A Survey of Microcomputers in Training Devices

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A SURVEY OF MICROCOMPUTERS IN TRAINING DEVICES

BY

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ABSTRACT

This report surveys the use of microcomputers in existing and emerging training devices, with an emphasis on military training devices. Other major purposes of this report are to familiarize the training device designer with the capabilities of the microcomputer and present the designer with a set of issues to consider in determining if a microcomputer could be used in his particular trainer. After providing a description of training devices, this study addresses the definition and capabilities of current microcomputers. Current applications of training devices that utilize both single and multiple, or distributed, microprocessors are given. Next, an overview of the selection considerations that must be addressed in determining if a microcomputer could be used in a training device are presented. Finally, areas of future research that are appropriate to microcomputers in training devices are discussed.
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CHAPTER I
DESCRIPTION OF TRAINING DEVICES

A training device can be generally defined as a simulation or stimulation of an actual system or sub-system in order to produce a realistic training scenario/situation. Training devices can vary in cost from $5,000, consisting of a small desk-top computer and one or two simple electronic "boxes," to multi-million dollar complex suites of large computers and equipment. The U.S. military is the largest purchaser of training devices and uses them in applications ranging from teaching maintenance principles on radio receivers to tactics training on sophisticated E-2C "Hawkeye" Airborne Early Warning (AEW) aircraft. Probably the most familiar and documented type of training devices are military aircraft flight simulators which include a motion (or platform) system, a computer-generated visual system and an exact replica of the cockpit controls and indicators. An example of such a device is the 2F110, which is an operational flight trainer (OFT) for the E-2C aircraft. Systems such as these are controlled by a sophisticated computer system with varying computer system architectures. However, in general, training device computer systems can normally be classified as having either a single central computer system or a distributed multi-processor system.
These complex devices were not invented overnight. They have evolved over the last couple of decades in leaps and bounds. These advancements can be directly attributed to one factor, the emergence of the digital computer. The digital computer first appeared in training devices in the late 1950s and early 1960s and provided significant advancements in training capability. Reprogrammability, improved accuracy, ability to develop hardware and software independently and ability to use the digital computer to test the entire training device were all favorable characteristics which led to the evolvement of the digital computer as the heart of the modern training device.

Since it was first introduced in training simulation, improvements in the computer's abilities such as more instructions, faster speed and larger word sizes have strengthened the role of the digital computer. Between November 1965 and January 1977, the number of digital computers inventoried by the Naval Training Equipment Center rose from 51 to 587. As system complexity increases, it becomes more and more difficult for digital computers to provide realistic outputs to the student in real time. Often enough, students (i.e., training device users) complain that it does not "feel," "look," or "sound" like the real system.

Microcomputers, and their associated microprocessors, have evolved to the point today where they can perform many of the tasks previously associated only with larger computers (i.e., minicomputers
and mainframes). Therefore, the widespread use of microcomputers in complex training devices is occurring at a rapid pace. Lower costs of microprocessor systems and significantly less development time are also factors which make the microcomputer an ideal addition to training devices. Not only can the microcomputer be used to drive small training devices such as part task trainers, but they can also be used to drive larger devices if used in a multi-processor distributed configuration (Ellison 1981).

As previously mentioned, a training device can be a simulation or stimulation of an actual system. Simulation refers to a training device which is built to resemble the appearance and operation of an operational system, but which does not employ any actual hardware used in that operational system. This type of training device is commonly referred to as a simulator. Stimulation refers to a training device which utilizes some or all of the operational hardware, and incorporates additional hardware and computers to inject signals into (i.e., to "drive") the actual operational equipment. This injection of proper signals causes the actual equipment in the training device to behave as it would in the field, and thus create a realistic training scenario.

Training devices procured by the Naval Training Equipment Center in Orlando, Florida, can generally be categorized as either land, subsurface (i.e., submarines), surface or air trainers. Each category can be further broken down into specific training device
types. For example, there are many types of Trident submarine trainers including the periscope trainer and the radar land mass trainer. Since each training device has totally different training requirements, each device varies significantly in terms of hardware and software configuration (Fraas 1984).

A typical suite of trainers is demonstrated by the E-2C aircraft training devices. These devices are known as the 15F8A/B tactics trainer, the 2F110 operational flight trainer (OFT) and the 2C20A cockpit procedures trainer (CPT).

The 15F8A/B tactics trainer consists of a simulation of the combat information center (CIC) compartment of the E-2C aircraft. The trainer includes all of the necessary computer, video generation, instructor consoles and audio systems required to conduct realistic training sessions at a ground base for the three CIC crew member trainees. The training objective of the 15F8A/B is to teach the CIC crew to perform in the tactical environments in which the aircraft is expected to operate as presented on displays and communications systems. These tactical environments/functions include strike and traffic control, area surveillance, search and rescue guidance, navigational guidance and communications relay (Grumman Aerospace Corporation 1982). Where possible, actual aircraft hardware is used in the trainer. The trainer consists of three major functional areas. Trainer personnel stations are located at two of these areas, the Problem Control Complex and the Trainee Complex. The third area
consists of the simulation equipment, mainly the simulation computer (SIMCOM) and the Radar/IFF Simulator (RIS).

The E-2C Operational Flight Trainer (OFT), device 2F110, provides a realistic training environment for the pilot and copilot in all areas of flight, navigation and communications peculiar to the E-2C aircraft, under direct supervision of an on-board instructor. The trainer also promotes initial qualification, transition, requalification proficiency and tactical flight training under instrument conditions. The operational flight training objectives include cockpit familiarization, preflight procedures, startup, takeoff, navigation, instrument flight, landing, shutdown and postflight procedures under normal and emergency conditions. Simulation realism is achieved by authentic reproduction of an E-2C aircraft cockpit, a sophisticated six-degree-of-freedom motion system, a simulated aircraft sound system and a computer generated visual system. A diagram of the E-2C OFT is seen in Figure 1 (Grumman Aerospace Corporation 1978).

The E-2C Cockpit Procedures Trainer (CPT), device 2C20A, provides basic procedural/knobology training for pilot and copilot trainees. The CPT is similar to the OFT in that it includes a realistic simulation of the cockpit section of the E-2C aircraft. However, the CPT is not as complex as the OFT in that it has no motion platform system nor does it have a visual system. The pilot trainees learn flight procedures and the functions of each control and indicator
Figure 1. E-2C Aircraft Operational Flight Trainer, Device 2F110.
in the CPT before advancing to the OFT. The diagram of the CPT, as depicted in Figure 2, shows the instructor seated at the instructor station in the rear of the simulator. The pilot and copilot's stations are contained within the cockpit (Grumman Aerospace Corporation 1976).
CHAPTER II
DEFINITION AND CAPABILITIES OF A MICROCOMPUTER

To precisely define a microcomputer is difficult because there is no standard definition that is currently accepted by all computer experts. One reason is because microcomputers have advanced over the past several years to the point where the distinctions between minicomputers and microcomputers are vanishing. In *Microcomputer Interfacing*, Artwick (1980) defines a microcomputer as a "fully operational computer system built around a microprocessor. Included in the microcomputer are memory, clocks and interfaces. A personal computer with a CPU card, a few memory boards, a power supply and interfaces would constitute a microcomputer." Since a microcomputer is built around a microprocessor, one must attempt to define a microprocessor. According to Artwick (1980), "a microprocessor consists of one or more large-scale integrated (LSI) circuits designed to work as a sequential computational or control unit by executing a pre-defined or user-defined set of instructions contained in a memory." A typical microcomputer system and its interfaces can be found in Figure 3 (Artwick 1980).

Some people classify, or characterize, computers on the basis of cost. One could say a micro is any computer that sells for $5,000 or less and a mini sells for $50,000 or less. However, these
Figure 3. A Typical Microcomputer System and its Interfaces.
boundaries are changing constantly, as we can buy a significant amount more for $5,000 today than we could three years ago.

Microcomputers are usually classified according to the word size of their microprocessor (e.g., 4, 8, 16 and 32 bits per word). Their performance is judged by many criteria. The major criteria include the variety of their instruction set, by the bit efficiency of their programs (the number of bits that need to be stored to implement a given set of tasks), by the speed with which they execute their programs and by the amount of memory capability they have (e.g., random access memory, or RAM) (Bohl 1984).

Motorola and Intel Corporation are two of the leading manufacturers of microcomputers today. Motorola has three microprocessors which many consider to be the best available. These are the MC68000, MC68010 and MC68020. The MC68000 is referred to as a 16/32 bit microprocessor because it processes 32 bits/word internal to the processor, but can only receive and transmit 16 bits/word. The 68000 is available in clock speeds of 8, 10 and 12.5 MHz, has 17 general purpose 32 bit registers and up to 16 megabytes of linear address space. The MC68010 is very similar to the 68000 except it has virtual memory capabilities. The MC68020 is the first complete 32 bit microprocessor (both internal and external). It also has clock speeds of 12.5 or 16.67 MHz, 4 gigabytes of linear address space, a coprocessor interface and can execute between 2-3 million instructions per second (MIPS). The MC68020 is the first microprocessor to have
a coprocessor interface which extends the capabilities of an MC68000 system beyond the capabilities of any single microprocessor (Motorola, Inc. 1984).

Intel Corporation has three comparable microprocessors currently on the market: the 8086, 80186 and 80286. The 8086 is a 16 bit microprocessor with clock speeds of 5, 8 or 10 MHz. It has direct addressing capability of 1 MByte, and 14 register sets (16 bit). The 80186 is a 16 bit microprocessor with clock speeds of 6 or 8 MHz. The 80186 also has 1 MByte of direct addressing capability, is compatible with more languages than the 8086 and doubles the performance capabilities of the 8086. Intel's most advanced microprocessor is the 80286. It has 16 MBytes of physical address space, clock rates of 4, 6 and 8 MHz and outperforms the 8086 by as much as six times. The 80286 is compatible with the 8086 and 80186 and is also a 16 bit microprocessor. Unlike Motorola, Intel has not developed a full 32 bit microprocessor. However, Intel has announced that its 80386 will be a full 32 bit microprocessor and will be available in late 1985 (Intel Corporation 1985).
CHAPTER III
CURRENT APPLICATIONS OF MICROCOMPUTERS IN TRAINING DEVICES

Over the past decade, microcomputer performance has improved to the extent that microcomputers may rival some of the best minicomputers currently available. Microcomputers may be used in training devices to offload a minicomputer in areas such as real time handling of input/output (I/O), number crunching, monitoring hardware status or replacing the minicomputer in its entirety. A relatively new concept (in terms of microcomputers in training devices) known as distributed, or parallel, processing has advanced to the point of allowing microcomputers to replace minicomputers that drive larger training devices. In a distributed microprocessor system, multiple microcomputers are used in a configuration that allows them to share necessary common data and still operate in a real time manner. Each microcomputer is given a specific function within the training device to perform, such as the visual system, motion system or instructor station. This chapter gives examples of how single microcomputers are being used in smaller training devices and also cites examples of the new concept of multiple microcomputers (or distributed/parallel processing) in training devices.
Electro-Optic Infantry Weapons Trainer (EOIWT)

An electro-optic based, microcomputer controlled, prototype device that enables tactical infantry weapons training under a simulated high-stress battlefield environment has been developed. In a short period of time, a trainee can be subjected to a large variety of combat situations where each trainee's performance is analyzed in real time, and immediate feedback is given to both the trainees and instructor. Combat scenarios can be changed to fit any potential battlefield requirement. The trainer shown in Figure 4 is presently configured for a squad consisting of five infantrymen.

The system has two motion picture projectors: a visual and an infrared IR projector. The visual projector displays the battle scene including visual targets. The infrared projector provides invisible infrared target areas at which the weapon must be aimed in order to score a hit. Lead is programmed into the infrared target, which the weapon detects, requiring the trainee to lead the target. Figure 5 shows the visual target on the left and the infrared target on the right indicating that the target is moving to the right.

Each trainee has a simulated weapon with an attached infrared, IR, detector. The IR detector is a four quadrant photo diode. The four quadrant target information and microcomputer logic determine kills, eight areas of near misses and total misses.
Figure 4. Electro-Optic Infantry Weapons Trainer.
Figure 5. EOIWT Block Diagram.
When the trainee fires the weapon, he hears a simulated bang and feels a recoil. Recoil is generated by a short pulse of air released near the front sight which drives the weapon high and to the right. An 8080 based microcomputer determines where the round would have hit and supplies this information to both a computer-generated voice unit and a CRT display on the instructor's station. The computer voice unit drives both the trainee and instructor headsets. When a target appears on the screen, the IR projector outputs a target present signal. This signal starts a clock in the microcomputer which measures the time until the trainee fires, for his reaction time. The target present signal is also used to determine: the number of targets that appeared, targets ignored, targets shot at and if the trainee shot when no target was present. Five trainee's results are continuously displayed in five columns on a CRT display on the instructor's station. At the completion of the exercise, the results, analyses and response time are printed by a terminal at the instructor's station (Marshall, Towle and Shaw 1978).

A-6E TRAM Detection and Ranging Set Maintenance Trainer (DRS MT)

The A-6E TRAM DRS MT is a simulated Avionics Maintenance Trainer (SAMT) whose function is to train organizational maintenance of the A-6E DRS system. Features included in the design of the A-6E TRAM DRS MT are:
1. Realistic simulation of the appearance, operation and performance of the actual aircraft equipment

2. Rapid feedback to the student of the correctness of his procedures and decisions as he progresses through the training syllabus

3. Complete direct and remote surveillance by the instructor of student progress during the training syllabus to permit remedial instruction at precise points of student error

4. Automatic means of recording student performance during training to afford a means of evaluating his diagnostic ability and readiness to assume on-aircraft maintenance duties (includes hard copy printout)

5. Selection of trainer parts and equipment arrangements to provide sufficient reliability and maintainability for the trainer to be used 8 hours per day, 6 days per week, for 10 years without major overhaul

6. Minimum cost

The A-6E TRAM DRS MT utilizes a Z-80 8-bit microprocessor as the heart of its computational system. Complimenting the Z-80 and packaged within its framework are 46K of Static RAM, 4K of ROM and Direct Memory Access (DMA) for interfacing the RAM components with the microprocessor bus structure. Dual floppy disks of 242,944 bytes each are utilized to store the operational and utility programs. The microprocessor is packaged within a separate instructor station which contains an interactive CRT and keyboard for controlling the training exercise and providing instructions and commands to the student. Student responses are also monitored by and recorded at the instructor's console. The student station is a full size replica of the A-6E TRAM aircraft right hand seat depicting, via simulated panels and controls,
the Detecting and Ranging Set System. Non-related or non-functional aircraft panels and controls are photo etched simulations to improve fidelity of the trainer by providing a more realistic environment. A computer controlled random access slide projector displays test patterns on a simulated screen to provide the student with realistic simulations of the actual displays encountered during Organizational Level maintenance. Additionally, a Student Response Panel is included such that removal and replacement cues can be received and evaluated by the computer and instructor (Grumman Aerospace Corporation 1985a).

Computer Aided Portable Training and Instrument Navigation Simulator (CAPTAINS)

CAPTAINS is a microcomputer-based maritime training aid that provides a simulated "hands-on" type of training for shipboard personnel. Until now, real time training has only been available at the helm of a ship or at the controls of a multi-million dollar full-size simulator. CAPTAINS is a portable system on which marine personnel can familiarize themselves with new ports and/or new ships, develop knowledge of basic ship controllability features and learn and/or enhance ship handling, navigation and radar interpretation skills at a fraction of the cost of full-size simulators.

The CAPTAINS system provides a realistic simulation of approach to and departure from any port in the world, as it would appear from the bridge of a wide variety of ship types and sizes. Equations used in CAPTAINS software accurately represent the behavior of a ship under
all maneuvering situations and have been designed for use in radar and ship handling simulators worldwide. The visual display may be switched between the following:

1. Daylight view from the bridge showing channel buoys, with a jackstaff and current ship's heading displayed
2. Same view at night
3. Port, starboard and astern views for both day and night
4. Radar display with variable range scale and current ship's heading displayed
5. Instrument panel display giving current heading, rate of turn, rudder and engine setting, and speed

Range and bearing to any channel buoy may be instantly calculated and displayed on any visual, except the instrument panel. The CAPTAINS basic system includes a microprocessor, a color video monitor, all necessary cabling and interfaces and complete software for one ship and one port. Virtually any port in the world may be modelled and various ships are currently available. In the event a particular ship is not currently available, special arrangements can be made to model the ship (E.C.O., Inc. 1985).

The CAPTAINS microcomputer utilizes a Motorola 16/32 bit 68000 chip and 1 megabyte RAM. The device sells for $29,900 per system which includes three ports and one ship.

Modular Interactive Training System (MITS)

MITS is a 2-D and 3-D maintenance training device capable of providing hands-on instruction. The 2-D common core student station
includes a TV monitor, video disc player, microcomputer, floppy disc drive, instructor CRT, keyboard and a hard copy printer. The 3-D hands-on plug-in module is designed to provide equipment-specific training. The MITS system is a generic maintenance trainer in that it can be used to teach maintenance on many types of electrical equipment. The customer simply identifies the equipment and the tasks to be trained, and the MITS system is then tailored to the equipment.

The 2-D station utilizes the video disc player and TV monitor to present basic maintenance instructions. The instructional material is presented in a variety of ways by graphs, charts and tests. Student interaction with the MITS system is via touch sensitive panel.

The 3-D station is independent of the 2-D station and features realistic simulation of the appearance, operation and performance of real world equipments. Fault insertion is performed by an instructor which the student must learn to troubleshoot and repair.

Using video disc (54,000 frame capacity) and microprocessor technology, the MITS design adapts to train maintenance on a broad range of hardware. The system software is written in C and can be utilized on various types of microprocessors including the Z-80 (8 bit), Motorola 68000 (16/32 bit) or Intel 8086 (16 bit) (Grumman Aerospace Corporation 1985b).
Multiple Microcomputers in Training Devices

MACE/MICRO-DISC

An effective, low-cost battalion (BN)-level battle simulation system, the MACE/MICRO-DISC, has been developed by the U.S. Army Combined Arms Training Development Activity. The MACE simulation, based on microcomputer-video disc technology, stores military maps on a video disc and displays them on color monitors. Unit location, status and action are shown in a graphical map overlay generated by the microcomputers. Operators/analysts can examine the simulated battle situation by scrolling the map using a joystick. The overlay is keyed to map coordinates and scrolls with it. In addition, the operator can zoom to focus on a selected area. The areas displayed can range from 4 to 40 km on a side. The MICRO-DISC system employs distributed processing supported by multiple personal microcomputers and video disc players sharing a common hard disk mass storage unit. This distributed processing architecture and local area networking permits graceful degradation in the event of failure of one of the microcomputers; an exercise can continue to function with other microcomputers in the system performing the functions of the disabled microcomputer. Local area networking also permits easy expansion of the system for more complex situations. Operational tests of the system by the 9th Infantry Division at Ft. Lewis, Washington, have produced results exceeding expectations.
Command and control in battle is highly stressing. Therefore, the MACE simulator must stimulate the players both physically and mentally. On the physical level, the play area must look and sound like a tactical command post near the front. From the mental perspective, the effects of orders and the results of conflicts between friendly forces and the enemy must be objectively determined.

Basically, the MACE simulator allows a BN commander and his staff to play war games in a room using microcomputers and a large display of a military map (displayed via a video disc system). Battle sounds are provided, operator stations are actual mockups, and orders are handed down which move various military units around on the display. The simulation provides real time outputs for battle assessments, casualty reports, ammunition and supply reports and personnel reports. The MACE simulator demonstrates what can be done with microcomputer and video disc technologies combined with distributed processing concepts (Brekka and Charity 1982).

SIMCOM Aircraft Simulator

SIMCOM Systems, Inc. in Orlando, Florida, has developed a flight trainer using the distributed processing concept. The basic simulator is an actual CESSNA cockpit stimulated by microcomputers to perform like the actual aircraft during flight. The simulator also utilizes a 150-degree horizontal computer-generated imagery (CGI) system. The simulator consists of two basic units: a Configuration
and Controller Unit (CCU) which communicates with an Instrument Interface Unit (IIU). The IIU is a microcomputer system configured to simulate various aircraft by communicating all of the necessary flight dynamics characteristics through a high-speed communications channel which allows the student to be trained using pre-recorded training lessons. The IIU interfaces to all aircraft controls and instruments including simulated navigation radios. The control input is processed in real time by the IIU and the instruments are controlled in accordance with the flight dynamic equations for the applicable aircraft to give realistic simulation.

The computer system consists of two Intel 8086 (16 bit) microprocessors, 256K bytes of RAM, two floppy disk drives (double-sided/double density disks) which total 2.5 megabytes of on-line storage.

SIMCOM's simulator is the only major operational multi-microprocessor flight simulator discovered during research for this paper. It is a complete twin-engine flight simulator with a sophisticated visual system. Having flown in this simulator during a site visit, the only drawback, or fault, that could be found with the simulator was the low update rate of the visual system during a landing. As the "aircraft" approaches the runway, the visual system must bring the trees, buildings, people and other ground objects into focus (i.e., provide greater detail). In order to provide this amount of detail, a large amount of equations and number crunching must be performed. This slows
the update rate of the visual system down to a noticeable level. The human eye cannot discern update rates above approximately 20 Hz. However, SIMCOM's visual system's update rate slowed to about 2 Hz (i.e., one-half second per update). This was quite noticeable and distracted from the realism of the simulator. However, with the faster, 32 bit microcomputers, this problem will be significantly reduced, if not eliminated (SIMCOM Systems, Inc. 1985).

Visual Technology Research Simulator (VTRS)

The Naval Training Equipment Center is conducting research on converting its VTRS computer system from three SEL minicomputers to a multiple distributed microcomputer system. The VTRS is a Navy twin-engine trainer jet simulator which includes both a weapon system and a motion system. The research to convert the simulator to a multiple microcomputer system began three years ago and is continuing. Presently, NTEC has submodules of the simulator operating on microcomputers, but has not reached the point where the simulator is fully operational with the microcomputers. NTEC plans to use Motorola's 68020 microprocessor which is a full 32 bit chip. Once this simulator becomes operational, which is expected to be early 1986, it will be the most extensive utilization of multiple microcomputers in a training device. A rough diagram of the VTRS is shown in Figure 6 (Kotick 1985).
Figure 6. Visual Technology Research Simulator (VTRS).
Microcomputers are being used more extensively in training devices than at any time in the past. With the advent of 32 bit micros, these "portable" computers appear to have enormous possibilities in the area of training devices. This chapter deals with a generic set of issues a training device designer must consider in determining if a microcomputer would satisfy his requirements, and presents two trade-off tables relative to the selection of a computer for a training device.

1. What is the purpose of the microcomputer in the training device? Two major purposes are most common: electronic data processing (EDP), otherwise known as number crunching, or control (e.g., to turn a valve on or off). Most training devices require an EDP type processor. If the device requires extensive EDP, a processor with a broad word width (i.e., 16 or 32 bit words) will be necessary. The designer should also examine the instruction set of the microprocessor to ensure it has instructions such as arithmetic shifts and can accommodate signed numbers.

A control type microprocessor might be better suited in a maintenance type (electro mechanical) training device where valves must open and shut, lights blink on and off, or knobs and controls rotate. A narrow word width microprocessor (4 or 8 bits) may be sufficient in this type training device.
2. What are the processing speed (or execution) requirements of the training device? The more realistic and complicated the training device, the faster the speed requirements. Processing speed is the rate at which a microprocessor executes the application program, and this depends on three basic specifications: the clock rate of the microprocessor, the number of cycles required to execute a given instruction, and the instruction repertoire itself. The designer must determine the degree of realism he desires, calculate the necessary processing speed to achieve the realism desired, and then find a microprocessor that can achieve that speed.

One common measure of microprocessor execution performance is MIPS (million instructions per second). The MIPS value states only the number of instructions that can be executed in a unit time. "MIPS" ignores the instruction set, internal and external architectures, and the efficiency of the language. MIPS can be a deceptive indicator of a processor's performance.

Benchmarks are special programs written to determine the performance of microprocessors. Benchmarks can be a better technique than "MIPS" for evaluating microprocessor performance (Sylvester 1983).

3. What are the storage/memory requirements of the training device? Most Naval Training Equipment Center specifications require at least fifty percent spare memory. This allows for future growth and enhanced capabilities of the device. The direct memory addressing capability of a microprocessor has a considerable impact upon the total
system capability and performance. The more extensive the memory (including virtual memory and memory management functions), the more flexible and adaptable the microprocessor (and thus the device) becomes. Adequate memory reduces the burden of software engineers to design around memory limitations.

Memory usage can be categorized into two types (local or private and global). Local memory capabilities should be used as much as practical to enhance the realism of the training device. Local memory access times can be up to 300% or 400% faster than global memory. Microprocessors are now available that have local memory capabilities of up to 16 megabytes (Sylvester 1983).

A study of training devices in the Navy inventory indicates that a cockpit procedures trainer (CPT) typically requires 96 Kbytes storage and an operational flight trainer (OFT) typically requires 256 Kbytes of storage (Healy, Wyndale and Baker 1982). Therefore, a microprocessor with local memory of 16 megabytes could easily meet these memory requirements. However, it should be stressed that each training device's memory requirements differ greatly depending upon the user's requirements and complexity. The designer must attempt to identify the device's memory requirements and choose a microprocessor which has the necessary capabilities.

4. What are the life cycle costs of using microcomputers versus larger computers? If the training device is a relatively small one and involves only one microcomputer, then obviously the cost would be
cheaper to use a microcomputer. However, if a multiple microprocessing network is being considered, the cost may not be cheaper than using a minicomputer. Adding additional microcomputers adds to interface costs, software costs, and peripheral costs.

5. What risks are involved in using a microprocessor? A small training device with one microcomputer poses no greater risk than using a larger computer (assuming the microcomputer meets all of the technical requirements). However, a larger training device requiring multiple microcomputers adds considerable risk. Several training devices do exist that utilize the concept of multiple microcomputers, however they are not considered to be large or complex relative to many NTEC devices. The concept of distributed or multiple microcomputers has yet to be proven in a large aircrew training device with a visual, weapon and motion system.

6. Does the microprocessor meet the maintainability, reliability and availability requirements? Generally, microcomputers are highly reliable, require little maintenance and, therefore, have high availability. One advantage of using microcomputers is if they do break down, it is cheaper to replace a microcomputer than a minicomputer. Environmental factors such as temperature, humidity and vibration will have an impact on reliability. If the training device is going to be used in a field environment, it must be ruggedized in order to withstand the abuse. However, ruggedizing a computer and peripherals adds significantly to the cost of the system.
7. What is the expansion capability of the computer system?

Single Microcomputer: The most advanced microprocessors today have the potential of $2^{32}$ bytes of memory in RAM and nearly unlimited global memory (or hard disk). If the expandability requirements of the training device were non-real time, the microcomputer may handle the expansion quite well (within RAM). However, if the requirements were real-time, then additional microprocessors (or a minicomputer) may be required. Additional microcomputers could add significantly to the overall software cost due to increased complexity of partitioning the software. However, initial modular software design could help reduce this cost. Multiple Microcomputer: This configuration of microcomputers offers the easiest expansion capabilities. Since the training device has already been subdivided (or partitioned), and each subsystem is being handled by individual microcomputers, adding additional microcomputers is not difficult. The major concern in this situation is exceeding the bus bandwidth. Bus bandwidth is the computer system transfer rate capability to distribute data among various sources and destinations across the system bus or buses. It is essentially the lifeline of the computing system (Sylvester 1983). When the bus bandwidth is exceeded by various demands, the training device's real-time capability will diminish. Larger Computers (Minicomputers and Mainframes): If the training device was designed properly to begin with, there should be at least fifty percent spare memory capability built into the computer.
requirements. Therefore, when dealing with minicomputers and mainframes, the training device's memory requirements would have to increase significantly before additional computers would be required. In the case where the spare memory is exceeded, serious problems are encountered (in terms of costs). Such increases can lead to doubling the number of minicomputers or purchasing another mainframe. In recent times, computer capabilities are advancing so rapidly that when the old computer's memory capabilities are exceeded, it is simply replaced entirely by the next generation minicomputer or mainframe. (This very case just occurred on the E-2C "Hawkeye" operational flight trainer, device 2F110.)

8. What are the portability requirements of the training device? Most major training devices in the military inventory are not required to be portable. In this situation, it does not matter whether a small or large computer is used. However, the Department of Defense is buying more and more smaller, subsystem training devices each year that do require portability. For example, the AN/ALR-66 (V)3 electronic warfare training device is a passive RADAR detection system for training P-3 personnel. The U.S. Navy required that it be capable of being reassembled and stowed on a P-3 aircraft by one maintenance technician within a time frame of one hour. Obviously, only a microcomputer could have satisfied this requirement. This portability requirement severely limited the
technical capabilities of the training device (as the designer originally intended to use a minicomputer).

These training device considerations are displayed in Table 1. The single microcomputer is an excellent choice for small (low complexity) training devices. It can also be used on a medium-sized training device, depending upon the application. In general, however, a large training device with extensive real-time training cannot be driven solely by one microprocessor. In contrast, however, the multiple microprocessor is emerging as a viable alternative to medium-size/complexity training devices. However, as can be seen from Table 1, the multiple microcomputer concept is still considered high risk for a large complex training device.

A study recently performed by several NTEC engineers and the president of a local simulation company evaluated various computer configurations for simulation purposes. Their study addressed the problem of what computer configuration should be used in the computer complex of a multiple-cockpit flight trainer. Their study is appropriate to this report and is summarized here because it addressed similar issues in performing the evaluation. The various computer classes they evaluated (for their flight trainer) were large computers, super minicomputers, minicomputers and multiple microcomputers. The results of their study is shown in Table 2. Their analysis indicated the best approach for implementation of a complex multiple-cockpit flight simulator was with a super
<table>
<thead>
<tr>
<th>Table 1</th>
<th>Microcomputers in Training Devices - Trade-Off Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>Purpose</strong></td>
<td><strong>SINGLE MICROCOMPUTERS</strong></td>
</tr>
<tr>
<td>EDP (i.e., number crunching)</td>
<td>limited</td>
</tr>
<tr>
<td>Control</td>
<td>yes</td>
</tr>
<tr>
<td>2. <strong>Speed/Execution Requirements</strong></td>
<td>yes</td>
</tr>
<tr>
<td>Non-real time</td>
<td>limited</td>
</tr>
<tr>
<td>Real time</td>
<td>yes</td>
</tr>
<tr>
<td>3. <strong>Storage/Memory Requirements</strong></td>
<td>$2^{32}$ bytes</td>
</tr>
<tr>
<td>Local (i.e., RAM)</td>
<td>unlimited within state-of-the-art</td>
</tr>
<tr>
<td>Global (hard disk)</td>
<td></td>
</tr>
<tr>
<td>4. <strong>Life Cycle Costs</strong></td>
<td>low</td>
</tr>
<tr>
<td>Hardware</td>
<td>low</td>
</tr>
<tr>
<td>Software</td>
<td></td>
</tr>
<tr>
<td>5. <strong>Risks</strong></td>
<td>low</td>
</tr>
<tr>
<td>Small/Simple Training Device</td>
<td>high</td>
</tr>
<tr>
<td>Medium Complexity Training Device</td>
<td>high</td>
</tr>
<tr>
<td>Large/Complex Training Device</td>
<td>N/A</td>
</tr>
<tr>
<td>6. <strong>Maintainability, Availability, Reliability</strong></td>
<td>high</td>
</tr>
<tr>
<td>7. <strong>Expandability</strong></td>
<td>fair</td>
</tr>
<tr>
<td>8. <strong>Portability</strong></td>
<td>high</td>
</tr>
<tr>
<td></td>
<td>SEPARATE MINICOMPUTER FOR EACH COCKPIT</td>
</tr>
<tr>
<td>------------------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td>Hardware Cost</td>
<td>medium high</td>
</tr>
<tr>
<td>Software Cost</td>
<td>medium</td>
</tr>
<tr>
<td>Expansion: Major</td>
<td>good</td>
</tr>
<tr>
<td>Minor</td>
<td>fair</td>
</tr>
<tr>
<td>System Availability</td>
<td>fair</td>
</tr>
<tr>
<td>Maintenance/Logistics Cost</td>
<td>medium high</td>
</tr>
<tr>
<td>Life Cycle Cost</td>
<td>medium high</td>
</tr>
<tr>
<td>Risk</td>
<td>low</td>
</tr>
</tbody>
</table>
minicomputer. The two major problems they found with the multiple microcomputer system were significantly high software cost and high risk. According to the authors, the problems of control of multiple microcomputers in the simulator environment is being studied, but there is not a suitable proven solution. Partitioning the software for the microprocessors is another unanswered question (Healy et al. 1982).
CHAPTER V
AREAS OF FUTURE RESEARCH

The use of microcomputers in training devices appears to be a growing trend in the U.S. military. Single microcomputers are being used presently for a wide variety of relatively small training devices as they are limited in their ability to provide a vast quantity of real-time data. On the other hand, multiple microprocessors which utilize the concept of distributed processing have unlimited possibilities in the field of complex, multi-system training devices. However, further research needs to be performed in order to reduce the risks. Work in partitioning the problem, control algorithms, and configuration of processors and memory for this application should be continued. This research will be applicable to both minicomputer networks in the immediate future and to microcomputer networks now becoming a viable method for training devices (Healy et al. 1982). The Naval Training Equipment Center (Code 74) is currently performing state-of-the-art research in this very area, however more support from private industry is necessary in order to quicken the technology advancements.
CHAPTER VI
SUMMARY

This paper presented examples of where microcomputers are being utilized in training devices. Two types of training device computer configurations were presented: single microcomputers and multiple (or distributed) microprocessor systems. Multiple microprocessors are a relatively new concept in training devices and have not been operationally proven in the highly complex type training devices. This report also documented the current capabilities of (a selected set of) microcomputers. Next, this report provided the training device designer with an overview of the selection considerations necessary to determine if a microcomputer is applicable to his specific trainer. Finally, areas of future research involving multiple microcomputers in training devices were discussed.
REFERENCES


