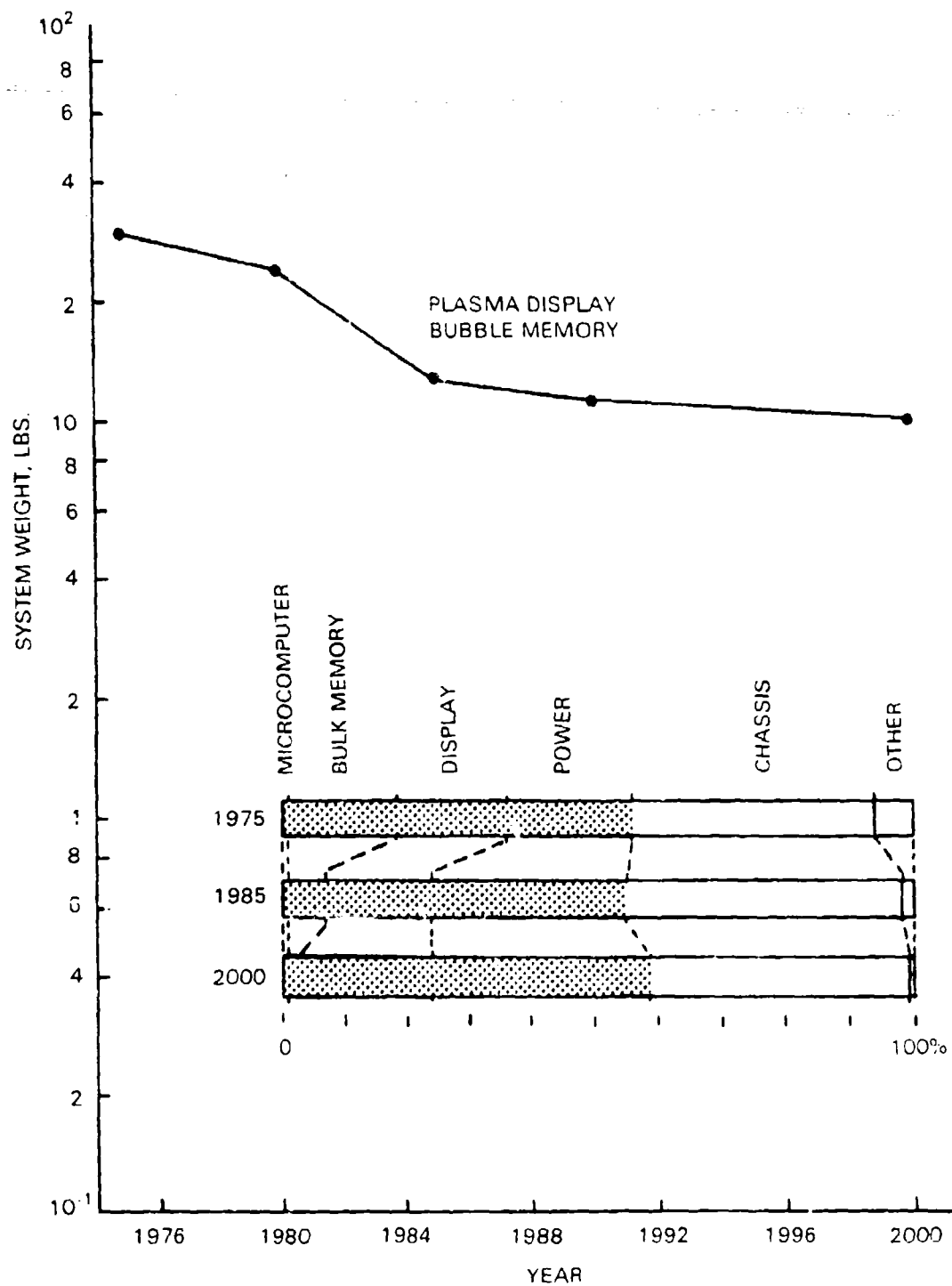Figure A-10   System Weight (Ground Based) (From Adler, 1977)

Figure A-11. System Weight (Airborne) (From Adler, 1977)

dominated by the memory. Figures A-9 and A-11 demonstrate the relationships of memory to microcomputer/processor. Even in 1975, however, these two elements combined were far overshadowed by other components such as display power supply, "packaging," etc. The figures indicate that the proportion of total systems accounted for by the processor and memory is expected to shrink even more dramatically. Adler et al., conclude that by 1987 most of the complexity of computerized airborne systems will reside in the microcomputers, yet these will not contribute significantly to the power needs, size, weight, or cost of their systems. They also anticipate that the speed of these small, light, sophisticated, and relatively inexpensive microcomputerized airborne systems will be largely limited by peripherals.

The validity of these predictions is born out by the manner in which microprocessors and microcomputers, complete computers-on-a-chip are already embedded in various systems. The LORAN C digital receiver, for example, embodies a sophisticated computer but the overwhelming bulk of the unit is accounted for by the display, controls, and other components. Similarly, the bulk of "intelligent terminals" of ground-based computer networks, each being the equivalent of a mini- or larger computer, is in the keyboard, display, printer, etc., rather than in the computer per se. Thus, increasingly the "size" of a computer will have meaning only in terms of its computational capability and not in terms of its physical dimensions.

System reliability is a combination of hardware and software reliabilities. software consistently has been a major source of system unreliability. And the larger and more complex the computer and its application, the more difficult has it been to develop fault-free software. This problem is expected to be reduced in severity by such means as "emulation" (i.e., designing new systems to use software developed for older systems), (Spectrum, 1978, p. 29); high level languages (HLL) that permit programmers to use more natural instruction language and the computer itself to generate the detailed machine instructions; and certain forms of standardization. A significant increase in software reliability is also expected to result from converting certain software functions to hardware components in the form of preprogrammed or programmable microprocessors (Spectrum, 1979, p. 32). Software reliability is also expected to be better for those computer systems produced in relatively large numbers for specialized purposes compared with those relatively limited production or general purpose systems.

Although some limited and variable improvement in system software reliability appears possible, it seems that little improvement in hardware reliability is possible. Adler et al. (1977) estimated that the reliabilities at the chip and microprocessor levels in 1977 we. .bout 99.95 percent per 1000 hours of operation at 70°C at the 90 percent confidence level. They expected reliabilities to increase to 99.99 percent, under the same conditions, by the early 1980s, with little if any improvement thereafter (pp. 54 and 70).

Kosy, (1974, p. 93), basing his projections on Turn's 1972 forecast (Turn, 1972) anticipated that hardware reliability of militarized command and control computers would increase from 4,000 hours mean time between failure (MTBF) in 1975 to 8,000 hours MTBF in 1980 and 15,000 MTBF (625 straight days) by 1985.

During 1977 the Air Force Space and Missile Systems Organization (SAMSO) anticipated the early 1980s availability of an airborne computer with a 95 percent probability of surviving unattended in a hostile environment such as space without performance degradation for a period of five years (Spectrum, 1978, p. 65).

Some military applications cannot tolerate system failure. In such situations the trend is increasingly toward designed redundancy. Thus, "faults" can be "tolerated" since

they do not degrade performance, or do so only partially. The incorporation of automatic fault detection and correction circuits onto LSI chips by the 1980s was projected by the Adler group in 1977 (p. 55).

Hardware reliability is heavily dependent on operating temperature in that LSI chips tend to be subject to thermal failure at temperature much in excess of 70°C. A key factor in the operating temperature is the generated heat that must be dissipated. Technology is steadily reducing the power requirements of computer circuitry. In part, this power reduction results from denser "packing" of components on an LSI chip. But while density may reduce power requirements, and thus heat to be dissipated, density means that what heat is produced is more concentrated. Localized temperatures can therefore be quite high and there is no simple one-to-one relationship between power requirements and practical operating temperatures. There is, however, a general trend to lower power systems and lower operating temperatures. This translates, practically, into lowered sensitivity to thermal requirements and increased reliability.

The above indicates that the hardware components of computer systems are so highly reliable that there is little practical room for improvement. This condition holds for components in production long enough, characteristically about two years, for manufacturing "bugs" to have been eliminated. Improvements of various degrees can be expected in hardware resistance to failure induced by "hostile" environments such as space, high or low temperatures, etc. Coast Guard missions do not, for the most part, involve these extreme environments. Thus, computer system hardware reliability is seen as not a significant factor in Coast Guard applications of computer technology. Software reliability for small, dedicated, or special application microprocessors, microcomputers, and perhaps, minicomputers is similarly seen as not an especially significant factor. Software reliability for complex mini- and macrocomputer systems will probably be a major problem--far greater than any hardware reliability program.

Programming has traditionally been the major cost of computer "ownership" and has tended to increase relative to the costs of hardware. Software costs, however, have been reduced over the years, simply not as dramatically as have hardware costs.

One means of limiting or reducing software costs has been "emulation." Emulation is simply the building of new machines that will use existing software for the same or another product line. This approach was gaining popularity in 1976 (Spectrum, 1977, p. 40) and has continued.

Also in 1976, the Navy was working toward standardization of microprocessor modules for avionics systems. Similar efforts were being made by the Air Force. The Department of Defense began long-term developmment of a common service-wide high level language; identified at the time as DOD-1. All future computers, from micros on up, would have to be programmable in some version of DOD-1 (Spectrum, 1977, p. 77).

The IEEE notes in Spectrum (1977, p. 77) states that:

> Various estimates place the cost of software at about $45 to $75 per instruction to write, and up to $4000 per instruction to change or maintain. These high software costs evolved for several reasons: improper documentation, "start-from-scratch" system development, patchwork maintenance, and proliferation of special-purpose computers.

The IEEE reports one means of reducing the programming problem (Spectrum, 1977, p. 77):

> Microprocessor and associated circuits would be packaged into four modules: central processing unit, memory, input/output, and special function. Each of the four modules would be so configured as to have standard interface signals, regardless of differences in technology, word length, and other distinguishing features among microprocessors and memories. The interface proposals include one for distributed processing, in which up to eight microprocessors could operate asynchronously in the same system.

In 1977, interpreters-on-a-chip (or half-chip) appeared on the market in the form of a single chip containing National Industrial Basic Language (NIBL) for use with National Semiconductor's SC/MP microprocessor. A BASIC interpreter-on-a-chip was also available for use with 8080-type microprocessors (Spectrum, 1978, pp. 26-27).

According to Spectrum, (1979, p. 32), microprocessors became the hardware equivalent of software for minicomputers in 1978, giving minicomputers the ability to handle High Level Languages (HLL) that large computers have always used. Practically, this allows programmers to use relatively conventional language, which the computer itself translates into appropriate and efficient detailed machine instructions. As an example of the effect of this development, the software programming resources and execution speeds of a minicomputer comparable to a PDP-11/45 were incorporated into a single, high density, 16-bit CPU chip containing the equivalent of 20K to 68K transistors and the ability to manage a minimum of 1 megabyte of RAM.

The above shows a trend toward reduction in programmer requirements. This will be accomplished by the use of preprogrammed microprocessors or microcomputers in systems where standardized or "canned" programs or program modules can be utilized. Reprogramming, if any, of such systems will be largely by means of a High Level Language (HLL), thereby minimizing or eliminating the need for the programmer to learn and work in the system's specific machine language. HLL programming will also be applicable to larger computers. Standardization on a single HLL, such as PASCAL, and emulation, where computers will be designed such that programs developed for other machines can be used directly on the new machines, will further lower programmer qualification requirements. This should not be interpreted, however, to mean that "just any recruit" will be able to program computers. Effective system operation still requires efficient use of the computer's capabilities. And that requires a specialized knoweldge of the computer, the computer language, and the task or tasks to be performed by the computer.

The distinction between microcomputers and minicomputers is expected to become increasingly difficult. In general, microcomputers will consist of one or a few LSI chips, have limited I/O, and will be applied primarily in dedicated applications. Minicomputers will have more flexible I/O, will be general purpose in nature, but will be built around microcomputers (or possible networks of them). In terms of performance, microcomputers will soon replace present minicomputers, while minicomputers will replace present macrocomputers. For example, the PDP-8 CPU is now available on a single chip and larger computers, such as the PDP-11, are expected to follow suit (Adler, 1977, pp. 57 and 60).

Amdahl (Datamation, 11/15/78, pp. 18 and 20) noted that: "Minicomputers are rapidly moving into the megamini range. ..." Thus, while the microcomputer moves into

the minicomputer range, the minicomputer is moving into the macrocomputer range and the macrocomputer is growing even larger in capacity and capability.

Adler et al., (1977, p. 86) observed that:

> In data processing, we have already seen hand-held electronic calculators evolve to the point where they are capable of performing functions which a few years ago were reserved for minicomputers. Some minicomputers such as the PDP-8 have already seen their CPUs reduced to a single chip and it is generally felt that most 1975 minicomputer-CPUs will be realizable on a single chip by 1980. By 1985, large machines (by today's standards) are expected to follow suit. The prospect of a processor composed of 10^4 gates, 64K-bits of RAM, and 128K-bits of ROM on a single chip is very real for 1985.

The projection appears to have been conservative, for the IEEE Spectrum (1978, p. 39), reporting advances in 1977, noted that:

> Microprocessors have passed an important milestone with the introduction by several manufacturers of models that can be described as single-chip microcomputers. Contained within a single LSI circuit are many of the functions that used to call for a host of peripheral and interface circuits, in addition to the central processing IC. Now, in several cases, even memory--in capacities sufficient to allow both system-program storage and data processing--has been brought onto the CPU chip.

As another example, Spectrum (1978, p. 39) reported:

> Intel's recent microcomputers exemplify a number of the improvements forged by the industry. For example, the 8085, a next-generation design based on the 8080, architecturally resembles its predecessor. Yet, within the 8085 CPU chip are all of the functions that used to require three chips of the 8080 family--clock generator, system controller, and the CPU. The 8085 increases maximum data rates to 3 MHz and can form a minimum microcomputer system with one RAM and one ROM multifunction chip. As a three-chip system, the 8085 provides enhanced features such as four hardware interrupts, 38 input-output lines, and a 14-bit timer. Program memory has come aboard the CPU chip in several designs. Within Intel's 8748 CPU, for one, reside 1024 bytes of ultraviolet-erasable electrically programmable ROM. Its availability is seen as speeding system development, as user-generated programs may be loaded, run, and even altered, within minutes. Once software has been developed, a user may switch to a functionally identical CPU, the 8048, which has the same amount of resident ROM, but is masked, permanent form--a procedure that parallels a common use of programmable and masked ROMs in system design. Still larger amounts of resident masked ROM--2048 bytes--have been incorporated within Intel's most recent offering, the 8049.

By January 1979, Spectrum (1979, p. 53) could report that the same industrial control task previously performed by a minicomputer costing $1500-$2000 could now be accomplished by an 8-bit microcomputer system on a single printed circuit (PC) board

costing about $300-$400. Actually the microcomputer system would be more efficient. The industrial control operation, like those of many military applications, does not require all the computing power of a minicomputer, thus, under-utilizing its capabilities. Further, according to Spectrum, the microcomputer, being less complex and using simpler, less costly software, would be easier and less expensive to reconfigure or reprogram for changing industrial control applications.

As Adler et al. (1977, p. 86) noted:

> In some instrumentation and control applications, we are approaching
> the time when the cost of digital control may well be less than not
> only the system sensors, but the hookup wire itself. Microcomputers
> will be used much as bi-polar latches are used today--as building
> blocks for larger systems.

Baker (1979, p. 60) reported that whereas "only a few years ago similar functional capability would have required a room full of bulky air conditioned equipment," in 1979 a general purpose processor, complete with memory and I/O ports, could be manufactured on a single chip. He noted that VDU controllers contain in their hardware functions previously handled by software. He further observed that memory costs continue to fall while "instruction set capability of present microprocessors approach or exceed earlier minicomputer capabilities."

A continually increasing range of computing capability is being made available. Distinctions among micro-, mini-, and macrocomputers appear subject to almost yearly change. Classifications of micro, mini, and macro are thus only relative and for a given time. More and more, attention will likely be given to what computing capability is desired rather than on the level of computer to be used.

Based in part, upon trends toward increasing requirements for computational capabilities, increasing modular configuration of system design and increasing tri-service procurement of computer systems, Turn (1972) projected that the distinctions between ground-based, airborne command-post, and avionics computer systems would become less and less. He expected these trends to lead to the creation of modular components (i.e., I/O devices, processors, and memories), which could be selectively assembled to satisfy various operational requirements and each of which would meet the environmental demands of air-, sea-,, and ground-based use.

Five years later, Adler et al., (1977, p. 190) predicted that by 1987 numerous types of airborne systems based on microcomputers would be feasible. These were expected to be small, light, sophisticated, and relatively inexpensive. Although the microcomputer was expected to contain most of the complexity of the system, it would not contribute significantly to the size, weight, cost, or power demand of the total system. Regarding ground-based computer systems, the same report (p. 191) projected that:

1. Ground-based computers are expected to proliferate as the results of LSI technology. Many functions that are now centralized will be implemented in distributed, dedicated LSI computers in the future.

2. During the next quarter century, the LSI data-processing computer will see its speed improve by a factor of 50, while power, size, weight, and cost will improve by a factor of 10 or more.

3. Compared with the most advanced large machines in 1975, LSI technology of 1985 should produce an equivalent machine, operating at approximately the same speed,

dissipating 150 times less power, consuming 150 times less size and weight, and costing between one and two orders of magnitude less.

4.   In dedicated applications where speed requirements can be reduced, further reductions in power, size, weight, and cost will be possible.

Large scale integration has resulted in the production of complete "computers" on single chips, thereby minimizing or eliminating the need for separate I/O, processor and memory modules in many "computerized system" applications.   In such cases, the computer-on-a-chip is embedded in the larger system. With continuing advances in large scale and very large scale integration, such embedded computers will likely be called upon to perform increasingly complex and sophisticated computational tasks.

Interactive computer systems (i.e., those that permit man to input data or instructions into the system and obtain outputs of some sort from it), cannot, of course, be reduced to a single chip. As was noted earlier, the processor and memory constitute only a minor part of a computer's total size and weight. The input-output device, the power supply, and the packaging are the primary determiners. Processors and memories can easily be tucked into consoles or "intelligent" terminals about the size of an office typewriter. Numerous "desk-top computers," (e.g., Radio Shack's TSR-80), are readily available. Individual machines offer different capabilities and features and plug-in ROMs and RAMs, as well as various accessories and/or peripherals that permit such systems to be adapted or tailored to a variety of users and requirements. Although modules or peripherals from different manufacturers are generally not directly interchangeable, efforts are being made to standardize on various interface characteristics. If these standards materialize, there will be an even greater opportunity for custom tailoring a computer system to the exact needs of the user.

Continuing developments of computers qua computers can be anticipated. The most significant computer impacts are expected to be within a larger system context (i.e., within computerized system). For these applications a variety of components are needed to interface the computer with other machines and the analog world. As Adler et al., (1977) describe these relationships:

> The elements required in this peripheral interface area at present
> include a large and diverse array of components ranging from line
> drivers, multiplexers, level shifters,, and data converters which are
> required to change the strength, origin, and format of the analog or
> digital signals, to the input/output devices (sensors and actuators)
> required to interface between the electronic system and the physical
> world. From a circuit standpoint, many of these devices require a
> mix of both analog and digital functions, and this has tended to keep
> them physically as well as functionally separate from the processor.
> The sensor/actuator area is frequently interdisciplinary and highly
> specific to a given application, restricting its suitability for high-
> volume batch production.
>
> As the capability to produce low-cost LSI circuits has developed, the
> number of separate interface circuits required for system implemen-
> tation has dropped rapidly, and there has been an increasing effort to
> define and develop standard interface elements for many machine-
> machine interfaces (pp. 88-89).

The Adler report goes on to state that:

> The analog-to-digital converter is probably the most significant peripheral interface component for next-generation instrumentation systems. A wide number of designs are now available at the eight and ten-bit levels, offering a wide range of conversion times and chip complexities. Future progress extending resolution beyond the twelve-bit level will be relatively slow as a result of both market demand and the extremely high component match and stability required. Resolution levels should nevertheless reach sixteen bits during the 1980s, probably using new conversion techniques and possibly using sophisticated microprocessors to ease the stability requirements on the converter. At the eight-bit and possibly ten-bit levels, ADCs will be part of the microcomputer chip by the early 1980s or before.
>
> Conversion time will show steady improvement as smaller dimensions and improved processes are employed; however, conversion time will continue to be comparable to several microcomputer instruction cycles. Cost will decline relatively slowly at a given resolution level, particularly at ten-bits and above where extensive testing and trimming is required. At ten-bits, converter cost comparable to that of the microcomputer chip is expected, while for higher accuracy the converter cost could be several times that of the microcomputer (pp. 103-104).

The function of A/D and D/A converters is to interface the digital processor with various analog I/O devices. Alder (1977) notes that:

> The requirements on such converters include high speed, high accuracy, and low cost, and efforts to satisfy these requirements have motivated the joining of high precision analog technology with a batch-process production environment (p. 90).

There are many analog-to-digital conversion (ADC) techniques addressing a variety of requirements. Figures A-12, A-13, and A-14 demonstrate typical speed, accuracy, and cost trends expected for ADCs.

"Gigabit electronics" can be expected to have significant impact on ADCs in the near future. Bosch (1979, pp. 372-373) reported 1 and 2-Gbit/s data rate intersatellite communications systems under field test. He anticipated that by 1983 logic circuits in the 2 to 7-Gbit/s range will be commonplace. This, he concluded, would move analog-to-digital interface further up front in computerized systems (i.e., closer to the analog sensor). For example, gigabit circuitry for a real-time, or near-real-time, analog-to-digital converter for special purpose radar applications, under development in 1978, was expected to be demonstrated in the laboratory in the near future.

Although there is often a delay between laboratory development and practical, commercial production and although commerical "introduction" of a device or capability is often optimistic, it is clear that at least near-real-time, if not real-time, ADCs are virtually certain by the mid-1980s. This capability will likely have significant impact on a variety of computerized sensor and communications systems, which could have applications in Coast Guard missions.
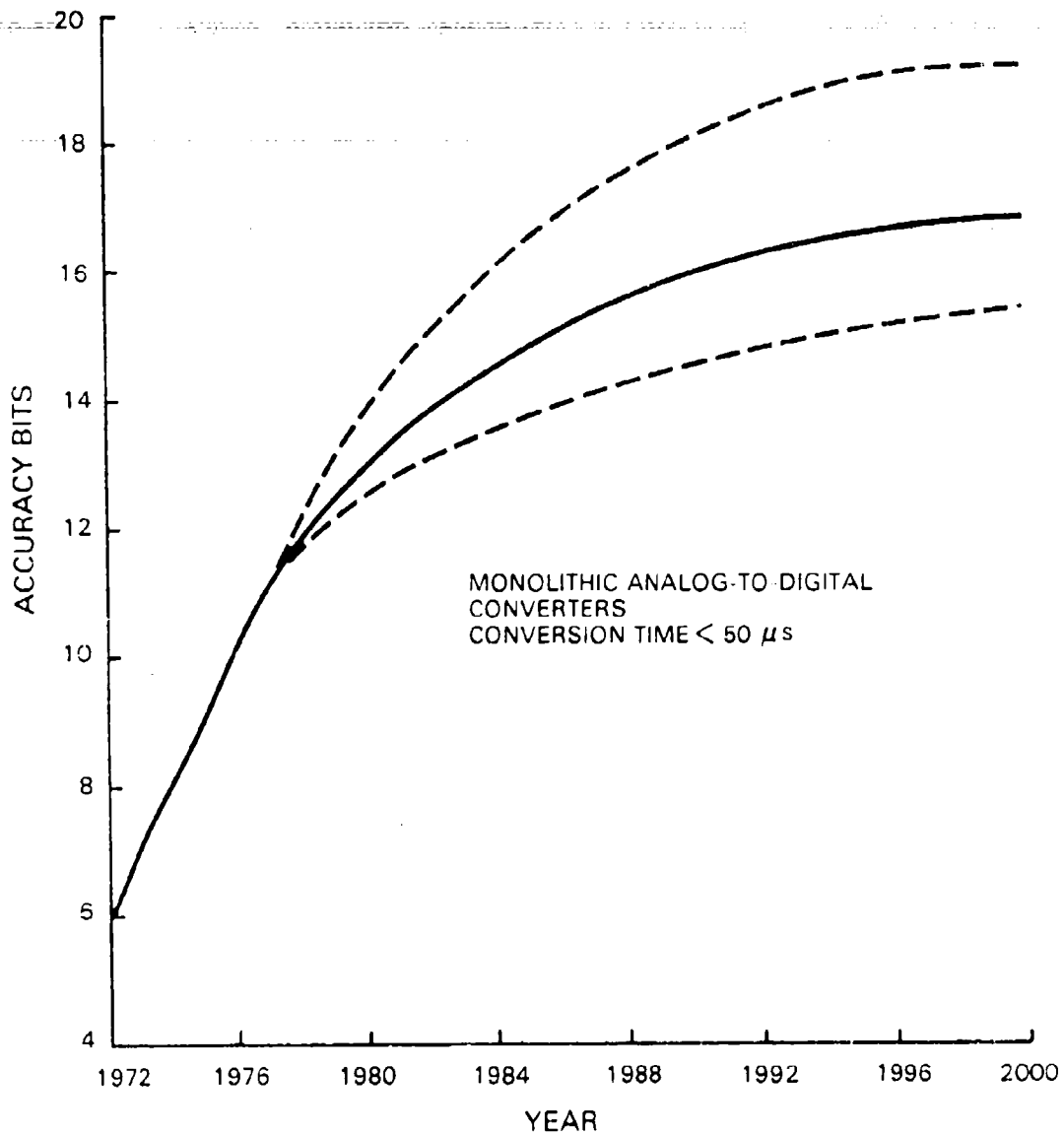
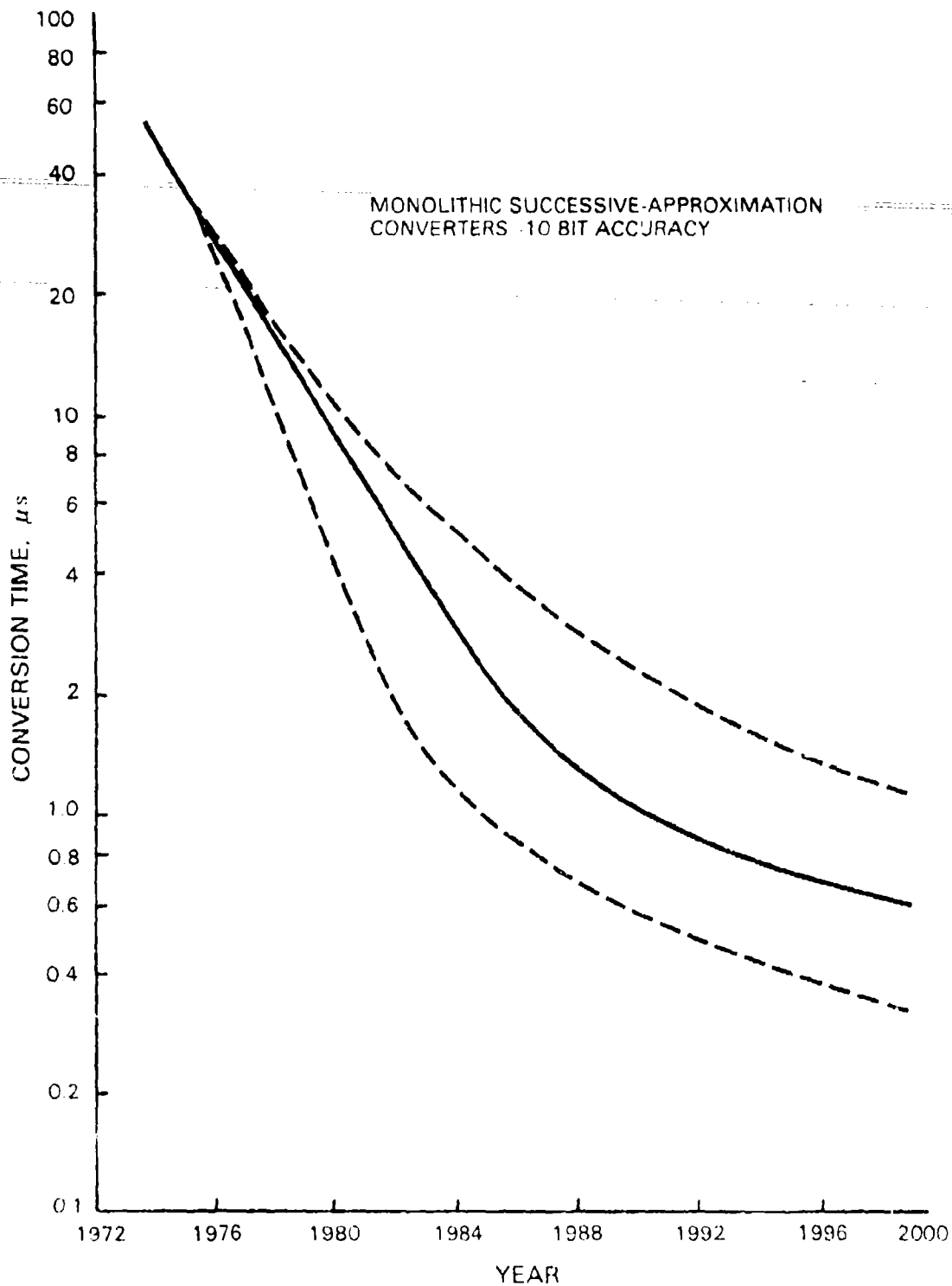Figure A-12. Anticipated Accuracy for Monolithic Analog-to-Digital Converters (From Adler, 1977)

Figure A-13. Conversion Time for Successive Approximation Analog-to-Digital Converters (From Adler, 1977)
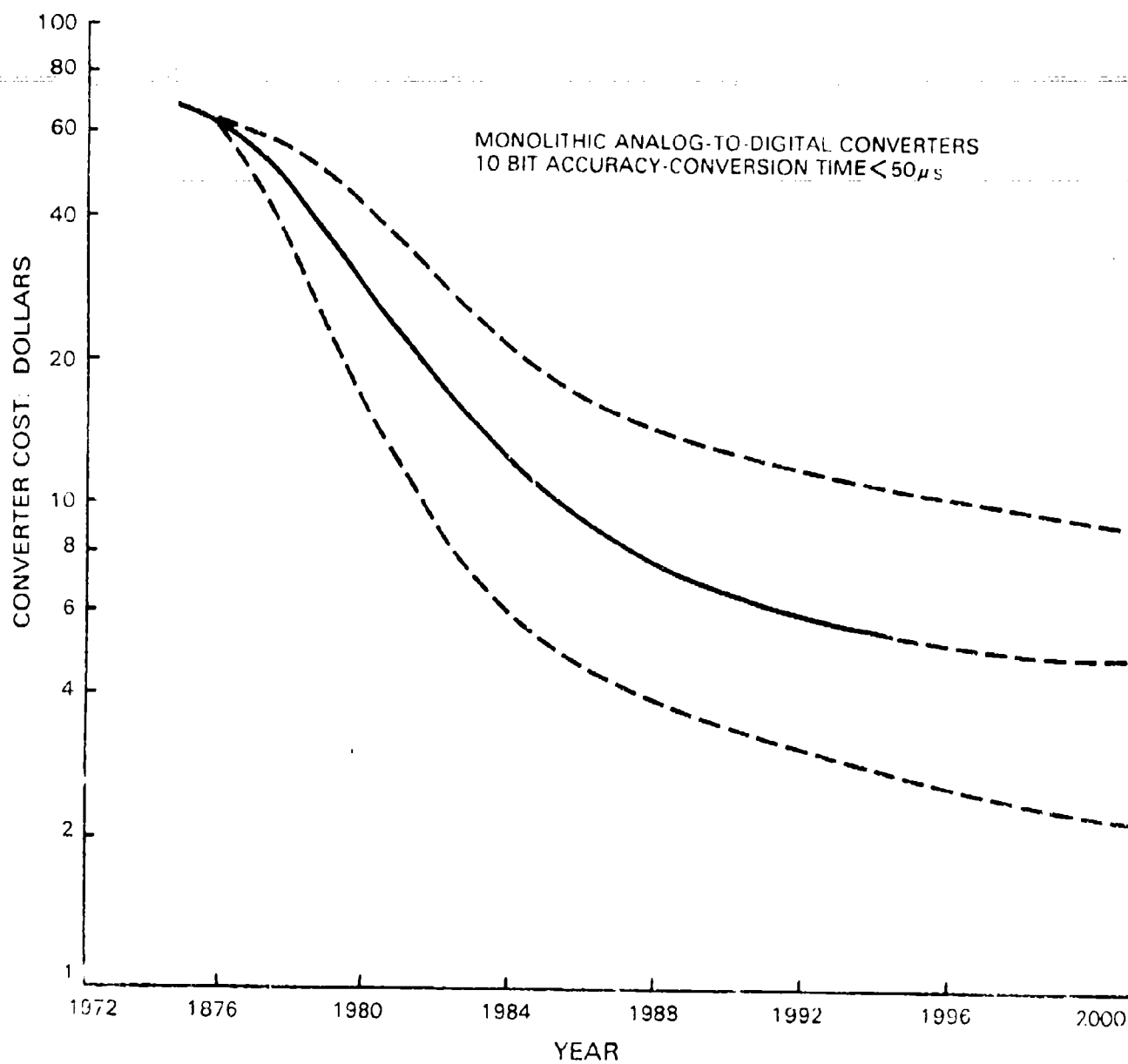
Figure A-14. Anticipated Decline in ADC Cost as a Function of Time
(From Adler, 1977)

It is difficult to define "computer technology" except in rather arbitrary terms. Whether looked upon as the body of technologies necessary to produce computers or the product resulting from those technologies, there is little that is identifiable as exclusive to computers. Computer production is dependent on a variety of sciences and technologies such as materials (metals, ceramics, etc.), electronic theory, mathematical theory, "photography" (lithography, xerography, holography, etc.), display technology, various manufacturing techniques, etc. Each of these have applications in fields other than computers.

Traditionally, the image of computer technology has been dominated by impressive, massive, data processing computers. Despite its size, however, a computer is essentially only a complex system of two-position switches. Initially the switching was done with vacuum tubes, then by bi-polar transistors. With the advent of integrated circuits, many non-computer applications were found for these switching circuits in fields other than "computing" (e.g., as control of industrial type processors). Denser and denser packing of functional circuitry, however, has resulted in the equivalent of a virtually complete computer on a single "chip." Such microprocessors or microcomputers have become an essential, integral component within such technologies as sensors (radar, laser, infrared) and communications. The speed and power of solid-state computer components are basic to the functioning of laser devices. Laser technology, in turn, is being used or developed for use in the production of Large Scale Integration (LSI) and Very Large Scale Intergration (VLSI) chips. It is also being used, and additional developments explored, as a component of computer memory devices.

The image of a computer as a large scale information storage and retrieval device or a large, powerful mathematical problem solver remains. But increasingly greater use is being made of computers as data processors. As Adler notes (1977, pp. 34-35):

> Developing technologies embedded in an expanding population have an insatiable appetite for information. Every new system, from manufacturing to banking to air traffic control, presents new demands for the generation, storage, transmission, and transformation of various types of data. Digital computers are at present the only way to fulfill these needs. ... As each new application area is brought under control through the use of computers, new refinements and capabilities in that same area immediately suggest themselves, continuously increasing both system size and complexity. In addition, each application acquaints more people with the power versatility of the digital computer, and suggests further applications in their own particular fields.

Increasingly, as technologies and applications interact, the distinctions between and among them would seem to be of decreasing significance. Of greater importance will be technological interrelationships and the interactive support necessary to develop a functional capability to answer an operational need.

Computer audio outputs such as buzzers, tones, etc., have become fairly common in warning or signaling applications. Adler observes (p. 130):

> As microcomputer and memory costs decline, voice output should be practical for airborne avionics. At present, phrases are stored digitally in memory for recall by the processor. As this technology advances, storage of individual words may be feasible so that phrases may be synthesized directly by the machine. Voice output systems should be practical for avionics during the 1980s.

Voice actuated devices of one sort or another are also fairly common. In most cases, however, the voice serves merely as a signal source to activate or deactivate a sound-sensitive switch. Sophisticated voice interaction with computers is, as Adler points out (p. 130):

> ... a more difficult problem, involving computer recognition of specific words in the face of regional accents and differences in pitch. Systems have been developed which recognize digits and a few words, but the cost is still very high and vocabularies are very limited. ... Limited-vocabulary systems may be available for air traffic control by the mid-to-late 1980s, but it is unlikely that voice-entry systems will be available for airborne applications before the 1990s.

The development of the capability for voice input to computers appears to be primarily a problem of linguistic rather than computer technology. Research into the characteristics of language and of the human voice is being actively pursued within the scientific community. These investigations are addressing not only the problems of accent and pitch, mentioned by Adler, but also such difficult and demanding problems of context, idiomatic word usage, and the like. Much more rapid progress is being made in this area than Adler anticipated. Computer generated "speech" output is not unusual now, and even certain microcomputers are capable of accepting limited voice inputs. Voice interaction with computers, using a completely unrestricted conversational vocabulary, idiom, and syntax, may be decades away, but voice interaction using extensive, flexible, specialized vocabulary should be available by about the mid 1980s.

Despite a probable increase in direct/automatic interfacing between computers and external systems, man will likely still retain a monitor/override function or option in many of them. For most computer (or computerized) systems the task or operation to be performed will ultimately be directed by man and the result will ultimately be presented to him (Adler, 1977, p. 115).

The primary types of displays are character (or alphanumeric) and imaging. The other major types are audible (buzzer, tone, etc.) and visual (lights) to display simple alarm, annunciator, etc., type information. For character-alphanumeric applications, Adler et al., (pp. 127-128) foresee that light-emitting diodes (LED) and liquid crystal displays (LCD) will not be displaced during the 1980s. Similarly, the cathode ray tube (CRT) will continue to be the dominant TV-type imaging display throughout the 1980s, although gas-plasma devices (GPD) are expected to begin to be used for some applications about 1985 (p. 129). The IEEE noted in January 1978, however, that, although not an immediate, aggressive challenge to the CRT, "flat" display technology (including LEDs, LCDs, and plasma panels) was advancing rapidly with a lengthening and broadening list of applications (Spectrum, 1978, p. 38). Other technologies do not appear sufficiently advanced to present likely, practical, cost-effective successors to the above display technologies before at least 1990.

"Hard copy" output from computers characteristically has been by means of electro-mechanical printers. Their relatively slow speed has been, in many applications, a major limiting factor in the speed of the man-machine system operation. A laser-beam printer was introduced in 1975, however, (Spectrum, 1976, p. 46) which was reported to be "dramatically" faster than electro-mechanical printers. It was projected that anticipatable improvements in speed, cost, etc., would make this type of device a contender to replace currently standard print-out devices, and/or offer an alternative continuous strip-

chart type display. Since then "ink-jet" printers have made their appearance to contest with the laser beam printer. The computer system speed restrictions due to print-out speed limitations would therefore seem to be easing significantly.

In the field of computer input technology there appears to be no challenge to the alphanumeric keyboard for man-to-computer input. Devices such as light pens, ball tabs, and the like will continue to be used for special purposes but are not contenders to replace the keyboard as the primary direct input device.

Infrared Technology

Thermal, or infrared (IR), detectors of one sort or another have been in use since the discovery of IR radiation and the demonstration of IR imaging by Herschel in 1800. This discovery and demonstration was followed by Nobili's invention of the thermopile in 1829 and the development of thermocouples by Nobili and Melloni in 1833. The next advance was that of the holometer by Langley in 1881. In 1873, Smith had observed a drop in the electrical resistance of selenium exposed to light. But it was not until 1917 that Case used this photoconductive effect in thallous sulfide to detect IR radiation. Thallous sulfide, however, was very unstable. Its usefulness was therefore very limited until 1941 when Cashman managed to improve the stability of the material enough to make it productively practical. Similarly, Bose first reported the photovoltaic effect of PbS crystals in 1904, but the phenomenon was not developed for operational IR detectors until World War II. The early 1920s saw the development of infrared photography. The first workable scanning thermal sensor was introduced in 1929 and the first intensity-modulated CRTs made their appearance in the late 1930s.

Technological developments accelerated after World War II with the application of photoelectric emissions of semiconductors in low light level systems in the late 1940s and early 1950s; with the introduction of the volometer, which gave good image resolution, but was very slow; and with the pushing of both "intrinsic" and "extrinsic" detectors to a high state of development.

Infrared technology goes back 180 years, but only within the last 30 years has it become an operationally practical technology. Indeed, modern IR technology has been in large part dependent on the development of solid-state physics and, perhaps even more, on solid-state technology (Potter, 1975; Levinstein, & Mudar, 1975; Looft, 1979).

An infrared sensor system is, conceptually, quite simple. It consists of an optical lens to gather and focus IR radiations reaching it; a sensing surface capable of responding to those radiations; electronic circuitry to amplify, convert, and process those responses; and a display to interface with a human operator. While virtually all substances are responsive to IR radiation, few are practical for sensor applications. Until recently most of these few required cryogenic cooling in order to function properly. Indeed, one of the technological thrusts of the 1960s was the search for thermal detectors operable at ambient rather than cryogenic temperatures (Potter, 1975). While progress has been made in this search, Looft reported as recently as 1979 that cooling is the most troublesome of IR sensor subsystems because of its complexity, unreliability, weight, and power require-ments. He also notes that the lens is the most costly, in part because of the precision required and in part because special and expensive materials that pass IR frequencies are required.

Some proponents of IR technology seem to ignore or minimize these inherent problems. For example, Stringer (1974) stated that:

> The results of fundamental research have made it possible for operation on land, sea, and in the air to penetrate darkness, poor visibility, and smoke or haze in such a way as to offer the possibility of allowing combat capability 24 hours a day, in all weather.
>
> The sensors can be used to examine objects up to several thousand meters ahead and in either the visible or infrared waveband passively. In addition, it is possible to penetrate smoke, haze, or fog. ... The impact is significant... in that it offers an ability to fly manually in poor visibility, and to identify and record the position of land and marine targets.

As promising as this claim was, five years later Looft (1979) identified poor performance of IR systems under adverse weather conditions of fog, zero-contrast atmosphere, and target noise as among the major problems still to be solved. He also noted that the 1979 cost of $1000 per pound of system was another stumbling block. Thus, while significant advances have been made in IR technology, significant improvements are still necessary to develop a really good, practical, reliable, maintainable, and economical IR imaging system.

Early IR systems were relatively simple heat detectors for use in self-guided missiles. They needed only to detect the most intense heat source or the presence of certain IR radiation frequencies within range. Other systems would then "lock on" to the detected target and guide the weapon to it. Thermal imaging systems are necessarily much more complex. They must somehow "scan" an area and provide a "picture" of what is "seen." This is a much more difficult process in the IR spectrum than in the visual spectrum.

> The details of a scene are contained in the variations in the scene radiance arising from local variations in the temperature, emissivity, irradiance, and reflectance of the objects in the scene. The contrast present in the image is a function of both the variations in the scene as well as the average level of radiance in the scene. A fundamental limitation of thermal imaging arises from the fact that the changes in temperature and emissivity are small and the background radiance is large, resulting in poor contrast. (Krishnan & Ostrem, 1976, p. 5)

Kohn et al., (1977, pp. 2-3) describes the situation thus:

> A prime concern in the development of any thermal imager is the large background radiation present in the thermal scene. A typical requirement for a thermal viewer is to make possible recognition of an object at 300.1K in a uniform 300K scene. In this case, the "signal" is the difference between the number of photons arriving from the hotter object and the number arriving from an equal solid angle of the background. This signal can be less than 1 percent of the background, but, in order to detect it, the sensor must read the entire background. It is this requirement of handling the entire background that taxes the target-storage and beam-density capability of standard Vidicon tubes and makes the solid-state alternative so attractive. But, regardless of the capability of the detector to handle the background without saturating, the presence of the background

severely aggravates the problem of detector nonuniformity. If the detectors were to vary in sensitivity by just a few percent, the nonuniformities in the picture due to the background would overwhelm the signal with fixed-pattern noise.

Complicating the problem is the fact that most types of infrared detectors cannot be produced even as uniformly as detectors fabricated for the visible part of the spectrum. Detector nonuniformity is not a problem for visible imagers because of the high contrast usually present in the reflected visible light from normal scenes, but it is always a major consideration for thermal imagers. That is why, in FLIRs, the separate amplifiers for the 100 or more detectors in the linear array must be trimmed individually to compensate for differences in detector sensitivities. This compensation method contributes to the high cost of line scanners and is clearly impractial for an area imager.

While there have been, and are, other IR sensing systems, the family known as Forward-Looking Infrared (FLIR) has been the most successful to date. Levine, Beideman, and Youngling (1978, p. 1) provides a succinct overview of FLIR developments:

Early FLIR systems were predominantly of parallel-scan configuration, while more recent systems have tended towards a serial or serial/parallel combination employing fewer detectors but providing higher signal-to-noise (S/N) ratios by temporal integration of signals from several detectors. ... These systems typically use a hot spot tracker, but because of their limited resolution capability, difficulty is encountered identifying small tactical targets. the new generation FLIRs have a resolution capability competitive with TV and low light level TV systems and can provide a high resolution real-time sensor for target discrimination.

Typically, FLIR sensor outputs are imaged on a cathode ray tube (CRT) display mounted in an aircraft cockpit. An observer views the FLIR image and reacts to targets as they appear. The observer's capability to acquire the target, given an IR target signature, is a critical factor in the successful utilization of FLIR as an air-to-ground target acquisition system.

Levine et al., (pp. 19-20) go on to note that:

Early FLIRs produced moderately good image quality accompanied by problems of limited dynamic range (signal-to-noise ratio (SNR) and contrast), angular resolution, and image blemishes such as streaks, shading, and flicker.

From an image quality or observer utility view point current and "advanced" FLIRs have higher resolution and sensitivity. The truly advanced FLIRs will have slightly smaller apertures and reduced weight, size, and costs. The major part of these advances will most likely be accomplished through focal plane arrays of detectors, charge coupled device readout techniques for the video preamplifiers. Future systems will have response capability in both the 3-5 μm region as well as the 8-14 μm region of the spectrum.

The above development projections were supported by Sheehan (1979) who observed that a solid-state thermoelectric (TE) cooled focal plane array FLIR was expected to go into Engineering Development for the Army in 1980. He also anticipated that an uncooled IR imager, which began with basic research in 1973, would probably go into Engineering Development by 1986. Additionally, he foresaw a high-density, large focal plane array FLIR going into production about 1985 or 1986.

Infrared reconnaissance (i.e., the reconnaissance use of IR), is, in Norling's (1979) view, a relatively mature technology. He estimates that the efficiency of IR systems is currently about 80 percent of "background-limited" performance (i.e., limited by the target-surround contrast and the characteristics of the atmosphere between target and sensor). He considers the charge-coupled device (CCD)--originally a computer technology generated development--to be a breakthrough for focal plane array IR detectors. CCDs permit integrating signal processing with the detector array itself. This may be accomplished either as a monolithic IRCCD (Infrared Charge-Coupled Device) in which the CCD concept and construction is extended into the IR range or as a hybrid IRCCD in which the detection and signal processing functions are performed by separate but integratable components. It may be noted that Kohn et al., (1977, pp. 1-4) also see CCD technology, especially in the form of hybrid design, as a promising approach to improved IR capability and imaging performance.

Without placing dates on developments, Norling anticipates a trend toward real-time operation of IR reconnaissance systems, either with direct data linking of imagery to a ground-based operational command center for analysis interpretation and decision, or with real-time scanning and automatic screening for only those targets of interest. It may be noted that the Air Force has developed an electronic solid-state, wide-angle camera system, which transmits visual range photography directly to ground-based film recorders (EOSD, 1979, pp. 11-12). Thus, refinement of the IR sensing and on-board processing would bring Norling's prediction close to fruition.

Lacey (1979) also predicts the availability of a two-dimensional, high density, monolithic, focal plane array sensor by 1988. He expects this system to provide more data than its operator can handle in real-time. Automatic screening, possibly by utilizing a computer to analyze data and draw circles around targets on the display, will be essential.

IR technology inherently has a very demanding challenge--namely how to use the IR spectrum. Infrared spans almost eleven octaves of the electromagnetic spectrum from the upper level of the visible range at about 0.75 μm to the microwave region at 1000 μm. But, as Hudson and Hudson (1975, p. 104) note, only a small portion of this tantalizingly broad range is usable for IR sensing. the Hudsons subdivide the IR range into four bands: near infrared, from 0.75 μm to 3 μm; middle infrared, from 3 μm to 6 μm; far infrared, from 6 μm to 15 μm; and extreme infrared, from 15 μm to 1000 μm. Unfortunately, the Hudsons point out, the earth's atmosphere is essentially opaque to frequencies in the extreme infrared range. Thus, most of the IR band is immediately excluded from consideration for remote sensing purposes. In addition, fog and cloud particles, to the degree that they are present, make the atmosphere opaque to frequencies in the 2 μm to 20 μm range. There are, however, spectral intervals or "atmospheric windows" that are relatively transparent. These, of course, are of greatest interest to the technology for "all weather" sensing. The problem, so far not completely solved, is to find materials sensitive to these frequencies, which also exhibit the other necessary or desirable characteristics (e.g., do not require cryogenic cooling).

Current IR sensor systems generally operate in a relatively restricted frequency range, limited by the thermal response characteristics of their sensor materials. The sensor materials, in turn, are selected in part on the basis of the thermal radiation characteristics of the anticipated target objects. Some consideration is being given to the concept of multispectral scanners (i.e., ones that will have a capability for scanning and detecting a wide range of IR frequencies). Levinstein and Mudar (1975, p. 12), however, point out that the design of such systems are beset by a major problem: different spectral bands are best detected by different detection modes. As examples, they note that frequencies in the visible range are best sensed by uncooled photomultipliers. Silicon is good for the near infrared range, with uncooled PbS effective to about 2.5 μm. Photovoltaic detectors of InSb serve well in the 2.5 μm to 5.5 μm range. Nitrogen cooled photoconductive $Hg_{(1-x)} Cd_{(x)} Te$ is the preferred sensor from 5.5 μm to 14 μm. And for frequencies for 14 μm to 30 μm, liquid helium cooled Ce:Cu is their proposed best detector. Considering the magnitude of this problem situation, it appears that a single-unit broad-range, multispectral scanner is not likely to be operationally available in the foreseeable future.

Although such a sophisticated multispectral scanner may not be operationally feasible for some time, less ambitious systems are likely to be available within the decade of the 1980s. Levinstein and Mudar (p. 12) report:

> The applications of infrared technology to remote sensing problems have become quite diverse, covering such fields as law enforcement, crop identification, meteorology and atmospheric physics, urban planning and land use, environmental pollution monitoring, geology, oceanography, astronomy, etc.

They go on to state:

> The current trend in remote sensing applications is the use of multispectral data. [Note: The data are not necessarily obtained by the same device, as they would be by a multispectral scanner.] In this application, each spectral channel or band can be regarded as an independent coordinate in an n-dimensional space. The range of signals for each channel for a given target (wheat, hot water, cloud, etc.) defines a volume in this n-dimensional space. If the volume for a particular target is sufficiently separated from other target volumes, the particular target can be uniquely identified. This type of identification is particularly amenable to machine data processing using analog, digital, or hybrid techniques.

The applicability of this approach to a variety of Coast Guard missions is obvious. Indeed, the concept has already been successfully demonstrated (Aukland, Sohn, and Rasmussen, 1971).

While the foregoing may imply that IR detectors are necessarily passive and dependent upon the thermal radiation characteristics of the scene viewed, this is not the case. They can be designed as active systems that have inherent advantages over passive systems. According to Krishnan and Ostrem (1976, p. 14):

> In an active imaging system a laser (called the laser illuminator) illuminates the IR scene, and the reflected radiation is collected to produce an image of the IR scene. The primary difference between active and passive imaging systems is that for passive imaging,

broadband thermal radiation must be imaged but for active imaging the radiation to be detected is reflected or scattered laser light with a narrow bandwidth. For passive imaging, it is important to collect as much of the emitted IR scene radiation as possible. In fact, as we shall see in later sections, among the major disadvantages of the coherent upconverters as compared to the FLIRs for thermal imaging are their small bandwidths and small acceptance angles. For active imaging the situations reversed. The smaller bandwidths of the coherent upconverters is an advantage when detecting radiation of a particular frequency, since this affords effective discrimination against the broadband thermal background without the need to employ a cooled filter in the system optics.

The foregoing indicates that no dramatic advances should be expected in operational IR systems before the mid-1980s. What developments do appear likely, will be merely evolutional improvements on what is now available. Beyond 1985, however, major strides can be anticipated in such areas as staring focal plane array sensors, uncooled thermo-electric IR imagers, IRCCDs, integrated laser-IR detector systems, and perhaps multi-spectral scanners, or devices, which approximate multispectral capability.

There is no evidence, however, that significant improvements will be made in one critically important aspect of the employment of IR imaging, namely the interpretation of the IR display. The "reading" of an IR image is somewhat akin to that of a photographic negative. Most people have extreme difficulty "reading" a photographic negative, especially a color negative. The shades and colors are all wrong, which makes it difficult to perceive even the form of otherwise familiar objects. IR image interpretation is, at least, an order of magnitude more difficult in that not only does an object's IR "shape" not necessarily coincide with its visual shape, but the object's IR image is constantly changing as it and its background warm or cool. IR interpretation can, of course, be learned. Real-time interpretation may, however, place an unacceptable burden upon the operator, especially if he or she has other, especially visual spectrum related, functions to perform. In any event, any proliferation of IR sensors in Coast Guard facilities will generate a recruiting/selection demand for personnel with aptitude for the task and an increased training burden to develop their aptitudes.

Laser Technology

Forrester's (1974, p. 2-1) excellent, layman-understandable discussion of lasers traces the technology back to the first, pre-1960 observation of coherent optical oscillation. In 1960 pulsed visible light from a ruby crystal was first observed. There followed a flurry of investigative research and development in laboratories throughout the world. In but two decades, what started out as a laboratory curiosity has now become an active and advanced technology.

"Laser" is an acronym for Light Amplification by Stimulated Emission of Radiation. In use, however, the acronym has come to be applied variously to the beam of light produced (i.e., the "laser beam," the light beam producing device, and as an adjective), to devices or systems using a laser device as a component or subsystem (e.g., "laser gyroscope" or "laser printer"). The emphasis herein will be primarily in this third context.

A laser device produces a beam of "coherent" light (i.e., an extremely narrow or "tight" highly directional beam, in contrast with "incoherent" light sources), which generally radiate in all directions unless focused by optical or other means. There is one environmental factor, however, which severely restricts the development of laser

systems, at least for use within the earth's atmosphere. While, theoretically, a laser beam can be of any frequency from the infrared range of the spectrum to ultraviolet, practically, the whole spread of frequencies is not usable. Dust, moisture, pollutants, etc., in the air scatter and absorb transmitted light, thereby limiting the amount of light available for the performance of the desired function. A few frequency bands or "windows," however, are less susceptible to scatter by "atmospheric crud" than are others. Laser research has, therefore, emphasized solid state, gaseous, and semi-conductor materials and devices most effective and efficient at those frequencies. Each material tends to have its own set of advantages and disadvantages, as well as frequency-applicability. Some materials require cryogenic or thermoelectric cooling, although operability at "room" (i.e., ambient), temperature is preferred, especially for avionic applications.

Despite these limitations, Forrester (1974, p. 2-1) observes that:

> ... the laser possesses many properties which make it superior to conventional light sources for a variety of systems applications. This arises mainly from the high degree of spacial and temporal coherence of the laser which leads to the generation of highly directional beams, whose brightness, in terms of power per unit bandwidth per unit solid angle, exceeds conventional sources by many times. Almost any technique used in the microwave region can now be applied to the optical region; for example, mixing of optical frequencies can be used to produce superhetrodyne detection thereby offering considerably greater sensitivity than conventional optical receivers. Also, the ability to generate very short optical pulses leads to a variety of applications which include rangefinding, target marking, and communications.

The attractiveness of lasers for various applications has led to a high level of laser research and development by both military and industrial laboratories. While the literature is replete with reports of the results of this effort, the vast majority of these reports address the technical details of laser physics and engineering rather than operational systems applications of interest for this forecast. No attempt, therefore, is made to survey or summarize those reports.

The obvious military applicability of the characteristics of lasers is a major reason why laser technology has had long stanaing and continuing support from the military establishment. Laser developments have, therefore, been largely oriented toward military applications (e.g., for communications, surveillance, and weapons). Not all developments have been military oriented. Thus, our attention has been directed to those developments, military or non-military, which appear applicable or adaptable to Coast Guard use.

One of the more promising emerging applications of laser technology is to the development of laser gyroscopes. The idea of laser gyroscopes is, of course, not new. Honeywell, for instance, introduced a small laser integrated gyroscope in 1965. This, however, was viewed more as a feasibility demonstration, the beginning of an effort aimed at developing a practical laser integrating gyroscope of inertial-grade performance (Laser Focus, February 1979, p. 89). It was not until about a decade later that practical operational systems came into being. For instance, Sperry (UK) delivered its first British designed and built laser gyro unit in 1976, and Sperry (US) delivered its first "production ready" laser gyroscope to the U.S. Navy in 1978 (Laser Focus, March 1979, p. 24).

Spectrum (January 1978, p. 67) reported that in 1977 the laser gyroscope moved out of the laboratory and into a tri-service program to develop a Ring Laser Gyroscope (RLG)

for use in aircraft navigation, missile guidance, etc. Then Laser Focus, (February 1979, p. ??) reported that in 1979 Honeywell was ready to go into production of a RLG having an accuracy about equal to that of inertial systems, but at about half the cost. Also, with a Mean Time Between Failures estimate of 45,000 hours, it would have over 10 times the performance reliability of most non-laser systems. This, however, was not an airborne system, and avionic gyros present problems not present, or not present to such an extent, in shipboard systems. A major problem in both avionic and shipboard laser gyros is "noise" within the device. Integrated components (i.e., semiconductors), and improved optical fibers (fiberoptics) are expected to provide a major improvement in the "noise" situation. Both Laser Focus (March 1979, p. 24) and Optics and Laser Technology (April 1979, p. 63) anticipate that "strap-down" laser gyro aircraft navigation systems will become operationally available about the mid-1980s. If such systems do become available it would appear that they may be useful not only in Coast Guard aircraft but in smaller cutters, which present certain environmental demands upon equipment more akin to those of aircraft than of larger ships. Perfection of the Ring Laser Gyroscope may not be the last word in aircraft navigatin, however. Dr. J. E. Goell of ITT (Goell, 1979) suggests that by 1985 a "fiberoptic gyroscope" smaller than a laser gyro will be a reality.

Military weapon system research has included efforts to use lasers to improve capabilities for target detection, designation, location, ranging, and tracking. These same basic functional requirements occur in a variety of Coast Guard missions and operations. The main difference between the military and Coast Guard applications appears to be that the ultimate objective of the military is to be able to destroy the target while that of the Coast Guard is to be able to save it or take other non-destructive action. Steady progress is being made in these military applications in terms of reliability, range, resolution, weight, size, power requirements, etc., although specific performance characteristics are obviously classified. Many of these laser weapon developments will be adaptable to Coast Guard uses. But where maximum operational range, is a factor, these adaptations will probably find use primarily on aircraft and larger cutters and at shore installations. This is due to the fact that lasers are currently limited to line-of-sight applications and thus, for maximum range, the illuminator (and sensor, in active systems) must be installed in an elevated position.

A new "laser radar," however, has been reported by Fowler (1979) as currently entering "early bread board" research and development. This system will utilize an active, coherent laser transceiver and will sense the presence of a target by Doppler processing of moving target indicator or engine or other vehicle vibration data and by flints from man-made objects. The device is looked upon as "a new approach to target finding," and it has obvious applications in the Coast Guard environment. Fowler, however, admits there are a number of significant problems yet to be solved. Because of these problems, it is unlikely that a production level operational laser radar will be a reality before the late 1980s.

An innovative scanning laser system of potential utility to the Coast Guard was reported in Optics and Laser Technology (August 1978, p. 163). This system was developed to investigate the feasibility of charting coastal water depths from the air. It employed a pulsed neon laser beam, which was reflected from both the ocean surface and bottom. Differences in elapsed time between the two returns provided the basis for calculating water depth. There was "excellent agreement" with existing charted water depths, although maximum depths were not given. It was estimated that an operational version of this system would be able to chart from eight to forty times the area per hour that existing hydrographic methods can now cover. Such a system, if eventually capable of penetrating a great enough depth of water, would seem to be adaptable to rapid search for submerged objects from the air, should the Coast Guard's SAR mission be extended to

the subsurface env'rc ..nent as a result of increased under water recreation, mining, farming, etc. The ..t noted that the experimental system was also to be tested for flourosensing abiuty to detect and identify oil spills, pollutants, algae, etc. If successful in this regard, the system would certainly be of use in the Coast Guard's Marine Environmental Protection mission.

A major emerging application of lasers is in the field of communications. This will be addressed in the discussion of communications technology next.

Communications Tech nlogy

The overwhelmin₆ majority of electromagnetic communications systems employ modulated sinusoidal carriers. Of growing interest, however, is the use of general periodic wave carriers, usually as rectangular pulses. As used in a typical telephone application, the Pulse-Code Modulation, which converts oice signals into coded pulses, doubles the capacity of standard cables. In a "digi radio" application, an 11 GHz icrowave operated with 1344 voice channels capable of transmitting 90 Mb/s on a single polarization (Spectrum, 1977, p. 47). Among the advantages reported were the need for fewer repeaters, the ct that the signal could be regenerated virtually an unlimited number of times, and that it is far more tolerant of interference than analog systems. Two years later, Spectrum (1979, p. 39) verified these advantages, reporting that a Canadian digital radio network operating at 8 GHz handled voice traffic, digital data and video--or any combination of them--with greater reliability and better fidelity than an existing Canadian 4 GHz analog microwave radio network.

Digital radio is, of course, not an especially new or exotic breakthrough. The key elements of the underlying duobinary technique were originated in the 1960s (Spectrum, 1979, p. 47). The applications of the technique, however, when coupled with computer and other technologies, present a potential for a dramatic, if not revoluntionary, change in the manner and amount of data and information that can be communicated and utilized.

Another technological development that promises to impact upon communications operations involves the use of laser as a communications medium. Meredith (1979, p. 87) quotes Derossi:

> A laser communications system was really inevitable as the military developed a need for higher and higher data transmission rates. ... The higher the frequency of a transmitting beam, the more information it can carry--and light beams can be millions of times higher in frequency than radio waves.

Meredith reports that the "lasercom" system can send data at the rate of one gigabit (i.e., one billion pulses per second or the equivalent of the entire Encyclopedia Britannica or 13 full-color television channels). The lasercom utilizes two laser beams at both the transmitter and receiver. One is the usual narrow beam laser for data transfer. The other is either "spoiled" so as to emit a wide beam or is used in a scanning mode to locate and lock on to the target system. A lasercom satellite, to be orbited for system tests in 781, will employ a Wide-Field Receiver capable of "watching" an entire continent, receiving "call-up" beams, and automatically verifying their legitimacy and prioritizing response to them.

There are two major limitations on the use of lasers as a communications medium. One is that they are operable in "fair weather" only. Clouds, mist, fog, atmospheric

pollution, etc., can block the beam, or at least disperse it enough to make transmission unreliable. The other is the line-of-sight limitation resulting from the very tight and very directional characteristics of the laser beam. Neither of these limitations would, of course, apply to laser communications between aircraft operating above any atmospheric interference or between such aircraft and a satellite. Even communications through the atmosphere do not necessarily require continuous fair weather conditions. Only a brief, momentary "hole" or "window" in any interference condition is needed to permit transfer of vast amounts of information.

Satellites, of course, are not new nor are they limited to use in laser systems. Indeed, most satellites employ radio frequency transmissions. The potential usefulness of satellites for navigational purposes has long been recognized. Thus, the Coast Guard is participating in the NAVSTAR Global Positioning System scheduled to become fully operational in the late 1980s. When operational, 24 satellites will provide continuous, three-dimensional navigation signals around the world, which will permit an appropriately equipped ship to determine its position to within a 10-meter radius (Bender, 1979, pp. 29-30). Another use for satellites is as a locator of distressed craft. Schmid (1977) reported a demonstration of an orbiting satellite to determine the location of an emergency tansmitter to within a 10-kilometer radius.

The generally acknowledged current "glamor boy" of communications technology is "fiber optics." It has been common knowledge for a long time that light can be made to travel around corners if confined within a plastic or glass rod. If such a rod is of small enough diameter, it becomes a "fiber." A fiber optic "fiber," however, is neither as fine as those used in fiberglass fabrics or insulation batts nor as brittle. It is more analogous, in size and flexibility, to common electrical wire. Indeed, the optical fiber conducts light energy in much the same way as copper wire conducts electrical energy and thus, an optical fiber can be used in many applications where metallic wire traditionally has been used. Where it can be used, fiber optics offers several inherent advantages over metallic conductors.

Their lightness make fiber optics attractive in any application where weight is a major factor. They are totally immune to radio frequency interference. Conversely, the "leak" no stray radiation that might be used for a surreptitious "wire tap." They, thus, permit almost totally secure communications. They have a wider bandwidth than metal wire and thereby allow the movement of more traffic on a given size carrier. They require no electrical shield and, of course, cannot be electrically grounded. The lack of a need for thick sheathing means that a finished cable may be thinner. No electrical grounding, shorting (or sparking) means that fiber optic cables may be run through water, in direct contact with metallic materials and through explosive atmospheres with complete safety. If a fiber optic cable should fail, no damage to other system components will result, as is often the case when electrical wire grounds or shorts. Finally, fiber optics are currently price competitive with metal wire. With further fiber cost reduction in the face of increasing costs of metals, fiber optics will soon be significantly less costly than wire. In reviewing these and other advantages, Morris (1979, p. 49) observes, "With all these advantages, it's a wonder that fiber optics haven't made a bigger impact on industrial controls before now. The hardware is available, for most applications, right now. It only takes a little initiative to select proper parts to make a fiber optic system." While Morris was concerned with industrial control applications, the same situation would probably apply to many applications aboard a Coast Guard cutter or aircraft.

The main applications of fiber optics, however, remain in the field of telecommunications, according to Spectrum (1979, p. 41). Although there have been no startling breakthroughs, steady progress and some major advances have been made.

One of the problems confronting telecommunications applications of fiber optics has been the length of a single fiber that could be drawn. Uninterrupted fiber length is important because it dictates the longest run that can be made without some sort of a splice. A minimum number of splices is desirable in telecommunications because each connection produces some loss of signal strength, from about 0.24 dB to 1.3 dB, simply due to dimensional differences in the coupled fibers (Morris, 1979). Unfortunately, this is not the only coupling loss. There are basically four means of splicing fiber optic cables: end-to-end butting with a mechanical connector; an optical lens coupling system; encapsulating of fiber ends, typically with head-cured epoxy; and fusion welding of ends. These various techniques typically result in signal strength losses of about 2 dB for mechanical butting, 1 dB or less for optical couplers, and as little as 0.5 dB for encapsulation and welding (Morris, 1979, p. 51). Clearly, the longer the fiber the fewer splices will be required and the fewer the splices the lower the signal loss from that source and the fewer booster-repeaters that will be necessary to regenerate the signal--both couplings and repeaters adding to the cost and detracting from the potential reliability of the installation.

Progress has been made in the production of optical fibers. In May 1975, Corning was producing a 500 meter, six-fiber cable that had a 20 dB/km loss per fiber at 820 mm wavelength. By December 1975, Corning was producing a one kilometer cable with a signal loss of 10 dB/km (Spectrum, 1976, p. 43). By 1977, "Standard Grade" fibers characteristically had a 10 dB/km loss at 200 MHz and the Japanese were producing seven kilometer fiber cables (Spectrum, 1978, p. 31). Losses were lowered to 2 dB/km in the most commonly used 800-900 nm wavelength fibers and to as low as 1 dB/km in 1100-1300 nm fibers by 1979 (Morris, 1979, pp. 49-50). Also by 1979, production technology was about ready to produce optical fibers of virtually unlimited length (Goell, 1979).

Of more practical importance for operational communications is the volume of data that can be transmitted over optical cables. Bell Laboratories-Western Electric demonstrated in 1976 an installation capable of a data transmission rate of 44.7 Mb/s--equivalent to 672 voice channels--without error or measurable cross-talk, over its entire 64.4 km length incorporating 11 intermediate repeaters and 2 teminals. Bell Laboratories-Western Electric were even then working on a 274 Mb/s (4032 voice channel) system (Spectrum, 1977, p. 43). By 1977, a data rate capability of 140 Mb/s was fairly common and the Japanese were testing an 800 Mb/s optical system (Spectrum, 1978, p. 38).

The key elements of a communications system are the transmitter and the receiver. Currently, according to Morris (1979, p. 51), transmitters rely on solid-state technology for two major light sources: light emitting diodes (LEDs) and injection lasers. LEDs are well established and low priced products are readily available that can operate at transmission rates of 50 Mb/s. Lasers offer the advantages over LEDs of high power outputs and better coupling alignment with cable fibers. For example, IBM introduced an experimental integrated fiber optics "package" in 1977. This package integrated all of the electro-optical elements of a fiber optic transmitter on a single chip: a semi-conductor 13-laser array, a cylindrical silica fiber lens 130 microns in diameter, and an ordered array of 13 fiber optic light guides for coupling to a fiber optic cable. The three components were mounted on a 6 mm square silicon wafer containing thin-film drive electrodes for the lasers. The silicon wafer was laminated to a thermoelectric cooler to maintain a junction temperature of 30°C. The individual lasers were reported to have an output power of up to 50 mW in continuous operation with up to 70 percent light transfer into optical cables (Control Engineering, 1977, p. 35; Spectrum, 1978, p. 31).

The major drawback to lasers are that they are temperature sensitive and have yet to demonstrate the 100,000 hour MTBF demanded by the telecommunications industry. One

laser is currently available that operates at 800 to 900 nm bandwidth and which carries a guaranteed 10,000 hour minimum life. Part of the problem with the 100,000 hour MTBF requirement is that it represents a life of about 11 years and no accelerated aging test has been devised and agreed upon. Emerging laser technology, however, especially in the 1100 to 1300 nm bandwidth, is expected to eventually meet the requirement and offer transmission rates up to 1 Gb/s (Morris, 1979, p. 51).

Receivers are generally dependent on two technologies: avalanche photodiodes (APDs) and PIN photodiodes. APDs have an order of magnitude advantage in sensitivity over PINs but are highly temperature sensitive and require high bias voltages (Morris, 1979, p. 52). Further development and progress in fiber optic receivers is necessary.

Little of this progress in fiber optic telecommunication technology is directly applicable to Coast Guard missions. The impact will likely occur when telephone wire lines are replaced by fiber optic cables. The change-over will probably be gradual. It might be expected, however, that land lines connecting major communities where Coast Guard installations are located will be converted by about 1990. The capability for reliable transmission of massive amounts of data among Coast Guard installations will then be available.