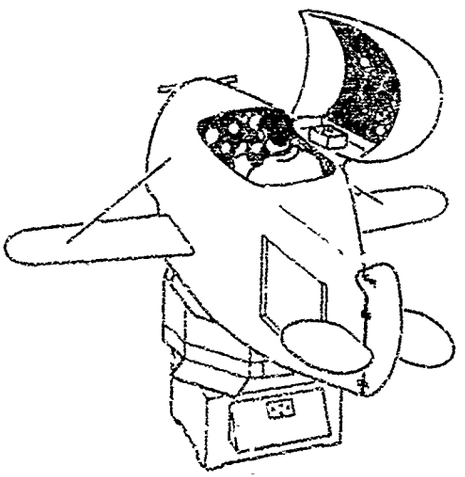
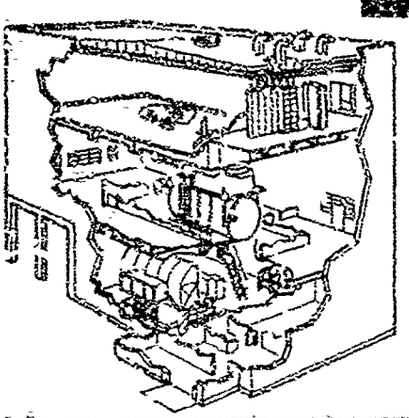
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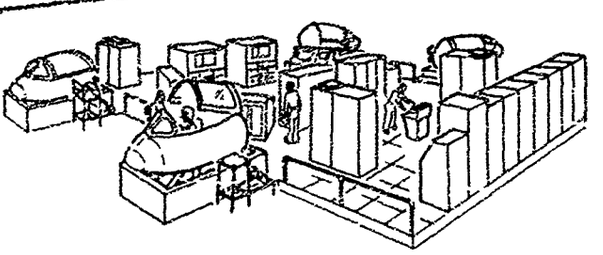
NAVAL TRAINING DEVICE CENTER

25TH ANNIVERSARY

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Included are both the technical history of training devices and the issues which currently confront their design and use.

These subjects are discussed by a group of distinguished scientists and engineers to commemorate a quarter of a century of progress in military training. A blend of human factors and engineering papers reflects the twin thrusts that make up the educational tools that are training device systems.

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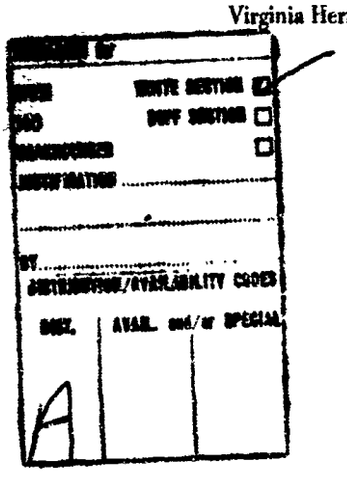
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FOREWORD

The Naval Training Device Center's 25th Anniversary Commemorative Technical Journal documents both the technical history of training devices and the issues which currently confront their design and use.

These subjects are discussed by a group of distinguished scientists and engineers who were invited to record their views to commemorate a quarter of a century of progress in military training. The blend of human factors and engineering papers in this volume reflects the twin thrusts that go to make up the educational tools that are training device systems.

The organization of the Journal is intended to present the reader first with an introductory background to the role of training devices and their history. Flight simulators and the problems associated with the interaction of human vision and motion are then discussed. Complex team trainers, their development, characteristics, and influence on trainees are presented next. Then, there are papers addressing the fidelity of the simulation issue, followed by some more specific discussion of specific simulators and their development. Finally, papers on user acceptance of training devices and how devices are assessed for training effectiveness are presented.

The editors selected a representative range of topics. However, they have not tampered with the authors' styles, or points of view. The result is, hopefully, a comprehensive statement of the development of simulator technology for training systems through these past 25 years, and problems to be addressed in training systems of the future.

DR. JAMES J. REGAN
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Editors

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TWENTY-FIVE YEARS: PROGRESS, PROBLEMS, AND PROMISE

This 25th Anniversary Commemorative Journal reflects on the contributions of research and development by industry and Government in the fields of simulation, technology, and training methodology. The increased importance of this technological base has recently been underscored by the "HOMEPORT" review initiated by the Chief of Naval Operations, Admiral Zumwalt. In this review of the role of in-port simulators in assuring the readiness of a dollar-constrained fleet, that steams less, the item of first priority in considering the use of simulators is better utilization of the existing capability. Past utilization shows a spotty record. Thirty to forty percent utilization of some of our surface ship trainers, as has sometimes been our experience, is a poor mark. On the other hand, the newly delivered 2F88 for the F4J aircraft has been called on by the Fleet for a 20-hour day during its initial contractor support period after delivery. (The procurement plan for the 2F88 had envisioned an 8-hour day for this initial breaking in phase.)

The second revelation of "HOMEPORT" was the need for the Navy to arrive at a centrally managed program of augmentation of existing simulation capabilities, based on a detailed engineering appreciation of an evolving state-of-the-art in simulation as it trades off against the cost of achieving a given capability. Many new dimensions are evident in such a program: more at-sea and, possibly, pier-side simulation requirements; multi-threat exercises linking shipborne and school groups; better quantitative scoring of the quality of embarked readiness. Perhaps task forces will not sail to an exercise area until a minimum competence has first been demonstrated in a simulator ashore. The Naval Training Device Center is uniquely equipped to manage the material acquisition aspects of "HOMEPORT" as a Principal Development Activity.

A standard college text on accounting defines a business as being "a collection of economic resources devoted to a particular purpose or goal." Under this definition, the Naval Training Device Center is a unique business, unique in the Department of Defense and, indeed, in the Free World. For the Navy, the Army, the Marine Corps, and the Air Force, NAVTRADEVCEN's function is to blend together the research, engineering, acquisition and field support experience of a twelve-hundred man workforce that focuses its attention on the *training* needs of the operators of weapons in all warfare areas, to produce the machines called "training devices" on which uniformed men acquire and maintain their combat skills. At NAVTRADEVCEN there is no search for identity; no need in dollar-short times to scurry to define its contribution to national security. While ever mindful of the efficiency of its internal operation, NAVTRADEVCEN's principal function, of late, has been to make certain that external lack of understanding does not inadvertently disrupt or fail to utilize the unique leverage on total weapon system effectiveness embodied in operator training devices, whose impact and effectiveness is felt right at the important interface between man, the operator, and his machine.

Unlike many of the Navy's laboratories and activities, NAVTRADEVCEN has a fully visible, combat-essential end-product – training devices delivered to the Fleet. In the language of the accountant, NAVTRADEVCEN is a "direct" contributor to forces in the field, not one that is "indirect," general, administrative and diffuse. Because of internal parochialisms in the Navy, and in the other services, too, only a relatively few perceptive individuals in the past several decades have understood the keystone contribution that the Center's product makes to effective training. Organizationally hidden and neglected by those whose responsibilities have been oriented towards maintenance requirements, "MTBF," and how many spare parts to buy (now formally called the Integrated Logistics Support part of the weapon system acquisition process), NAVTRADEVCEN's excellence in *operator* training devices has lain quiescent in a fallow unfunded and unimaginative support portion of the budget. Here, research and development dollars are nonexistent, and program decisions are made by administrators, who scramble over inadequate procurement funds, and not by training system engineers, who are responsible for explicitly facing up to the tasks required of the man in the loop. This neglect of NAVTRADEVCEN and training simulation through the years has been only part of the larger neglect of training. This has not been a neglect of activity or of total dollars spent, but rather a neglect of management coherency and coordination which has resulted in energy dissipated and dollars wasted. Fortunately, the recent creation of a Chief of Naval

Training gives promise of a reversal of past malpractice, making training a primary, not a collateral, consideration in fielding effective forces.

Against the backdrop of the past lack of priority for training, it is useful to define with some precision what is meant by the term training "device." Many individuals do not understand the distinction it tries to convey. Simply stated, a training device is a machine or apparatus designed from its inception to facilitate the learning and maintaining of operator skills--decision making, procedural, motor, or some combination of these three. Unfortunately, considerable training is attempted on, what it is convenient to call, training "equipment" – extra units of actual operational hardware diverted ashore to schools because of the collateral need to provide out of each weapon system an ILS package of the system's pipeline needs: publications, spare parts, and training. This type of training "equipment," by its very genesis and definition, has been designed for fleet or field battle use in a harsh combat environment, not training use. It must be bullet-proof, sailor-proof, and operate over a complete spectrum of MIL SPEC conditions. Its cost is usually high. Failures are consciously engineered "out" of operational equipment. They are consciously engineered "into" training devices so that the trainee can learn to cope with them, in complete safety.

Historically, the Navy has probably misspent, and wasted several hundreds of millions of dollars acquiring operational equipment, instead of training devices, to support training ashore. The attendant training has been less effective. It is not that operational equipment cannot, in certain cases, be the best way to provide the required training material assets. It is just that a deliberate comparison or tradeoff between the two possible approaches, training devices versus operational equipment, is never called for by those responsible for the parent program and its priorities. Training has never been afforded the luxury of a systems analysis.

A significant bill for training material has been paid by the Navy through the years. The current inventory estimate is $2.5 billion, including operational equipment, devices, and miscellaneous training aids. For every dollar invested in training devices, four dollars have been spent on operational equipment diverted to training. These figures quantify the tragic waste that has resulted from the general neglect of training and its requirements. How much more effective might our fleet be today if the historic ratio between devices and operational equipment were, say, 2:3 or 3:2? Instead of the past practice of management of training by default, a deliberate training systems approach would have yielded a more balanced ratio between operational equipment and devices, at a considerably lower total dollar cost, a savings of more than enough to pay for the research and development investment that has been so critically needed.

Enough about problems. Let's talk about promise. Thanks to a vigorous and innovative simulation industry and the dogged involvement of NAVTRADEVCEN, properly designed training devices are beginning to justify themselves for two reasons beyond the classic reason for economy. First, as the airlines are beginning to demonstrate clearly, *better* training is often obtained in the simulator. Thus, certain classes of casualties and failures can only be practiced in a trainer. Similarly, only in a trainer can an instructor observe "over-the-shoulder" performance of pilots of single-place aircraft.

The second payoff, available only in training devices, is an ability to exercise the trainee through the full decision-making and procedural envelope of his weapon system, under conditions that exceed the abilities of available test ranges to accommodate. The trainee can shoot 50-mile missiles, for example, for 50 full miles, time after time, varying launch and target conditions. There is no concern for firing range limitations or restrictions in target maneuvers. Conversely, in terms of the world of training "equipment," the trainee may be allotted (statistically, in the missile procurement plan) only one quarter of one missile to fire during his three-year squadron tour. That is his official "training allowance." Firing a quarter of a missile is, physically, a difficult thing to do.

This situation drawn from real life illustrates the second important "plus" of training devices, to wit: only through performance demonstrated in simulators will the force commander have established any credibility that his advertised weapon system capabilities are indeed practiced and ready. It has been said that "a Navy never serves better that serves in peace." It can only be through visible and validated training, largely achieved by utilizing training devices, that a peaceful Navy can be assured of possessing the potential for destruction that its presence on station is meant to imply. The Naval Training Device Center is proud of its contribution to sustaining such a Navy.

FRANK H. FEATHERSTON, Captain, USN
COMMANDING OFFICER
NAVAL TRAINING DEVICE CENTER

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The History of Training Devices at the Naval Training Device Center

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Created as a desk in the Bureau of Aeronautics and developed into a vital training support activity by the successful creation and application of Aviation Training Devices during World War II, the Special Devices Center of the Office of Naval Research was commissioned on August 13, 1946, as a continuing peacetime activity devoted to the concept of contributing to the improvement of fleet readiness through the development of simulators and training devices.

On a broad basis, the new organization viewed training as a function which could be made more effective by scientific analysis of the man-machine interface, the learning process and by application of technology to the development of simulators, devices and aids as tools for training.

This paper presents an overview of four broad fields of endeavor in which considerable resources have been invested and from which extremely fruitful results have been obtained during the past 30 years. These fields are: (1) Classroom Instructional Media and Equipment; (2) Real Time/Real World Simulation of Warfare Systems and Environments; (3) Human Factors Related to Design, Development and Application; and (4) Logistic and Material Support.

This is a history of the Naval Training Device Center (NAVTRADEVCEN) from its inception. It begins with a description of the state of Naval training on 30 April 1941, when the NAVTRADEVCEN was established; provides an overview of the NAVTRADEVCEN shakedown period; and describes the NAVTRADEVCEN mainstreams of professional effort and some of their most significant contributions.

Prior to her entry into World War II, the United States found herself in a precarious position—thousands of individuals without military backgrounds had to be trained in the ways of the military. In addition, they had to be trained on sophisticated equipment and molded into combat ready crews. This was a gigantic task, since the crews were needed immediately.

To accelerate the training process, the Navy established within the Bureau of Aeronautics (BUAER) the Special Devices Division (SDD), which later became the Naval Training Device Center (NAVTRADEVCEN), more informally referred to as "the Center." The mission of SDD was to exploit safe, novel training techniques, which could be achieved through simulation and mass training media. This was a new concept to BUAER, whose function had been that of procuring operational aircraft.

The first step taken by SDD was a survey of available products and facilities. This survey indicated that operational military equipment was inefficient, often hazardous for training purposes, and in short supply. It also revealed that defense plants could not be used to manufacture simulators as they were already committed to higher priorities. In view of these constraints, support of training was limited to products such as 16mm motion picture films, slides and strip films, disc recordings, manuals, and charts. These media could not meet the need. Through innovative genius of Navy and contractor personnel, the SDD developed novel devices which simulated the real world for purposes of training.

Since the SDD was a part of BUAER in its beginning, it was natural that the earliest training devices were developed for aeronautical training. These were adaptations of quickly-available products which had already been developed. The initial and primary emphasis was devoted to developing Operational Flight Trainers (OFT's) for pilot indoctrination. It was quickly evident,

however, that other types of trainers were essential and feasible. An example is the Dual Image Gunnery Trainer, which used two synchronized 16mm film projectors. One film showed enemy aircraft in various simulated attacks and breakaways against cloud backgrounds. The other film showed the correct point of aim when the instructor wished to show it. This new approach was applied in Device 3A2, the Antiaircraft Gunnery Trainer. It was so effective in improving the marksmanship of gunnery personnel that it was installed for training on all aircraft carriers, battleships and cruisers in the Pacific.

The most prominent group of the aeronautical trainers was the fixed and free gunnery simulators, with other groups developed for teaching bombing, celestial and Loran Navigation. Based on factory overhead crane technology, the ultrasonic radar trainer was designed and built. The radar trainer, using sonic pulses on an earth model in a water tank, proved to be quite a workhorse, and for many years was simply modified to activate new airborne search radar systems. Perhaps the most notable of all the aeronautical trainers of this era was the PBM-3 Simulator. This trainer, Device 2F1, which was built in 1943 by Bell Laboratories, was probably the first OFT that attempted to simulate the aerodynamic characteristics of a specific aircraft. This electronic analog computer-controlled device is the one from which the present type OFT was evolved. The present generation of OFT's consists of more than one cockpit operated by a single digital computer. To date, 103 different fixed-wing Navy aircraft have been simulated, with a total of more than 1,000 OFT's. So effective is this concept of training that the Federal Aviation Authority has approved the use of the flight simulator for certain aspects of commercial airline pilot certification.

Not all simulators were designed for training combat personnel during those early years. For example, the NAVTRADEVCEN acted as the design agent for the Bureau of Medicine's Human Angular Acceleration Device, High Altitude Pressure Chambers and two Human Centrifuges. The first centrifuge, a 15G force unit, was procured in 1943, and the second, a 45G force unit, in 1955. It is interesting to note that the 45G force centrifuge, which was installed at the Johnsville Naval Air Station in 1955, was used by the first United States astronauts to train in a high G environment.

The surface and subsurface warfare type training devices began appearing around 1944. The 16C23, Radar Planning Device, was among the first. This was a simple simulator, which consisted of light reflected from a special terrain model, providing a synthetic radar scope presentation. Prior to bombing missions, this device provided the U.S. Fleet with simulated radar presentations of target areas such as Tokyo, Yap, Yokohama, and Iwo Jima. Then came many radar trainers. They encompass Device 15V1, which carried the night air-to-air attack from radar acquisition through visual attack; radar target generators, which began using analog and recently shifted to digital computers; and various types of landmass simulation and electronic countermeasures trainers. The first Submarine Attack Teacher, Device RS11, was also of World War II vintage. From this device, others, such as Devices RS16 and RS1C, evolved. All devices of this series were multi-target types with provisions for using periscope, sonar or radar for simulated torpedo attacks. In addition, the RS1C contained harbor reconnaissance and recognition facilities.

Toward the conclusion of World War II four mainstreams of professional effort became apparent at the Center: (1) Classroom Instructional Media and Equipment; (2) Real Time/Real World Simulation of Warfare Systems and Environments; (3) Human Factors Related to Design, Development and Application; and (4) Logistic and Material Support. Though these streams are closely integrated and overlap to a degree, they are examined separately in the following paragraphs.

CLASSROOM INSTRUCTIONAL MEDIA AND EQUIPMENT

When early World War II studies at Ohio State University showed the superior efficiency of total-form ship and plane recognition over the Wings, Engine, Fuselage, Tail (WEFT) system, the Center generated a new family of flash projectors. Flash projectors are still used in recognition training and have become the heart of high speed reading systems. Early research in magnetic recording, principally by the Armour Institute, was used as the basis for development and production of the first ground and airborne wire recorders, to replace disc recording for communication procedure training. Terrain models, traditionally used for combat planning and briefing, were turned into mass-produced, easily transportable devices, by molding them in

plastic and imposing details on them by a photographic process. They were further utilized in conjunction with a "grain-of-wheat" lamp to provide a synthetic radar scope presentation. The overhead projector, one of the most used pieces of equipment in the classroom today, was developed under contract in 1944 to project plot charts for navigation training and sketches drawn by the instructor on the glass surface.

When the war ended, hundreds of different NAVTRADEVCEN audio-visual devices and media had been developed, produced and distributed. The variety and general level of efficiency and sophistication of these devices was amazing when considered in the context of the low level of the "state-of-the-art" at the beginning of the war, the restrictions on materials and technology imposed by the war, and the continuing priority on speed of production and issue. A large share of the credit, of course, must be given to American Industry, which played a vital role in the conception and production of most devices.

After the war, the NAVTRADEVCEN and Industry team began a period of further research and development of new audio-visual media and devices, coupled with improvement and modification of those developed during World War II. The overhead projector, for example, with improved optics and better light sources, became the device known today. Its popularity, however, was really made possible by the introduction of diazo foils. Originally a European development, these foils were introduced in this country for another purpose. Because of low cost, easier local preparation and better light transmission, the Center recognized their potential for use in large color transparencies, and worked closely with several industrial firms in improving them to current standards. Today the Center has developed hundreds of different series of instructional transparencies using these foils. In 1950, audio-visual personnel developed the first animated transparency for the overhead projector. This has moving colored-plastic parts to give an x-ray type view of how the components in a mechanism move during a cycle of operation. Also utilized to demonstrate motion was the process now called "Technamation," which uses polarized film and a "spinner" fitted on the head of the projector.

With the postwar advent of commercial television (TV), the Center became interested in its use as a possible media for mass training. In 1946, design was started on an experimental Instructional Television (ITV) production facility. By 1949 this complete facility, the first in the Department of Defense (DoD), was in operation on-base. During the next six years, the Center, assisted by Fordham University psychologists in a formal evaluation, originated over 1,000 different training programs. These were transmitted either directly by microwave and network or by kinescope recording to test training groups. During this period, the Center served as a source of expert guidance for both DoD and civilian agencies in the media. In DoD, the Center was the first activity to use kinescope recording, first to measure and validate the effectiveness of ITV, first to establish guidelines for the equipment required and the training of personnel to operate and maintain it, first to document the elements of effective presentation, and first to build and use mobile production facilities.

In this same period, interest developed in new techniques for nonprogramed, real-world visual simulation to be used in conjunction with the major air, surface and subsurface trainers. Two of the many approaches explored were TV Insertion, in which targets were inserted in wide-angle backgrounds, and Point Light Source Projection, which provided an extremely wide-angle visual simulation that changed realistically in direct response to movement of the controls in the trainer. Both techniques were used in a number of important training devices.

In 1951, audio-visual (AV) engineers at the Center were ased to develop a type of slide projector which would be operated by the classroom instructor while at his normal station in front of the class. In response, the Remote Control Slide Projector was introduced. This unit was capable of using 2 x 2-in. slides in any type of mount, stored in a movable tray and provided their controlled showing either forward or reverse from any reasonable distance. This was the original building block in a 1958 development, the sound-slide projector, which combines a tray-loaded projector and continuous-loop magnetic tape player unit with slide changes, cued by inaudible pulses.

The graphics and editorial personnel of the AV Engineering Department prepared demonstration programs to show the capabilities of this device, and thus paved the way for one of the most requested products of the NAVTRADEVCEN

today, the Sound-Slide Program. In response to requirements from all training agencies of the Navy and the Marine Corps, several hundred subjects are developed and produced each year in such diverse technical areas as electronic countermeasures (ECM), aircraft weapon systems, hydraulic contamination control and mine sweeping. The popularity of these programs is based on the speed with which they can be supplied, their low cost as compared to motion pictures, and the ability to revise parts of them to reflect design and doctrine revisions.

Developed, improved and produced during the early 60's were such products as: (1) the 180-degree projection Cineglobe (complete with air-supported dome enclosure for easy portability). This became an effective public information tool and was used by the Navy at the World's Fair in New York and in a series of traveling exhibits around the country; (2) the table top tutor, an improved personnel rating machine; (3) wound moulage kits to simulate war wounds for training exercises; (4) new families of more sophisticated animated transparencies, sonar trainers, tape recorder-reproducers and projection equipment; and (5) an automated machine for producing master terrain models which accepts inputs from a terrain map and forms the model in a tenth of the time previously spent.

Since 1965, the AV Engineering Department has continued to develop new devices for training including the universal display panel, computer trainers, classroom mockups and cutaways, code trainers, and sound recognition trainers. NAVTRADEVCEN personnel designed and had installed a large multi-classroom ITV at the new Navy Recruit Training Center, Orlando. This system has become the showplace of the Navy, exhibiting what can be accomplished with this media. Complete classroom and individual training complexes have been designed at such Naval Training Centers as Pensacola and Jacksonville.

REAL TIME/REAL WORLD SIMULATORS

Recognizing the limitation of current computer technology for simulators, the Center in 1945 entered into computer and computer component development. The results of these developments and studies culminated in AC and DC electromechanical computer prototypes, digital computers and electronic analog computers. The names given these early computers were symbolic of the speed at which they operated. This speed, of course, compared to today's standards, was very slow.

The Cyclone computer, built in 1945 and operated for the Office of Naval Research by Reeves Instruments, became the first practical rapid guided missile simulator in the United States. The contractor later utilized many of the Cyclone components and design in the REAC of commercial market fame.

Whirlwind I and II were begun in 1945 at MIT, for the purpose of developing a digital OFT. The field was so new that Whirlwind I was devoted to the development of Whirlwind II and digital computing circuits with which to build the digital airplane simulator. The Whirlwind II, though the largest capacity digital computer of its time, could not represent an aircraft in real time; nevertheless it became the world's most sophisticated scientific computer.

In 1950, the NAVTRADEVCEN contracted with the University of Pennsylvania to conduct a feasibility study on use of digital computation in simulation. As a result of the findings of this study, the Center contracted with the Sylvania Corporation to build the Universal Digital Operational Flight Trainer Tool (UDOFTT), which was completed in 1960.

Also, in the late 1940's, the Center contracted with RCA Laboratories to build the Typhoon computer for high-speed missile simulation. This computer, installed at the Naval Air Development Center, used newly developed electronic computing circuits.

In 1948, a contract was awarded the Raytheon Company jointly by the BUAER and the Air Force through the NAVTRADEVCEN for two Hurricane computers. These were digital computers with a radio data link for remote operation and flying missile control. One was installed at Point Mugu and the second at Fort Hollaman.

From this beginning, design and research in the simulation computer field gave impetus to the forthcoming computer revolution. As mentioned earlier, the present air weapon system trainer concept evolved as one of the descendants from the efforts of the 1940's.

After World War II, aircraft cockpit instruments became more numerous and taxed the ability of pilots. The Center began pioneering in the field of

cockpit simplification through instrument displays such as Device 6N, the Hoover Directional Horizon Indicator, which was flight tested in 1947. It combined several instruments into one to provide pilots, under blind flying conditions, an instrument which more nearly simulated the real world. This series of NAVTRADEVCEN instruments was the first to be tested by an aircraft simulator before air testing. This work was instrumental in the Center being invited to be a member of the Army, Navy Instrumentation Program.

Radar countermeasure simulators changed little over the years. They consist of low-powered radio frequency (RF) jammers, RF radar transmitters with variable parameters, classroom and shipboard devices using electronic or video inputs to radars. Notable among these simulators were Device 15X6 of 1948, a very flexible radar transmitter installed in an aircraft, and Device 15E1 of 1956, a transmitter which had a unique antenna that mechanically changed its parabola shape to modify its antenna pattern. At sea today the 15E15 jams radars via the intermediate frequency (IF), while the 15E27 Recorder activates the EW passive receivers. The 15E13 is part of the shore-based Tactical Advanced Combat Direction and Electronic Warfare (TACDEW) trainers at Dam Neck and San Diego, and has the capability of presenting hundreds of different signals, 20 at a time, to several passive receivers. In recent years, the Center has developed simulation of hostile radars. In fact, the two largest trainers built by the Center are in this category.

The major surface team trainers are the Combat Information Center (CIC) type trainers with titles such as Antiaircraft Warfare (AAW) Trainer, Antisubmarine War fare (ASW) Trainer, CIC Trainer, Maneuvering Tactics Trainer, and so on. Mainly, these trainers consist of several ship CIC mockups, having helm control for friendly vessels. The trainers are used to simulate ships operating in a fleet problem. The first of these, the 1BZ2, was installed at Newport, R.I. in 1948 to teach ship maneuvering and tactics. Since then, there have been more than 20 devices of this type utilized by the Navy. Some of these are large systems which occupy an entire building and train up to 250 task force personnel simultaneously. One, Device 14A6, has 36 rooms, each representing a ship or aircraft, which presents itself as a target for integrated fleet ASW exercises.

In the late 1940's, the Army National Guard expressed an interest in various gun mockups and oversized models which the Center supplied the Marines. Eventually, this resulted in U.S. Army interest in the NAVTRADEVCEN operation. Since 1950, the Army Training Device Agency, which until recently was the Army Participation Group, has been an integral part of the NAVTRADEVCEN. Hundreds of simulators to satisfy Army Training needs have been researched and developed since 1950.

One recent, renowned simulator of this type is a system which uses a gallium arsenide laser to train military personnel in M-16 rifle weapon firing against pop-up targets. The system is eye-safe—customary elaborate range safety precautions are unnecessary, can be operated in bright sunlight, has a range in excess of 500 meters, and is very economical to operate—firing more than 1,000,000 shots on an internal inexpensive battery.

Device 21B20 was the first Submarine Diving Trainer built with an electronic computer. It was installed at New London in the early 1950's. Using a DC analog computer, it could operate either a large SS-564 platform or a universal joy stick submarine platform. The 21B20 was a great improvement in diving trainer control and was so exciting that it made the TV news programs of that day. A digital computer was later substituted for the analog computer, allowing both platforms to be operated simultaneously. Today, eight other Submarine Diving Trainers serve the fleet.

One device that should be mentioned, particularly as a tribute to the NAVTRADEVCEN and industry team, is thought to be a world's first. In 1955, the Navy's first sonar recorder for directly recording sonar sounds from a ship-installed sonar was developed for the Center by the DGC Hare Company. Two years later, the Navy's second unit, a more versatile recorder, was developed by ITT. Both of these devices were designed to record magnetically on tapes actual sonar sounds for classification training. However, Navy quickly recognized the device as a much-needed operational piece of equipment, for permitting a sonar operator to listen to and look at a target a second time while underway. Thereafter, the 14E1 and 14E2 shipboard recording and playback units, which were placed aboard ship to collect tapes for the Bureau of Naval Personnel schools, performed a dual purpose.

In the late 1950's, construction of three submarine attack teachers was begun. Unlike the World War II analog design, this generation of submarine attack teachers utilized digital computers. These are the only multisubmarine, multitarget submarine attack teachers in existence.

From the beginning, research to evolve better simulation techniques or component development has been necessary to meet simulation requirements. The research is sponsored by the Center both in-house and under contract. There has been research in simulator instrumentation, computers, magnetic recording, wide-angle nonprogramed visual presentations by point light source, holography and TV techniques, self-propelled submarine targets, sonar signal simulation, equations of motion of ships, pyrotechnics, target materials, indestructible targets and automatic scoring systems, computer generated images, smoke generation and smoke abatement, map making techniques, training ammunition, and so on.

HUMAN FACTORS

Though Human Factors is a post World War II discipline, its roots can be traced to World War I. Chronologically, threads of this discipline have been called Selection Research, Perceptual Motor Skills, Human Engineering and finally, Human Factors. Many techniques used in this discipline were borrowed from time and motion study, operations analysis and industrial engineering. The central theme of Human Factors is the improvement of the man-machine relationship, with the primary role at the NAVTRADEVCEN being that of supporting training.

In the early days many Human Factors Laboratory projects were devoted to system analysis, display control problems and equipment layout problems, such as: (1) The Systems Research Project, which principally was directed at solving a variety of applied shipboard problems, but some attention was devoted to such basic matters as how we see and hear. A lecture series called "Men and Machines" (Technical Report 160-1-19) was developed, later amplified and then published under the title, "Applied Experimental Psychology." This was the first text in the new discipline of human factors; (2) Project Therblig, which was a parallel project devoted to the submarine world. A notable contribution was the development of the concept of one-man submarine vehicle control known as "flying the submarine;" (3) The Aviation Psychology Project, which was devoted to providing answers to problems of aircraft instrumentation, cockpit standardization and vehicle control. Among the developments of this project was a landing approach trainer which combined very simple hardware with extremely sophisticated training technology. This trainer was used by the Naval Air Training Command for many years to help trainees avoid landing difficulties; and (4) Project Cadillac, which tackled the problems of team performance, communications, instrumentation and layout relative to airborne CIC. The results of this project were far reaching. They contributed in the development and overall CIC design concept for the modified Constellation aircraft, the WV-2—they contributed to the development of the first dynamic laboratory CIC system used in human factors experimental work and they contributed toward solution of other military problems at the Rand Corporation, the Systems Development Corporation, the Institute for Defense Analysis, the Naval Research Laboratory and the Federal Aviation Agency.

The first source book on human factors was published during this period. This was in Technical Report 199-1-2, which is entitled, "Handbook of Human Engineering Data." This pioneering effort led in 1963 to the development of the tri-services "Human Engineering Guide to Equipment Design." Both publications are now "trade standard."

In the late 1940's, two projects in mass media training methods were set up: (1) The Instructional Film Research Project, which thoroughly explored the development, utilization and effectiveness of training films. The project reports, which were published in toto in two volumes, have seen extensive usage in universities offering courses in training film development; and (2) The Television Research Project, which demonstrated the use and effectiveness of this medium in a variety of Army and Navy training situations. Evaluative studies were conducted, first using students at the Kings Point Merchant Marine Academy and later, using census enumerators. The findings are widely reflected in present day Educational Television.

Other NAVTRADEVCEN research efforts of the late 1940's included transfer of training experiments conducted in a variety of knowledge

and skill acquisition areas. The stimulus-response characteristics of both training and transfer tasks were systematically varied. This research established the procedures and methodology which have since been used in the evaluation of training aids and devices. Six measures of transfer of training effects were developed to cover the range of foreseeable applications.

This led to OFT evaluative studies which were conducted at the Naval Air Training Command, using the SNJ, PBM and PB4Y OFT's. In addition to in-flight performance, criterion measures included attrition, accident rate and time required for training. These studies were the first to yield hard data on the training potential of the OFT concept, and provided the initial impetus for the acceptance of the OFT as a necessary adjunct to pilot training.

Finally, still in the 1940's, two extensive programs of voice communications research involved the areas of speech intelligibility, message content, training procedures and supporting equipment. This research provided needed information on communications procedures and on training methods. Primarily, the results were used in the development of training procedures and devices for pilot and aircrew training.

Human Factors work in the 1950's became more diversified. Studies of electronic maintenance led to another NAVTRADEVCEN first, the publication of the Maintainability Handbook for Electronic Equipment Design (Technical Report 330-1-40). Much of this material was later incorporated in a Bureau of Ships' handbook and in the tri-services Guide to Equipment Design.

NAVTRADEVCEN in-house work in the 1950's led to development of several innovative devices. Some of these are: (1) The Relative Motion Demonstrator, Device 9U87, which is used for the carrier approach. The device compared the path of the aircraft as seen by the Landing Ship Officer with its actual path through the air mass. It was used at NAS Pensacola for many years in explaining relative motion; (2) The Green Light Rater, Device 11H6, which was a simple mechanical device using immediate feedback. Questions in multiple-choice format were displayed. Pushing a button caused a colored indicator to drop, green if the answer was correct and red if it was incorrect. After all questions were answered, a single control action cleared all indicators, preparing the device for the next person. A number of these devices were developed and are still in use; (3) The Human Engineering Principles Demonstrator, Device 20F10, the first model of which demonstrated various control-display relationships and was widely used by the Center at expositions and air shows. The second model features a pursuit tracking task and has been on display for many years at the Chicago Museum of Science and Industry, where it has been the most popular long term exhibit.

Impetus for development of part task trainer concepts, such as the cockpit familiarization trainer and the cockpit procedures trainer, stems back to the analytic and experimental work conducted in the Aviation Psychology Project mentioned earlier. The pilot's tasks were analyzed in terms of procedure and tracking behaviors, and appropriate device concept developed. Comparative evaluations were made using in-flight performance to determine the transfer results from various levels of part-task training. The results are reflected in the extensive present day use of part-task trainers.

Selected major training systems or devices in use were evaluated quantitatively from a training effectiveness point of view. On the basis of these evaluations, specific recommendations were made to the using activities and to cognizant Center personnel on design improvements and utilization. Use patterns of existing devices have changed as a result.

In the 1960's, the Human Factors Laboratory tackled many operational problems. Some of these were: (1) ASW Helicopter Communications Problems. Pilots were given a course in effective team communications. They performed 19% better on Device 14H4 than pilots not given the team communications course. As a result, FAETUPAC, North Island recommended to Commander Fleet Air, San Diego that a two-day course, using the curriculum developed, be given to experienced ASW pilots. In addition, it was found that team communications could be used as a measure of assessing trainees' performance; (2) Tactical Decision-Making Problems. Navy tactical decision-making tasks were classified and analyzed to determine what decision-making problem parameters and what aspects of information displays are important for training Naval personnel in making tactical decisions. A technique for translating laboratory decision-making research into a form applicable to the operational ASW/AAW training environment

was then developed. Methods for training tactical decision-makers were described. These methods are being exploited in the Navy's Advanced Training Device Development Program, Technical Development Plan N43-08X; (3) The Problem of Developing a Military Specification for Flight Manuals. The organization, content and format of flight handbooks to best serve pilot's needs for a training test and source book were determined. A flight handbook specification was prepared. This is now undergoing final review before publication by the Navy; (4) The Problem of Developing a Generalized Sonar Maintenance Trainer. The hypothesis that functional and design similarities exist among contemporary sonar systems, giving rise to a common set of maintenance requirements and maintenance skills, proved to be correct. An experimental trainer was built and tested in two Navy schools. The training and cost effectiveness of the devices were demonstrated. Production devices were then built and are being used in Sonar Maintenance Training Schools; (5) The Problem of Developing a Submarine Advanced Casualty Ship Control Training Device. It was demonstrated that multi-class emergency ship control training by means of a generalized casualty control training device is feasible. Detailed functional characteristics for such a device were provided. Production of a Generalized Submarine Advanced Casualty Ship Control Training Device is being planned; (6) The Problem of Analyzing Tactical Air Control Officer (TACO) Task/Training Effectiveness. The tasks performed by the TACO in the P3 ASW aircraft were analyzed and the knowledge and decision-making skills required of the TACO were specified. The design criteria for a training device to train TACO's were established. Based on this study, production of a device to train TACO's is in planning; and (7) The Problem of Developing Instinctive Firing Training. A device to train in firing from the hip was developed and evaluated. As a cost effective and safe method of training, this device has Army interest.

Current NAVTRADEVCEN Human Factors interest in advancing training technology are: (1) Visual Search Training. A visual skills trainer for training in pursuit tracking was developed. It produced sizeable (40%) increase and lasting (retention of 80% of the increase) improvement in visual performance. It can significantly affect training of skills having a large visual component, and is now in experimental use at the Naval Training Center, Orlando, in remedial reading training of recruits; (2) Adaptive Flight Training. Design data were provided for incorporation of adaptive training schemes into flight trainers. These techniques are incorporated in the Army's Synthetic Flight Training System and are being incorporated into other flight trainers: (3) Automated Weapon System Trainer. The design criteria for automating selected instructor's functions in a weapon system trainer have been developed and automated. Ground Control Approach training has been implemented on the Center's Training Device Computer System; and (4) Device 2F90, TA-4J OFT. Recommendations included the provision for computer automated scoring, the development of mission profiles and the presentation of demonstration maneuvers to the trainee. This device is the first in actual training use with these features. Acceptance by the user command has been very satisfactory.

LOGISTIC AND MATERIAL SUPPORT

The Logistic and Material Support (LMS) program lagged the emergence of the other three mainstreams of effort. It was not until World War II ended that this effort started to manifest itself as training device inventories grew and assumed a permanent role in the training structure.

The first field office was established in 1948, and NAVTRADEVCEN Sections of the Branch Offices of the Office of Naval Research in Chicago, San Francisco and Pasadena were utilized for support liaison with fleet activities. In addition, the Center's role in keeping devices current through modification and modernization programs was initiated and the first Training Device Guide was published in 1949.

Since 1955, the training device inventory has experienced a considerable growth, and a significant increase occurred in the activity of logistic functions of maintenance, repair parts provisioning and replenishment. To cope with these changes, the Bureau of Supply and Accounts (BUSANDA) established a Training Device Support Office on 1 July 1956 as an adjunct to the NAVTRADEVCEN. This organization performed inventory management and responsibility for repair parts through May 1959. At that time, inventory management of training devices was returned to the Center and inventory management of training device repair parts was assigned to the Electronics Supply Office. Other

accomplishments during this time frame include distribution in 1956 of the first Field Service Bulletin, and the beginning in 1959 of the Training Device Utilization Measurement Program.

Field Engineering and logistic support gained stature during the decade of the sixties. Some items worthy of mention are: (1) The first Directory of Naval Training Devices with a descriptive section was issued by BUSANDA in 1962. (2) In 1965, the Naval Training Device Center implemented the conversion of contractor engineering and technical services personnel to field engineering representatives, under the employ of the Center. This program was effectively completed in 1966, when the Center became the first and the only Naval activity to accomplish 100% conversion. (3) In 1965, concurrent with the relocation of the NAVTRADEVCEN from Port Washington to Orlando, a major reorganization of the activities engaged in logistic support was undertaken. This reorganization resulted in the present Logistics and Field Engineering Directorate (Code 40) and elevated the Logistics Support, Maintenance Management and Modification Programs to a management level, co-equal to Research Development and Engineering. (4) Under the guidelines established by DoD and the Secretary of the Navy, on 1 June 1966, the Center initiated the Integrated Logistic Support (ILS) Program for training devices. During this period, the first Planned Maintenance System for the training devices (A-7A WST, 2F84) was delivered to the Fleet. At this time, the first maintainability demonstration of a training device was performed. On the basis of this, specific maintainability requirements were developed for future acquisition programs. (5) In 1967, the Center initiated the Quality Assurance and Revalidation Program under the Commander Naval Air Force, U.S. Atlantic Fleet. This program was expanded under the direction of an OPNAV instruction for all major training devices. (6) In 1970, the Center started the initial application of the Navy Maintenance and Material Management Program (3M) to training devices on a test basis at NAS Oceana. (7) During this period, the Center formalized the Training Device Utilization Data Collection Program for the Deputy Chief of Naval Operations (DCNO) for Air, and at the request of DCNO for Operations, expanded the concept to surface and sub-surface training devices. The analysis of data collected under this program revealed a number of deficiencies with regard to utilization criteria and utilization effectiveness. As a result, the Chief of Naval Operations engaged the NAVTRADEVCEN in new efforts concerning training device cost and utilization effectiveness.

WHAT'S AHEAD?

At no time in the past has training in the military been emphasized to the extent that it is today.

With the advanced state of operational equipment, the quality and effectiveness of what is taught and what is learned is more important than ever before. Thus, the Center is evaluating individual instruction, programed instruction and computer-assisted instruction. These techniques, which can significantly accelerate the learning process, will be employed in our future military training programs.

As for training devices, they will no doubt become as technologically sophisticated in the future as the operational equipment itself. For example, it is not at all farfetched to state that: "In the next decade, a single master computer at a central location may be used to provide simulation at many geographical locations simultaneously."

In the future, as in the past, by utilizing available funds, manpower and materials, the NAVTRADEVCEN team will accomplish its mission in the most efficient and economical manner.

ROBERT G. DREVES
Director of Logistics and Field Engineering
Naval Training Device Center

Mr. Dreves is the Director of Logistics and Field Engineering. He attended the College of Engineering and School of Commerce of New York University. Before being called to active duty in the U.S. Navy in 1943, he was employed by the Sperry Gyroscope Company in the Flight Research Department. He performed two and a half years of active duty with the Navy during World War II. He was assigned to the Special Devices Division of the Bureau of Aeronautics. During this time, he was responsible for the introduction of the first Operational Flight Trainer into the flight training program of the Operational Training Command at NAS Banana River (now Patrick Air Force Base).

After World War II, he remained with the Special Devices Division of the Office of Naval Research and held successively more responsible supervisory positions in the Plans and Programs, Engineering, and Field Engineering organizations of the Center. Before his selection as Director of Logistics and Field Engineering, he was Head of the Aerospace Engineering Department. Mr. Dreves is a member of the American Institute for Aeronautics and Astronautics and Society of Logistics Engineers. He has received several awards for his outstanding work at the Training Device Center including the Navy's second highest civilian award for Superior Civilian Service.

Mr. R.R. POMEROY
Head, Audio-Visual Communications Division
Naval Training Device Center

Mr. Pomeroy earned his engineering degree, BS(CE), from the University of Colorado in 1939, becoming a member of two honorary societies–Chi Epsilon and Sigma Tau–in the process. He also took graduate work in aerodynamics and advanced mathematics before beginning his professional career with the Bureau of Reclamation in Denver. While there, he worked as a junior engineer in the Hydraulic Structures Test Laboratory, with collateral responsibility for special photographic equipment used in testing.

When Mr. Pomeroy entered the Navy as an Ensign in July 1942, he was assigned to the Special Devices Section of the Bureau of Aeronautics and immediately started work in developing and procuring new types of audio-visual equipment for training, training films and instructional recordings. He was directly connected with the development of some of the early film gunnery trainers, wire recorders, and first self-tutoring devices.

Following the war, Mr. Pomeroy returned to his civilian position in the Bureau of Reclamation, but after a few months came back to the Center to stay. He has participated in much of the technical development efforts in such areas as instructional television, individual instruction equipment, and improved classroom equipment and facilities. For the last eleven years, he has served as Head, Audio-Visual Communications Division.

Mr. HAROLD A. VOSS
Psychologist, Human Factors Laboratory
Naval Training Device Center

Mr. Voss earned his Bachelor of Arts and Master of Arts Degrees in Psychology from Fordham University in 1935 and 1937, respectively, His experience includes ten years in industry performing marketing, selection and training research. During World War II, he was involved in the selection and training of amphibious crews, destroyer personnel and antiaircraft gun crews. He was Project Director in two National Defense Research Committee programs.

Since 1947, he has worked as a research psychologist in the Human Factors Laboratory at the Naval Training Device Center. He is the author of over thirty technical publications.

Army Training Devices—1950-1980

LTC MYLES H. MIERSWA, SR.
Commanding Officer, U.S. Army Training Device Agency, Orlando, Florida

This article describes the history of the U.S. Army Training Device Agency (USATDA) since its establishment in March 1950 as the U.S. Army Participation Group, Special Devices Center. Utilizing the resources of the Naval Training Device Center, the USATDA provides the Army a capability in the design, development, and procurement of training devices. Its significant achievements during the past 21 years are highlighted, followed by several ongoing development projects, with a projection of anticipated effort in the 1970-1980 time frame. The USATDA has been responsible for fielding $100 million worth of training aids and devices since its establishment in 1950.

In 1949 and 1950, during the austere days following World War II, the Army began to recognize the contribution that training devices and training aids could make toward better training and more effective combat capability. This recognition resulted in the signing of a joint agreement between the Secretaries of the Army and Navy in March 1950, providing the Army with the full capability of the Naval Training Device Center (NAVTRADEVCEN) in the design, development, procurement, and evaluation of training aids and devices. This agreement is still in effect today.

The first group of officers assigned represented the various arms and services of the Army. Their primary effort was to review what the Navy had done during the previous nine years, and determine whether some of the developments could be applied to ongoing Army training programs. In a short period of time the ubiquitous vu-graph, or overhead projector, along with an ozalid kit for reproducing transparencies, was proliferated throughout the Army. Animated transparencies of the .45 caliber pistol, tank track suspension, and others poured out of the model shops. Working models of the M-1 Rifle, M-1 Carbine, and the Browning Automatic Rifle were procured and distributed in large quantities. Atomic weapon simulators were developed to add realism to training exercises.

All of the above were comparatively simple and inexpensive items designed to support training for uncomplicated mechanical equipment. Cost and lead time estimates were easy to make and procurement procedures were not bogged down in bureaucracy. Many of these items were obtained by simple purchase order and delivery was prompt. The training establishment of the field Army, as the recipient of this unprogramed and unexpected bonanza, was very happy. This halcyon period lasted for approximately three years. A gradual awareness developed that a wealth of talent existing at NAVTRADEVCEN could help the Army to solve its own unique training problems. The role of the project officer has gradually transitioned from that of buyer to innovator.

Feedback from the Korean War indicated that there was a need to improve rifle marksmanship training. This problem was examined and led to the development of disappearing type "E" and "F" targets which ultimately led to the trainfire system currently used in the Army.

The well-proven technique of aircraft simulation was applied to a series of tank turret trainers; these devices were designed for the purpose of realistically simulating an operational tank, with respect to the tank turret and the gun which it carried.

It was during this time frame that the Nike Air Defense System was deployed; it soon became obvious that these isolated units had a much more complex training problem to maintain an on-site state of operational readiness. The Air Force was reluctant to furnish sufficient over-flights to exercise the large number of dispersed units, and, of course, the firing of live missiles was prohibited.

In order to prevent these units from stagnating, a crash program was undertaken to solve the training problem. The 15D2 Radar Target Simulator was developed to generate synthetic targets for the Nike System. This simulator proved so effective that after years of use as an on-site trainer, it was gradually transitioned to the White Sands Missile Range where the synthetic missile image is still being used as the target for live missile firings. Concurrently, the Army's race to

catch up in the surface-to-surface missile field was on the verge of full-scale production. Again it became apparent that no provisions had been made to accommodate training prior to the deployment of these systems, and a crash program was undertaken to solve the problem. The first of a family of missile simulators developed was the Redstone Field Artillery Unit Proficiency Analyzer. Training in fueling, erecting, and firing the missile was given. All actions were carried out in exactly the same manner as in the actual firing of the Redstone, thus preventing expensive operational missiles from becoming "Hangar Queens." After this crash requirement, a series of follow-on programs for the Sergeant, Honest John, and Little John missiles were developed in a more orderly fashion.

Despite the achievements related above, the U.S. Army Participation Group (APG) sensed that something was wrong with the existing method of procuring training devices. The crash programs were very expensive and often resulted in hardware of marginal maintainability and reliability. A hard look at the existing method of procurement disclosed that in most cases the breakdown was caused by late identification of requirements. In many cases, the operational equipment had already been produced or was ready for production. A system of bringing the developer and user together was needed. Accordingly, during the late fifties and early sixties mid-range and long-range planning desks were established within APG. A closer examination of the Army's future weaponry and doctrine was conducted. In 1958, the first civilian member was assigned to ensure continuity of programs within APG. The project officers at APG were directed to write and staff military characteristics for training devices which would support future weapons systems. Army regulations for the procurement of training devices were promulgated encouraging the user to submit ideas for training devices. A logistics group was established within NAVTRADEVCEN to support the devices already in the field.

Many smaller but much needed training devices were produced; such as, the pneumatic subcaliber mortar and howitzer trainers, machinegun noise simulators, tank gun fire simulators, cargo handling trainers, and "Drawings for Army Training Aids" (DATA). They were given Army-wide distribution to permit training aids centers to manufacture a wide variety of training aids by using their own resources.

On a larger order of magnitude the Hawk Air Defense System was equipped with an excellent synthetic target simulator. A large gap in atomic warfare training was filled by the development of a radiac survey system that would permit survey crews to plot atomic fallout patterns without being exposed to deadly radiation.

This partially improved procurement system continued to function until 1962, when a major reorganization of the Army was implemented, by the establishment of the Army Materiel Command (AMC). This action abolished the old technical services of the Army such as the Signal Corps, Ordnance Corps, Chemical Corps, and others. The intent of the reorganization was to bring all Army procurement activities under one roof and to establish a closer relationship between user and developer.

Since the APG was a procurement activity for training devices, its functions were transferred from Continental Army Command (CONARC) to AMC. This had a major impact on the method of establishing Training Device Requirements (TDR's) and their procurement. The old role of APG project officers as CONARC proponents, for the establishment and staffing of military characteristics, was abolished. The transfer of function also placed the USAPG under an entirely new set of procurement regulations. The Department of the Army Life-Cycle Management System for Materiel was equally applicable to training devices.

New AMC regulations directed that the commodity managers and project managers use the capabilities of USAPG to the maximum practicable extent in their training device procurements. The burden for the preparation of Small Development Requirements (SDRs) or Qualitative Materiel Requirements (QMRs), which replaced the old Military Characteristics (MCs) for training devices, was placed on the user. The intent was to insure that any weapons systems developed by AMC would be supported by training devices delivered concurrently with the equipment.

One outstanding example of the AMC in-house cooperation was when the AMC Project Manager for the Sheridan Weapon System (M551 Gun-Launcher Tank) realized that the equipment he was developing would result in an expensive, highly sophisticated product. The addition of a Shillelagh missile launch capability would make the cost of training with live missiles prohibitive.

During the early stages of development of this system, the project manager approached USAPG for a solution to the training problem. This resulted in a concurrent development of training devices and hardware.

When the Sheridan System was deployed, the USAPG/NAVTRADEVCEN team was ready to field its training devices to support the system. One device was the XM40 Sheridan Weapon System Trainer; 28 were produced, at a cost of 4.5 million dollars, and their acquisition cost was amortized during its first years of use. The other device was the Conduct-of-Fire Trainer for the Shillelagh Missile (XM41–XM42). During a recent briefing for the Chief of Staff of the U.S. Army, the Commander of the U.S. Armor Center and School made the following remarks: "At one time, it was believed that the firing of as many as seven actual missiles per gunner would be required to acquire proficiency on the weapon. However, results of a missile gunner evaluation conducted at Fort Knox in the fall of 1969 indicated that with the use of the XM41 and XM42 trainers, three missiles are adequate to achieve an acceptable level of gunner proficiency. At the cost of approximately $2,300 per missile, it is obvious that use of simulators, even with their high initial procurement cost, quickly result in sizeable overall savings."

Another item which demonstrates the contributions of the USAPG to the efficiency of Army training is the Synthetic Flight Training System. This system had its origin in guidelines established in a memorandum by the Secretary of Defense to the Director of Defense Research and Engineering, the ASD (Comptroller), and the ASD (Manpower) on August 15, 1965, wherein he stated: "After reviewing last year's $3 billion education and training program, I am struck by the absence of any significant research and development activity to improve our effectiveness in this area. I am also aware that there is no social science research and development directed toward improving our education and training capabilities. A greater effort should be made to apply recently developed, modern training techniques and education concepts to existing defense training and education programs."

At the time this memorandum was written, the Army was undertaking a rapid expansion of its aviation capability to meet the requirements of Vietnam and the student load for aviator training had increased over ninefold. The hugh increase in cost of aviation training resulting from this expansion clearly illustrated the need for an economical synthetic flight trainer, which could reduce the need for operational aircraft for training purposes. To fulfill this need, the Army approved a Qualitative Materiel Requirement for development of the Synthetic Flight Training System. This system, when complete, will consist of eight devices simulating the UH-1H helicopter for instrument training purposes and one CH-47C helicopter operational flight trainer.

An engineering development model of the instrument trainer subsystem has been delivered to the U.S. Army Aviation School. It is comprised of four simulated UH-1H helicopter cockpits, mounted on motion platforms, with five degrees of freedom to provide motion cues, a third generation digital computer complex, and an instructor station. A sound system is included to provide aural cues. All training functions for each cockpit can be controlled by a single instructor through the computer, which is programed to perform many of the repetitive operations traditionally assigned to the human instructor. Use of the latest digital computers in the Synthetic Flight Training System enabled two innovative features to be included. These are: (1) The adaptive training mode wherein the level of difficulty of a particular lesson is adjusted to the skill level of the trainee, and (2) the capability of automatically scoring the student's performance in relation to selected parameters. These features, in combination with the high level of fidelity to the helicopter being simulated, will result in a reduction of up to 45-hours flying time per student in the training program. Annual savings accruing from this reduction in utilization of operational aircraft will amortize the procurement cost of the Synthetic Flight Training System in approximately three years.

An example of a user generated requirement is the Moving Target Simulator (MTS). The U.S. Army Air Defense School realized that practical training for Redeye gunners utilizing devices and targets of opportunity was costly and inefficient. Further, this training was subject to interruption due to range and weather conditions. As a result of this training problem, the MTS was developed.

The MTS displays an aircraft image moving around the inner surface of a 40-foot diameter quadraspherical screen. An invisible spot of IR energy is superimposed on the aircraft image during appropriate intervals of each trajectory.

Redeye gunner trainers, utilizing the XM49 Tracking Head Trainer, practice proper procedures in acquiring and tracking the target image to the point of launch. The MTS provides a variety of aircraft in progressively more difficult trajectories. Since each trajectory is identically repeatable, the instructor can establish well-defined performance levels and can determine student performance against these levels. The MTS is not affected by weather conditions and can be used 24 hours a day. These features allow the U.S. Army Air Defense School to provide low cost, effective training to a variable student load. As a result of the inherent difficulties associated with the use of radiological materials, a requirement was generated for a training device that would permit generation of simulated radiological information, thereby enabling personnel, who may be required to perform radiological surveys, to develop and maintain a high degree of proficiency. The Radiac Training Set, AN/TDQ-T1(V), was developed to fulfill this requirement. The device is extremely versatile in that it may be used in a number of training situations ranging from a few personnel on foot in small areas to full-scale division exercises utilizing vehicles and aircraft at ranges of up to 50 miles, thus providing cost-effective training that could not otherwise be obtained.

Another device developed in response to user request is the Air Traffic Control Radar Operator Trainer, Device 15G16. It is the outgrowth of the establishment of a school at Fort Rucker, Alabama, to train Army air traffic control personnel in the techniques and procedures peculiar to Army aviation.

The primary task of an air traffic controller is the proper coordination and control of enroute and terminal flights of many aircraft on differing types of flight plans. This may involve mixing traffic composed of aircraft with markedly different performance capabilities, e.g., helicopters and fixed wing aircraft, in a relatively small area. Device 15G16 is specifically designed to accomplish this type of training.

The device is a laboratory complex composed of ten "minilabs" operated through a Sigma 5 general-purpose computer. Each minilab has student stations for a precision radar approach controller, an area surveillance radar controller, and a flight data man. These positions are realistic in appearance and incorporate the standard operational equipment and communications facilities as found in the field. Simulated air traffic is provided by target control units, also operated by students.

The Army's major tangible return from use of the 15G16 device is the development of a controller who is more qualitatively trained on the equipment he will operate in the field. By eliminating much of the previously required on-job training, the Army is provided with a more highly trained specialist at lower cost in terms of time and dollars while concurrently adding a potential savings in lives and equipment.

This capsule history indicates a progressive trend to improve the staffing procedures for training device requirements. A review of the procedures used during the sixties disclosed that the preparation and staffing of the required Qualitative Materiel Requirement and Small Development Requirement was a major deficiency in the system. According to regulation, the drafts for these requirements were staffed through the Combat Developments Command (CDC). This staffing period became excessive and at times one to two years were required for approval. This tended to discourage the user from submitting requirements.

In July 1969, the Department of the Army promulgated AR 71-7 for "Military Training Aids and Army Training Aid Center System." Among other things, the AR abolished the need for QMRs and SDRs and for their staffing through CDC. The format for "Training Device Requirements" was established but their preparation still remained with the using agency. With assistance from the U.S. Army Participation Group when requested; however, the staffing responsibility was assigned to USCONARC in place of CDC. These simplified procedures were brought to the attention of all concerned through an intensified selling program at all of the major Army training activities. Many visits were made to the using schools and centers to brief them on the capabilities of the U.S. Army Participation Group and the Naval Training Device Center, with emphasis being placed on the importance of training devices, and the cost savings potential for the Army of the future.

A significant assist came from the Chief of Staff of the Army when, during the 1970 Chief of Staff's Forum for Center Commanders, General Westmoreland suggested that all center team commanders visit the USAPG/NAVTRADEVCEN facilities. As a result, some 14 General Officers, representing nearly all the Army training establishments, were briefed on capabilities of the

USAPG and the NAVTRADEVCEN. Many of them commented on the fact that perhaps a name change would give the organization greater visibility throughout the Army. Accordingly, action was taken in this regard, and on 1 July 1971, the U.S. Army Participation Group was redesignated as the U.S. Army Training Device Agency.

Paradoxically, it appears that the Army's strength posture in the 1970's will approximate the situation that prompted the establishment of USAPG in the 1950's. With the phasedown of the war in Vietnam and the beginning of the Modern Volunteer Army, manpower resources will be scarce, but the need to maintain an Army with a high degree of operational readiness capable of responding quickly to any future emergency will remain.

Based upon lessons learned in the past, USATDA has already conducted an analysis of equipment planned for in the 1970-1980 time frame. This analysis of the XM803 Main Battle Tank, Cheyenne Helicopters, Armored Reconnaissance Scout Vehicle, Surface-to-Air Missile, Mechanized Infantry Scout Vehicle, and others, shows that these major items of equipment are becoming increasingly sophisticated, costly to procure, and costly to operate and maintain. The requirement to supplement this equipment with cost-effective training simulators is apparent and is being pursued along with equipment development.

However, there are other areas in simulation technology that require investigation. The increased use of sophisticated sensing devices and ground and air surveillance equipment requires investigating to determine simulation requirements for training. The application of holography and lasers must be applied to the requirement for visually simulating the combined arms combat environment. The impingement upon our training areas, by our ever-increasing population trend, demands that combat training for both troops and commanders be conducted under simulated conditions.

With the twenty-one years of experience in providing cost-effective training devices for the Army, the U.S. Army Training Device Agency is ready to meet this challenge. The first major step was taken during the briefings of the Center Team Commanders stressing the need for prompt determination of training device requirements, and early initiation of development, so that advance preparations can be made for the Army's forthcoming austere posture. Second, a review must be made of operational equipment allocation for training at the highest level to determine an adequate mix of simulators to equipment to be used for training. Third, the accumulation of favorable cost-effective data on the devices recently delivered to the field must be accomplished. Fourth, and by far the most important of all, is early involvement of USATDA during the concept formulation phase of all future weapon systems. Thus, standing on the threshold of its third decade, the USATDA faces the future with confidence in its ability to assist the army in maintaining a high state of combat readiness, despite reduced manpower and dollars.

LIEUTENANT COLONEL MYLES H. MIERSWA, SR.
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Lieutenant Colonel Mierswa, Artilleryman, Senior Army Aviator, helicopter and fixed wing qualified, entered the Army as a Private in 1946. He was commissioned at Fordham University in 1951, as a Second Lieutenant in the Regular Army, after achieving the honor of Distinguished Military Graduate.

His first assignment, after graduating from the Battery Officer Course, at Fort Sill, Oklahoma, was to Camp Carson, Colorado, then to Korea as a Forward Observer. Wounded twice, LTC Mierswa was medically evacuated to Japan.

His early assignments included duty as Assistant Professor of Military Science at the University of Minnesota, Intelligence Staff Officer at Headquarters XVIII Airborne Corps Artillery, and duty with the 24th Aviation Company, 24th Infantry Division in Augsburg, Germany.

In Vietnam he flew as a member of the Army Concept Team, where he wrote the evaluation of the armed helicopter as it was used in Vietnam.

LTC Mierswa graduated from the Command and General Staff College in 1966 and on his third tour in Vietnam commanded the 4th Aviation Battalion, 4th Infantry Division.

His last assignment, prior to his assignment to the U.S. Army Training Device Agency in Orlando, was as an Author/Instructor in the Department of Joint, Combined and Special Operations at the Command and General Staff College.

His decorations include the Silver Star, Legion of Merit, Distinguished Flying Cross, the Air Medal with 11 clusters, the Army Commendation Medal with cluster, and the Purple Heart with cluster. He also received the Cross of Gallantry with silver star, and the Honor Medal, First Class, from the Vietnamese Government. In 1969, Fordham University honored Colonel Mierswa by awarding him the College Alumni Achievement Award in the field of Military Science.

Analyzing the Training Problem

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Four key questions are examined, and principles and guidelines for dealing with each are presented.

1. Is there a training need?
2. What specific training content is required?
3. What training methods/media are appropriate?
4. How can the training be evaluated?

Orientation of students, instructors, and managers toward performance-oriented training is discussed as a part of the overall training problem.

Suggestions for methods of identifying training needs are presented, with emphasis on ways of separating training needs from other types of needs in response to symptoms of deficiencies in system performance.

Determination of training content should be based on several factors to produce an efficient and effective program. These sources of training content are identified, and guidance provided on how to use them.

Selection of training methods and media is related to type of behaviors to be learned, proficiency to be attained, and administrative and practical constraints within which the training must be conducted.

Methods of measurement and the question of their validity and the validity of training are discussed, and suggestions given for dealing with the question of the criterion toward which the training is directed.

The effects of application of modern instructional technology on the role of the instructor, the concept of classes, and administrative matters are discussed, and guidance offered for dealing with these issues.

Analyzing a training problem is a complex matter. It is complex because training is complex. The number of dimensions that should be considered are many, and the interactions among them are intricate.

A first question to be addressed is "Is there a training problem?" Training problems are usually generated by:

1. The introduction of a requirement for a new or different personnel performance capability.
2. A need to increase the effectiveness of an existing training program.
3. A requirement for an administrative change in training (such as reducing cost).

Frequently, unacceptable performance by personnel in a certain job results in the conclusion that training is deficient. Performance deficiencies, however, do not necessarily result from training deficiencies. A performance problem, therefore, may not necessarily indicate that a training problem exists. It may be, rather, that the particular tasks require behaviors that exceed the normal limit of human capability. Additional training will not help significantly. The system within which the tasks are performed may have to be redesigned to bring the requirements more in line with human capabilities. For example, performance in a radar system, which overloads the information-handling capability of most operators, cannot be significantly improved through training. The system has to be changed to unburden the operator.

The first step in analyzing the training problem is, therefore, to make reasonably certain that a real training problem exists. Unless a substantial portion of an observed performance deficiency is attributable to learnable skills, attempts to improve performance through training are bound to be unsuccessful.

Assuming that there really is a training problem, three significant questions must be answered in order to solve the problem:

1. What specific training content is required?
2. What training methods and media will be most effective?
3. How can the training be evaluated?

Several documents have been prepared in the last several years which provide guidance in answering these questions for systematic development of training:

1 Guidelines for Training Situation Analysis (NAVTRADEVCEN 1218-4).
2. Systems Engineering of Training (CON Reg 350-100-1, Army).
3. Instructional Systems Development Plan (Air Training Command Reg. 52-33 and AF Manual 50-2).

The contents of these documents will not be summarized here. Rather, factors to be considered in following their guidance will be discussed.

All three of the above-mentioned guidance documents emphasize development of performance-oriented training. That is, they generally begin with a task analysis, which serves as the basis for specification of performance objectives to be achieved through training. Desired training content, methods, media, and measurements for meeting the objectives are then specified.

CONTENT DETERMINATION

Generally speaking, there are three possible reasons for inclusion of specific items of content in a course:

1. It is required to learn or to perform certain tasks, or is a prerequisite for later parts of the training.
2. Management desires that graduates possess the specified skills or knowledges.
3. It is required for later advancement in rank or level.

Some Basic Definitions

Knowledges are defined as items of information which are necessary to support task-related decision making. They involve four general classes of information:

1. Symbolic—including codes, jargon, and organizational and functional relationships.
2. Procedural—involving sequences of steps or activities. (This class does not, in itself, require performance of a sequence, only the ordering of its performance parts.)
3. Perceptual—involving discriminations of conditions which meet or do not meet specified criteria.
4. Decisional—inductive and deductive reasoning following specified strategies and/or principles.

Skills are defined as combinations of behaviors which cannot be performed at required levels of speed or precision on the basis of the possession of knowledges alone. Behaviors classified as skills must be *practiced* to meet training and performance standards. It is necessary to define the practice situations and training equipment which must be provided in the training regimen.

Three types of behaviors can be used to classify skills and knowledges:

1. Normal repertory behaviors (NB) require skills/knowledges within the capabilities of the trainees, when supported by specific nomenclature of the hardware and some kind of checklist or guide for response sequences in a procedure.
2. Generalizable behaviors (GB) are skills and knowledges not NB, which are common to many tasks. Categories of generalizable behaviors include:
   a. System geography and nomenclature.
   b. Dial reading and use of standard measuring devices.
   c. Use of simple hand tools (tool kits).
   d. Interpretation of graphic and symbolic displays.
   e. Avoidance of hazards.
3. Special behaviors (SB) are skills/knowledges which are not in the NB and GB categories and which an individual would not be able to perform with only knowledge of system nomenclature and geography. SB consists of behaviors unique to a task which must be learned.

Identifying Job-Derived Content

The first step in identifying training content based on job performance requirements is to find the difference between what the trainees must be able to do and what they are able to do before training. This difference, called the "performance differential," is the starting point for decisions about content for performance-oriented training. It is a list of behaviors that must be performed on the job, but which the trainees are unable to perform. From this list, other behaviors can be derived for inclusion in training.

The performance differential is the starting point for decisions about training content, and is not equated with course content. Some of the behaviors may be left out of the course. Others may be added for reasons given earlier.

The total behaviors of job are identified through an analysis of the job. The trainer must, therefore, have some method of analyzing the job. Many such methods are available. Some methods are better suited for one kind of job. For a highly structured job, for example, in which the operator gets certain information from a machine, a method that specifies the particular cues and the required outputs for each step may be suitable. The method

used and the kind of information collected about the job will determine the picture obtained of the job.

It is desirable to use a method that examines three parts of behavior:

1. The inputs the job performer receives--what he hears, sees, touches, smells.
2. The outputs required--body movements, spoken words, other actions.
3. What goes on between input and output--the information processing required of job performer.

Performance standards are an important part of any job or task description. It is not enough, for example, to state that a technician must be able to troubleshoot. What kinds of problems? How fast? What kinds of errors? Since performance standards will partly determine the training objectives, they must be stated as specifically and quantitatively as possible.

The next step is to subtract the capabilities the trainees already have when they enter training from the required job behaviors. The most direct way to do this is to give the input trainees an input repertoire test (IRT). Sometimes, however, a secondary method must be used, such as, examining the background and experience of the trainees and judging what they are able to do.

Regardless of what method is used to appraise trainee input capability, it is certain that they will not all be at the same level of proficiency on all the required behaviors. Solution of this problem requires considerable judgment based on facts which are not easy to get.

If the average input capability is used, approximately half of the trainees will get training on behaviors they can already perform. Another half will not get training on behaviors they cannot perform. If the consequences of error on the job are great, then it is better to include unnecessary training. If error consequences are not severe, and the cost of the training is high, take the opposite choice.

Other factors affecting this decision are turnover rate and frequency of occurrence of various job behaviors. If turnover is high, and one kind of job behavior very seldom occurs, a particular trainee may never be called upon to perform that behavior. Consequently, training every trainee on that behavior would be inefficient.

In identification of skills and knowledges for inclusion in a course, it is easy to erroneously infer skills and knowledges that are not required if you do not first obtain clear, unambiguous statements of the actual task behaviors. (Example: Task statement--"Interpret symptom of malfunction." Erroneous inference--"Must have functional knowledge of operation of equipment." Further investigation may show that "symptom of malfunction" meant a light was on, and that "interpret" meant that the "on" light indicated an open interlock. The detailed facts give a very different picture from the inference about "functional knowledge," which may have resulted in including in the course much information about the equipment.)

One effect of this type of error is that many skills and knowledges may be incorrectly included in training, resulting in valuable training time and resources being diverted to these items rather than being used effectively on necessary training content.

In addition to skills and knowledges to be included as part of course content, some conditions that may affect job performance should also be included in the analysis.

It is important to set the intended training in the context in which the student must perform in the job setting. Only those contextual factors, which have significant influence on job performance, will be specifically identified and included as part of the training objectives.

These contextual factors can be classified into three groups. Each category has implications for training. The classes are:

1. Extraneous contextual cues--the general irrelevant environmental cues which might accompany task performance in the operational situation.
2. Performance degraders--forces which cannot readily be overcome or compensated to any appreciable extent by practice. Their effect is relatively constant and serves to lessen performance capability.
3. Performance disruptors--forces which are disruptive at first, but which can be gradually and partially overcome with practice.

If the training specialist can sort the contextual factors into these three classes, he can decide which should be simulated in the training by following three rules:

1. The addition of extraneous contextual cues may increase initial training time while not producing any corresponding increase in later on-the-job performance.

2. There will be little if any benefit derived through the simulation of performance degraders in training.
3. Performance disruptors such as G force and vibration should be simulated during training if there will be no opportunity for terminal practice under operational conditions.

SELECTION OF INSTRUCTIONAL METHODS AND MEDIA

Instructional *methods* refers to the process by means of which the instruction is to occur. Instructional *media* refers to the devices used to implement the methods.

While not meant to be an exhaustive listing, the following are representative of various methods of instruction:
1. Lecture
2. Demonstration
3. Practice Exercises
4. Self-Study (including homework).

The method of Practice Exercise can be elaborated into a large variety of instructional methods. The selection of method of instruction must be done by the training analyst on the basis of the specific knowledge or skill to be learned, and his knowledge and experience with training principles and methods.

The method of instruction must be stated in terms of the activities of the instructor. Instructor activity includes what the instructor does, his relationship to the student, and the kind of support in demonstration, guidance and feedback, which he must provide. Initially, at least, cost-effectiveness considerations (i.e., personnel, time, special facilities, etc.) should not control the selection of methods for instruction. It should be directed toward optimum training rather than being governed by cost or other constraints. A more opportune time for conducting cost-effective evaluations is after the various learning elements have been clustered to form larger units of training. What may seem to be a poor cost-effective training method for an individual learning element may prove to be acceptable for a series of learning elements.

Training media should be selected on two factors: (1) Psychological–those that will do an effective training job; and (2) economic/administrative–those that will fit the circumstances and cost the least. Selecting media on psychological grounds is difficult. Many different ones will meet the psychological criteria. Their effectiveness depends on how they are used. It is almost impossible in many cases to choose one over the other on the basis of the category in which it happens to fall. The choice should be made from the learning point of view. Look at the functions it must perform to bring about learning. Identify all media that will perform those functions adequately, and from them choose on economic/administrative grounds the ones to be used.

For learning to take place, a stimulus must be presented, the subject must respond, and feedback must be provided. Training media must, therefore, perform five critical training functions:
1. Stimulus generation–the stimulus to be presented has to be provided.
2. Stimulus presentation–to the trainee.
3. Response acceptance–the trainee needs something to respond to, with, or on.
4. Response appraisal–measurement and comparison with a standard.
5. Feedback presentation–to the trainee.

If any of these functions is performed poorly, the training will be less effective.

The type of medium to be used with each learning objective should be specified, in functional terms, and the specific media to be used with each objective chosen from among the following:
1. Texts
2. Programed instruction
3. Television
4. Workbooks
5. Motion pictures
6. Projected still pictures
7. Simulators and mock ups
8. Operational equipment
9. Multimedia presentation.

These types of media can be selected on the following factors for applicability to the various learning elements in a course:
1. Effectiveness of the various types of media in performing various instructional functions. (Display stimulus, accept response, record response, provide feedback.)
2. Content to be presented and the nature of the behavior change to be produced.
3. Total number of students to be trained, and the number that can be accommodated at one sitting.
4. Contemplated degree of individualization and self-pacing.

5. Proficiency level required by the learning objective.
6. The degree of simulation fidelity required for adequate generalization of training to the job situation.
7. The desirability of providing variety in the media used with a single trainee.
8. Anticipated frequency and degree of changes in course materials and the ease with which such changes are accomplished.

As with the training method, consideration of cost-effective parameters of training media should be minimized until final clustering has taken place.

It must be kept in mind that the appropriateness of given instructional methods and media is a function of many factors. One of the strongest factors is the stage of learning of the student. At early stages of learning, description of the task, demonstration, and coaching with detailed feedback are appropriate, with activities occurring at considerably less than criterion speed. It is also desirable at early stages of learning, to "purify" the task so that error in the system, other than that attributable to the individual learner, is minimized. At later stages of learning, description, and demonstration are less appropriate. The kind of feedback should change and the amount should be reduced.

It is sometimes thought that experience is really the best teacher. The best is the one that performs the five training functions best. Experience may do very well on some of the functions and not so well on some others.

One of the main values of experience is that it presents the learner with a wide range of situations. Usually it is not possible to include the whole range of job situations in training. Part of this function is left to experience, which also permits performance of required responses by the learner.

Response appraisal and feedback are less well handled by experience. The supervisor keeps an eye on the new worker, evaluates his performance, and gives him feedback. Learning, however, is affected by the time or events that take place between response and feedback. The supervisor cannot watch the new worker every minute. Considerable delay may therefore occur before feedback is given, resulting in a less effective learning situation. The new worker may also make many responses and get no confirmation. He may also get confirmation of incorrect responses, which will then be learned. The trainer, therefore, must be reasonably sure that the trainees have learned the correct responses to the various classes of stimuli. Experience can then present a wider range of stimuli to which they can apply these responses.

EVALUATION OF TRAINING

Measuring the effectiveness of training is a difficult problem. It involves questions of criterion validity and reliability, test construction, and practical problems in obtaining acceptable measures of what the trainees can do. It is tempting to set aside the behaviors the trainees are to learn and to use a knowledge test. Such a test, in which more or less factual questions are asked, and which measures how many the trainees get right and wrong, is much simpler than a performance test.

If the training program has a good set of objectives, the battle of developing an effective training evaluation is half won. The statement of the objectives provides the means for evaluation of training that is valid by definition. Specific test items, and a suitable scoring system, must then be devised to measure the ability of the trainee to perform that which the training was designed to teach him.

Since the beginning of written history (and probably earlier), the problems associated with developing and sustaining human performance have been complicated by inability or unwillingness to specify at a useful level of detail what is to be performed. In recent decades, as human performance technology has developed, this complication has come to be called the "criterion problem." Briefly stated, it is the problem of determining what measures adequately describe job performance for any of a variety of purposes, such as development of training curricula, prediction of job success, validation of abstract predictors, and many more.

The literature of psychology and education contains references to no more persistent problem than that of criterion selection, yet little new thought has been added since the 1940's. Though much attention has been given this problem, both during and since World War II, there exists today no method for dependably selecting criterion measures which have the virtues of relevance, reliability, and discrimination within the bounds of practicality. It is perhaps an overemphasis on this matter of practicality, which has led education

and training specialists, within and outside the military to shun performance testing on the grounds of its expense. Currently, the belief is growing that this notion may result in false economy.

Instruments designed to predict job success must be referred to criteria, which are composed largely of job/task performance items, if the criteria are to meet the requirement of relevance, the *sine qua non* of criterion selection.

The difficulties associated with performance testing have been described by so many, for so long, that by now virtually everyone with an interest in this area knows that such tests entail great expense, long test administration time, apparatus, which may break down at inconvenient times, scoring difficulties, narrow applicability, unreliability, etc. The problem is to develop performance tests which minimize these difficulties, while providing valid measures of performance.

It is important to recognize that validity is not assured through use of actual job tasks as test items. It is also necessary that the variety of tasks be sufficient to account for the variability in the hypothetical ultimate criterion, and that the test tasks be performed under conditions similar to those found on the job with a minimum of interference from the test administrator. Further, if validity is to be assured, the scoring of individual items must reflect their importance in the context of the total job or task.

Measurement and Scoring Techniques and Procedures

Certain measurement and scoring problems are inherent in all performance tests and must be resolved if a satisfactory test is to be developed. The following four questions deserve special consideration:

1. Should "products" or "processes" be scored?
2. To what extent should the measurement process be permitted to interfere with normal task performance?
3. What kinds of measures should be taken?
4. Multiple cutoff scores vs. single-weighted score?

"Products" or "processes": Should you measure the extent to which a "right answer" was obtained, or the extent to which the proper procedure was used, regardless of the final result, or some combination? For example, one way to score within-stage troubleshooting is to determine whether the subject is or is not able to identify the defective component. This method scores only the product of troubleshooting. If such a scoring scheme were used in this case, it would be impossible to determine which of the many possible causes resulted in failure to solve the problem. The subject may have made errors in the use of his technical data, he may have made errors in the use of his test equipment, or he may have made logical errors in deciding where to check. Close observation of the process of his performance would have enabled identification of the causes for his failure.

Another problem that may occur in scoring products alone is that there may be only a single task in the task category; if we observe only the product of that task we get only a single measure on each subject for that task category. This must certainly reduce the reliability of our estimate of performance for this part of the criterion.

Finally, for some tasks there is no product at the end of the process. An example is the checkout procedure. Many checkout procedures begin by energizing the equipment to be checked, making all the required checks, and deenergizing the equipment. If we did not measure performance of the process in conducting such a procedure, it would be impossible to determine whether the procedure had been done correctly—and this is the fact in which we are most interested.

Three conditions can thus be stated under which processes should be scored in addition to, or instead of, products:

1. When more scores are needed to increase item reliability.
2. When there is no product at the end of the process.
3. When diagnostic information is required.

It is clear that for most tasks, process scores are required. Trouble-shooting problems are likely to require more scores than "right vs. wrong" if adequate reliability is to be achieved. Checkout procedures produce no product that can be scored. And finally, in almost every case, diagnostic information about performance is desired so that proper remedial action can be taken.

"Assist" or "non-interference": Should an "assist" method of scoring be used, or a "non-interference" method? In the "assist" method, the test administrator helps the trainee perform those parts of the task that the trainee does not know how to perform. If the "non-interference" method of scoring is used, serious distortions of the scores will result when

inexperienced personnel take the test. In most situations it will be impossible to find out how much of the task they can perform because so many of the tasks require proper performance of previous steps before following steps can be performed. The situation may arise so that if the scorer does not in some way assist the task performer in step 1, it is, in effect, impossible for the trainee to take the test, even though he may be able to do all of the steps that follow step 1.

It cannot be denied that the intervention of the administrator introduces some distortion into the meaning of the score. A slightly distorted score, however, is better than no score at all. If the assists can be kept to a minimum, the distortion is likely to be relatively minor. Experience with applications of this type of scoring indicates that it can be used effectively. Since most tasks consist of steps, with performance of later steps, depending on performance of earlier ones, the "assist" method is almost mandatory.

Multiple cutoff scores vs. single-weighted score: Single scores, developed from a composite of weighted individual scores, are typically used if a test score is to be correlated with some other criterion measure, since better correlations can often be obtained with differentially-weighted composite scores than with individual task scores. There are, in addition, technical reasons for avoiding combined scores and good reasons for the use of multiple criteria, or profiles, rather than composite criteria. Composite measurements frequently involve elements of overall performance that do not mix metrically. Where the time required to perform a series of tasks is the dimension measured, the composite scores can be used because time is a unitary dimension. Accuracy, however, is multidimensional: Measures on these various dimensions cannot always be validly combined into a single score.

NON-TECHNICAL ASPECTS OF TRAINING PROBLEMS

Increased emphasis on performance, with the parallel decreased emphasis on theory, has been difficult for some training people to accept. In some ways, performance is harder to teach; some instructors may not be as knowledgeable about task performance as they are about equipment theory; some may find difficulty in perceiving training as a process of developing desired behavior patterns in students rather than as primarily a process of conveying information to students.

This has meant that the instructors who are to use performance-oriented material should participate, to the degree possible, in its development. They must see for themselves the validity of the material, born of the basic logical validity of the process by which it was developed.

Increased emphasis on performance learning, rather than on information learning, brings about a change in the primary role of the instructor, which some find hard to accept. A common concomitant of performance-oriented training is that the students do more individual work—learning specific skills, working practice problems, and the like. If the program is well-prepared, much of it may be learner-centered. The instructor's role as a lecturer to a class is attenuated. His role becomes more of a facilitator of performance learning and less of a conveyor of information. He can (if he will) serve as a tutor to a particular student, on that student's particular problem, at the specific time (in most cases) that the student needs help.

The instructor's role becomes less authoritarian, and the trainees ask very hard questions when dealing one-to-one with the instructor. Meeting the challenge of this changing role requires specific orientation for the instructors—again including their participation in development of some of the materials.

CONCLUSION

Training problems have been analyzed many times, in many different ways, by many different people—both expert and not-so-expert. Many perplexing and difficult issues remain unresolved.

Guidance documents have been prepared to assist training developers to do a more effective job analyzing and solving their training problems.

This paper has attempted to provide some insights and ideas to fill the gaps "between the lines" of these guidance documents.

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The Technology of Education and the Design of Training Equipment

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The purpose of a training device is to provide, as economically as possible, a learning situation which will allow the learner to develop specified behaviors that have a high probability of positive transfer. Training equipment is meaningful only in the context of the instructional system in which it is to be used. The effectiveness of a device within a training program is directly related to the degree to which it complements the program in incorporating the principles of behavioral technology. Each device must be designed to provide the maximum cost-effective change in performance of the learner as he progresses to terminal behavioral objectives. Industrial Dynamics models provide a framework for analysis and trade-offs in this area.

Some years ago, there was a great deal of discussion about how computers would make business operations more efficient, improve management decisions, and reduce the cost of operation. Impressed, businessmen added a computer to their inventories. . .then they added operators. . .then they added programers. . .then they added analysts. They standardized their business practices, and then found them too inflexible to accommodate the specific needs of daily operations; they were inundated with detailed data that they didn't know how to use. It was not until the computer was placed in perspective as an integral part of a total information and data management system, and the entire operation adjusted to effectively utilize its capability, that the real value of the computer in business applications began to emerge.

There is reason to believe that an analogous situation is taking place in the field of education and training. Efforts to impose innovations and new instructional concepts on existing training operations indicate that new technology, added (as auxiliary) to traditional training systems, has little or no impact on the cost effectiveness of the system. There is a need to perceive and analyze the application of technology and training equipment to training problems at the "total instructional system" level. There is a need for systems analysis tools and techniques to support first, the design of cost-effective training programs and equipment, and second, the transition to their operational utilization.

The application of systems analysis techniques presupposes a process which is essentially rational and sufficiently disciplined to permit the response of the system to variations in selected parameters to be predicted. To design equipment into a training program, the following criteria for general feasibility should be examined to show that:

1. The objectives of the equipment operations can be clearly defined.
2. There are good reasons to believe that the conditions exogenous to the equipment will remain the same for a useful period of time.
3. Current program operating practice leaves plenty of room for improvement.
4. The program operations are describable by a reasonably manageable model:

–The number of controlled variables is large.

–The number of relevant uncontrollable variables is small.

–The relevant variables are measurable, and the data are good.

If concept studies can describe a new state of operations in relation to these criteria, bringing together information and analysis from research and development, and if adequate sensitivity to alternative operational modes can be demonstrated, confidence can be gained in the reduction of risk, and the assurance of cost-effective improvement in system operations. The sequencing of study, simulation, and full operation tests will permit major, multi-variable innovations to be made with reasonable cost-to-risk ratios.

The first part of this article discusses the technology of education which provides the

rationale and the set of variables that permit the techniques of systems analysis and modeling to be gainfully employed in the design of instructional systems. The second part of the article considers the framework of Industrial Dynamics modeling as a potential tool for analyzing the cost effectiveness of training programs and equipment at the instructional systems level.

The application of technology to the training problem is based on three postulates:

> First, that there is a phenomena known as "transfer of training" wherein the training and operational situations may be widely dissimilar from the standpoint of physical duplication, yet achieve performance features desired in operational situations.
>
> Second, that there are definable, observable, replicable conditions of learning. Learning is not a random event, and therefore, a solution may be "designed" to maximize the probability of its occurrence.
>
> Third, that individual differences in background, learning styles and ability are of sufficient magnitude to significantly impact the cost effectiveness of a training program.

TRANSFER OF TRAINING

The concept of transfer of training is based on a principle known as "phenomenal equivalence," that is, different, but similar, situations cause them to be perceived as the same by the human observer or evoke the same responses despite their physical or objective differences. The extent to which a learning situation may be modified with little or no loss in transfer of training depends upon conditions within the trainee; hence, learning situations which are widely dissimilar from the standpoint of physical duplication, may be functionally identical from a practical training point of view. The confidence which can be placed in a training situation is not limited to the degree of physical simulation employed. The compromise between engineering simulation (duplication) and psychological simulation (equivalence) is based on cost and training objectives. In general, as engineering simulation increases, the cost increases exponentially; hence, incremental gains in trainee skill may become uneconomical in terms of training device design, fabrication, and maintenance costs. The design of an effective training device should not necessarily strive for physical fidelity, but rather should incorporate what is necessary to enable the trainee to transfer the responses he has learned to an operational setting.

The second dimension of the transfer of training tradeoffs is associated with the degree to which a training situation increases the probability of proper performance in the operational setting. For example, it may be worth several million dollars to increase by one percent the probability of the proper performance of an astronaut in making a moon landing; however, it likely would not be worth this investment to increase by the same amount the probability of proper performance of a caterpillar tractor operator in leveling a parking lot. If one training situation is significantly more expensive than another, and the former does not provide a significantly higher probability of proper performance in the operational setting, the cost effectiveness of the higher cost situation must be questioned. The final criteria for selection lies in the operational situation.

There are then, two variables implicit in the concept of transfer of training which submit to analysis and tradeoff: first, engineering vs. psychological fidelity, and second, the degree to which the probability of proper operational performance is increased.

CONDITIONS OF LEARNING

Learning is not something that "just happens," it happens under certain conditions which are observable. Some of these conditions are internal to the learner; some are external. Those that are internal are primarily associated with "possessing prerequisite behaviors" and with motivation. The conditions which are external to the learner are such things as medium and format of stimulus presentation, number and rate of stimulus-response sequences, form of response, feedback on performance, physical comfort, etc.

The "possession of prerequisite behaviors" (as a condition of learning internal to the learner) describes the obvious fact that a trainee must possess the necessary knowledge and skill which enables him to take the "next step" in learning. A training program, then, becomes a series of instructional events sequenced in accordance with a generally hierarchical behavioral order. Students will progress from "enabling" to "terminal"

behaviors. The flexibility of a training program to adapt to the needs of the individual by allowing him to maximize his own progress "through" these instructional events, will be a mark of its efficiency.

Motivation (as a condition of learning internal to the learner) can be influenced through the use of contingency management techniques. Matching high probability with low probability behavior is an application of Premack's principle wherein a response that is low on an individual's response hierarchy is reinforced by causing a response which is higher on the hierarchy to follow it. Rewarding achievement, and "punishing" poor performance creates an environment in which the trainee will tend to devote the necessary attention to learning.

The creation of the conditions of learning which are external to the learner is based on the selection of a presentation form and media which are appropriate to the type of learning involved. Media which convey motion, provide retention for study, require active student response, provide immediate or delayed knowledge of results, integrate stimulus and response with real-world dynamics, provide repetition of stimulus-response patterns and/or permit practice of performance, contribute with varying degrees of cost effectiveness to creating the required learning environment. The presentation form and media can vary from the simplicity of a workbook to the sophistication of a full mission simulator. One of the most challenging problems in the design of instructional systems is the grouping of training objectives to permit cost effective selection of media and design of training devices.

The fact, then, that there are observable, replicable conditions of learning in which the variables are a function of the type of learning and, therefore, of the training objectives, provides the basis for the application of systems analysis, trade-off studies, and cost-effectiveness criteria to the design of instructional systems.

INDIVIDUAL DIFFERENCES

The individual trainee brings to every learning situation, behaviors which either transfer positively or negatively to that situation or have no impact at all. In addition, some prerequisite behaviors may be completely lacking. Hence, each individual will, to a greater or lesser degree, uniquely approach a given learning situation. A strategy which seeks to solve this problem by creating homogeneous groups through testing and screening, pays the price of eliminating good potential performers; a strategy which takes all students into the group, pays the price of retarding the rate of progress of the more "ready" students; a strategy which designs a training system to accommodate individual differences, pays the price of multi-media, multi-path material, and the administrative costs in individualized instruction. Clearly, there are alternatives that submit to analysis and optimization. Trade-offs of various policies and implementation strategies can be made and will significantly impact the cost effectiveness of a training program.

TRAINING SYSTEM DESIGN

The requirements for the design of a training device should proceed "top down" from the design of the training program. Trade-offs have to be made as to what training objectives should be achieved in what sequence, and how they should be grouped to minimize duplication of training events and equipment. Within the general sequencing constraints provided by the hierarchy of enabling and terminal objectives discussed above, training objectives can be changed from one "learning module" to another in order to optimize the selection of media and/or design of training equipment. Since a training system will often transcend organizational lines and responsibilities, as well as interface with, and overlap other training programs, there is a need for an organized framework for analysis and design trade-offs. This "framework for analysis" should be structured so as to encourage system optimization rather than sub-system optimization and should provide the capability for analyzing the impact of variations in the parameters outlined above. Since continuity with existing on-line training programs and responsibilities must be maintained, the requirement is to simulate the existing system with a model which is sensitive to available decision options and to show the optimal (and alternative) changes which these options allow.

For over ten years, the dynamics of managerial systems has been studied in various universities and industrial settings. The field of "industrial dynamics" has emerged. Industrial dynamics studies how the various feedback and control

loops in a managerial system produce the dynamic characteristics, and hence, the operational efficiency of that system. More recently, this basic concept has been applied to the broader fields of social and urban planning. The resulting field might better be termed "institutional dynamics" since its scope of application goes far beyond industrial applications.

There is a strong analogy between a manufacturing process and the dynamics of a training program. For example, in a manufacturing process raw material is brought in and is sent in sequence from one station to the next, where it is cut, bent, melted, drilled, etc., as it is gradually shaped toward a predefined end product or products. At each station where this material is processed, there are tools (drills, solder irons, etc.) and people required to operate and change its characteristics. There is in-process and end-process testing where materials not meeting specified standards are rejected. The processing tools and equipment at each station wear out and are depreciated by age and use; failures create significant queing problems.

The analogy to the training problem is obvious. Students are "processed" through a sequence of instructional events, each instructional situation requires training equipment and resources which are depleted in some way by the students using them. The number of students and their rate of processing will determine the quantity of training resource requirements; however, more efficient training equipment can process more students faster, and hence, may (or may not) be a wise investment. Equipment can be designed with more or with less capability and capacity depending on where and how it relates to the total process. The problem is to derive a systematic way of defining the most cost-effective learning modules and their appropriate training devices/equipments. Again, the requirement is for both system and subsystem optimization.

Industrial Dynamics modeling uses three basic building blocks to structure a problem for analysis: levels, rates, and a network depicting the flow of information.

Information available to a decision maker is in the form of "levels." A level may be the number of employees at a given plant, or the number of items per week produced by a given machine.

The second building block, "rates," control the flows between levels. Management decisions control levels only by controlling the rates which govern the flow between levels. Hence, a managerial decision to put station X on two-shift operation should double the items per week.

The third building block documents the flow of information about levels to the decision makers and other elements in the system. Delays and errors in this information network would clearly impact the decisions regarding the rates (control valves) and; hence, the levels in the system.

No complex mathematical models are used; the computer keeps track of a vast number of small incremental level changes due to rates, and the resulting rate changes due to changes in levels (feedback) and the management decision factors. Extremely complex non-linear interactions can be accommodated according to any set of assumptions set into the model. The general strategy is to validate the model against the known behaviors of a system, then experiment to explore the effects of change options.

Our purpose in the following paragraphs is to illustrate how this framework for problem structuring might be applied to the instructional system and equipment design requirements problem, and so provide a mechanism for integrating the control variables discussed above into a coherent "model," which permits change options to be evaluated at a systems level.

Figure 1 illustrates a simple application of this modeling concept to the instructional system design problem. The central element in the system is students. Students move through a series of instructional events which are designed to change behavior. Hence, the levels may be defined by a number of students in the process of acquiring a certain set of behaviors. The flow of students from one level to the next—from one behavior set to the next—is controlled by various management decisions and policies.

What are the management decisions that might be made in order to change the flow rates between levels so as to change the levels, so as to reduce (or increase) the resource requirements, so as to reduce (or increase) the costs of operation?

The policy that a student, who already possesses the behaviors of a given set or sets, will skip the associated instructional events and enter the course at the behavior set where he is lacking, might result in fewer students in the earlier phases, and still maintain the same student output level. The cost savings would be in terms of reduced resources (facilities, instructors, training equipment and materials) in the early phases, as

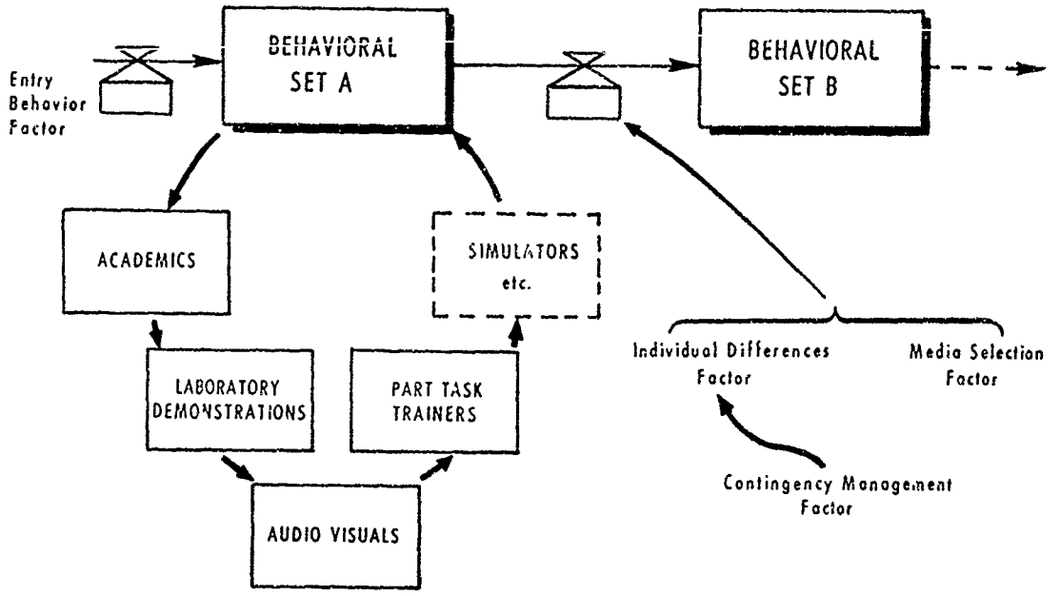


Figure 1. Instructional System Model Concept

well as in trainee salaries. The "prerequisite behavior" concept was defined as a condition "internal to the learner," in the discussion of Conditions of Learning, above. Hence, the management decision would be in keeping with the predefined instructional system variables or change options. This change option is shown as the Entry Behavior Factor in figure 1.

Another management decision which would impact the flow rates, and therefore the levels, would be a change option in which trainees would be allowed to progress through the course at their own maximum learning rate. This could be coupled with a change option that created an environment in which the principle of contingency management was used to encourage the trainee to proceed at his maximum rate. Such a policy might result in a significant percentage of the trainees completing the course in less time. This would reduce the number of students in all levels, reduce the load on training resources in all phases and decrease the total trainee salary expense, yet maintain the same student output level. Both "individual differences" and contingency management were discussed above as variables which the instructional system designer should use to optimize his design. These change options are shown as the Individual Differences Factor supported by the Contingency Management Factor.

A third area of management decisions which can influence the flow rates is related to the selection and utilization of media, training devices, and learning materials, i.e., those factors associated with the "conditions of learning external to the learner" discussed above. Again, decreasing trainee pipeline time saves both training resources and trainee salaries. However, in this case, it may be necessary to increase the investment in training equipment and materials with the intention of increasing the effectiveness and/or efficiency of training to where the net result is a decrease in cost with no compromise in essential training objectives.

Figure 1 is a simplified sketch of a problem that obviously has many intricate feedback loops and change options. The sub-loop of academics, laboratory demonstrations, part task trainers, etc., each contribute to the cost of the environment which produces the behavior change associated with the Behavior Set. Each of these elements in the sub-loops have their own support requirements of instructors, consumables, preventive maintenance, maintenance and operations, etc. Obviously, the management decisions that apply to Behavior Set A may or may not apply to Behavior Set B, and so forth. Many of the factors associated with the change options would be empirically determined, either from special R&D

projects or by analysis of other programs where the various options are already being employed.

Translating the above discussion into the language of industrial dynamics modeling:

1. SA.K = SA.J + (DT)
(NSA.JK - GSA.JK - DOA.JK)

where

SA.K is the number of students in level A at time K.

SA.J is the number of students in level A at some previous time J.

DT is the length of the time increment JK.

NSA.JK is the rate at which new students enter set A during the time period from J to K.

GSA.JK is the rate at which students graduate from A during the time period from J to K.

DOA.JK is the rate at which students drop out of A during the time period from J to K.

2. NSA.JK = NST.JK - EBF.JK

where

NST.JK is the rate at which new students enter the total program during the time period from J to K.

EBF.JK is the entry behavior factor.

EBF is the rate at which new students enter the other levels (i.e., behavior set B, C, etc.). In a conventional course, where students progress as a group from one phase of the program to the next, and all students, regardless of their backgrounds, enter behavior set A, NSA.JK would equal NST.JK. However, if the management decisions were made to allow students to enter the training program at whatever level was appropriate to their entry behavior, the EBF would reduce the rate of entry into set A. Hence, equation 2 allows the impact of the change option wherein students who already possess a given behavior set may skip the corresponding level of instruction and move directly to the level appropriate to their entry behavior, to be tested.

3. NST.JK = GST + DOR

where

GST is the rate at which students will be required to graduate at some future time X, where X is the nominal length of the course (GST is an exogenous variable).

DOR is the rate at which students will drop out of the program.

4. GSA.JA = [SA.J + (NSA.JK)(DT)]
[IDF + MSF]

where

IDF is the individual differences factor.

MSF is the media selection factor.

The IDF permits the management decision of having students progress at their own maximum learning rate to be tested; the MSF permits the relative efficiencies of alternate media and/or training equipment configurations, to be examined. Hence, if no allowance is made for, say, individual learning rates, the number of graduates becomes a direct function of the media and instructional methods; if individualized progress was permitted, the effect would add (algebraically) to the media factor and adjust the student output accordingly. Obviously, the levels of non-training time, the "transfer of locations," time, etc., could be built into the model for management scrutiny.

The above equations illustrate the feasibility of structuring the training system design problem, in terms of levels of students involved in behavior change and the "control" variables which contribute to the cost effectiveness of training. The expansion of this concept to include all levels of instruction, support, administration, supply, facilities, logistics, costs, etc.; building from these very simple, individual model elements, to the complexity of a pilot training or navigator training program, is within the state-of-the-art in industrial dynamics modeling.

TRAINING EQUIPMENT DESIGN

Structuring a training program in terms of sets of training objectives and/or student behaviors has particular significance to the design of training equipment. If the levels or behavior sets of the model are selected to correspond to instructional media and/or training equipment, the capability and capacity of the media/training equipment, as well as its contribution to the overall training program, becomes explicit. The contribution of the training equipment can be evaluated in the context of the total instructional system in which it is to be used. Sets of training objectives can be examined for commonality—that is, for subsets of behaviors which are the intersection of the larger sets. This provides the basis for examination of training equipment requirements to determine the minimum configuration. Within the constraints of

the hierarchy of enabling and terminal objectives (which limit the sequencing options), the objectives should be grouped to permit efficient definitions of part-task trainer and learning material requirements. It is in this context that the tradeoffs of engineering vs. psychological fidelity must be made; it is in this context that the "increase in probability of transfer" must be examined. In short, the proposed framework for analysis permits the training system requirements to be synthesized in the perspective of the total instructional system—including the learner-centered change options associated with transfer of training and individual differences.

CONCLUSION

A training program consists of an integrated sequence of learning events which progress toward some terminal set of student behavior. The concept of industrial dynamics models provides a framework for analyzing this sequence of specified behavior changes and relating the events to the variables in an instructional environment, which contributes to the cost effectiveness of training. The model can be structured to relate directly to media/training equipment requirements. The concept provides the potential for optimizing a training program and training equipment requirements at the system, rather than subsystem, level.

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The Development of Flight Trainers

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This paper discusses the demands of the service to build pilots of the highest proficiency and to perform missions of almost infinite complexity. Today, as a product of 25 years of extensive experience, there are three major forms of trainers being used by the Navy.

The first, the general purpose trainer, whose forebearers were first bought in the early thirties, is used broadly to teach and maintain instrument proficiency and navigation. Too, operation of basic airplane systems is required in these offsprings of the Link blue box.

Though these efforts were successful to a degree, the need for a more accurate reflection of the unique qualities of a particular airplane and the often delicate refinements of a sophisticated electronic system presaged the development of the Operational Flight Trainer. Thus, the second type of aviation trainer in common use today. It is an offshoot of efforts to modify and adapt earlier general purpose trainers to a particularized version of a specific airplane, and to broaden its purpose to teach complete airplane systems operation in addition to the normal flying tasks.

One of the first trainers of this type was the PBM Trainer, developed by Bell Laboratories for the Navy during World War II. From these somewhat primitive beginnings has grown the OFTs for the century series fighters, which are used so successfully today for transition and for maintaining refresher skills, for both the aircraft and instrument work.

The third type is the hugely complex and enormously sophisticated trainers called Weapons System Trainers. The addition of massive computers and other simulation hardware transforms what would otherwise be an OFT into a device that can allow an entire crew to train for a complete mission. Such a WST is the P3A, whose antisubmarine and detection mission can be duplicated with surprising exactness providing a crew with the opportunity to rehearse every phase of its complicated work. Special devices simulate sonar, MAD, and other ASW systems. The presence and evasive maneuvers of the "enemy" can be duplicated, as well as the release of sonobouys and other action. The role of each crew member during the flight can be reviewed and every detail of his performance evaluated.

Trainer development has occurred as a result of increased airplane sophistication and increased understanding of the training contribution of simulators. As airplanes grow more complex, as tactics become more demanding, and as economy grows more critical, the Navy will continue its technological development and broader training use of all three types of trainers.

Man's ability to design machines surpasses his ability to teach other men to use those machines properly. This is true today and was surely true during the early days of airplane development. The problem of landing, taking off and maneuvering the early fragile and fractious airplanes was not a simple task. Verbal explanations and hand demonstrations produced, at best, minimal comprehension of the vagaries of flying an airplane. In the end, a sink-or-swim philosophy prevailed.

Because of this problem, some inventors sought, in parallel with the airplane development, a means of better teaching student pilots how to fly. There were myriads of proposed solutions to the training problem, most of which saw little success or even physical embodiment.

Two of the earliest machines were the "Sanders Teacher" and the "Eardley-Billing Oscillator." Neither of the devices had more than limited usage because they were primarily jiggling mock-ups of airplanes and did very little to give the student the feel of flight or the necessary mental training to produce effective learning. Later, there developed during World War I a method of indoctrination which became known as the "Penguin System." This involved the use o fourteen-foot wing span, landborne airplanes which were meant to give the fledgling pilot a feel of the controls as he taxied swiftly up and down the runway. Their flying capabilities emulated the penguins, and thus the name.

During these early days, naval aviators were sometimes introduced to flying by swiftly taxiing an operational aircraft on which a throttle lock had been placed to permit taxiing but not takeoff speed.

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In early 1929, after years of experimentation and flying, and experience with the training of pilots, Edwin A. Link devised a machine that would produce an understanding of control function and of maneuvering the airplane with those controls. It was known as the "Link Pilot Maker." The machine had many shortcomings, but it was the first effective method of teaching on the ground the function of the stick, rudder and throttle.

In the meantime, the Navy had continued to search for more effective methods of training. On June 16, 1931, Commander H. B. Cecil recommended purchase of a Pilot Maker in an internal naval memorandum, saying, "I think we should buy one and send it to Pensacola for trial particularly in connection with training in instrument flying."

Although the unit was found to have value, it was not completely satisfactory to naval aviators since it dealt mainly with elementary control and power functions. Thus in 1936, the Navy procured an advanced Pilot Maker named "The E Special," which added simulation features to allow practice in radio navigation and included a broader complement of instrumentation.

Its improved performance temporarily satisfied naval aviators, but the requirement for more realistic training led to requests for such features as trim tabs, more complete instrumentation and more accurate simulation. The C-3 Trainer obtained by the Navy in 1939 sought to meet these needs.

The initial purchases of general purpose trainers culminated in the Army and Navy producing a joint specification which resulted in the Army-Navy Trainer, Model 18 (ANT-18). It included simulation of the latest gyro instruments, the A-N range, radio compass, and the new localizer landing system, which enabled the pilot for the first time to learn on the ground the problems of instrument flight and radio navigation, from takeoff to landing.

The Navy recognized that the aviators' problems were not simply those of holding the airplane level by instrument reference or of navigating by radio. He also had to keep the airplane systems operating and was responsible for fuel management, engine operation and proper use of gear and flaps. This was particularly important following World War II, when one of the Navy's primary missions was that of training to keep its force at operational levels of proficiency.

Thus, in 1947, the Navy obtained a 1CA1 Trainer which had elementary engine simulation and variable control pressures with trim tabs. In addition, it had radio range signals, which were produced automatically and more perfectly than the manual simulation which had been used previously. Wheel and flap simulation was included with dynamic response characteristics for the first time. Also, the Y-G carrier navigation system was simulated to permit practice in the critical rendezvous phase of carrier flying.

In parallel with this development, Dr. Richard Dehmel had been designing an electromechanical trainer which, utilizing a more classic servo system, computed more accurately flight values and radio signals. This allowed the pilot to train more effectively for instrument flying and navigation while still on the ground. Thus was ushered into Navy general purpose trainers, a new era characterized by more precise come computation and expanded features of simulation.

The next step in this new era was Device 2F23, which was the Navy's first electronic analog jet trainer, acquired from Link in 1951. Here the pilot could be introduced to the problems of high speed, high altitude flight in a jet airplane. In addition the 2F23 was designed to simulate the sensitive nature of jet engine operation, and the peculiar response characteristics of instruments and navigation equipment in high speed flight. These particular factors of early jet flight made ocean navigation and return-to-base problems of more critical significance to the naval aviator.

The increasing number of twin-engine aircraft in the Naval inventory prompted many aviators to observe that it was undesirable for a pilot who was flying twin-engine airplanes to train in a single-engine instrument trainer. The problems of operating the two engines, and particularly handling one-engine-out situations on instruments, were greatly different from that of a single-engine airplane.

Therefore, in 1955, the Navy produced Device 2F25, developed by Mr. Henry Berliner. This device presented much more complete and advanced radio simulation, to train the twin-engine pilot in the proper use of the greater amount of radio equipment normally found aboard such aircraft. It also afforded both pilots the opportunity to practice crew coordination procedures under both instrument and some emergency situations.

Thirty years after the purchase of the Pilot Maker, naval aviators' demand for more precise and realistic performance led to the next major advance in general-purpose trainers.

In 1963 the Navy acquired its first digital-type trainer. The application of this new technology was also used, for the first time, in simulating the Navy's first helicopter trainer, Device 2B10A, which generally was based on the HSS-2 Helicopter. Using digital computation techniques, the 2B10A reproduced the basic instrument flight problems of a helicopter, including coordination of rudder, collective pitch and cyclic controls. While maintaining sufficient forward speed, the student could practice control of a helicopter by instrument reference.

The digital computer was utilized on the 2B21 to produce another landmark in general purpose trainers in 1966, when four cockpits were hooked to a single computer. This utilized all of the advantages of more precise computation, which contributed to the instructor's effectiveness. Not only did this produce great economies in hardware acquisition cost, but it allowed one instructor to work with more than one pilot at a time, if desired.

In 1970, with the development of the 2B24, naval aviation training development reached a zenith in effectiveness and efficiency. Four cockpits operated simultaneously from a single computer, producing maximum accuracy in computation and presenting a broad perspective of flying cues. At the same time, the computer was programed to give basic instructions to the pilot, through a recorded voice and flight maneuvers. This trend towards automatic instruction, so that the student may see perfect performance, *ab initio*, has been picked up and carried on in later OFT's and will continue in future general-purpose trainers.

Just as aviators had demanded improved simulation in the instrument flying characteristics and radio navigation features of the general-purpose trainers, they continued to press for more exact reproduction of cockpit environment when they entered operational squadrons. Also, they called for reproduction of the systems of their operational aircraft so that they could practice normal and emergency modes of flying. Finally, they wanted the tactical and strategic equipment associated with the mission to be simulated, so that they might be able to practice all aspects of an operational flight, from takeoff to landing.

Initially, the result of this was an attempt to duplicate more precisely the cockpit environment and system operation of each specific type of airplane. These came to be known as Operational Flight Trainers (OFT's).

The first real attempt to design and build an OFT was during World War II. This occurred in 1943, when the Navy, working with Western Electric, produced trainers with airplane-like cockpits, based on the PBM, F6-F, and PB-4Y airplanes. At the beginning, these were little more than animated cockpits without basic radio aids. Later, as radio-aids simulation improved in connection with general-purpose trainers, these features were added to the fledgling OFT's to produce more rounded training. Rudimentary tactics training was added the same way.

With the advent of more practical electromechanical analog computers, the Navy acquired, in 1951, the first true examples of OFT's in the F3D and the F2H1 from Link and Curtiss Wright.

The F2H1 was a fixed base trainer, reproducing the cockpit with moderately complete systems simulation and comparable tactic simulation for the F2H1 aircraft. It was intended that this type OFT should be located at major naval air stations, to be used by the currently assigned squadron. Concurrently, there was a second Navy program, based on the concept that OFT's should be made part of a squadron's basic equipment list, and should transfer from base to base with the squadron, as its point of assignment was changed. Accordingly, the F3D OFT was specified to have normal simulation features, but, in addition, was to be located in a trailer suitable for over-the-road transport. The two systems would be compared to determine which was the more desirable approach.

The F3D OFT became the first of a long series of OFT's to be trailer based. These trailers became more complex and self-sufficient, even to the extent of having portable power supplies. Later they were designed to be expandable, when in use, and were even taken aboard ship so that they could be used while at sea. Some were even located with the squadron during periods of overseas, land-based assignments. The story of the development of OFT's, with sufficient complexity to do the training job and at the same time observing maximum size limitations of a forty-foot length and an eight-foot width within a trailer, is a magnificent story. It rivals the sardine packaging

industry. The hazards of the road transportable feature added shock and vibration conditions, not unlike those of airborne equipment.

The F3D was capable of simulating both crew positions. It was coupled with a separate trainer, suitable for producing the features of the F3D airplane in detail. Thus, the pilot, with his radar operator, could complete a full mission including search, radar attack, and firing their Sparrow missile. The crew was given a score on the success of their interceptions.

The problems of simulating the high speed, low altitude environment of attack aircraft offered special challenges to the Navy. There was experimentation in the basic computation systems that would provide more rigorous solutions of differential equations and, thus, would be more suitable for producing the wider range, higher rate performance of jet attack aircraft. Reeves was given a contract to produce an advanced analog OFT to provide this complete performance envelope of the AD1 airplane.

Acquired in that same year, was the F2H3 simulator, which combined with the Device 15V1 Radar Simulator to produce an OFT for training the F2H pilot in his full mission. In this simulator, the student was presented with enemy targets, which could take typical evasive action. Also, a variety of failures could be introduced in more complete form, in order that the pilot could practice his emergency procedures in some detail.

As previously mentioned, the Navy's new high performance aircraft were bringing to the pilot a broader range of performance, in terms of values and rate of change. Consequently, naval aviators were asking for more precise simulation at each end of the range. AC analog simulators had certain technical limitation which made precise computation difficult over the full range of performance. Thus, in 1956, the Navy acquired an F11F OFT, which utilized direct current analog computation with electronic integration. From the pilot's point of view, these were mysterious matters, except that he found the presentation of the simulated airplane's performance to be smoother and more like the dynamic responses in the real airplane. This marked improvement in flying characteristics was also achieved by the introduction in the OFT of a hydraulic control loading simulation system.

In 1958, the Navy procured a simulator to reflect the more sophisticated capabilities of the A4D2. This incorporated the many improvements in the ten current state of the art, plus the broader training potential provided by the Navy's first landmass radar simulation. With this simulator, pilots could practice radar navigation and terrain avoidance, which were features in the A4D airplane itself.

Also in 1958, the Navy acquired its first helicopter OFT in Device 2F64, which reflected the performance of the HSS2 from Melpar. The problems of developing a helicopter simulator were considerably different from those encountered in the development of fixed wing aircraft OFT's, yet the need was even greater. The helicopter, inherently an unstable machine, challenged builders of simulators to arrive at adequate mathematical representations of the rotor blades throughout the flight envelope, and to reflect these highly complex forces in the simulator. While the HSS2 accomplished these tasks, it also pointed out the need for greater equation solving capability than the current analog computers offered.

The Naval Training Device Center sought a solution to some of these training problems by contracting for a study of the practicability and feasibility of using digital computation in simulation in 1950. This study was conducted by the University of Pennsylvania. The resulting report specified a Universal Digital Operational Flight Trainer Tool (UDOFTT), which was constructed by Sylvania in 1960. This constituted the first practical step in the application of digital technology to training simulation. It finally allowed the Navy to accomplish for the first time, in fact, many of its original training goals, which existed when it purchased the Link Pilot Maker forty years ago.

The first operational use of this advanced digital technology came in 1965 with Device 2F75, an OFT based on the HRB-1 Helicopter. The more rapid and accurate calculations that became possible, as well as the other advantages of digital computation, such as more accurate repeatability, greater reliability, lower power requirements and easier maintenance, made this OFT a landmark in Navy simulator development.

The greater capability of the digital computer was demonstrated again in 1969 with the Navy's acquisition of Device 2F90 from Goodyear. This device connected four TA4J cockpit simulators to a single digital computer complex. The computer in this instance was also used, for the first time, to present pre-programed instruction directly to

the student. The naval aviator now practiced flight maneuvers using not only more accurate computation, but his instruction was accomplished in a more scientific manner.

This training application of the computer will be carried even further in the 2F101, which is in procurement now. The 2F101 will be programed to demonstrate standard maneuvers, "performed perfectly," to a student and then to monitor his performance as he flies. It will incorporate audio instructions and be capable of playing back a student's flight path for analysis and evaluation.

While many of the more advanced OFT's of the Navy allowed a flight crew to practice most of its mission, there were significant omissions in most OFT's, and the complete crew's role was accomplished by bringing together several independently designed and fabricated part-task trainers. The naval aviator and those responsible for trainer logistics felt that a much more complete and accurate training mission could be performed, if a trainer were designed and built as a single, total system. To distinguish this approach from the earlier combinations of different trainers, the term, Weapons System Trainer (WST), was used. The specifications were more exact and complete in that they were created as a single integrated document. The hardware technical design was compatible and conceived with the view to maximum economy in component complexity and, therefore, lowest cost. More importantly, the aviator benefited in that the latest technology in all phases of weapons simulation would be contained in the trainer, whereas in the OFT different generations of simulation designs with accompanying approximations were used.

Thus in 1960, the Navy procured its first WST for the F4H1 airplane. This was a trailerized simulator which afforded its two crew members the opportunity to fly their complete takeoff-to-landing mission, with simulation of flight and tactical systems involving the latest technical solutions to the simulation problem. It could simulate both interdiction missions and standard over-the-shoulder bombing.

A significant advance in simulation technology followed quickly. In 1961, the A3J simulator was procured. This was a second generation WST. Its specification was developed with the objective of reproducing in detail all normal and emergency aspects of operation for both crew members. The airplane was being developed as the final answer to the attack mission. The WST systems represented an attempt to provide more accurate simulation over the total range of performance than has been previously attained. The size of the WST reflected this objective, inasmuch as it took three trailers to hold the simulator. The engine simulation was the most accurate to date, in that the various functions were generated for the first time by digital computation techniques. Also, an improved radar landmass simulation system was included, in order that the ground mapping radar aspect of the mission could be fully simulated.

The greatest opportunity for application of the WST concept occurs in naval ASW missions. These aircraft contain many crew positions, each calling for highly skilled operators, in their own fields. A high degree of crew coordination is necessary for the success of the mission. Thus, a typical ASW WST involves highly complex simulation systems, which can operate either independently or as a part of the total trainer system.

In 1950, an early version of the P2V5 had brought together a flight simulator, as well as a tactics simulator The two trainers could be used either separately or the crew could train together. It was not until 1964, however, that a full scale ASW WST was developed for the Navy. The P3A incorporated all of the major state-of-the-art developments of the time, and allowed a crew to perform a complete ASW mission within the confines of its relatively compact trailer.

In fact, the size of the P3A WST problem dictated an almost insurmountable technological and economical task for the engineer, who was faced with the problem of including the necessary hardware in the limited trailer space. Because of the necessary design compromises, naval aviators did not accept the analog P3A WST's as adequately complete to provide the desired optimum training. All systems were functional, but many aspects of the mission problem were approximated.

Therefore, in 1967 the Navy contracted for a P3C WST, which utilized digital computation techniques. These digital methods produced each of the crew stations, with the exception of the flight deck, which was included only to the extent of providing heading, air speed and altitude. Those other features, related to the crew member performance, i.e., sonobuoys, enemy targets, friendly targets, undersea and on-the-surface, were presented with extremely realistic results. The simulation problem was further compounded by

the fact that the airplane itself has an on-board digital computer which selects the appropriate weapons, opens bomb bays and awaits only the pilot's command to proceed with the attack. Yet at any one instant the on-board computer may be overridden by a crew member who, in his judgment, feels that some other alternative is more desirable.

This training trend was given added momentum with the procurement of a fixed base WST for the F4J. Reflecting the vast capability of that airplane, the two man crew is able to fly ground-to-ground or carrier-to-carrier and perform a wide variety of missions. It simulates not only radar landmass functions, but also attack radar, electronic warfare and counter-measures, as well as radar homing and warning. Additionally, it can simulate the fully automatic carrier landing system used by the F4J.

The technological sophistication of aircraft flight trainers for the U.S. Navy has kept pace with the ever increasing demands of the service. That is, to build and maintain pilot proficiency at its highest levels and to perform missions of almost infinite complexity. Today, as a product of almost forty years of broad experience, there are three major forms of trainers being used by the Navy: (1) The General Purpose Trainer; (2) the OFT; and (3) the WST.

The General Purpose Trainer provides a modern solution to the problem of learning the basic skills of instrument flying and navigation. The OFT provides accuracy of computation and delicate refinement of sophisticated requirements needed to learn the particular cockpit and operation of a specific aircraft. The WST represents the ultimate in man's ability to simulate the hugely complex and enormously sophisticated air weapons of today.

Tomorrow, naval aviators will demand even better simulation. Engineers will conceive better solutions for these demands. The Navy will develop such trainers.

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Mr. Kelly has been intimately associated with flight training and the Link trainer throughout his career. After graduation from New York State College for Teachers at Albany and a short stint at teaching high school, he entered the U.S. Air Corps in 1941. There, he became closely acquainted with instrument trainers as a member of the USAF Instrument Flying Standardization Board. After discharge in 1945, he joined Link Aviation, Inc. as Director of Education. In 1963, Mr. Kelly became President of the Link Company. He is presently Group Vice President, Education and Training Products, The Singer Company, and is a member of its Board of Directors. Mr. Kelly was the first recipient of the DeFlorez Training Award, given by AIAA in 1965. He serves in a number of professional and community organizations and is Chairman of the Executive Committee of NSIA.

To Move or Not To Move?
The Problem of Motion in Training Simulators

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In this paper an examination is made of the trainer motion problem in an attempt to sort out the important variables, examine the evidence, and draw conclusions. The question of motion vs. no motion is taken up and, where trainer motion is to be used or studied, the important problem of the quantitative physical description of the trainer motion is discussed in some detail. Variables of importance upon which the utility of motion is dependent are the experience level of the trainee, the response dynamics of the vehicle being simulated, the maneuvers being performed, and the visual displays being used by the trainee. The interactive effect of these variables with motion is considered.

To move or not to move, is that really the question? Whether 'tis wiser in the training of men to suffer the swings and jolts of outrageously invented motion or, taking umbrage with the hammer and steel approach, gird ourselves to dispel the pall of confusion surrounding the question and, through reflection and systematic experimentation, end it.

A title usually indicates what the reader may expect to encounter in a paper but it can seldom convey the complete intent and substance of the article. In this instance it is more appropriate to ask "To move or not to move? Is that really the question?" The answer here is "No, not completely."

The real question is "To move or not to move, and if to move, how to move and how much?"

The guiding thesis for what is to be said in this paper is that the focus is on the training of *Man*. In this sense his training needs and his perceptual capabilities dictate the motion requirements of the devices used in his training. In order to promulgate such a thesis into specifics, a conceptual frame of reference with assumptions and "givens" about man's capabilities and performance must be adopted. Further, from the practical side of actually getting trainers built, the physical stimuli which have been shown to be appropriate for stimulating the trainee's receptors to elicit the desired perceptions and behaviors must be described in terms which are not foreign to the trainer designer.

Before a decision can be made to move or not to move the training device for any operational vehicle, consideration of a number of variables in the training situation is required. This paper lists and defines some of these variables and discusses how they may be considered in making decisions about motion. Assumptions as to the perceptual capacities and qualities of human operators are included in this discussion. The problem of defining motion in a way which is meaningful in terms of the operator's perception of movement is also considered.

It is intended that the approach taken here will provide a framework from which to make deductions about kinds and degrees of motion and, perhaps more importantly, will provide a basis from which discussion, argument, and directed investigation may spring. In the final analysis, any exposure to the trainer motion problem points up the serious lack of the "numbers" necessary to lend precision to any model or scheme used to guide motion decisions. The determination of these "numbers" is one of the prime concerns of those working in this area.

The reader who expects to find hard data and immutable direction in this paper will be disappointed and should stop here. The space is too limited to present the relevant data with all of the qualifying remarks which should accompany them. The reader who wants to look at an approach to working with the problem which may

help him in evaluating and using what data are available is invited to continue.

Throughout this paper the motion problem is treated as trainee centered and answers to equipment design questions are sought in the sensory, perceptual, and operating behavior characteristics of the man. With this approach, where motion cues are indicated, the stimuli for these cues are sought through examination of man's sensory apparatus rather than solely through analysis of the physical world of the vehicle.

Finally, the determination of what motion, if any, is to be incorporated into a training simulator for a given vehicle is seen as being a two-step process. First, it is necessary to determine those motion characteristics of the vehicle which are perceptible by the operator, either as useful cues to control or "noise" in the system. Second, it is necessary either (1) to determine empirically whether incorporation of these perceptions of motion in the trainer contribute to the training value of the simulator or (2) to assume that maximizing the perceptual equivalence between the vehicle being simulated and the trainer maximizes its training value. The hard-nosed empiricist will be comfortable only with the former while the pragmatist will be satisfied with the latter, taking every opportunity to accumulate empirical transfer data. The authors take the pragmatist's position.

TRAINING SITUATION VARIABLES

Dynamic Responses of the Simulated Vehicle.

The variable of vehicle dynamic response covers the range of dynamics across types of vehicles, across dimensions of movement of a given vehicle, and differences within a dimension of movement for a given vehicle as a function of other vehicle parameters (e.g., speed and altitude of an aircraft). Consider, for example, how it enters into the trainer motion decision for closed loop control tasks such as controlling the attitude of an airborne vehicle.

In considering control of aircraft attitude the assumptions to be made and the deductions to be drawn may be better accepted and appreciated by asking the reader to draw some conclusions of his own, on whatever basis, under some *different* conditions of vehicle response dynamics.

First, one should imagine himself controlling the heading changes of say a large aircraft carrier or passenger ship. Then he should imagine himself controlling the heading of a small sports car going through an obstacle course. He can then ask himself, "If I were to close my eyes, in which of these situations would I be likely to perceive motion as a distinct entity among the totality of my perceptions?" Next he should ask, "If I perceive the change in the vehicle's heading, both visually and by means of my motion senses, which perception occurs first in time?" Perhaps this exercise will serve to set the stage for appreciation of, if not total acceptance of, the assumptions and deductions which follow. But, in order to further set the stage for adopting the assumptions about the human's perceptual repertoire, the physical reality of moving a mass such as an aircraft carrier or a sports car must be examined.

When a physical object is displaced in space the displacement is accompanied by derivatives of that displacement, namely, rates, accelerations, and rates of onset of acceleration. These are of interest as stimuli which lead to perceptions. It is assumed that the visual and motion senses have differing capabilities for sensing these aspects of physical motion. The visual modality is assumed to sense position and rate while the motion senses detect accelerations (i.e., forces) and rates of onset of acceleration (i.e., changes in force). Each of these sensory systems has its particular threshold which requires a certain level of the physical stimulus before detection occurs. Next, an examination of the time order in which the derivatives of the positional change of the physical object are sensed is necessary. Motion of the system when above threshold provides information about the system *in advance of* that provided by the visual senses. This "lead" information serves the dual function of triggering corrective motor responses and directing the visual sampling behavior of the controller. As such, perceptual equivalence requires that the response characteristics of the trainer be capable of producing this complex of perceptions.

Most manual control tasks required of the human operator can be accomplished solely by visual reference. That is, few vehicular designs are such that the operator vehicle loop would go unstable without the motion cue. However, the *precision* of control of many systems is improved by addition of the information provided by motions as evidenced in the literature. At the same time, in deciding the question of motion or no

motion, it must be recognized that the response dynamics of some systems and some dimensions of movement of systems are such that the triggering of the motion sensory apparatus does not precede the visual. There exists a crossover point at which the visual reactions lead the motion. Beyond this point motion does not add to precision of control and is superfluous in the trainer. Some limited data on this crossover point exist in the literature but they are less than sufficient as a basis for making predictive decisions with comfortable confidence.

It should be noted at this point that examination of the dynamics of a vehicle in a *single dimension* is not sufficient to determine if motion is superfluous by the above criteria. If the task is multidimensional, requiring time sharing by the operator, motion in the visually unattended channel very obviously may trigger response before vision. The effective vision-motion crossover point in such a case is shifted.

It is important to keep in mind that the operator is a signal generator as well as a signal follower. The active energy which he produces usually falls within the design dynamic bandwidth of the system but it is not limited to that bandwidth. Hence system response dynamics plus operator response dynamics must both be used as deciding factors in evaluating motion contribution.

Finally, with respect to vehicle dynamics, the question of trainer movement is not one of whether the trainer of X or Y system should move, but whether the individual dimensions of movement of any given system should be simulated. The variable of vehicle response dynamics, then, is relevant to questions of differences across systems, across dimensions within a given system, and to understanding the role of motion within any dimension of vehicle movement.

Trainee Experience and Training Task

The variable of trainee experience includes the changes in various sensory thresholds and sampling rates of the trainee as a function of his experience with the operation of the system and how these changes relate to motion as a source of information for control. This variable influences the trainer motion decision in two major ways. On the one hand the trainee's experience and prior training may have served to lower his visual or motion thresholds so that their relative importance is different from that of the less experienced trainee. That is, the transitioning student with extensive prior experience may have learned to "attend" to the motion stimuli and may have developed a repertoire of responses appropriate to this attention. Thus, the perceptual world of the experienced trainee is quite different from that of the naive trainee as it relates to his perception and use of motion in vehicle control.

On the other hand, the experienced trainee may, as a function of the task in which he is being trained, have no need for motion perceptions in learning the task. The trainee's level of skill in closed loop control of the systems he operates (e.g., aircraft) will often be such that he adapts quickly to controlling the new system or to learning that such control is not the primary learning task. This is often the case with large advanced weapon-system trainers. Here, unless the motions of the actual system are disruptive to the primary procedural learning task, motion in the trainer would be superfluous.

The more experienced trainee may be quite different from the beginner as a signal generator. His "driving" of the system may force the actual system to higher response frequencies than do the inputs of the beginning student. Thus, the simulator response characteristics appropriate for perceptual equivalence for the beginner may fail to meet the test for the experienced trainee.

VISUAL DISPLAY CHARACTERISTICS

The considerations of interest under the variable of visual display characteristics are the relative sensory thresholds of the visual and motion senses and how the relative "gains" of the displays for the two senses complement each other as information sources.

The discussion of the crossover point presented earlier is relevant here; i.e., in certain control dimensions the pertinent information may be sensed first by the visual sense, in others, by the motion senses. Through varying the gains or amplifying the physical stimuli, one or the other may be differentially brought into prominence for use in control. In a visual display used for control of aircraft pitch, for example, doubling or halving its size can be seen to affect the precision with which manual control could be exercised. An analogous situation exists with motion stimuli. It is these relative amplitudes of motion and visual

stimuli for any given movement which determine the importance of the motion stimuli for bringing about perceptual equivalence. A large, high-resolution, real-world visual attachment to the trainer may generate high perceptual equivalence with inadequate, or completely absent, motion stimuli. Indeed, trainer operators have been known to increase the gain on IFR instruments in fixed-base trainers beyond one-to-one relationships with the real world to bringing about an experientially closer perceptual equivalence with the vehicle being simulated.

DESCRIBING MOTION AS A MEASURABLE ENTITY FOR INCORPORATION IN TRAINERS AND FOR RESEARCH

To the training psychologist the search is for the means of causing the trainee to perceive stimuli and control the trainer in the same manner as he would the system being simulated. To do this some identifiable, measurable, and controllable parameter of physical motion must be explicated, and changes in it mapped against changes in the perception of motion. This is simply meeting the requirement that, if one is to build training simulators that move, motion must be defined in a practical way. It is also a necessary requirement to understanding and predicting perceptual equivalence through studies in which an independent variable (physical description of motion) is varied and the dependent variable (perception of motion) is observed.

The selection of the parameter and metric for describing motion should meet, as far as possible, two criteria. First, they should be derived from knowledge of perceptual phenomena so that the set of hypotheses relating physical to perceptual may be as valid and inclusive as possible. Second, they should be convenient and practical for use in trainer design and for manipulations as the independent variable in research relating the physical and the perceptual.

Until relatively recently (with the development of optimal control theory), the response characteristics of *physical* systems have been expressed in terms of time constant, rise time, settling time, maximum overshoot, etc., in response to pulse or step inputs.

These criteria are the easiest ones to "visualize" and from which to generate hypotheses. However, it can be shown that the time response of a linear system to any known driving function uniquely determines its frequency response; and conversely, if the frequency response of a system is known its time response to any specified driving function is uniquely determined. Given this deterministic relationship between frequency domain and time domain the way is open to taking advantage of the best of both. Since systematic analysis and synthesis procedures are more numerous in the frequency domain it is suggested as the means for describing the motion platform characteristics. This suggestion has been explored in detail and is being used as the basis for describing motions as the independent variable in research. The purpose of this research, supported by the Naval Training Device Center, is to provide "numbers" relating the physical to the perceptual and trainer characteristics to training value.

NOTE: To the reader who has maintained interest or has had it aroused, a more detailed consideration of the motion problem is given in Technical Report: NAVTRADEVCEN-69-C-0304-1, "An Investigation of Visual, Aural, Motion and Central Movement Cues," June 27, 1970.

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The Wide-Angle Visual Simulation Problem

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The most commonly used wide-angle display systems, the different information storage approaches and the resultant information processing problems are discussed, and their advantages and disadvantages weighed in view of training device needs. It is shown that most wide-angle display problems can be economically solved without endangering training effectiveness, if certain concessions with regard to realism are made.

The most important performance characteristic that a training device should have is that its use results in a transfer of training. That is, when the trainee is exposed to the real environment, he must be able to apply whatever should be and has been learned in training. To achieve such a transfer a training device must have two characteristics.

First, it has to provide with adequate similarity—fidelity is certainly not necessary and, in fact, in certain stages of training even undesirable—those cues that an operator should use in the real situation and environment.

Second, it has to provide, with adequate similarity, the means that an operator should use to execute his decisions in the real situation and environment.

The intelligent and skillful use of the controls of an operational system is initiated by external inputs—stimuli—to the human sensory system.

Among these the visual inputs play the most important role in most training situations. It has been estimated that 75% to 80% of all incoming information through the senses is acquired through vision.

Visual simulation for training devices is a major technological problem area. For the proper utilization of many operational equipments demands that the operator makes extensive use of the visual capabilities of his eyes and their scan capabilities, both by their movability in the head and by the motion of the head itself.

Moreover, the visual presentation of the environment faces in many cases an especially severe technological barrier, since in most trainers a nonprogramed visual presentation is required which provides the significant visual cues based on which the trainee shall make decisions and take actions. These cues then, as the result of the trainee's actions, have to change and provide to the trainee new cues. These new cues indicate to the trainee the new status of his system which, in turn, may lead to new decisions and actions.

Among the different visual environment presentations with which training device designers are concerned are a few that demand only the presentation of a limited scene of the environment. For example, the view from a submarine periscope or from the observation slot of a tank turret present only a very limited observation field. Fairly adequate solutions for such visual environment presentations exist. At least the observation display, in general, does not pose a problem that is too severe.

For all cases, however, where a trainee must be able to observe a wide-angle display in both azimuth and elevation, no technical approach so far implemented has been completely, that is technically and economically, satisfactory.

The reason for the deficiencies of present systems are multifold. They are partially due to problems in the information storage system, partially due to problems in the information processing system and partially due to problems in the visual display system (see figure 1).

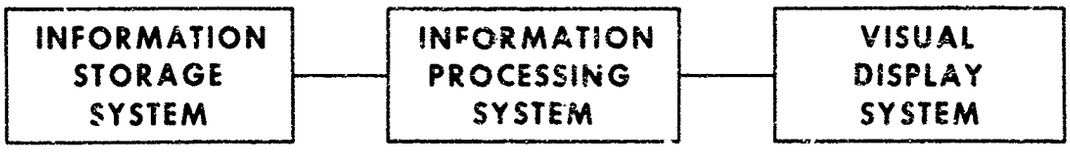


Figure 1. The Visual Simulation Chain.

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The wide range of possible combinations of approaches to these three problem areas and their diversified interrelationship makes an organized discussion difficult. However, in the following we will try to discuss these problems as systematically as possible. The sequence in which the different areas are discussed may appear unconventional and awkward for we will start with the visual display system; however, the chosen sequence will lead to a better understanding of the problems involved.

THE VISUAL DISPLAY SYSTEM

When we talk about the visual presentation of the environment, we have first to consider the fact that the environment we try to simulate is essentially at infinity, as far as the human sensory system is concerned. Therefore, it is desirable that the display gives to the human sensory system the impression that the observed scene is, or at least could be, at a large distance from the observer. This poses one of the technological problems.

Two basic approaches have been taken to the "at-infinity" display problem. One is the direct observation of a display that is at a sufficiently large distance from the observer. The other is the observation of the display through an optical system that apparently places the display at infinity.

The large distance display may be a screen onto which the display is projected, or it may be a number of cathode ray tubes which together provide the wide-angle display and which are arranged sufficiently far from the observer.

The display observation through an optical system may consist of an array of cathode ray tubes which are combined with refractive and/or reflective optical systems that make the individual displays appear to be at infinity.

As far as the direct observation of the display, i.e., screen display, is concerned it should be noted that the stereoscopic ranging capabilities of the eyes are minimal beyond ranges of 20 feet (6 meters). That is, a picture that is generated at a distance of 6 meters or farther from the observer will—if properly designed allow the impression of a realistic range.

Such a display system works satisfactorily in all respects if the projection of a transparency a movie film for example, onto a reflecting screen is used. A conventional movie film projection however, would of course not provide any nonprogramed training. Only an optical distortion system, such as for example the VAMP* system developed by the Singer-Link Corporation (figure 2) permits to a limited extent a nonprogramed

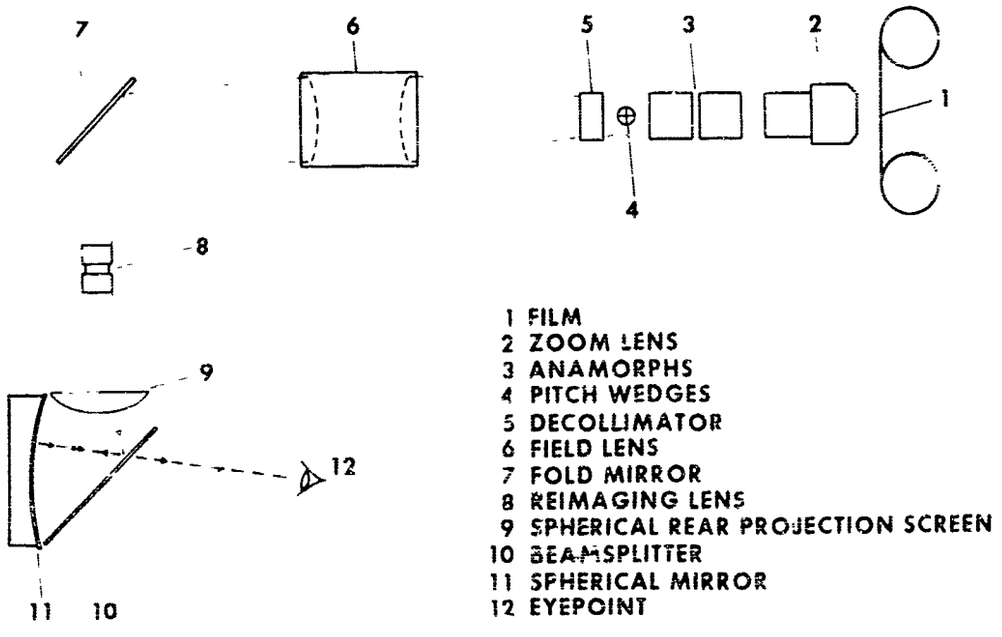


Figure 2. The VAMP System.

*Trademark

display to be shown from a movie projector. The nonprogramed maximum deviation from the center path of such a movie film system amounts at the present state of the art, for a display area of 60° in azimuth by 30° in elevation, to a range of about ±15° in yaw, +17°/-5° in pitch and ±20° in roll. Though a wide-angle VAMP* system has not yet been developed, it appears possible to apply the optical distortion concept to wide-angle film presentations.

Such an approach, of course, is satisfactory only in certain special training situations, namely those where only very limited deviations from a prescribed path have to be considered. This approach is, for example, acceptable for certain commercial airline training, the kind when only pre-prescribed takeoffs and landings are encountered, that is where only the straight ahead takeoff and landing phases have to be taught by the use of a visual environment presentation and where therefore only these phases require visual presentation.

Such a system, for example, will not allow to display the combination of the fly-around and landing phase on an aircraft carrier or the air-to-air combat situation or any other completely nonprogramed environment situation.

To overcome the limitations of such an optical distortion display system a holographic movie system, possibly in a 360° version (as developed in the NTDC laboratories), may solve the nonprogramed visual projection problem in the future. The "reduction to practice" of a satisfactory holographic projection display system has not yet been achieved.

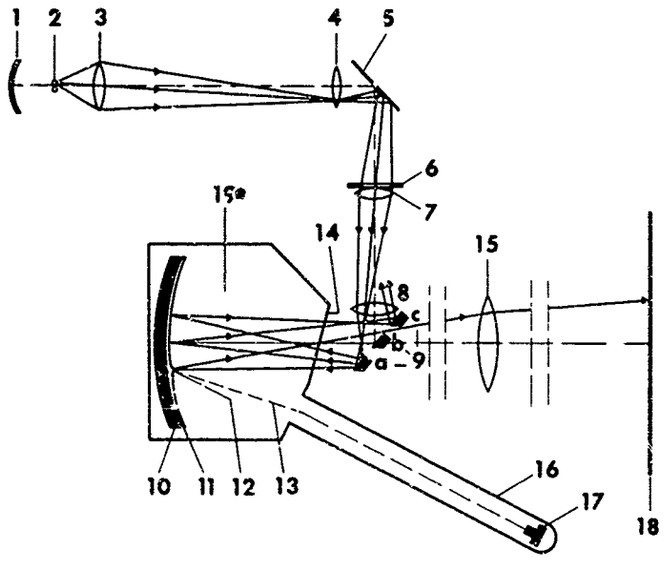
Another possibility for a nonprogramed screen display is the use of a cathode ray projection tube.

However, even the best cathode ray projection tubes available today provide only intensities that, at best, satisfy 60° by 60° displays, even at small screen distances such as three meters.

This relatively poor brightness, as compared to a film display, is partially due to the fact that in a film display each picture element is projected for a relatively long time, for example, 1/30th of a second, whereas the cathode ray tube generates only one picture element at any one time, and all picture elements of a scene share the frame display time.

Higher intensities can be achieved by systems that, by means of a cathode ray controlled intermediary, control the light generated by high power lamps.

Such systems are, for example, the Eidophor* (figure 3) or the General Electric Company Light Valve* (figure 4), which in combination with a wide-angle projection lens can provide a wide-angle display of good intensity.



1	AUXILIARY SPHERICAL MIRROR
2	EXTREME POINT OF THE LIGHT SOURCE
3	CONDENSER LENS
4	CORRECTION LENS
5	COLD MIRROR
6	PICTURE WINDOW
7	CONVERGING LENS
8	FIELD LENS
9a,b,c	BAR SYSTEM
10	SPHERICAL MIRROR
11	CONTROL LAYER
12	PERTURBATION IN THE OIL LAYER
13	ELECTRON BEAM
14	CLOSING WINDOW
15	OBJECTIVE LENS
16	ELECTRON GUN
17	CATHODE
18	SCREEN
19	VACUUM CHAMBER

*Trademark

Figure 3. Eidophor Principle.

*Trademark

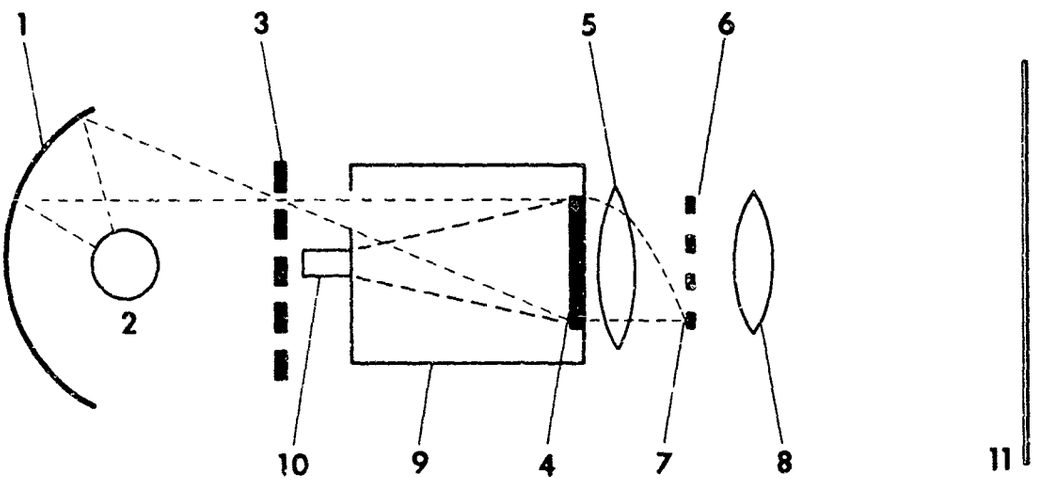
Finally, if we consider the direct observation of an assembly of cathode ray tubes, we are confronted with the problem of an extremely large number of channels. For a 50 cm by 50 cm (20 in. by 20 in.) display area cathode ray tube-about the largest technically economical covers only about 5° by 5° at a distance of 6 m (20 ft.), and therefore for a 180° azimuth by 60° elevation display which is generally accepted as a minimum display requirement the system would require several hundred display channels.

Let us turn now to display systems which use cathode ray tubes or other display means in combination with optical systems that make the observed display on the cathode ray tubes appear to be at infinity. We will need a multiplicity of channels, since the optical systems that are presently available cover only a field of view of about 70°. Several approaches have been taken to achieve the "at-infinity" presentation. They can be grouped into pupil-forming and non-pupil-forming systems.

The pupil-forming systems severely limit the freedom of motion of the head and even the so-called non-pupil-forming systems known so far allow only a very limited motion of the head within which the presentation remains sufficiently undistorted and the presentations on neighboring display channels match at their joints. This problem becomes even more severe if two observers are required to look simultaneously at the same display.

Possibly the least objectionable though still rather complex approach among these is the "Pancake Window"* system (developed by the Farrand Optical Co., Inc.) (figure 5), an ingenious compact design, which preferentially uses a pentagon shape display area of several cathode ray tubes in a dodecahedral arrangement (figure 6). Its light transmission, however, is very low (less than 2%) and the arrangement of a sufficient number in

*Trademark



1 REFLECTOR
2 LAMP
3 INPUT BARS
4 OIL SURFACE (NO RIPPLES)
5 SCHLIEREN LENS
6 OUTPUT BARS
7 LIGHT BLOCKED (NO OIL RIPPLES)
8 PROJECTION LENS
9 CRT
10 ELECTRON GUN
11 SCREEN

Figure 4. G.E. Light Valve Principle.

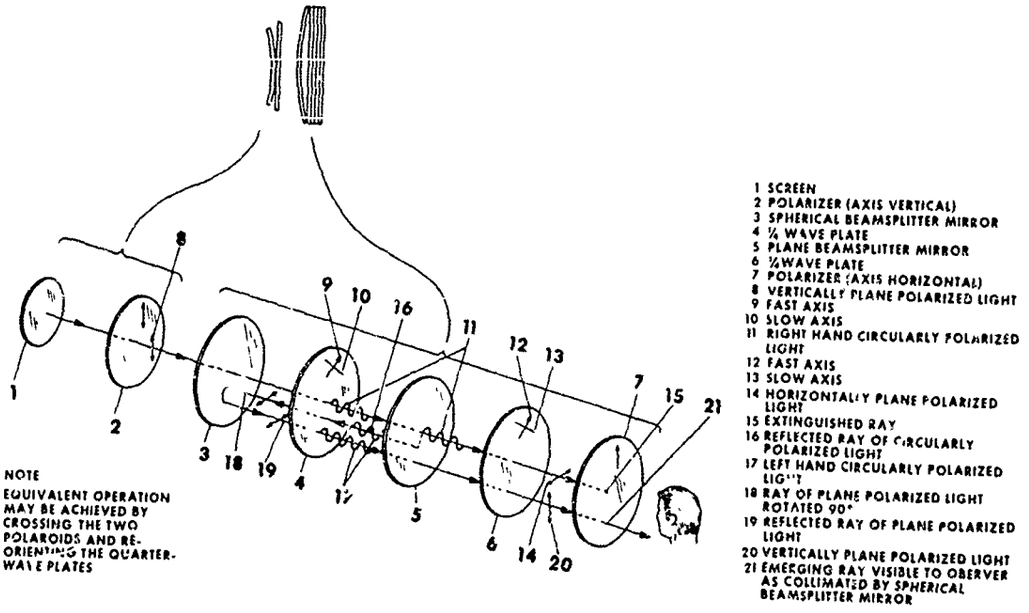


Figure 5. Farrand Pancake Window.

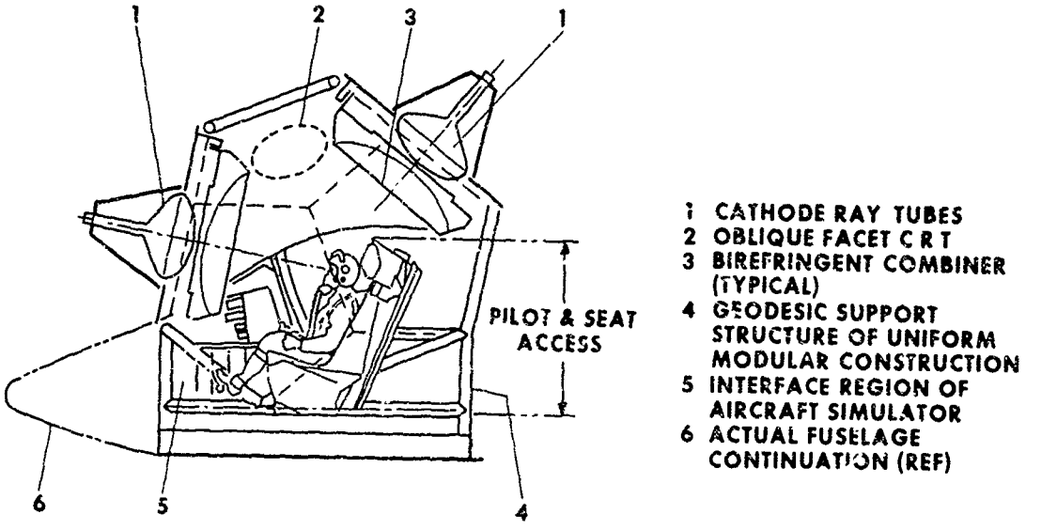


Figure 6. Dodecahedral Pancake Window Arrangement.

a dodecahedral array for example eight as it has been proposed is very costly

THE INFORMATION STORAGE SYSTEMS

If we turn now to the information content which is needed for the display and for which storage means have to be provided we can disregard the two-dimensional picture (movie or transparency), since in most cases -as discussed above - this approach limits the range of nonprogramed presentation too greatly.

This leaves us essentially with three storage possibilities: The three-dimensional model, the hologram, and computer storage.

The three-dimensional model, a straightforward approach, has the disadvantage of requiring a large space, if a large area variation has to be displayed. Also, it is fairly costly if fine details of the displayed area and a wide variation of observation range are required, which may demand the use of the rather costly Scheimpflug probe.

The hologram at the present state of the art of technology is very difficult, if not impossible, to generate from nature--mainly due to the limited coherence length of lasers. Except for relatively simple cases like aircraft carriers, generating holograms from models is costly due to the high cost of large fine detail models.

Finally, the storage of many especially very fine details in a computer is very costly and limits the use of computer storage to relatively simple display configurations. Contrary to the three-dimensional model approach, however, it has the advantage of being the only storage system that allows one to easily draw information simultaneously for several independent displays, as it is needed for multitrainee station trainers, if a common visual information storage system shall be used. Another advantage of the computer storage approach is that it allows for easy modifications or even complete change of the scenery.

THE INFORMATION PROCESSING SYSTEMS

All different display approaches that we have discussed, which are within the present state of the art and which could allow wide freedom of display motion, that is a wide range of nonprogramed views, make use of one or more cathode ray tubes or cathode ray controlled light sources.

If a one cathode ray tube wide-angle display is used, for example by means of a wide-angle lens, the information processing is relatively simple. In the case of a three-dimensional model, a television camera mounted on a gantry and movable to achieve different aspect angles and ranges can generate the video signals that after amplification control the cathode ray tube.

The television camera approach may also be taken in case of holographic information storage. In lieu of a gantry as means to vary aspect angle and range, optical-mechanical means can easily provide aspect angle and range variations.

Finally, as far as computer generated displays are concerned, changing aspect angle and range by computation does not present a basic problem.

Two different approaches for computer generation of visual presentations have been taken. One simply generates straight lines of any orientation in the display. Mostly white lines in a black background are used, though lines of different colors can also be presented easily. This system provides outline drawings but can also present surfaces by using a larger number of lines which are arranged to fill out the areas desired.

The other approach for a computer display generation uses conventional television scanning techniques in a color or in a gray scale display. The computer determines when a scanning line should change from one color to another (or from one shade of gray to another) and the new color (or the new shade of gray) stays on until a change signal is given. Thus, this sytem automatically provides the display of surfaces.

So far, to keep the discussion as uncomplicated as possible, we have not alluded much to the subject of picture quality, expressed in simple terms as resolution and freedom from distortion. The analysis of this problem will bring us back to the multiple cathode ray tube display system. For, if we consider that the healthy eye has under favorable circumstances a resolution capability of 1 min of arc or better, it may be able to distinguish about 10,000 to 11,000 picture elements along a line extending over a 180° azimuth. If we then consider a display of a 60° elevation and a 180° azimuth, assuming about equal values for horizontal and vertical acuity of the eye, and assuming the same resolution requirements for azimuth and for elevation, we need about 10,000 by 3,500, that is 35×10^6

distinguishable picture elements, and if to avoid flicker—these shall be displayed in 1/30 or a second, we need a video bandwidth of several gHz. The situation gets worse, if a color display is required which leads to a further increase in bandwidth requirements

Such a video bandwidth is, of course, way out of the present state of the art and even if it could be achieved, the light intensity of the cathode ray tube and its resolution cannot—at least at present—satisfy such display requirements.

For most applications, the combination of wide-angle display, of quality or bandwidth requirements and of intensity requirements demands the multichannel approach, where the display is assembled from several display tubes, each of which is provided with its own processing and, possibly, storage unit. Also, the multichannel approach reduces the tremendous demands a single-channel, computer-generated wide-angle display would put on computation speed and memory access.

OVERVIEW

Thus far, this has been a guide through the jungle of wide-angle visual environment simulation problems. It does not touch all relevant areas but at least discusses the most significant ones. We can see that technically the most difficult one among these problems presents itself in the visual display system. All others are technically, though not economically, of secondary significance. We must note here, however, that we have confined our discussion to the wide-angle visual display problem isolated from other requirements, such as the motion platform problem, which may limit the choice in display approaches even further.

We can then summarize that the nonprogramed wide-angle visual display involves a series of interrelated problems for which the state of the art does not, and most probably will not for many years to come, provide a general solution. Breakthroughs in more than one area are needed to meet all spelled-out requirements.

From the foregoing comments it might appear as if the problem/solution of nonprogramed visual simulation of the environment is at the present state of the art, an almost hopeless case.

We can find, though, economic approaches within the present state of the art, provided we are willing to make reasonable concessions.

REASONABLE CONCESSIONS

The preceding discussion shows that no matter which technical approach is taken to achieve a nonprogramed wide-angle visual presentation of the environment a multitude of concessions have to be made. The "realistic" presentation of the environment demands the real environment and—as mentioned before—is neither needed nor even always desirable.

Since we are concerned with training, or more specifically with successful transfer of training, we are actually not interested in a "realistic" simulation of the environment, that is, one that is pleasing to the eye. We are instead, as mentioned before, interested in a display that presents all those cues that are significant for the purposes of training.

Therefore, for each individual training situation we must analyze the real environment observation parameters and restrict our goal to a visual environment simulation which shows, in sufficient similarity to the real world, those visual cues that are needed to achieve transfer of training.

That is, we have to optimize economics, state of the art in training device technology and training strategy to match the physiological characteristics of trainees, as far as they have an impact on training.

Let us list the predominant problems and then see how important realism, or near realism, in respect to these parameters really is.

We have to consider—not necessarily in this sequence:

1. Distance between observer and apparent display.
2. Resolution.
3. Brightness.
4. "Gestalt"—distortion.
5. Field of view.
6. Contents of presentation.
7. Color.

To make acceptable concessions in a specific case, we have to first carefully analyze the specific training problem at hand and determine the sequence of priorities and their relative weights.

Let us review the parameters we mentioned before to get a better feeling for the impact of different concessions:

1. Distance between observer and apparent display—We discussed before the disadvantages of optical, at-infinity, systems for wide-angle (multichannel) displays, and the light intensity

problems that confront us if a direct screen observation at an observer-screen distance of 6 m or more is contemplated

It has been found in several research setups, for example in NTDC's Visual Simulation Laboratory, that direct observation of a screen at a distance of 3 m, or even slightly less, can provide the necessary visual cues and get the trainee involved in his training task. This is especially true if the screen is curved and designed and used such that it does not provide pronounced cues on its proximity, as for example through noticeable seams. Likewise, one has to avoid stationary displays that provide a pronounced reference for the distance, and large observer-screen distance variations, such as those due to motion. The absence of parallactic cues, which could be sensed in the real environment anyway only if the scene to be observed covers a range from a far out area (for example, the horizon) to a near area (not more than 50 m away from the observer), obviously does not inhibit effective training in most cases.

However, if the cues to be derived from observation are based on an object close-by and its relationship to a remote object, a parallactic presentation which calls for a composite picture generation that had to be a function of the head motion is required.

2. Resolution—We mentioned the visual acuity of the good, healthy eye which allows one to recognize a gap between two horizontally separated vertical lines, if this gap subtends an angle of about 1 min of arc. This is a good reference figure, though visual acuity as a measure, strictly speaking, is not only a function of the subject's visual performance characteristics, but also a function of the width of the vertical lines, their color, the background color, the lighting, the reflectivity of the screen and other parameters.

It is actually only in rare cases that we make use of the resolution capability of the eye. An example is the measurement of the subtended angle between mast top and waterline of a target in a periscope.

In observing a scene such as the visual environment from an aircraft, in most cases we actually do not use the resolution capability of the eye, but rather we try to distinguish between neighboring surfaces of different brightness and/or color, without precisely defining their boundaries.

This then puts considerably less stringent requirements on the information content of the display and its processing, since the presentation of an outside scene using picture elements which are covering a solid angle of 6 min of arc by 6 min of arc, provides a completely satisfactory area recognition.

Thus, for many cases a satisfactory 180° by 60° display could be assembled using three television channels of 1225 lines per frame with an equivalent resolution in scanning direction.

In cases where a high information content is required only for a limited area such as the carrier in a carrier landing approach, or the enemy aircraft in an air-to-air combat situation, whereas the background sky, horizon, ground or sea does not have to provide detail cues, even a 180° by 60° display can be synthesized using only two television channels: one to provide a large "coarse" background, the other one a small high resolution object which can be inserted electronically into the background.

3. Brightness—We mentioned before the problem of providing sufficient display brightness. It is certainly necessary to achieve a display brightness which brings us well into a brightness range that allows a trainee to readily recognize without strain all the cues that he has been taught to use for his decisions and actions. This brightness is considerably lower than full daylight brightness.

In fact, we could be satisfied with a brightness of about 3 to 5 mL, that is almost three orders of magnitude lower than that of the real outside scene.

The concessions which we suggested when we discussed the distance between the observer and the apparent display help to achieve such brightness within the present state of the art.

4. "Gestalt"—Distortion—A very important design goal has to be the representation of the desired cues in a "Gestalt" or shape that is sufficiently similar to the real target. This does not mean that a straight line in nature could not be slightly bent in the display, at least as long as the straightness of the line is not in itself the cue. It is, however, necessary to assure that a target passing from one display channel into another is not broken, such as to present a disturbing discontinuity in the shape.

This demand makes it highly desirable to avoid whenever possible the subdivision of the scene. Unfortunately, only few training situations permit this approach, that is, allow the use of an electronic projection system in combination with a wide-angle lens.

5. Field of view—Most of the problems and concessions discussed so far are due to the large

field of view needed in many training device systems.

Such a requirement does not exist in broadcast television, where the scene and details to be shown are under the control of the director. If he wants to show a detail, he just brings the observer closer to the part of interest by using a correspondingly reduced subtended angle to fill the display device presentation. Thus, an increased resolution for the area of interest is achieved.

The training situation, of course, does not permit us to vary the visual presentation range to provide high resolution, since it has to present the observed scene with the realistic subtended observation angle. Further, since the operator in the real environment is free to change the direction of his observation and the trainee in the training situation must be able to make full use of his capability to look around, scan and observe the scene in any direction, the visual simulation system has to provide a display of a reasonably large area, the size of which depends, of course, on the specific training task involved.

In most cases a subtended elevation angle range of 60° is needed. The subtended azimuthal angle varies widely.

For straight-in landing of a fixed wing aircraft a 60° azimuthal angle may be sufficient. A carrier landing approach, however, requires about 180° azimuthal angle and an air-to-air combat trainer may require close to 360° azimuth and elevation coverage, if a full complement of situations shall be pursued in the training program.

6. Contents of presentation–Theoretically, in lieu of a picture of the scene from which the trainee will derive cues, a symbolic display could be used and thereby the information content to be stored, processed and displayed could be minimized. However, hereby another layer of mental translation would be interposed which, in general, will have an undesirable effect on the training transfer effectiveness.

Therefore, information storage, processing and display have to be such that an analog simulation of the real scene, that is, a picture of the real world scene under observation is displayed that contains: first, all the cues that the instructor would want the trainee to deduce from the scene; second, the scene has to contain often sufficient irrelevant information that makes it a task for the trainee to derive the right cues and to discard the irrelevant information. This irrelevant information also has to be displayed with sufficient resolution to assure that the trainee does not discard it simply based on poorer quality of its display.

This is still far from a "realistic" simulation of the environment and demands only that the display presents the scene in sufficient similarity to the real world to accomplish the specific training task. Here, it might be mentioned that excessive demands on "realism" are often caused by the lack of a training situation analysis and, therefore, lack of a well defined training problem, training approach and training syllabus.

7. Color–Though user acceptance is greatly enhanced if color is provided–color television versus black and white television exposure is mainly responsible for this–the decision as to whether to provide color or not has to be based on the extent to which an operator makes use of color discrimination in the real world and on the importance of color cues.

The technology is available to provide color, though at increased cost and reduced resolution. For, all color systems that use several cameras and/or several display devices to achieve a color combination face the problem of picture element registration and even display means that provide color using a single electron beam achieve the color generation only at a reduced resolution. Even systems that use a black and white picture addendum to the color picture solve the resolution problem only to a limited extent.

On the other hand, as we concluded before, resolution is in many cases not as critical as area recognition and, therefore, often the cost of providing color cannot be avoided.

The use of color is, of course, mandatory if one or more specific colors in themselves provide significant cues, such as, for example, the "meat ball" and other landing lights for a night carrier landing trainer.

SUMMARY

As indicated before, this survey of the problem areas of nonprogramed, wide-angle visual simulation in training devices highlights most of the more important aspects of this field of engineering. It does not attempt to solve specific training device problems.

This survey is not intended for the specialist in this field, for most of the thoughts expressed in this article are known to many specialists in this field.

What we have tried to achieve, however, is to make those who are involved in establishing training device requirements, those who will use them, and those who have misconceptions about the real state of the art, aware of the problems that confront the developer and designer of nonprogramed, wide-angle visual simulation systems for training devices. If a careful training situation analysis is made, trade-offs between training device design and cost, on one hand and training methodology on the other will lead to reasonable performance concessions and permit thereby to build a training-effective and cost-effective training device.

Dr. HANNS H. WOLFF
Technical Director, Naval Training Device Center

Dr. Wolff was born in Berlin, Germany, and came to the United States in 1947. Prior to coming to America Dr. Wolff was with the Telephon Fabrik, J. Berliner A.G., and for 16 years, a Chief Engineer of the Loewe-Opta Radio A.G. After the war he joined the staff of the Technical University of Berlin and was in charge of the Chair for Theory of Electricity.

Dr. Wolff was on the staff of the W.L. Maxson Corporation and has held high technical positions in American industry. He served as Chief Engineer of the Electronics Laboratory of the Paul Moore R&D Center of the Republic Aviation Corporation prior to his assignment to the Naval Training Device Center in 1963.

Dr. Wolff has a Bachelor, Master, and Doctorate Degree in Electrical Engineering as well as a Dozent Doctorate Degree, all from the Technical University of Berlin. He has been awarded many patents from the United States and various other countries. He is also the author of many technical papers: mostly in the electrical/electronics field. From 1959 to 1966 he was an adjunct professor at the Polytechnic Institute of Brooklyn. He is a member of the IEEE, the American Physical Society, and the Research Society of America (Sigma Xi).

As Technical Director of the Naval Training Device Center, Dr. Wolff serves as the principal scientific and engineering advisor to the Command and is responsible for the planning, direction, implementation, review and evaluation of the research, scientific, engineering, and technical work and activities of the Center and its field offices.

The Sensory Interaction of Visual and Motion Cues

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Effective training design requires that the significance of cue interactions be established. Care must be taken to incorporate into the training device not only the cues required for training specific tasks, but the essential combinations of cues as well.

This paper discusses visual and motion interaction from the standpoint of: (1) illusions and spatial disorientation; (2) spatial orientation training; and (3) simulator sickness.

Experience with flight trainers has shown that motion cues are perceived and used differently when external visual cues are displayed. Motion can be sensed visually and proprioceptively. Acceleration cannot be sensed visually, however, until increasing velocity is noted. Conversely, the proprioceptive sense, though insensitive to velocity, is quite sensitive to acceleration.

Highly signficant interactions take place when the visual and proprioceptive senses are stimulated simultaneously. As a result, a secondary stimulus, presented at the same time as a stimulus of primary importance to a control task, may act as a distracting cue or as a source of confusion. Conversely, a secondary stimulus may supplement the primary one and aid in performance of the task.

Related to the problem of whether a secondary cue will inhibit or enhance the primary cue is the effect of the secondary cue upon the sensory threshold level for the primary cue. Experimentation has produced human sensory threshold data which can be applied to simulator design. However, sensory thresholds which have been determined for a particular sense modality must be used with caution in practical applications, because of the influence of other stimuli acting simultaneously on other senses. The combined effect of several cues could radically shift the sensory threshold level for any or all of the stimuli. The resultant sensory interaction should be given primary consideration in the design of training devices.

Since much of the following discussion is dependent upon descriptions of the human sensory system, some of the terminology will be defined. There has been some confusion concerning the terminology used in sensory psychology. This has resulted from the inability to distinguish clearly between closely related sensory functions and from the arbitrary grouping of these functions under different names, depending upon the classification scheme used. For instance, under the term *somethesis* are included the sense of movement (kinethesis) mediated by joints, muscles, and tendons; visceral sensations, touch, pressure, and other skin sensations. The term *somatic senses* is also used in reference to these senses and is used interchangeably with *somethesis.*

To confuse the issue further, we have the classification by Sherrington (1906). According to this scheme, the human receptor system can be divided into three groups: (1) exteroceptors, (2) interoceptors, and (3) proprioceptors.

The exteroceptors mediate such sensibilities as touch, superficial pain, temperature, tactile discrimination, vision, and audition.

The interoceptors underlie general and special interoceptive (visceral) sensibilities. General interoceptive sensibility includes perception of hunger, thirst, respiratory movements and visceral pain.

The proprioceptors mediate such sensibilities as sense of position, sense of movement, pressure sense, and equilibrium. The proprioceptive system may be divided into two subclasses: the kinesthetic and the vestibular. Kinesthesis (literally "feeling of motion") refers to the sensitivity of movements of parts of the body in relation to the whole (for example, arms, legs, tongue, and eyeballs) due to the excitation of receptor cells located in the muscles, tendons, and joints of the

body. The vestibular sense involves the perception of spatial movements and spatial orientation of the body as a whole, due to the excitation of receptor cells located in the non-auditory labyrinth of the ear (Crosc, 1967).

THE VESTIBULAR SYSTEM

The sensory information which conflicts most frequently with visual perception is that originating in the vestibular apparatus of the inner ear. This apparatus consists of two sets of sensors, one in each inner ear. One set, the semicircular canals referred to as the six "spirit levels" of the body by William James (1948) acts as the chief receptors for rotational acceleration. The second set, the otolith organs (utricle and saccule), responds primarily to gravity and linear acceleration. The semicircular canals and otolith organs interconnect and are filled with a fluid called endolymph. Currents are set up in the endolymph as a result of head movements and the resultant pressure triggers off the nerve impulses. In steady rotation the semicircular canals become habituated so that when the rotation is stopped, a sensation of rotation in the opposite direction is felt. This can persist for a relatively long time, up to 30 seconds or more. The otolith organs, however, cannot be habituated, and as long as the linear acceleration continues it will be sensed.

Under the influence of complex motion stimulus there appears to be an interaction of linear and angular accelerations on the vestibular receptors. In such situations the duality of function of canal and otolith mechanisms becomes hazy. The two organs no longer contribute separately but appear to behave as a unit in sensing the motion stimuli (Benson and Bodin, 1966). This is not surprising, considering the structural continuity of the two sensors. There is evidence that the semicircular canals are stimulated to some degree by position and linear acceleration (Wendt, 1951). In addition to possible vestibular cross-coupling effects, interactions presumably take place between the vestibular and somesthetic senses (Smode, 1971).

The vestibular apparatus senses the orientation and movements of the head, then stabilizes the eyes, thereby maintaining clear vision. The reflexes that stabilize the eyes during head movements are the results of the united control of the muscles of the eyes by four separate sources: vestibular, visual, neck muscle-receptor, and cortical (Wendt, 1951).

THE VISUAL SYSTEM

The visual system appears to lack proprioceptive feedback regarding moderate motions and the position of the eyes. The exact direction of gaze of the eye is known only by reference to the position of the object being observed and the observer's orientation in space. In the absence of a structured field, the observer rapidly loses the sense of direction of his gaze. An example is the autokinetic illusion—the apparent motion of a fixed point of light being fixated in the dark.

An illusion which serves to illustrate vividly the interaction between the visual and vestibular systems is the oculogyral illusion. This effect is associated with prolonged passive rotation and, like the autokinetic illusion, also involves apparent motion of a visual target. Under flight conditions, it is difficult to differentiate between apparent motion of a visual target. Under flight conditions that resulting from autokinesis, but both contribute to disorientation (Clark, 1963).

Tiling the head about one axis while it is being rotated about another axis (Coriolis effect) can modify sensations of turning and cause illusions (Stewart and Clark, 1965). Other effects conducive to spatial disorientation are listed in table 1.

THE VISUAL AND MOTION CLOSED-LOOP SYSTEM

Many experimental studies have tried to prove that in making spatial judgments, more reliance is placed on visual than on proprioceptive cues or vice versa. However, a survey of the literature, particularly the studies of Witkin and Asch (1948), indicate that both senses interact to the extent that the result is a derivative of their combined actions. When the two senses are in accord, perception of spatial orientation is correct. When the sensations are in conflict, however, the outcome is a compromise. The perception is then unstable and incorrect.

The human organism stimulates himself as he acts, and this stimulation, in turn, affects his action. The process is circular and has been compared to the feedback of servomechanisms (Wiener, 1961). In the words of Norbert Wiener, "The central nervous system no longer appears as a self-contained organ, receiving inputs from the

TABLE I. FLIGHT SITUATIONS CONDUCIVE TO DISORIENTATION

Actual situation	Subjective experience (false perception)	Cause
Level turn	Straight flight	Rate of change is insufficient to stimulate semicircular canals.
Level turn	Ascent	Resultant forces on otoliths are equivalent in both situations
Recovery from a level turn	Descent	Resultant forces on otoliths are equivalent in both situations
Protracted turn	Straight and level flight	Rate of change is insufficient to stimulate semicircular canals.
Left turn and head is bent forward suddenly	Falling to right	Stimulus is resultant of combined motions (Coriolis effect).
Skidding in a flat turn	Banking in opposite direction	Resultant forces on otoliths are equivalent in each case.
Maintenance of straight and level flight by successive corrections	Gradual turning	Rotary stimuli from yawing actions are cumulative due to endolymph inertia.
Straight and level flight parallel to another aircraft but at different speed	Turning	Misinterpretation of resultant of the two motions.
Straight and level flight at night approaching a row of ground lights at an angle to the direction of flight	Tilting or banking	Misinterpreting the row of lights as the true horizon dead ahead.
Level flight after a slow recovery from sudden roll	Continuing tilt and lean in opposite direction to compensate ("The leans")	Rate of change is not sufficient to stimulate perception of recovery movement.
Ascent or descent between two cloud banks. Aircraft attitude tilted from true horizontal.	Level of flight	Erroneous use of a titled cloud layer as the horizon reference
Gradual ascent or descent	Level flight	Forces are not sufficient to stimulate otoliths.

TABLE 1 FLIGHT SITUATIONS CONDUCIVE TO DISORIENTATION (Cont'd)

Actual situation	Subjective experience (false perception)	Cause
Slow bank	Level flight	Forces are not sufficient to stimulate otoliths.
Bank, correctly shown by attitude indicator	Tilt in opposite direction and increase true angle excessively in attempt to correct	Reversal of figure-ground relationships of attitude indicator resulting in control response to horizon bar instead of miniature aircraft
Approaching a fixed external light (e.g., star or beacon	Approaching or following a moving light (e.g., tail light of other aircraft)	Autokinetic illusion
Approaching fixed external object	Object is approaching	Misinterpretation of relative motion
Approaching the lights of two aircraft which are separating rapidly	One aircraft approaching	Visual cues from angular separation are equivalent in both situations.
Following lights of two aircraft in parallel flight	Seeing one aircraft which will be near or distant depending on amount of separation	Visual cues from angular separation are equivalent in both situations.
Approaching familiar terrain	Approaching strange terrain	Temporary dissociation or impairment of memory, fatigue.
Approaching strange terrain	Approaching familiar terrain	Temporary dissociation or impairment of memory, fatigue.
Propeller rotating normally during moonlit night flight	Propeller standing still during moonlit night flight	Stroboscopic illusion produced by moonlight streaming through propeller blades and reflecting back onto propeller
Flight in propeller-driven aircraft or helicopter	Disorientation ranging from mild irritation to nausea; even complete confusion and unconsciousness	Flicker vertigo caused by sunlight streaming through idling propeller or helicopter blades. (Light flashes at a frequency between seven and thirteen Hz.)

Source: Modified after Vinacke (1947)

senses and discharging into the muscles. On the contrary, some of its most characteristic activities are explicable only as circular processes, emerging from the nervous system into the muscles, and re-entering the nervous system through the sense organs, whether they be proprioceptors or organs of the special senses." The interdependence of the spatial behavior of the body with visual and proprioceptive motion feedback is shown in figure 1.

The importance of the integration of these three feedback loops is dramatically shown by persons suffering from ataxia, a disorder characterized by a marked disturbance in the coordination of voluntary movements. A person afflicted with locomotor ataxia cannot walk without constantly looking at his feet and the ground. If blindfolded he cannot walk, or even stand. Such a person has lost an important part of his kinesthetic sense and must depend on his vestibular and visual senses to guide his actions.

Figure 1 may be expanded to illustrate the man/machine relationships in a simulator incorporating a visual display and a motion system, as shown in figure 2. By reference to this diagram it can be seen that the operator of a simulator which incorporates a visual display and a motion system has three primary inputs: visual, kinesthetic, and vestibular.

THE CONTROL TASK

In piloting tasks, visual observation of instrument panel displays, the external environment as seen from the cockpit, and sensations of motion provide the primary cues upon which the pilot bases his motor responses. Variations in the gravitational-inertial forces affect the pilot through the motion sensors of his vestibular system. The pilot's visual function and his sense of orientation are, in turn, affected through these sensors. As a result of the interconnection of the vestibular and oculomotor control systems, effects produced on the pilot's visual system, in turn, influence the response of his vestibular system and his sense of orientation (Peters, 1969). The interplay between these two anatomical systems finally results in the effective, or ineffective, control of the aircraft or flight simulator. It is this interplay between visual and motion cues that makes the simulation problem particularly difficult. In analyzing a specific flight situation, it is important to differentiate between the visually-induced effects and those resulting from motion. Then, it must be known how these cues react in combination. In cases where both visual and motion cues are being presented simultaneously, unless the cues are realistic in both relative intensities and temporal factors, their

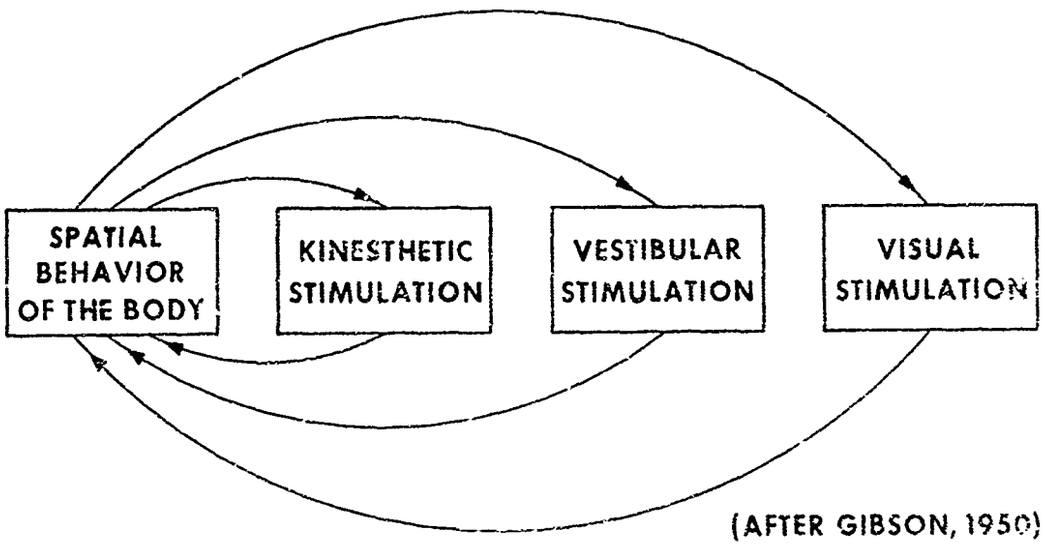


Figure 1. Visual and proprioceptive feedback.

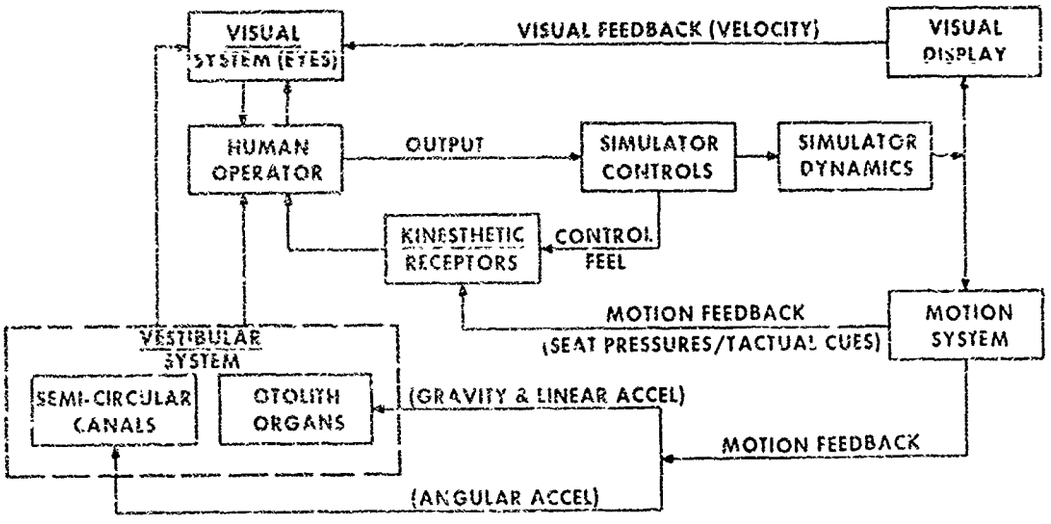


Figure 2. Visual and motion closed-loop system.

interactions may provide contradictory information and/or produce effects which are not representative of the operational situation being simulated.

ILLUSIONS AND SPATIAL DISORIENTATION

The illusions experienced in flight arise primarily from stimulation of the vestibular system and from visual phenomena. Illusions arising from visual phenomena refer to illusory perceptions of orientation or motion resulting from erroneous interpretation of visual information, are distinguished from visual phenomena caused by compensatory eye movements and eye reflexes caused by stimulation of the vestibular system.

Research in vestibular physiology has shown the importance of the vestibule in producing motion sickness and spatial disorientation. An example of this is shown by the fact that those deaf people who show no vestibular sensitivity do not get sick (Wendt, 1951) and are less susceptible to disorientation than normal individuals (James, 1948), (Olive, 1969).

A study correlating physical and medical data from 1,000 aviators over a 20-year period was made by the American Institute of Biosciences (Olive, 1969). An analysis of the data indicated that disorientation and vertigo are responsible for early problems of failure of flight training, and for many aircraft accidents, and that with increasing age, problems of disorientation and vertigo increase.

Peters (1969) states that although kinesthetic and auditory perceptions are involved in some illusions, they are of secondary importance. The issue is complicated, however. There is evidence to indicate that humans can detect linear motion more accurately by the kinesthetic senses than by the vestibular. Although there is little doubt that the vestibular apparatus provides considerable information on linear acceleration, a simple experiment will show that these are limited in their application. Armstrong (1952) has described the experiment as follows: "If the head is turned on its vertical axis 90 degrees to the left or right and the body subjected to a forward linear acceleration, the labyrinth should be stimulated in such a manner that the motion would be interpreted as being lateral instead of forward. Actually, this does not occur, the body motion being correctly interpreted, and this must arise from somatic sensibilities. This somatic sensing of motion has been recognized for years by pilots who aptly referred to it as 'flying by the seat of the pants'."

Further evidence of how sensory interaction can affect perception has been demonstrated by experimentation. Wapner, Werner, and Chandler

(1951) had subjects aline a luminous rod to the gravitational vertical in a dark room. It was found that if a loud tone was presented to one ear or if the chair was tilted approximately 30 degrees from the vertical, the rod was misaligned by several degrees. Apparently, auditory or kinesthetic inputs influence perception of the vertical.

The inability of the mind and body to differentiate clearly between sensations arising from different sensory organs is not necessarily detrimental to simulator design. It can sometimes be helpful in providing illusions of realism. An example is in the use of a dynamic seat, also referred to as a G-seat. This device is designed to produce a feeling of motion by controlled pressure redistributions across the contact surfaces between the body and the seat. The pressure variations can be produced by pneumatic or hydraulic inflation, direct mechanical deflection, or changes in tension of the seat covers. The sequence and magnitude of the pressures can be computer-controlled to simulate the somatic cues experienced during particular maneuvers. As it is introspectively difficult to distinguish vestibular from somesthetic sensations, this approach has been proposed as an inexpensive solution to the problem of simulating motion in a training device.

SPATIAL ORIENTATION TRAINING

A major causal factor of aviation-instrument, weather accidents is spatial disorientation. This generally occurs when the pilot unexpectedly loses visual reference to the ground, horizon, or a cloud layer, and as a result loses control of the aircraft. Some flight situations in which disorientation may occur are listed in table 1.

SIMULATOR SICKNESS

A factor which favors the inclusion of motion as part of a total simulation system is the inhibition of simulator sickness. It has been observed that symptoms resembling motion sickness develop when operating simulators that include a visual system providing apparent motion without accompanying real motion. It has been suggested that the attempt to interpret the visual cues in the absence of corresponding physical motion cues is one source of conflict that produces this effect. This cannot be the case according to Gibson's (1950) theory, which postulates that the absence of cues does not constitute a conflict of cues. An example in support of this is that the absence of some cues inhibits motion sickness, as shown by the fact (mentioned earlier) that deaf-mutes lacking vestibular perception do not get motion sick. However, we are not really considering the *absence* of cues. There are inertial stimuli which tell the individual that he is not moving, despite the visual cues which imply motion and/or a change in this vertical reference. This seems to be where the conflict arises. Experience has shown that in that it is not the visual illusion of motion *per se*, but the visual sensation of apparent *acceleration* and/or *change* in direction which triggers off the initial feeling of discomfort. Witkin (1949), in a rotating room experiment, indicated that the greatest discomfort occurred at the point of reversal of direction of movement, that is, at the position of greatest angular acceleration. This should not be surprising as the inner ear is extremely sensitive to any force acting on the body (gravity, for example) and to any acceleration of the body, but is not sensitive to uniform motion. One might hypothesize that the cause is related to the increase in neural activity from eye movements following a changing visual scene which is contrasted with the static physiological cues from the proprioceptive system. However, it is generally very difficult to isolate the causes of simulator sickness and it is even possible to develop simulator sickness in a static situation such as in a room tilted from the inertial vertical. According to Steele (1963), in these cases of visually induced symptoms, the cause appears to be over-stimulation of the inner ear.

The following hypotheses are some that have been advanced in an effort to explain simulator sickness:

1. Conflict between the apparent motion seen on the visual display and lack of any corresponding real motion of the simulator.
2. Optical distortion (both static and dynamic) in the visual display, particularly of vertical objects; the synthetic presentation of a visual scene which is a distorted representation of a real environment.
3. Poor resolution.
4. Rapid changes in brightness (flicker).
5. Wide field of view.
6. A highly structured visual field (too much detail).

7. A poorly structured field combined with peripheral flicker.

8. Excessive lag between simulator control and corresponding movement in the visual display.

9. High-frequency vibrations which disrupt accommodation.

10. Projection screen-to-observer distance insufficient for infinity focus of the eyes, producing conflict between actual distance of the display and the apparent distance of the scene.

Items 6 and 7, above, appear somewhat contradictory. This may have resulted from different interpretations of the term "structured field." Benfari (1964) reported that vertigo was most common when there was a combination of a poorly structured field and peripheral flicker. He found that motion and flicker could be integrated in a highly structured field without inducing vertigo. Benfari also found that flicker or poor structure by itself had no apparent effect. In his report, a poorly structured field was defined as: "(a) having a figure-ground contrast ratio of less than 2:1, (b) having poorly-articulated objects in the field, (c) lacking a definite frame-of-reference such as an horizon or vertical border, and (d) having a relatively homogeneous textural gradient."

An important factor in these experiments was that a 135-degree cinedome projection screen was used. This wide-angle screen produced a "compelling illusion of confinement by the boundaries of the visual field. Subjects who stood outside the boundaries of the cinedome were not affected as strongly by the vertigo inducing stimuli" (Benfari, 1964). Items 6 and 7 are, therefore, related to item 5 (wide field of view), and it is apparent that most of the factors listed above are, generally, interrelated.

When a definite frame of reference is missing, it is difficult to distinguish the visual field from what Gibson calls the "visual world." Gibson states that, "In some flying maneuvers, in amusement park devices, in a special type of vertigo, and in a number of experimental situations, the visual world and the visual field cannot be distinguished from one another and some illusory frame of reference—a non-gravitational vertical—may then dominate perception. The experience is disconcerting and unpleasant. It is in these situations that one loses equilibrium."

In two independent studies conducted on the 2FH2 Hover Trainer (Bell Helicopter Simulator) the first investigators (Havron and Butler, 1957) concluded that the basic problem resulted from a conflict between visual and proprioceptive cues due to a lack of cockpit motion. The second team (Miller and Goodson, 1958) concluded that the basic problem was caused primarily by conflicting visual cues produced by a combination of several optical distortions in the display.

A similar situation was encountered in an automobile driving simulator manufactured by the Goodyear Aerospace Corporation, in use at the Injury Control Research Laboratory, U.S. Public Health Service, in Providence, Rhode Island. Many subjects (40 to 50%) experienced simulator sickness on this device, and the cause was generally attributed to the lack of a motion system. However, it was noticed that the optical pickup and vidicon camera, which were suspended on the end of a movable carriage above an 87:1 (HO gauge) scale terrain model, vibrated as the gantry moved about. This vibration was magnified through the optical relay system and transmitted to the projection screen. Although the picture jitter was not too obvious, the observer's eyes were constantly shifting in an effort to stabilize the scene. It was subsequently believed that this was the cause of the simulator sickness, rather than the lack of real motion. Coincidentally, on the 2FH2 Hover Trainer there was also picture jitter produced when executing a turn or other abruptly changing maneuver. Subjects reported this as a contributing factor to the simulator sickness experienced on this device. However, since picture jitter coincided with the turning or other sudden maneuver, it could have been the illusion of acceleration due to the simulated maneuver, rather than the jitter, which produced the feeling of malaise. It would appear difficult to isolate the cause in this case. Another possibility is that jitter and the apparent acceleration were both contributing factors.

Recently, a new gantry drive mechanism, which virtually eliminated picture jitter, was installed on the Goodyear driving simulator but simulator sickness persists in the device. The Injury Control Research Laboratory plans to incorporate a dynamic seat into the simulator, which will move during acceleration, braking, and turning, in further efforts to eliminate the problem (Lewis, 1969).

An interesting aspect of the 2FH2 Hover Trainer study was that a higher percentage of instructors became sick (60%) than students (12%) (Miller and Goodson, 1958). Three hypotheses were offered to account for this:

1. Subjects are more prone to become sick when sitting as passengers than when they are actually "flying" the simulator (students had the controls the majority of the time). The fact that vehicle operators rarely become sick and passengers often do can be explained by the conflict of cues hypotheses. As the operator receives direct feedback from the vehicular controls (Barrett and Thornton, 1968), and is also in an optimum position for viewing the outside environment, he can anticipate what is to happen and does not experience conflict. On the other hand, the passenger who does not have these references may become ill.

2. Visual distortion is more apparent to an experienced pilot, who is continually scanning the scene, than to a student who tends to fixate on a particular area of the screen. Yet in order to reduce the tendency to experience vertigo, Sinacori (1967) instructed his simulator pilots to scan the total display frequently and to avoid staring at a particular point on the display. This is but one of the many paradoxes to be found in the literature of simulator sickness.

3. There was probably no cue conflict for the student pilots, since they had not learned the specific motion cues which are characteristic of helicopter operation. Conversely, the instructor pilots experienced cue conflict as a result of the absence of the proprioceptive sensations which they had been highly trained to interpret and respond to. Fitts (1951) found that visual control is very important while an individual is learning a new perceptual-motor task but as performance becomes habitual, proprioceptive feedback or "feel" becomes more important. This is readily apparent in learning to typewrite, to play a musical instrument, and in learning many other skills.

Habituation is also a factor applicable to simulator sickness. In some cases, instructors may find that they adapt to the simulator after gaining experience in operating the device, and subsequently will not suffer any ill effects. As an aid to reducing the effects of simulator sickness in a point light source simulator, Sinacori (1967) recommended the following procedures:

1. Wearing eyeshades which prevent direct light and extraneous reflections from entering the pilot's eyes.
2. Instructing the pilot to close his eyes during startup and shutdown procedures when exaggerated simulator visual motion occurs.
3. Frequent rests.
4. Frequent scanning of the total display and avoidance of staring at a particular point during a precision hover or maneuver.
5. Instill high motivation in the pilot.

A study by Northrop Norair Division (Sinacori, 1969) addressed itself to the issue of simulator sickness as part of an investigation to determine a ground-based simulator's capability to produce data representative of visual flight. A jet-lift V/STOL aircraft simulator using a point light source visual display with a rotational, 3 degree of freedom motion base, was used as the test vehicle. Fixed base operation of this simulator induced pilot nausea and reduced pilot-vehicle performance. Use of the motion system greatly reduced or eliminated the nausea and produced results comparable with flight results.

Another interesting aspect of this study was the attention paid to head movements which were found to be related to vehicle motions. Measurements showed that compensatory head movements occurred during lateral quick-stop maneuvers when peak bank angles exceeded 5 to 6 degrees. The head counter-rolled in order to reduce the total inertial rolling of the head during moving base operation. During fixed base operation, the head movement was reversed; the head tended to follow the visual scene which moved in the opposite direction to what the real motion would have been. The same pattern of head movements shown during moving base operation was observed by Sinacori for five other pilots while they performed the same task during flight in a helicopter.

Head movements may have some bearing on the higher incidence of sickness involved with wide-angle visual displays as compared to displays having narrow fields. However, wide-angle displays usually have more distortion than narrow-field displays, and, possibly more important, the pilot loses all sense of a stable reference in a wide angle system since the edges of the projection screen are not in the immediate field of view. Which of these three factors is the most important—head movements necessary to scan a wide field, distortion, or loss of a stable reference? Or, do they all interact to produce vertigo?

RECOMMENDATIONS AND RESEARCH ISSUES

1. Before incorporation of a motion system for the sole purpose of preventing simulator sickness, it must be definitely ruled out that the problem is not strictly a visual one. If it is a discrepancy in the presentation of visual cues (distortion) the addition of motion will not remedy the situation and may only aggravate it. Hall and Parker (1967) reported that in one Air Force, high-performance, tactical aircraft simulator (without a visual display) the motion system was not used often because it was unnecessary for what it taught and it *tended to make the students nauseous* (motion sick).
2. Experimental studies should be conducted to provide conclusive evidence to support (or reject) some of the hypotheses that have been advanced regarding simulator sickness. A relatively straightforward study which may yield information of practical importance is one which would contrast the effects of a dynamic visual system with and without real motion. It would attempt to show that the sickness produced by the perception of apparent motion on a visual display can be negated by the addition of real motion. Sinacori's (1969) validation study of ground-based simulation attacked this problem as a side issue. Unfortunately, only one subject was used in the primary evaluation, and as the susceptibility to simulator sickness shows wide individual differences, it would appear premature to make generalizations based on the results derived from a small sample. Continuation of this experimental work, using a large sample of both experienced and inexperienced pilots, should be encouraged.
3. A study should be conducted to determine the effects of wide versus narrow field of view displays as a contributing factor to simulator sickness.
4. It may be found that visually-induced (apparent) motion and real motion cannot be "mixed," but that the real motion must accompany the apparent motion synchronously in order to avoid simulator sickness. Visually-induced uniform motion may be an exception.
5. Detailed measurements of pilot head and eye movements during various stages of fixed and moving base simulations should be made and compared with flight data. This type of investigation may provide an explanation of the function of the ocular counter-roll reflex and its relation, if any, to simulator sickness.
6. Pilot instrument training is a known technique for preventing or recovering from spatial disorientation. In addition to instrument training, spatial orientation training should be employed to familiarize the pilot with the causes of the illusions experienced during disorientation, and to train him on countermeasures to prevent or overcome the effects of the misleading cues which cause the phenomenon.
7. Physical training is another area which merits consideration. Vestibular training by Soviet cosmonauts made it possible to raise their vestibular stability. Passive exercises were conducted several times a week alternated with special active exercises as part of general physical training. All cosmonauts showed higher vestibular tolerances to rotation after training (Yuganov, et al., 1966).

SUMMARY

No sensory system is completely isolated from the others. As a result, simultaneous stimulation of several senses will produce an interactive effect. The organization by the nervous system of various sensations into meaningful perceptions is an extremely complex process. It is not strange, therefore, to find that at times there are misinterpretations of cues leading to false perceptions.

The sensations which conflict most frequently with visual perceptions are those originating in the vestibular system of the inner ear. Sensory interactions between the visual and vestibular apparatus are very important to consider in simulator applications which couple a visual display to a motion system.

There are three general types of acceleration: linear, angular, and radial. The vestibular system serves to sense these accelerations in conjunction with the somatic senses. Although the eyes are stabilized by inputs from the vestibular apparatus, the visual system appears to lack proprioceptive feedback of its own. The direction of gaze is known only by reference to what is being looked at. In the presence of a well-structured visual display, therefore, the visual mode will be the primary, overriding input. With a poor visual reference, however, the motion cues will tend to take priority. In situations where the visual and motion inputs are sensed as being equally demanding, they will be reinforcing or

contradictory depending upon whether the cues are in or out of phase.

In conclusion, it may be stated that effective training design requires that the significance of cue interactions be established. Investigators can be misled by trying to extrapolate the results of single-variable experiments to complicated applications where many variables are present. Care must be taken to incorporate into the training device not only the stimuli required for training in specific tasks, but the essential combinations of stimuli as well. In addition, it is important that the perceived pattern of cue combinations actually represent those of the operational environment.

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Decision Making and Team Training in Complex Tactical Training Systems of the Future

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Current trends indicate tomorrow's Navy will be smaller, more automated, and use highly sophisticated systems in achieving the tactical mission. The tasks involved in operating these systems will require increased emphasis on decision-making skills, in both the operational and training environments. The implications of these trends are discussed in terms of the training of individuals and teams in tactical and decision-making skills.

The area of decision-making training has been characterized by a lack of research leading to implementable recommendations. Two contrasting approaches to training in decision-making skills are reviewed; a task-oriented approach and a decision-process approach. The terminal behaviors or objectives of training in such skills are discussed along with criteria of performance. A review of the literature also relates principles of effective team training to the area of decision making.

The requirements imposed by new tactical systems and reduced manpower imply a different direction for tactical training systems, both at-sea and ashore. The training capabilities required to support future Navy tactical systems are discussed in terms of automated training techniques. These capabilities will increase training effectiveness by allowing all team members to deal with emerging environmental patterns. Thus, tactical experience will be compressed and decision-making skills will be diffused throughout the team.

Today's Navy is faced with a number of crises which have far-reaching implications for both the operational and training establishments. The focus is the emergence of a Soviet naval force which threatens our command of the sea. This occurs at a time when our own forces are being reduced through material obsolescence and the inability to attract and retain qualified personnel.

Based on the resources allocated to new ship construction, it is evident that tomorrow's Navy will be smaller. Therefore, the goal expressed by Admiral Zumwalt (1971) of "...the achievement of a tightly organized and efficient and competitive force..." requires that the Navy become more automated, more specialized, and better trained. A trend in this direction is evidenced by the procurement of the 963-Class destroyer. Yet, concurrent with the introduction of complex hardware and system technology is the problem of a reduction in fleet operating time for training (cf. Goad, 1969). With an anticipated modification of the draft system, there is a projected influx of volunteers with marginal aptitudes and abilities (Fields, 1971). Thus, we have a number of factors which all voice the same theme: current training practices must be modified and enhanced if the Navy is to remain potent.

We can expect the following developments in the next decade. Tactical teams of the future decade will, of necessity, be smaller. Many of the current manual tasks will be automated. Thus, much of the existing overlap and redundancy of individual jobs and tasks will be shifted from man to machine and the focus will be more upon man-machine interaction relative to man-man. Since more of the routine procedural activities will be performed by computer, the human tasks will require a greater emphasis upon higher level cognitive skills such as pattern perception, problem solving, and decision making. Accompanying improvements in system and weapon technology will be a reduction in the time available for response. The net result of these developments is that the decision-making function will be diffused throughout the team structure. That is, each individual job will become more decision-making oriented. This trend points directly to the need for significant improvements

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in both individual and team decision-making training.

How can we best train individuals and teams in the skills required for effective tactics and decision making? Before we address this issue, we should define what we mean by the term *decision making* and, also, how to measure it.

First, let us deal with the problem of definition. Considering the pervasiveness of concern with the decision making in both the military and civilian environments, there is a surprising lack of agreement as to what constitutes a decision. Researchers in this field have indicated a wide variety of usages of the term, thereby leading to a multitude of tasks being classified as decision making (Kinkade, Kidd, and Rane, 1965; Osborn and Goodman, 1966). Similarly, the interpretation and application of research results become difficult when different behaviors all classified as decision making, are studied.

We may initially distinguish between two classes of decision. Strategic decisions are those dealing with long-range, broad, overall planning and execution of objectives. Tactical decisions are those concerned with selecting a course of action and use of resources when in direct enemy contact or providing immediate operation support (Brewin, 1964).

These two classes are not necessarily mutually exclusive and, in fact, suggest common processes. However, they typically differ with respect to the problem time frame and the resources available. Kanarick (1969) offered that tactical decision making consisted of "...diagnosing a situation and then selecting a course of action from the set of alternatives...under conditions of uncertainty." This definition, though general, describes the two process elements constituting the behaviors to be trained. For the purposes of this paper we will concentrate on the topic of training tactical decision making.

Given this definition of decision making, how do we measure whether trainees have acquired the skill? As there is not an easy or single answer. Unlike most other behaviors psychologists study, we lack a standard dependent variable, such as time-on-target, trials to criterion, or per cent correct. The many laboratory studies of decision making (cf. Edwards, 1969) have typically compared subjects' decision-making responses with "optimal" performance as defined by mathematical models (e.g., Bayes Theorem) or game theory solutions. However, these studies often employ abstract laboratory tasks which lack the operational correlates necessary for translation to existing or planned training programs. Furthermore, as the complexity of the decision task situation increases, a criterion of performance adequacy becomes more difficult to obtain.

Taking a different approach, Sidorsky, Houseman, and Ferguson (1964) considered this problem and identified five behavioral criteria for assessing tactical decision making:

1. Stereotype–the degree to which the decision response is predictable.
2. Perseveration–persistence in nonadaptive or nonresponse decisions.
3. Timeliness–whether the decision-maker has taken an action at an appropriate time.
4. Completeness–the degree to which the decision-maker uses all of the available information.
5. Series consistency–the extent to which the decision-maker makes consistent responses in a series of sequentially-dependent or interrelated actions or responses.

Notice that correctness of decision is not one of the criteria. Sidorsky *et al.*, deliberately omitted correctness, as it was their view that the fundamental criterion of tactical decisions is the adequacy with which such decisions relate to systems goals, rather than the "correctness" of calculations, discrimination, or the decision-maker's memory. The implication is that if stereotypy and perseveration are minimized, and the decision is timely, complete, and consistent, then the probability is increased that the decision still be a "good" one. It is the decision process which is being assessed, rather than the outcome.

These authors also identified operational criteria for use in evaluating tactical decisions:

1. Spatial relationship – the physical interface between own and enemy tactical unit during various phases of the tactical encounter.
2. Self-concealment – the extent to which information regarding own tactical unit is concealed from the enemy.
3. Information generation – the extent to which information regarding the enemy can be obtained.
4. Weapon utilization – the capability to destroy or otherwise counteract the enemy.
5. Conservation of resources – maintaining the integrity of own tactical unit, level of conservation, weapon reserves, etc.

Thus, from this line of research alone, there are ten criteria by which it is possible to gage

decision-making performance. Further, these criteria suggest the terminal behaviors which must be identified, in objective and quantifiable terms, in order for a training program to be effective. However, these criteria, in their present form, are only available by deduction after an exercise has been reconstructed. Therefore, the area of objective decision measurement remains one where new techniques are required.

Before we discuss how best to train in team and individual decision making, let us review briefly what we know of man's decision-making abilities. Despite the extensive amount of decision-making research which has been performed, it is difficult to define the behavior, and the process is still relatively poorly understood. Edwards and his associates, have, as a result of considerable research (cf. Edwards, Philips, Goodman, and Hays, 1968), concluded that when making diagnostic decisions, man is a conservative information aggregator. This says, in effect, that relative to Bayes Theorem (a mathematical formula for optimally revising hypothetical outcome probabilities in light of new information), man does not extract all of the information in the data. While these findings have been shown to be reliable, the underlying causal process remains a subject of controversy.

Alker and Hermann (1967) have shown that the degree of conservatism, as measured above, increased as a function of task complexity and importance (i.e., as the task becomes more "real"). Further, the subjects' initial opinions had a determining effect on what constituted optimal Bayesian performance. DuCharme (1969) has voiced the opinion that the decision-maker's response bias is the critical factor in conservatism.

Pitz (1969) has found that decision-makers, in a sequential task structure, develop an *inertia effect*. He hypothesized that the decision-maker often develops a commitment to a hypothesis over a sequence of information inputs such that contradictory or disconfirming data is processed, but the content rejected. Gibson and Nicol (1964, 1970) found a similar effect in a tactical setting in that it took more information to modify an opinion or hypothesis once it was formed.

Howell (1967; Howell and Gettys, 1968), studying decision making in a simulated tactical environment, found that humans performed diagnostic tasks 10-15 per cent poorer relative to an automated system. This disparity increased under conditions of time stress or information overload. Other studies (cf. Schroder, 1965: Hanes and Gebhard, 1966) have indicated that there are large individual differences in the ability to make decisions. Schroder (1965) noted that a critical factor which differentiates decision-makers is the ability to develop anticipating action strategies based on relationships between environmental inputs. Ability to perform high-level information processing characterized the good decision-maker.

Other characteristics of decision behavior are that people gather too much information (Gibson and Nicol, 1964, 1970) and, further, are not able to make sufficient use of what they do gather (Kanarick, Huntington, and Petersen, 1969). Interrelated with these, is that individuals may delay too long making a decision (Sidorsky and Simoneau, 1970) The seriousness of these characteristics for the tactical environment are readily apparent. With the increased dependence upon man as a decision-maker throughout the team structure, these failings cascade to the detriment of total system performance and suggest the need for training individuals as decision-makers. How may this best be done?

There have been two major approaches to the training of tactical decision making; one classified as a task/situation approach and the other a process/component behavior approach. The task/situation approach to decision-making training was recently summarized by Sidorsky and Simoneau (1970).

They have assumed that there are six "actions" encompassed by the term "decision making." These actions, which comprise the ACADIA taxonomy, are:

1. Acceptance – to establish the characteristics of an external unit (e.g., detection, classification).
2. Change – to increase the relative advantage of own unit as opposed to the enemy unit (e.g., continue or alter present course of action).
3. Anticipation – to establish future status of enemy relative to own unit (e.g., predict where target will be at time X).
4. Designation – to maximize congruence between own capabilities and emergent situational requirements (e.g., to select weapon type, search pattern, etc.).
5. Implementation – to resolve the tactical situation (e.g., firing a weapon, starting an attack).
6. Adaptation – to preserve own unit in face of unexpected circumstances (e.g., to avoid a torpedo or obstacle).

Thus, they hypothesized that effective decision-making training is dependent upon a determination of the unique features associated with each of these six dilemmas or tasks. Further, this training should emphasize general skills rather than merely practice on specifics. The need for general decision skills was identified after Sidorsky and Simoneau (1970) and Hammel and Mara (1970) noted that the decision skills necessary for surface and subsurface ASW were identical, although specific operator tasks and time dimensions varied. Hammel and Mara offered that ACADIA, in combination with the behavioral criteria discussed earlier, could be used as tools by instructors for monitoring, evaluating, and providing feedback on decision-making performance.

The second approach, training component tasks or processes, also implies a generalized decision-making skill. However, instead of training to detect the common elements (patterns) in the environment, the focus here is upon a set of common steps or processes which can be used regardless of the environmental situation. Kanarick (1969), in arguing for the process, contended that the ACADIA categories of "acceptance" and "change" comprise a situation diagnosis; viz, is there a target? what is it doing? what will it be doing? The "designation," "change," and "implementation" categories were viewed as action selection tasks. Thus, Kanarick suggested that it may not be necessary to identify separate situational dilemmas for purposes of training. Rather, training objectives could be stated in terms of using available information to diagnose the situation and to select the action alternative that has the greatest likelihood of satisfying the decision objective. This approach is, of course, consistent with the definition offered earlier.

Earlier, Kepner and Tregoe (1965) devised a training course to enhance decision-making by emphasizing component behaviors. Vaughan, Franklin, and Johnson (1966), in studying Army tactical decision training, concluded that it was necessary to train in the performance of component tasks (e.g., evaluate courses of action, anticipate contingencies) in the employment of forces against the enemy.

Both of these approaches are primarily directed toward individual decision making. They are not, however, mutually exclusive, as both argue for some generalized training to prepare for and complement on-the-job practice. We submit that the training in both component behaviors and component tasks is required for an effective training program. Thus, it is necessary to establish an awareness of the decision process first and then culminate training in task specific behaviors. Further, this approach can be readily applied to the team training environment. To aid in this transition, there is an extensive literature to consult on team training which should be related to decision-making training.

Due to the importance of developing general principles for a technology of team training, a number of research programs have been funded by the military services (primarily NAVTRADEVCEN) Typical questions which have been addressed by these programs relate to the efficacy of team versus individual training, the degree of simulation fidelity required, the most efficient team communication structure, the degree of feedback specificity required, and the like. The results of such studies, however, have not been without equivocation. As an example, a study by Schrenk, Daniels, and Alden (1969) found that team member replacement was a critical variable in terms of team-performance decrement. However, two previous studies (Horrocks, Krug, and Heermann, 1960; Briggs and Johnston, 1967) found that this factor was relatively unimportant, with the effects at worst temporary. The difference between the situations was both in terms of team structure and size and in the task characteristics. These task-specific characteristics may account for many of the conflicting results obtained in applied team-training research.

A team has been described as a synthetic organism with individuals as components (Alexander and Cooperband, 1965). It is considered to be relatively rigid in structure and organization with well-defined member tasks, roles, and communication links (Klaus and Glaser, 1970). Both of the above programs stressed that the performance of the team could be manipulated through the type and amount of reinforcement as an intact entity. However, with the project emphasis upon greater individual decision-making skills within the team structure, one cannot deal with the team to the exclusion of the individual.

One recurrent conclusion of the research on team training is that individual proficiency is the keystone upon which to build an effective team. Thus, the higher level goals of developing a team awareness and the ability to deal spontaneously

with unstructured situations (Alexander and Cooperband, 1965) require that each individual team member possess the requisite job specific skills. Each must understand and perform his own job well before he contributes to team effectiveness. Horrocks, *et al.*, (1960; 1961) found that when team coordination was stressed early in training, individual skill attainment was impaired. It was only when the higher levels of individual skill had been attained that the team product became equal to or greater than the sum of its parts.

Briggs and Johnston (1967) found that teams which interacted little performed best. Their task (air intercept control), however, involved relatively independent activities for the two subjects acting as intercept officers. They further recommended a parallel structure for team organization, for this permitted the shifting of workload between team members as a function of task contingencies. Also, in a parallel team, output was not limited by the skill level of the poorest operator, as in a serial arrangement. Klaus and Glaser (1970), however, stated that the redundancy of the parallel structure leads eventually to a decrement in team performance through interference between the activities of less skilled members with the activities of the more skilled members. The skilled members begin to devote more of their time to aiding their deficient counterparts and less to their own specific jobs. It is expected that the projected reduction in team size will lead to greater hardware system redundancy and less organizational redundancy, thus minimizing this problem.

Performance feedback is unquestionably the single most critical parameter in team or individual training. Briggs and Johnston (1967) found this variable to be particularly important when it was difficult to determine performance adequacy based on the task output alone. Klaus and Glaser (1970) emphasized that each correct response, whether team or individual, be promptly recognized. Thus, these investigators stressed the stamping in of correct behaviors rather than the punishment of incorrect ones.

Briggs and Johnston (1967) also discussed the appropriate combination of specific and general feedback. They observed that if highly task specific feedback was given prematurely (i.e., before trainees had mastered their own individual skills as well as preliminary team skills), acquisition of team proficiency was retarded. They concluded that a period of general feedback should precede concern with the task specific details.

A final issue concerns the need for team training. Briggs and Johnston (1967) found no advantage in team over individual training. Klaus and Glaser (1970) suggested that the necessity for team interaction subtracted from individual task performance. Thus, if one is dealing primarily with individual skills, the team setting is not an appropriate place for their initial acquisition. If, however, individual skills are at a requisite level, then this is the opportunity for the development of teamwork and coordination necessary to deal with the unexpected.

In summary, the major principles for effective team training appear to be: individual task proficiency, restricted team interaction, and prompt, specific and positive knowledge of results. These in turn, can be combined with conclusions from studies of decision making, such as the following, to produce an integrated approach in team tactics training:

1. Force the student to appreciate the probabilistic character of enemy and to consider a variety of enemy deployments and actions (Vaughan *et al.*, 1966).
2. Encourage the student to formulate alternative courses of action and to anticipate contingencies (Vaughan *et al.*, 1966).
3. Allow the trainee to practice decisions while at a tactical disadvantage to the enemy (Sidorsky and Simoneau, 1970).
4. Emphasize the overall goal rather than optimizing each temporal phase of the process (Sidorsky and Simoneau, 1970).

Despite the impressive amount of information which has been amassed applicable to tactics training, it is disappointing to observe the very low degree of implementation. A number of recent studies have noted that Navy tactical training is failing far short of achieving its stated goal. For example, Jeantheau (1969) pointed out that despite the impressive capability for simulation available today, the Navy has a problem in the way major devices are being used. According to Jeantheau the problem has several causes:

1. Devices are delivered with operating instructions, but not with training instructions.
2. Device use does not reflect state-of-the-art in training technology. (In fact, it ignores some fundamental principles of applied learning.)
3. Devices often serve as procedures trainers.

4. Trainers are often used for refresher training.

Hammel and Mara (1970), in a review of three advanced tactics team trainers, noted that no formal decision-making training exists at these devices because of the lack of instructor guidelines for implementing such training.

Another example of the causes which have been suggested for the suboptimal effectiveness of team training was offered by Daniels, *et al.*, (1971). These researchers observed a number of factors which essentially precluded effective team training. The factors included:

1. Intact teams seldom appear for team training sessions.
2. Individual team members often lack prerequisite skills.
3. Emphasis in team training is on training procedures.
4. Instructors are not adequately prepared.
5. Objectives and other basic materials for training are lacking.
6. Objective measurements of individual performance are seldom made.
7. Lack of relevant positive performance feedback.

A major factor highlighted by these investigations is the heavy emphasis currently placed on training procedures in the team training environment. Although procedural knowledge is an important aspect of a proficient team, the tactical training environment is not the appropriate place for training in such skill. Rather, tactics training should assume as a prerequisite thorough trainee knowledge of procedures and existing doctrine. Tactics training, then, should be concerned with the creative and innovative application of such procedures and doctrine.

The effectiveness of training, whether present or future, is not merely a function of what occurs in the team training environment. Rather, it depends upon the nature of the training which occurs prior to the team training setting. Team tactics training is but the terminal phase of what should be a planned progression of skill development. We propose three phases for training decision-makers and tactical teams. Initially, there is the need to train individuals in the procedural aspects of their jobs, doctrine, and the process approach to decision making. This training should be followed by a phase in which team members are instructed as a unit, learning the interactive and communicative requirements of team functioning. The final phase is devoted to tactical training where teams are taught to apply their procedural and interactive skills to uncertain situations requiring innovative and creative behaviors in the face of an intelligent enemy.

Although questions remain concerning the effectiveness of various methods and techniques for training tactical skills, a number of approaches are available today which appear to hold significant promise as the basis for meeting tomorrow's needs. In the paragraphs to follow we review some of them.

The first phase of training is at the individual level. Of paramount importance is that trainees become proficient in their individual jobs. This point cannot be minimized as it is a necessary antecedent condition for effective team training.

One training concept with significant potential at the individual level is Learner-Centered Instruction (LCI) (Valverde and Pieper, 1970). LCI is characterized by course content and training devices developed from the job's behavioral requirements. State-of-the-art instructional media and methods are selected to provide maximum practice of the relevant behaviors. With LCI, trainees work at their own pace, with the instructor no longer the focal point of training. Those tasks for which the job behaviors, stimuli, and the responses are well identified are most amenable to this approach. Depending on where the training occurred (onboard ship or at a shorebased device), the instructional media might include programed books, part- and whole-task simulators, nonfunctional mockups, lectures, and teaching machines. In some cases, media can be combined to produce a more efficient training program than any single medium alone might produce (cf. Briggs, Campeau, Gagne, and May, 1967). However, it should be pointed out that such multimedia approaches should be implemented only after careful study of the individuals to be trained and the skills to be acquired. Extensive literature has been compiled on the application of a wide variety of these instructional media (*viz*, T.V., student response systems, learning labs, programed texts, teaching machines, Computer Aided Instruction (CAI), portable instructor aids, dial access information retrieval systems, simulators) which could be beneficially applied to increase individual skills (Rhode *et al.*, 1970).

One medium, television, can likely offer significant advantages for increasing the skill level of trainees. For example, the televised videotape

lecture technique can allow for uniform polished presentations, economy of instructor time, and scheduling flexibility. TV classroom training has already begun at the Fleet ASW School, San Diego (Hansing and Matlock, 1970). The use of videotape also provides the capability to provide immediate feedback to a trainee after he has practiced some response or procedure. Videotapes permit comparison of different stages in a trainee's progress and can be used in the shorebased facility to refresh instructor's memories about an individual's or team's performance.

Because of the anticipated diffusion of decision skills throughout tactical teams of the future, we propose that all members receive training in the generalized skill of decision making. This might best be done via the process approach (cf. Kanarick, 1969; Schrenk, 1969) described earlier. Many of the capabilities available through the use of computer-controlled devices are applicable to training the decision-making process. At least three computer-based systems have been discussed for application to this area. One, known as TACTRAIN (Sidorsky and Simoneau, 1970) consists of a computer, CRT display, light pen, and specially designed computer-display interface. A feasibility study of the TACTRAIN system showed how it could be used to help train student command personnel in making optimum tradeoffs of various tactical parameters associated with ASW attack situations.

A second system, being developed by Honeywell as an operational tactical console, also holds significant promise as a decision-making training device. This system, Shipboard Integrated Man-Machine System (SHIMMS), uses a computer and CRT interface plus mathematical models to portray various ASW problem parameters to the student decision-maker (see figure 1). Through the use of a set of situation scenarios of varying predetermined difficulty, the trainee can learn and practice the use of sensors and weapon deployment with such systems. The trainee can also make the decisions which will actually be required in the ASW or other tactical situation without risking the loss of men or material. Siegel and Federman (1970) have presented a similar concept for training in the job of the airborne tactical coordinator (TACCO).

Although individuals are ideally trained to function as part of a smoothly operating team, individual training seldom includes the acquisition of the interactive skill required in the team setting. One attractive approach to initiating interactive skills earlier in the training cycle is through the use of synthetic or simulated fellow team members. Here, the actions (inputs and responses) of other team members can be stored on magnetic tape and played to the trainee at the appropriate time in his operation (cf. Blake and Brehm, 1954). In this way the individual trainee can develop the required individual skills in a situation more closely paralleling that which will ultimately exist.

The next level of planned skill development should involve training an assembled team. The emphasis here should be on interaction and coordination and the development of a sense of team awareness. The training can occur either on-the-job or at a shorebased training device. The objectives at this stage are to train what and how information should be transmitted to other team members. Something as simple as a special earphone, through which the instructor could prompt selected individuals so that the information flow could be maintained, might be used as an aid in meeting this objective. The command decision-maker (e.g., ASW Officer, TACCO) should be trained to exercise leadership control of the communication networks. From individual training, the command decision-maker, sensor operator, and other team members will have acquired knowledge of the basic stimulus patterns in team training to which they will be exposed. Now these personnel will acquire the ability to extract such stimulus information from a more noisy, but still relatively unambiguous, background and transmit it appropriately.

Training team awareness can also benefit from the application of a number of existing technologies. The split- or multiplescreen technique of television can be used to show team members their jobs in relation to other team members (cf. Krickel, 1964). Using this technique, a trainee (or trainees at a given station) could observe how a given action serves as a stimulus for some other team member. Similarly, a team member could determine the basis for some input that he receives from another station. Such training provides the trainees with a better appreciation of their individual roles in the team and of the need for effective communication and interaction. For example, this technology appears to be especially appropriate when used in conjunction with videotape to show how members of "good" versus "bad" teams interact. Videotaped television would be especially effective

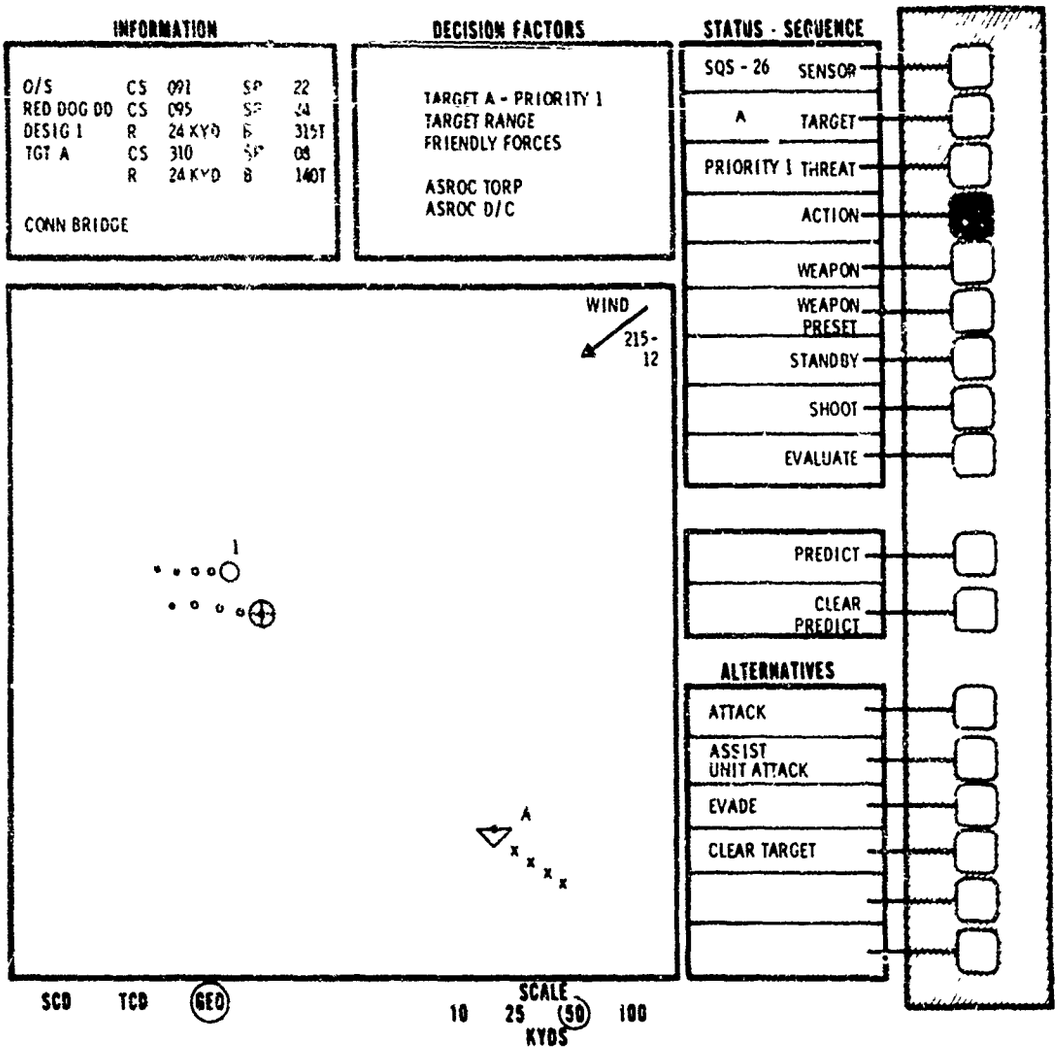


Figure 1. Shipboard Integrated Man-Machine System.

for establishing a team awareness in team training situations where portions of the team are physically separated from one another.

Once individual skills are mastered, and a sense of coordination or team awareness acquired, training can be concerned with the essence of tactics; *viz*, dealing with uncertain, ambiguous, or emergent situations. This involves a whole team in the process of modifying and generalizing from previously learned procedures to deal with an intelligent opponent or environmental hazard. The linking of existing submarine and surface and/or air ASW devices is an appropriate suggestion for this phase of training. This will require a fine degree of control if the situation is to be training rather than "free play." Here, teams would be exposed to situation specifics, as emphasized by the ACADIA approach. Further, training problems would be specifically selected to allow teams to make decisions while at a tactical disadvantage.

In the team tactical training environment, a computer can serve several additional functions to those already proposed for the individual and team awareness phases of training. For example, the computer can be used to automatically administer proficiency tests to trainees as they enter the team training environment. The results of such automatically administered diagnostic tests can help determine which individual team members are deficient in skill. Test results can also be used by

the computer to automatically match a program of instruction to individual and team skill characteristics.

To avoid wasting a team tactics training session because one or more team members come unprepared for team training, it may be advantageous to prompt individual operators within the team context. Prompting has been used effectively to train individuals in sonar discrimination (Annett and Peterson 1957), visual identification (Weisz and McElroy, 1964), and auditory detection (Annett and Clarkson, 1964). The techniques developed for such experimental studies could provide the basis for prompting in the team setting. As an example, all fire-control solutions for weapon delivery systems depend heavily on the accuracy of the sensor operator's tracking ability. If a sonar operator were in error beyond some predetermined amount, the computer controlling the trainer could be preprogramed to automatically prompt that operator. Such prompting could appear in the form of a more easily tracked, brightened target trace, the appearance of a reference dot at the appropriate tracking cursor position, etc. As a result, the deficient operator would be coached into accurate behavior, and the team training exercise would not be degraded.

The capability for automatic monitoring of trainee proficiency and progress provided through extended use of computers will allow the consideration of a technique known as adaptive training. In adaptive training, task or problem difficulty is automatically adjusted as a function of trainee performance level.

To date, the greatest amount of research on adaptive techniques has been in the area of individual perceptual-motor skills (cf. Kelley and Wargo, 1968). There is no reason to believe, however, that this technique cannot be expanded to cover all members of a team. Many problems, however, must be solved before adaptive training can be effectively implemented in the team, or any training situation (Caro, 1970; Leonard, Doe, and Hofer, 1970). Particular problems involved in using adaptive techniques for the team tactics situation are: (1) establishing valid and reliable performance measures, and (2) combining separate aspects of performance measurement into a single continuum for adaptation.

Certainly, the data base which could be collected with an automatic performance-monitoring capability such as is required for adaptive training can have another important application, namely, to allow for evaluation and evolution of the entire training system. Any effective training system must remain open to refinement through evaluative feedback and validation. As trainees become more proficient, either within or between the various stages of training, the curriculum must be adjusted. Using a computer to record trainee performance and to store and compare data longitudinally could permit long-term changes in overall performance to be detected and acted upon. In addition, data on individual training units can be used to monitor and analyze unit effectiveness in training requisite behaviors.

A further use of closed-circuit television and videotape techniques can be applied to increase the scope and potential effectiveness of this phase of team tactics training. This is monitoring of training from aboard ship. This application will permit the shorebased training facility to be extended to include additional subteams in remote locations. For example, the bridge unit of a maneuvering tactics trainer could be linked, via closed-circuit TV to the team's Combat Information Center aboard ship. Also, key personnel such as the Commanding and Executive Officers could participate in or observe and critique the shorebase, tactics training of their various teams without having to be present at the shore facility.

The view that we have presented of individual and team tactics training is not necessarily idealistic. With the existing data base, we possess a sound foundation upon which to develop these phases of training. However, we still lack answers to questions concerning the optimal ways to implement some of the techniques described. Through continued research investigations by NAVTRADEVCEN and its contractors, such solution can be found. To meet the challenge of providing effective training for tomorrow's Navy, an intensive effort is required today.

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The Evolution of Fire Control and Fire Control Simulators

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Airborne Radar Fire Control simulation has progressed hand in hand with three historical variables: (1) operational weapon system complexity–forced simulation complexity to keep in step; (2) basic hardware development–required new systems to be designed to take advantage of state-of-the-art hardware reliability, maintainability, miniaturization, and cost effectiveness; and (3) operational radar environment–involved simulation of external effects to the radar fire control system.

Tracing these three variables from classroom teacher with chalkboard to modern digital and hybrid simulation systems is the purpose of this paper.

Operational weapon systems, including radar range only gun control, missile control systems for air-to-air and air-to-ground missiles, and radar bombing control systems are reviewed. Basic hardware development, beginning with mechanical systems, through vacuum tube electromechanical and solid state electromechanical systems to hybrid and digital only systems are reviewed. Displays and display generation of simulated fire control symbol presentations to the trainee are shown to have improved through succeeding generations of training devices. Automated problem control and scoring are considered as products of hardware development.

The operational radar environment review considers the following items: (1) single and multiple air targets; (2) formation air targets; (3) ground targets; (4) active and passive jamming; (5) types of fire control attack solutions; i.e., pure pursuit, lead pursuit, lead collision, and their transition phases; (6) tactical problems; (7) radar return characteristics; (8) types of armament; (9) cockpit procedures; and (10) overall realism.

The history of the advances in radar fire control simulation technology parallels the advances seen in operational simulators and trainers. The interfacing of passive infrared fire control systems with active radar fire control systems is described in order to spotlight the applicable simulation techniques.

It may be said that a training simulator is an assemblage of equipment which imitates the action of controls and displays in prime equipment in tactical situations. Its complexity is related to the complexity of the prime equipment and the available technology for simulating that complexity. The first fire control trainers were fairly simple and inexpensive because they taught a relatively simple skill–the use of an optical gun sight–and they were largely improvised from components of prime equipment. Very early in the evolution of such trainers, however, such visual aids as motion pictures and such instructor aids as stop-action controls came into the growing technology. A modern system such as the AWG-9/PHOENIX cannot be imitated successfully for training purposes without the use of a wide array of peripheral equipment, including the indispensible computer.

EVOLUTION OF FIRE CONTROL SYSTEMS

The earliest device for airborne fire control was the optical gunsight. In World War I, pursuit airplanes carried one or two fixed machine guns synchronized to fire between propeller blades. Scout aircraft carried one or paired defensive swivel-mounted machine guns mounted in the rear cockpit. The fixed machine guns, aimed by pointing the aircraft at the target, were fired at point-blank ranges of 50 feet or less with the aid of an optical gunsight which did not compensate for range, lead, and elevation. To bring down an enemy airplane it was necessary to hit relatively small targets–the pilot or his engine. Air-to-air operations during conditions of poor visibility and at night were therefore ineffective and usually suspended. Heavy bombers of the time ranged freely in darkness, using spotlights on the underside of the aircraft to illuminate the ground at a height of about 400 yards when they were over their targets.

By the start of World War II, however, fighter aircraft and air-to-air fire control had vastly improved. Pilots now had the aid of an optical reflector gun sight that indicated range. Whereas air combat in 1918 had reached speeds of 125 to

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130 miles per hour at effective aiming ranges of less than a hundred feet, the British Spitfire and German Messerschmitt in 1940 contested at speeds exceeding 300 miles an hour at effective ranges of several hundred feet. Nonetheless, the concept of air attack remained the same—to maneuver the attacking airplane into a position from which the pilot could fire fixed guns directly into the target. Defensive turret guns for slower and less maneuverable aircraft remained swivel mounted and were operated by crewmen. Although these tactics were not to change essentially during World War II, major changes then occurring independently of each other pointed to a new concept. The introduction of military radar, of airborne rockets, and of missile guidance systems first proved the worth of this concept.

In 1928, the Naval Research Laboratory was assigned responsibility for finding technical solutions to operational problems, which included night defense and long range detection of enemy aircraft. The term "radar" was coined by the Laboratory as an acronym for "radio detection and ranging." The first airborne radar intercept equipment was successfully demonstrated to the RAF in 1939. When German night bombing of southern England commenced in the fall of 1940, a night intercept system was operational. The success of British night intercept radar accelerated radar development in the United States.

During World War II the United States and Great Britain cooperated closely to develop military radar. In 1940, the American National Defense Council, with the assistance of Great Britain, founded the Radiation Laboratory at Massachusetts Institute of Technology for intensive microwave exploration. In 1941, the Laboratory built fifteen experimental models of the AI radar for installation in the P61 Black Widow night fighter, and by September of that year one of these sets had been installed in an A20. The Navy plans for the F4V Corsair and F6F Hellcat, then in development, included AI radar. Marine night fighters were operating with radar in the Pacific in 1943.

The early applications of acquisition radar did not include fire control—that is, automatic tracking in combination with mechanical or electronic predictors to lock on a target. But steps had been taken in this direction as early as 1937, when the Army Signal Corps demonstrated a searchlight control (SLC) set designed to aid coast artillery during night attacks. Radar equipment evolved rapidly in the period 1941-1945. By the war's end, airborne intercept using only radar had been accomplished. Radar guided drones and missiles had also been developed. By this time, too, the second major element of modern air-to-air fire control—the rocket—had evolved independently to the point where an advanced guidance system was feasible.

First used during World War I to bring down artillery observation balloons, rockets were added to aircraft armament in World War II initially to increase fire power and for certain specialized missions. On January 7, 1943, the Commander and Chief, U.S. Fleet, directed the Bureau of Ordnance and Bureau of Aeronautics to collaborate in the development of aircraft rockets and launchers. Between 1943 and 1945, the Navy developed a series of air-to-ground rockets for primary use against German submarines and Japanese barges. Although less accurate than guns, rockets had the advantages of greater speed, powered flight, and the ability to penetrate hardened sites. Large airborne rockets developed at this time included the Navy 5-inch high velocity aircraft rocket (HVAR), nicknamed the "Holy Moses" and the "Tiny Tim." Without a satisfactory guidance system, however, rockets required high explosive warheads exploded at close proximity to the target, such as the unguided air-to-air "Mighty Mouse."

The problem of high speed fire control was compounded at the end of World War II by the introduction of the jet fighter operating at speeds of several hundred miles an hour. Now, the window during which the pilot could reasonably be expected to hit his target was measured in seconds. But in the years immediately after World War II, all the elements to design a modern fire control system which could cope with this threat—radar and infra-red guidance, rockets, and electronic computing equipment—were available. Work began on a new concept of air fighter, the airborne weapon system. By 1949, the AN/APS-19 radar permitted a night fighter to seek out and destroy a target using only radar to determine the direction of aim. At the same time, the Douglas F3D all-weather jet fighter (later designated F10) was equipped with a fire control system designed for both search and automatic firing of 20 mm guns. In 1949 work started on the McDonnell F3H Demon, the Navy's first operational guided missile fighter, to be armed with the Sparrow radar missile system as well as 20 mm guns. The design concept

for Sparrow I, a beamrider guided missile, included an X-band automatic tracking radar system, an airborne computer which determined flight path and lock-on at ranges to six miles. The McDonnell F4, begun in 1954 and first flown four years later, can fire a mix of weapons. It carries the APQ-72 radar and an infra-red search set. The latest and most advanced development of that unique combination of radar, rockets, computers, and data links, which we call a modern fire control system, is the AWG-9/PHOENIX missile system.

The AWG-9/PHOENIX fire control system is largely the result of a reevaluation of the role of aircraft and missiles which rapid advances in technology made mandatory in the mid-1950's. A Navy concept designated Missileer, like the experimental designs of World War II, did not become operational, but established the feasibility of advanced designs. Missileer was to carry six long-range Eagle missiles, each weighing about 1,400 pounds and having a range in excess of 70 miles. The program was cancelled in 1961 because of the single-mission capability and relative slowness of the proposed carrier aircraft, the Douglas F/D. But the AWG-9/PHOENIX fire control system, so complex that it compares only superficially with the AI radar system of 1940 from which it has ultimately evolved, is the nerve center of the new F14 multimission aircraft.

The PHOENIX Missile System is composed of the AN/AWG-9 Airborne Missile Control System and the AN/AIM-54A Missile. Designed to achieve air superiority through the detection and tracking of multiple targets and capable of performing simultaneous attacks against multiple targets using long-range air-to-air missiles, the PHOENIX can meet any threat of the 1970-1980 time frame. Attacks may be pressed against aircraft with or without ECM at low or high altitudes and at high-mach closing speeds. Secondary functions include air-to-air visual identification, radar navigation and air-to-ground weapon release. The radar subsystem (both high and low prf) functions as the primary target sensor, and the infrared subsystem as the secondary. During attack, the system provides radar illumination of multiple targets, thereby permitting guidance of multiple missiles. The infrared target detection and tracking subsystem can operate concurrently with any radar mode, either slaved to or independent from the radar system. The cockpit controls of the AWG-9/PHOENIX system permit the Missile Control Officer to make all necessary decisions for operation of the system in the time available for intercept. PHOENIX represents the current state-of-the-art in operational missile systems. Figure 1 depicts the evolution of airborne missile and fire control systems.

TRAINING SIMULATORS

The complexity of modern weapon systems requires hours of training under conditions closely approximating combat to assure that pilots will be able to carry out their missions successfully. The first aerial gunnery simulators were developed by the British Royal Air Force in the early years of World War II. With a limited number of airplanes available for use against the German Air Force, the British saw in simulation a means of training pilots under conditions like those of combat at relatively low cost without diverting airplanes from missions or risking mission failure because of pilot inexperience. The Link Trainer, designed to give simulated flying experience under controlled conditions and already in use in both Great Britain and the United States, was incorporated into many aerial gunnery simulators for full simulations of airborne operations. As in the case of airborne radar, American development of aerial gunnery began in cooperation with the British.

The earliest method for simulating fire control experience in World War II was classroom training in visual sighting using gunnery cards, film projector systems, fixed and free guns training aids, and early cockpit trainers. Techniques used to determine firing ranges, dead angles, and trajectories were described as the "Two Thirds Second," "Apparent Speed," and "Position Firing" methods. The introduction of radar into the gunnery problem at first did not relieve the pilot of visually sighting and attacking the enemy.

In 1940, the U.S. Navy development of trainers was accelerated when Captain Luis de Florez, USN, travelled to Great Britain to gather information on the RAF synthetic trainer program. A copy of his report, available for reference at the Naval Training Device Center Technical Library, describes a program in which each air station was allocated funds to develop its own training device. Captain de Florez visited a series of air stations and wrote descriptions—which included photographs—of fixed and turret gun simulators and other devices, some incorporating the Link Trainer. On his return to the United

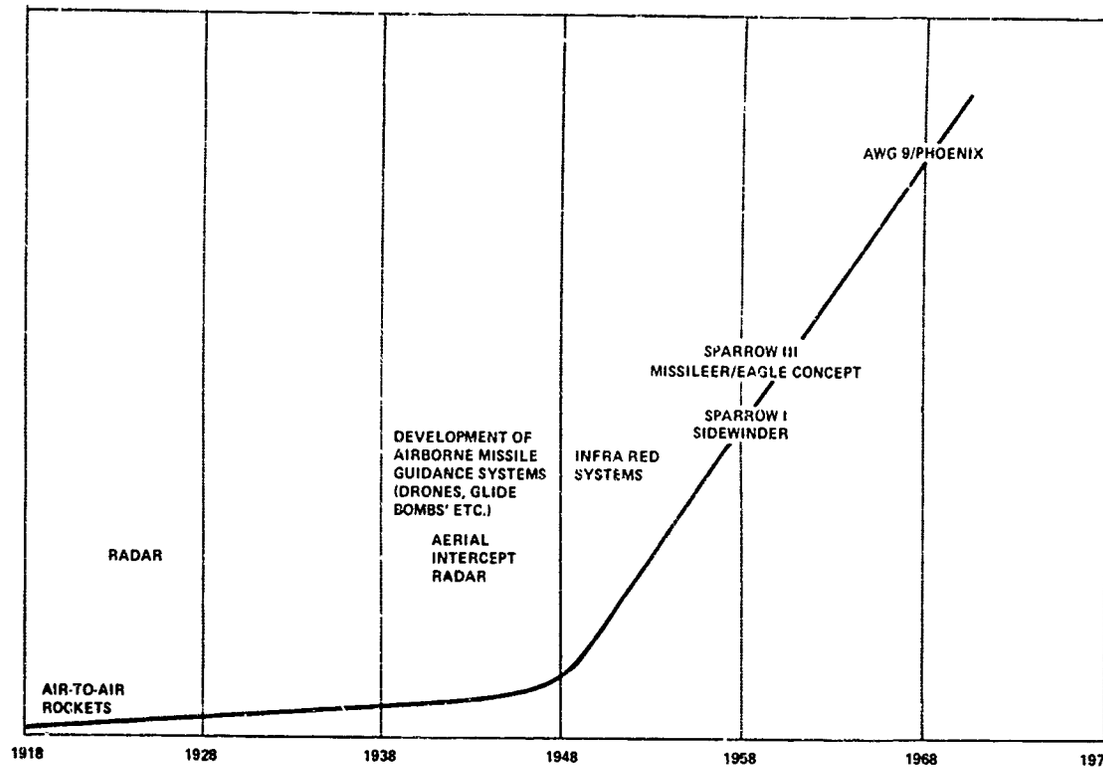


Figure 1. Major Elements in the Evolution of Airborne Missiles and Fire Control Systems.

States, Captain de Florez was active in establishing a training simulator program here. The Special Devices Division in the Bureau of Aeronautics and its successor, Naval Training Device Center, are direct results of Captain de Florez' efforts.

Beginning in 1940, the United States has produced a variety of trainers paralleling advances in prime equipment. The following devices are typical of each era.

Gunnery Training Devices

Early training devices for pilots and bombardier/navigators during the mid-1940's were Gunairstructor, Device 3B1; Fixed and Free Gunnery Training Sight, Device 3A5 series; Ultrasonic Trainer, Device 15Z1; and Aircraft Interception (AN/APS-6) Trainer, Devices 15A1, 2, 3, 5, 7, 8, 9.

AI Radar Training Devices

Radar Contact Trainer (15V4), Night Fighter Trainer (15V5), and All Weather Radar Trainer (15V6) were used with operational flight trainers in the later 1940's and 1950's to train pilots and radar intercept officers. These trainers simulated one maneuverable synthetic radar target. The 15V4, delivered in 1949, included GCI and radar search, and simulated gunfire aimed by radar. The 15V5, in 1953, simulated the APQ-35B radar with airborne search, aim, and fire by the use of radar only for training pilots and radar intercept officer teams. The 15V6 Type II, in 1957, trained pilots in radar search, acquisition, lock-on, and firing of Sidewinder, Sparrow III, and conventional weapons.

Advanced Radar Intercept Trainers

A series of 15C4 classroom trainers were developed starting in 1959 and continued through the 1960's to train F4 and F8 fighter radar intercept officers (RIO's) independently of weapon system trainers. Periodically, the 15C4 trainers were updated to reflect changes in airborne fire control systems and to reflect changes in state-of-the-art hardware. These updates included simulation of pulse doppler Sparrows, the addition of six air and three surface maneuverable targets, provisions for electronic interference and electronic countermeasures, improved classroom controls and displays, completely transitorized circuitry, and integrated circuits.

Weapon system trainers (WST's) employing hybrid analog and digital computers were in use in the mid-1960's and are continuing into the 1970's. Typical of the earliest hybrid system are the 2F65 and 2F67 WST's.

As the requirements for simulation became more complex, advanced training methods and equipment were produced. The 15V4 accepted—through suitable conversion units—flight inputs from various "synthetic flying units" (flight trainers), such as Device 2F2 (F6F) and Device 61A (F8F). Device 15V6 is representative of training devices during the mid-1950's with flight and tactics simulators housed in separate van trailers and using analog simulation. The tactics trainer is dependent upon the flight trainer for own aircraft inputs. The simulation is implemented with vacuum tube circuits and 400 Hz. analog computers.

As the requirements for realistic simulation became more sophisticated, a concurrent hardware evolution occurred in the development of computational elements, circuits, and displays.

Computational Elements

Early simulator computational attempts combined pulleys, cams, springs, and cables with film projection systems. But the pure mechanical computer soon gave way to the electromechanical elements used today in airborne radar fire control simulation. The electromechanical computer evolved from the ball and disc integrator, through the novel watt hour meter integrator, to present day servomechanism systems with tube, magnetic, and transistor amplifiers. Both the size and driving power of each computer element were dramatically reduced while accuracy, resolution, stability, and reliability were increased.

Solution and Equations

The first training aids for airborne fire control solved the deflection problem by the simple expedient of a book of pictures. Shown a particular aircraft at a certain range and heading, the gunner was told the ranges and lead angles needed to score a hit. Film projection systems used the same method with the exception that the displayed equation (enemy aircraft and interceptor) was in motion. This rote technique was followed by the first cockpit gun trainers. A target silhouette was projected in front of the gunner and modified in size (range), angle, and velocity during training. The pilot's inputs via stick, rudder, and throttle varied the projected image, while an instructor did the same with target controls. Progress to lead-computing simulation removed angle and relative velocity estimation from the pilot's problem, leaving only range estimation.

Early radar fire control simulation calculations added nothing more to existing equipment than an extension of the gunsight and target silhouette as a display on a CRT. No new computations were necessary until automatic radar tracking fire control systems were introduced. The interceptor air data computer simulation, concurrent with analog fire control simulation and without approximations and assumptions, combined problem variables to solve the aeroballistic equations. Each fire control simulation mechanization was based on interceptor and target flight parameters, projectile ballistics, environment, and the particular operational airborne fire control system being simulated.

Circuits

Radar targets, receiver noise, and environmental effects have been simulated in airborne radar control trainers from the beginning, but the circuits controlling them have changed with advances in technology. Tube circuits on large box chassis have been replaced by: (1) tube circuit generators on flat plug-in panels, (2) tube circuit generators with printed circuit wiring, (3) transistor circuit generators with printed circuit wiring, (4) integrated circuit generators with printed circuit wiring, and (5) integrated logic circuits. Single target generators for low prf pulse radars have been replaced by: (1) multiple air and ground target generators, (2) multiple target generator for high prf doppler radars, and (3) combination generator systems for pulse and pulse doppler radars.

Displays

A major function of modern fire control simulator displays is to show radar return data and record pilot proficiency. All operational radar fire control systems have a CRT display or multiple displays. To assure fidelity at lowest cost, most trainers have used the operational radar's display package. Television camera pick-up of an

operational radar CRT has proven to be an excellent cost-effective method for repeating fire control information on classroom-size displays.

Pilot proficiency record-keeping at first involved straightforward angle comparisons, with a counting mechanism to total the number of hits compared to rounds per gun burst. But added data on where and why and when misses were occurring was required. Pen and ink recorders, which were and still are a basic recording mechanism, were added. Servo driven scribe projectors were also used to record interceptor and target ground track and then display the recorded data on a projection screen. Latest recording methods involve alphanumeric and situation type CRT displays refreshed by digital computer rapid access disc and core memories.

TYPICAL TRAINING DEVICES OF EACH ERA

Twenty-one 15C4 training devices, divided into four types, are typical of nine years of classroom tactics trainers for 11 operational radar types built between 1959 and 1968. A significant reduction in training cost was achieved by divorcing flight and tactics. Uncramped space requirements permit the training of up to 11 students with the aid of large scale radar and fire control displays.

The early 15C4 series simulated straightforward pulse radar systems while later versions simulated pulse and doppler radar systems.

First Type

Device 15V4, Radar Contact Trainer, was an add-on radar training device to existing operational flight trainers (OFT). Flight information, consisting of true air speed, flight elevation angle, compass heading, roll angle, pitch angle, and altitude, was acquired from the OFT in the form of shaft positions using mechanical linkage and servo followers. The OFT was provided with a modified operational AN/APS-19 Radar Set. A gun trigger was also installed.

An instructor control unit containing target controls and a combat information center display was provided.

Courses were created by means of a special integrator using a modified commercial watt-hour-meter (WHM) type of rotating disc. A current representing velocity caused the WHM disc to rotate at a rate which was directly and linearly proportional to the input. Three neon lamps and a phototube furnished an output voltage which, when amplified by then standard push-pull 6L6 vacuum tubes, drove a motor synchronized with the WHM disc. The motor, in turn, drove potentiometers and counters representing velocity x time. "Calculating units" were implemented using rotatable transformers, two-phase motors, synchronous transmission units and indicators, pots and variable autotransformers. These components composed a 60 cycle a.c. computer system.

The air intercept radar simulator received flight data from the synthetic flying unit and position data from the calculating units, and combined these inputs with instantaneous direction data from a radar antenna. The simulator used the actual APS-19 antenna mechanism to obtain the correct pattern of antenna motion.

Radar simulation consisted of target, altitude line, sea return, random noise, and receiver tuning.

Counting mechanisms recorded trainee accuracy of aim, firing range, and rounds per burst.

Second Type

Device 15V6 Type II was an all weather radar simulator for use with the F3H-2N OFT. The radar simulator and flight trainer were housed in two van trailers parked side by side. The flight trainer housed the cockpit, flight instructor's console, and a special purpose analog flight computer.

The radar simulator van contained a radar instructor's console, a student fighter director console, and an analog computer. Device 15V6 Type II simulated the AERO 19A fire control system. Armament simulation included four 20 mm cannon, sidewinder missile, and nuclear weapons.

Intercept problems were realistically simulated and the pilot's performance was monitored and evaluated by the flight and radar instructors. The student pilot was directed to an intercept by a student fighter controller through a simulated radio link. The student fighter controller was evaluated by the radar instructor.

The armament control panel on the flight instructor's panel contained switches and indicator

lights for selecting the type of missile or stores loaded for the problem.

The student fighter director's console contained two radar indicators (PPI and RHI) and radio link controls.

Third Type

Device 15G4E, Radar Scope Interpretation Trainer, provides supervised basic and advanced classroom training in interpreting radar presentations of the AN/APG-59 radar and the AN/AWG-10 fire control system in the F-4J aircraft. The device provides the trainee with complete all-weather tactical training, including all types of intercepts, armament, ECM, and team training of radar intercept officer (RIO) and pilot personnel.

The RIO-instructor console contains controls for both the RIO and the instructor. The instructor's position contains problem control, initial position, and ECM panels. These panels contain the necessary controls and indicating instruments to enable the instructor to fly enemy targets and friendly interceptors, position surface ships, operate the AN/APG-59 radar, and control the use of ECM. Take-control logic permits transfer of radar control from instructor classroom demonstration position to the RIO training position. The RIO console has interceptor instruments, a radar indicator, and duplicate radar controls. A television camera and mirror arrangement are mounted on the RIO position so the instructor and classroom students can monitor the radar display on the basic display rack.

The basic display rack, which faces the classroom, contains a high resolution television monitor and large heading and altitude difference instruments. The television monitor presents an enlarged picture of the RIO's radar indicator. The plotter rack has six special projectors for creating either of two classroom displays on a six- by six-foot projection screen. One display shows the target and interceptor movements on horizontal X-Y grid coordinates; the target track is projected in red, the interceptor in green. The other display has an interceptor silhouette at the center, a target silhouette at the proper position relative to the interceptor, and superimposed radar beam, range circles, and relative azimuth. The interceptor and target silhouettes rotate to show headings in geographical coordinates. The antenna beam rotates to show search and tracking operation of the interceptor radar antenna.

The computer rack houses the video and analog computer assemblies. The computer receives inputs from the RIO-instructor console for complete problem control of targets, interceptor, and ECM. The computer also responds to radar and fire control inputs from the instructor and RIO. Realistic displays are created for the RIO and classroom displays. Readouts are provided to aid the instructor in the generation and control of flexible problem formats.

Typical components in the computer rack are the 400 Hz. servo and the 400 Hz. summing amplifier. Servo components which are geared together are the motor and tachometer, potentiometers, synchros and resolvers.

Fourth Type

Device 15C8,* Missile Control Officer Trainer (MCOT) (figure 2), is the latest in-service digital computer based airborne radar fire control simulator. Specifically designed to provide a dynamic, realistic, trainee-centered capability for PHOENIX Missile Control Officer (MCO) training, the 15C8 provides training in tactics development and operational checkout, evaluation of weapon employment procedures, preflight evaluation of weapon system updates and changes, and all basic PHOENIX missions. Its major features include:

1. Realistic simulation of PHOENIX AMCS controls and displays; limited simulation of pilot flight control and display equipment.
2. Simulation of 96 targets with realistic dynamic characteristics freely maneuverable in a 1000 by 1000 mile area of operation.
3. Control and programing to allow for simulation of the effects of a wide range of ECM.
4. Provision of extensive problem formulation aids to assist creation of exercises; repeater displays which allow the instructor and observers to view the effects of student actions.
5. An Attack Geometry Display which allows instructor monitoring of the total tactical situation.
6. Provisions for stopping, resuming, recording and replaying the exercise to assist in the critique of student performance.

**Information on the MCOT was provided by the Hughes Aircraft Corporation, who designed and built the trainer for the U.S. Navy.*

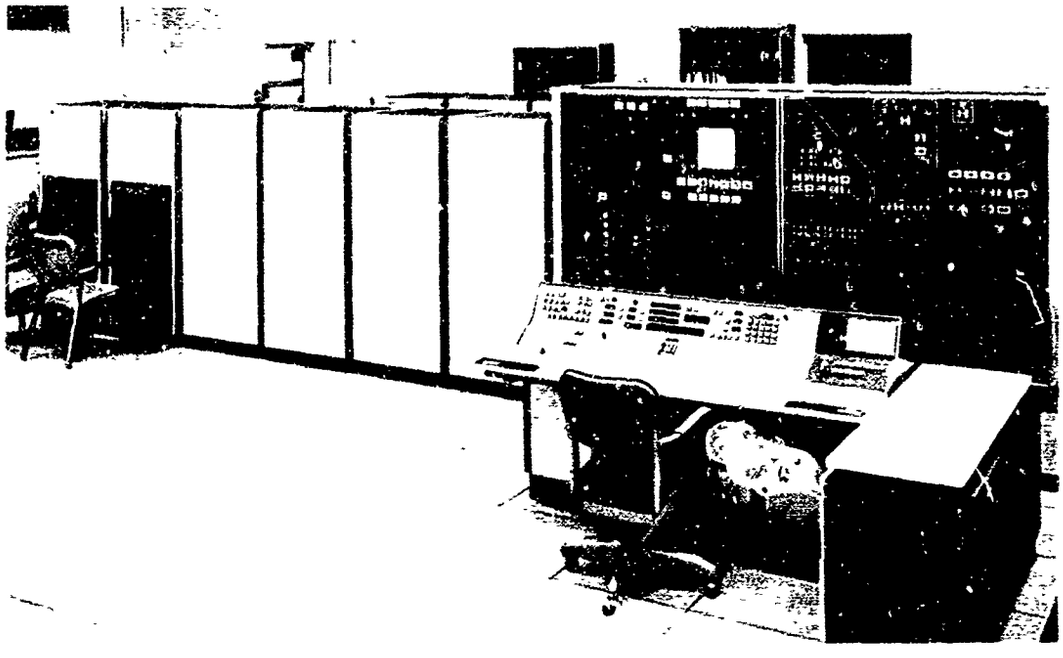


Figure 2. Device 15C8 Missile Control Officer Trainer.

7. Potential capability for integrating with an OFT—effectively providing a full Weapon System Trainer capability.
8. Generation of target data and complete control of trainer functions through use of a general purpose digital computer.
9. Digital techniques in display data processing and sensor simulation.

TRAINING FACILITIES

The trainee facilities of Device 15C8 consist of a simplified pilot position on the left and an MCO trainee position on the right. These positions provide the controls and displays necessary for both MCO trainee operation of the PHOENIX (AN/AWG-9) AMCS and pilot control of own aircraft maneuvering. The spatial relationships among the equipments at each position—in terms of height from the floor, arm reach distance, mean eye level, etc.—closely approximate those found in the actual aircraft cockpit.

The MCO trainee position approximates the functional capabilities, interrelationships, appearance, feel and reactions found in the aircraft while avoiding an unnecessary duplication of the cockpit details not directly involved in MCO PHOENIX tactics. It consists of an entirely simulated complement of PHOENIX AMCS controls and displays which include the Detail Data Display (DDD) panel, the Tactical Information Display (TID) panel and the right Hand Control (MCO) unit.

Instructor Console

The instructor console enables the instructor to formulate and control training exercises. Displays visually indicate status of the exercise as well as the operations being performed by the MCO trainee. The Attack Geometry Display provides the instructor a detailed view of the exercise tactical situation as it develops and presents programed targets whether or not they are being shown on the MCO trainee displays. The symbology on the AGD identifies the type of target, the track number assigned to the target, and other tactically significant data. The MCO Repeater Display presents a twice-normal size duplication of all displays and controls available to the MCO trainee and allows real-time monitoring of the MCO trainee actions and reactions. The primary trainer mechanism for supplying feedback is an extensive Record/Replay facility. At the option of the instructor, all actions taken by—and displays presented to—the MCO trainee and the instructor are recorded by the trainer computer. Through appropriate control manipulations the instructor can stop ("freeze") the exercise, specify any prior exercise time, and command a real-time

replay of all actions and displays which occurred subsequent to the specified time. This replay occurs on the MCO trainee and instructor equipment and is an exact replay of occurrences with the exception of physical position changes of controls. Furthermore, the instructor may command a freeze at any point during the replay and then continue the replay, or he may cancel replay at that point and begin the training exercise again, but with the tactical conditions that existed when he stopped the exercise. The instructor may use his controls to command display of an arrow ("Comm Mark") on the MCO trainee's Tactical Information Display pointing to a target or area in order to provide concurrent evaluation data through the intercom.

The following controls and displays available to the instructor allow him to monitor every aspect of the MCO trainee's performance:

1. Trainer Management Group—used to formulate activities, specify the exercise and the mode and control to be used, the Attack Geometry Display, intercommunication, and the cursor.
2. The Track Specification Group—provides the capability to track, specify and ascertain any of the various track parameters pertaining to an instructor-specified track. (These parameters range from target positional and performance characteristics through definition of aircraft type and a wide range of ECM threats. In addition, this group of controls provides the specific data definitions required in creating and editing exercise problems.)
3. The Own Aircraft Group—provides instructor facilities for "flying" the own aircraft, specifying missile loading and PHOENIX AMCS status, specifying missile and PHOENIX AMCS malfunctions, controlling the sea return simulation process, and performing the necessary pilot "enable" functions in the weapon launch sequence.
4. The Power Control Group—provides facilities for power application.

Two sets of instructor displays are provided, the Attack Geometry Display (AGD) and the MCO Repeater Display (MRD). The AGD consists of a 20-inch diamter CRT, three sets of indicators which illuminate in response to actions taken in the Trainer Management Section of the ICP (i.e., Symbol Brighten, AGD Scale specification and Symbol Erase), and a digital Exercise Time Clock. This display facility is used extensively during both the formulation of problems and the conduct of an exercise. During conduct of the exercise, the AGD furnishes an overall view of the planned tactical situation as it develops, unaltered by the actions of the MCO "real world," and becomes a critical facility for the instructor's evaluation of the trainee. By referencing the AGD, the instructor may compare the "real" tactical situation to that being operated upon by the trainee in accordance with the trainee settings of the simulated AN/AWG-9 sensor controls.

One of the most interesting capabilities of Device 15C8 in comparison with earlier systems is the automated blackboard provided by the AGD and MRD. These displays, used as a problem formulation aid, permit the creation, editing, altering, and review of exercises. They serve the same purpose as the blackboard and chalk of thirty years ago brought up to date with advances in technology.

Device 15C8 is a complete simulator using no operational radar equipment. The radar simulator implementation includes doppler and conventional radar with an IR subsystem. Its basic computational element is a commercial general-purpose digital computer supported by both core and disc memory systems. A special logic system is provided to incorporate an interface between the digital computer and the display and control devices.

THE FUTURE OF FIRE CONTROL SYSTEMS

The evolution of fire control systems and simulators began in the years immediately preceding World War II. At that time, two major new devices in airborne weaponry—radar and rockets—pioneered the way to completely new concepts of air-to-air combat. Simulators were required to provide the hours of training under controlled conditions necessary to operate the new equipment. But paradoxically, as prime equipment became more and more automated, additional training was required to give the pilot the full capability to take over as the automated equipment failed. In the decade to come, as new systems involving radar, IR, and possibly laser are produced, we can expect the training requirement to increase because missile control officers simply will not be able to get the experience they need for coping with occasional failures of their automatic equipment. In the coming years,

therefore, we are likely to see expanded trainer stations, some accommodating many missile control trainees simultaneously for maximum utilization, with correspondingly expanded controls and displays. Advanced trainers will make use of the latest state-of-the-art for higher reliability. And of course there will be new trainers for new systems.

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His experience includes work on guided missiles, airborne and ground-based radars, digital and analog computers, complex trainers and simulators, antenna and microwave systems, and electronic test equipment.

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Development of Multiship Tactical Trainers for Task Force Command and Control

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For many years, multiship tactical trainers for task force command and control have constituted an important class of simulator-based training devices developed for the Fleet by the Naval Training Device Center. Cost-effective devices have been developed to provide training in shiphandling, combat information center operations, antisubmarine warfare, and fleet air defense activities. These trainers make possible coordinated crew training on exercises difficult and expensive to conduct with operational fleet equipments. This paper traces the development of representative devices in this class, and shows the impact of advances in technology on the sophistication and fidelity of the simulation provided, as well as on the reliability and maintainability of the trainers. The advances in technology analyzed are primarily with respect to computations, scoring and monitoring, automated problem control, and display techniques. A summary of the characteristics of the training devices considered to be in this class is included.

Throughout its twenty-five year history, the Naval Training Device Center (NAVTRADEVCEN) has devoted major efforts to the development of tactical trainers for implementation of Navy training programs in task force command and control. Resulting from these efforts have been several successful series of multiship simulators providing command-level training in shiphandling and tactical maneuvers, antisubmarine warfare, submarine attacks, Combat Information Center (CIC) operations, and fleet air defense. The story of the development of these trainers forms an interesting chapter in any history of naval training devices.

Though not as well known–particularly to the lay public–as the multitudinous Link "blue boxes" of World War II reknown, or as the well-publicized Apollo simulators which provided training trips to the moon for our astronauts, multiship tactical trainers are major training systems which have played–and continue to play–an important role in assuring the readiness of our fleet. They have greatly reduced the cost of task force command and control training and have made possible coordinated team training, which is almost impossible to provide through fleet exercises with operational equipment. There is every indication that the requirement for trainers of this type will extend well into the future and with increased dimensions.

The multiship tactical trainers which we are describing are primarily environmental simulators Although operational mockups of ships' bridges, CIC rooms and other crew stations are required, and certain vehicle and equipment operating characteristics must be simulated, the primary concern is with the creation of realistic tactical environments. Thus, some of these trainers reproduce gaming areas extending over thousands of square miles, and upward and downward from the surface of the sea. Introduced into this environment are varying numbers of ships, aircraft, submarines, landmarks, and other environmental features. The simulated environments include, in many cases, representations of hostile forces.

Stated differently, multiship tactical trainers for task force command and control, as commonly conceived, are not designed to provide basic training in vehicle or equipment operation. Rather, equipments and vehicles are simulated from a functional point of view, to the end that an adequate environment is provided for complex multiship training exercises. The objective is to train command personnel to deploy their vehicles and weapon systems so as to achieve a team

objective; e.g., the tracking and destruction of an enemy submarine.

NAVAL TASK FORCE COMMAND AND CONTROL OPERATIONS

In the earliest days of our naval history, task force command and control implied little more than the transmission of orders between closely-spaced ships by voice, flags, lights, swimmers, or men in row boats. The maneuverability of the ships was limited and targets were almost always totally visible. Today, naval maneuvers and tactics frequently require the coordination and command of many surface, air, and shorebased units employing a variety of sensors, weapons, and communications means. The detection of targets may require the most sophisticated of equipments.

Shiphandling and tactical maneuvering can now be accomplished by the use of radar in the darkness of night, or in weather conditions which severely limit visibility. Air intercept control can be effected from a ship or shorebased CIC, using information relayed by data link from an airborne early warning radar. Coordinated attacks on enemy submarines can be made by ships, aircraft, and submarines which may not be within visual range of each other at times during the attack. Fast moving amphibious assaults can be directed by a single task force commander on a real-time basis. And warnings of enemy attacks can be relayed from one CIC to another with lightning speed. The utilization of digital computers, especially in conjunction with data link systems such as the Naval Tactical Data System (NTDS) and the Airborne Tactical Data System (ATDS), has further broadened the scope of naval task force command and control activities and, in turn, made more complex the problem of training officers and other personnel for these operations.

The importance of the task force command and control function was emphasized by Lieutenant Commander M.F. Talbot (S.C.), U.S. Navy, as early as 1933. Writing in the United States Naval Institute Proceedings in January of that year, he raised the query, "With nearly equal fleets, on what will future victory rest?" and proceeded to answer by saying, "Not, I believe, on material perfection per se, nor on any slight numerical superiority allowed by treaty ratios. Nor will success in battle depend upon the administrative machine that is so often hailed as the essence of command. Rather it will rest on the skill and intuition of the commander in chief, aided by captains and flag officers whom he can trust... The will to win, the master's genius for battle, *complete understanding between commander and subordinates* forming a 'band of brothers'- these are elements of war more powerful than mere tons and guns."

TRAINING FOR TASK FORCE COMMAND AND CONTROL

From Fleet Exercises to Synthetic Training Devices

"Man goes to battle armed with sword and shield, the weapon that slays and the cover that gives to the slayer some measure of protection against his enemy's counterthrust. Add to these the concept of movement and the clash of armed men, and we have in their barest fundamentals the three basic elements of tactics: striking power, staying power, and mobility. The study of tactics is at bottom a study of the possible combinations of these three elements against an enemy himself armed, armored, and fleet of foot. Local success results from the application of superior hitting at some point in the arena of battle."*

Training in tactics involving many ships has a number of basic by-products which have been recognized for many decades. First of all, by exercising the individual weapon, the crew becomes familiar with its specific task. Secondly, when exercising a multitude of equipments, the specific shortcomings of the weapons systems can be ascertained under operational conditions. Thirdly, and probably most important, the team work required for successful operations of vast projects (such as naval warfare) and the establishment of confidence in the ability of commanders and subordinates to perform under the required stressful conditions, are established. However, in no sense can the stress of battle, with real men using real guns, be simulated either

*Lt. Cdr. M.F. Talbot (S.C.), Tactics and Command, A Historical Sketch, U.S. Naval Institute Proceedings, Jan. 1933.

synthetically or in a fleet exercise, as illustrated by the following excerpt.

> *"Real war and sham war both have their advantages and disadvantages. In real war -especially naval warfare -a combatant may go for a month, or a year, or the whole duration of the struggle, without engaging in real fighting. In sham war he will always get his 'fighting' according to a schedule prepared long in advance, but it will never be real fighting."*
>
> *"Sham war—the war game- is an attempt to gain war training in peacetime by duplicating as nearly as possible the conditions of war. Attaining an approximation of the real thing at a minimum cost of lives and material is the main thing in its favor. Against it is the fact that it will never be quite possible to parallel war conditions and motivation when the life and death of men and nations do not hang in the balance. Subject to this limitation the war game is highly useful and the science of it- and therefore the tangible results from it—are improving year by year."*
>
> *"This is especially the case with the game of naval warfare. It is because there are more vital things to be given the near-acid test of near-war at the present time than ever before that the United States naval maneuvers of 1929 are by far the most important ever held by our own or any other country."**

The early training methods to develop the skills in the use of available weapons, and proficiency in team tactics invariably involved exercises and maneuvers at sea. A typical example of this was the exercises by the ships of the Atlantic Station in 1886, as a result of which regular yearly exercises and drills were proposed. The purposes of these exercises were the same as those which the 1970's synthetic training system was designed to achieve. The reports issued by responsible officers at the conclusion of the exercise recommended improvements and incentives for obtaining more skilled personnel, pointed to shortcomings of the operational equipment, and praised the enhancement of morale and efficiency brought by successful team efforts.**

The history of synthetic tactics training devices for task force command and control dates back at least to the early days of World War II, when the British, sorely pressed to develop their anti-submarine warfare capability, devised tactical maneuvering trainers for this purpose. A principal feature of these early trainers was the use of projectors which could be rotated about two axes to throw spots of light on a large screen to depict the positions of various ships and planes in an exercise.

These early British trainers were seen by U.S. Naval Officers -notably Admiral Luis de Florez--on a survey trip in 1940. Upon the recommendations of Admiral de Florez, this type of device was introduced into the U.S. Navy, first through purchase from England and later through the development of improved models by the (then) Special Devices Center.

The necessity of requirements to train large numbers of officers for task force command and control assignments, and the cost, time, and safety problems associated with the use of operational equipment for this purpose were the catalysts which prompted the development and use of synthetic devices in this area of training.

*Difficulty and Cost Involved in Using Operational Equipment**

Naval task force command and control training can be achieved in two ways. One is to use operational equipment, the other is to use synthetic equipment. Ships and aircraft are the training tools of the first method; simulators and special training devices, the tools of the other.

Training with operational equipment is straightforward in concept, but is fraught with difficulties and limitations. Ships and aircraft must be provided in sufficient quantities to permit crews to become proficient in their use through experience in actual operation. Where complex techniques and skills must be acquired, many hours of operation are frequently necessary. Training carried out with operational ships, aircraft, and equipment is inevitably accompanied by high operating cost and material wear and tear. Further, such training frequently results in the loss of ships and aircraft through accidents, many of which are caused by the inadequate skill levels of the trainees.

An antisubmarine exercise is a typical and frequent naval training problem. If operational equipment is used, it requires the availability of aircraft, submarines, and certain expendable tactical equipment. Frequently, this availability is delayed by operational commitments, equipment failures, or weather. If the weather is satisfactory

*Lewis R. Freeman, RNVR Special Correspondent, The 1929 Maneuvers, New York Times, Feb 11, 1929.

**U.S. Navy Dept., *Report of Exercises by the Ships of the North Atlantic Station in 1886*, Washington Government Printing Office, 1887

*Adapted from Lt. J. Gordon Vaeth (USNR), *Synthetic Training for Economy and Readiness*, U.S. Naval Institute Review, December, 1953

and if all participating units are operating and available, they ordinarily proceed to rendezvous. Time is consumed as these units proceed to and from the rendezvous point, where additional delay is encountered while communications are established and the participants take position for each run.

When the submarines dive and the problem begins, the aircraft execute search and attack operations in accordance with established doctrine. Ideally, when tactical errors are made, those portions of the exercise should be repeated until operating proficiency has been established and errors eliminated. Furthermore, it should be possible to reconstruct the operation in such exact detail as to enable a critical post-flight analysis to be made of the aircraft's tactical performance throughout the entire exercise. Unfortunately, aircraft fuel limitations, sometimes the weather, and usually the general arrangements under which the exercise is held do not permit such ideal training conditions. The problem normally ends with a return to base, a post-flight conference and a conclusion, usually based on none-too-accurate or detailed information, regarding the aircraft's effectiveness against the submarine.

Advantages of Synthetic Training

Simulated missions, in contrast, are carried out under the close supervision of a specially qualified instructor. Aircraft flight path is permanently recorded in three dimensions, as is the course of the simulated submarine. These records are combined and synchronized on a time-related basis, which makes it possible to assess crew performance at virtually every instant of the exercise. If required, the exercise can be stopped and certain phases repeated to correct for errors in crew procedure or for failure to adhere to established doctrine. To save time, the problem can be speeded up; i.e., parts which are unimportant can be accelerated. If necessary, the trainer can be operated around the clock and a large number of crews trained in the problem in a relatively short time.

Emergencies and equipment failures can be introduced into the problem from the instructor's station. This is an important safety consideration and has been a major factor contributing to the increasing acceptance of the synthetic training concept, especially by naval aviation and commercial airlines. It is not unusual for as many as thirty equipment failures to be capable of simulation in a single operational flight trainer. This enables training in emergency procedures and acquisition of correct instinctive pilot response to be achieved without danger to aircraft or crew. In the actual aircraft, there may be no "second chance" when these or other dangerous situations arise. Flight simulators and synthetic training equipment allow mistakes to be made, "second chances" to be had, and "crashes" to occur. Simulation of emergencies has had an impressive psychological—often emotional—effect upon trainees, particularly upon those who unintentionally "crash" the trainer.

Simulation equipment is admittedly expensive. Trainers sometimes represent an investment of several million dollars. But the cost, like everything else, is relative.

Operations, maintenance, and repair costs must be included in any assessment of the economic value of simulation equipment and techniques. Such costs are substantially lower in the case of the simulators than in that of the actual equipment. Differences in the operating expenses of synthetic and actual equipment largely account for much of the enthusiastic support of flight simulators by cost-conscious airlines.

There are other costs to consider. With the use of simulation equipment, the services of operational craft for training exercises can be reduced. Submarines, for instance, need not be diverted from tactical deployment, in order to serve as targets for air antisubmarine training; they can be freed for assignment to war patrols. Similarly, the fleet need not be deprived of the availability of operational ships and aircraft to carry out strictly training functions. Surface and air units can be more directly employed against enemy or potential enemy threats. Ships and aircraft can be made to spread further and material procurement requirements made to decrease. In the air, on the surface, and beneath the sea, material-wise and operations-wise, naval costs can be reduced by substituting synthetic for operational training.

For reasons of low cost, efficiency, flexibility, and safety, simulation provides the means for effective training. It points the way to increased naval economy, greater personnel proficiency, and a higher state of fleet readiness.

SHIPHANDLING AND TACTICAL MANEUVERING TRAINERS

Shiphandling and tactical maneuvering represents the oldest class of naval operations. Shiphandling in the days of sailing vessels differed drastically from- and required far more muscle than–the handling of a modern aircraft carrier or destroyer. And tactical maneuvering in the very earliest times simply meant maneuvering one's ship to achieve the optimum angle of attack for ramming the enemy's ship!

Device 1BZ2–Maneuvering Tactics Trainer

Perhaps the first trainer for this class of operations developed by the United States was the Maneuvering Tactics Trainer, Device 1BZ2. This device, built in the late 1940's and installed at the Officer Candidate School, Newport, Rhode Island, has been described as "affording realistic drill or practice in tactical maneuvering problems that involve surface craft, airplanes, and torpedoes." Housed in a building 80 feet long, 40 feet wide and 30 feet high, the device, which is still in use, can train up to 52 students at one time. Originally, 16 projectors were used to show the positions of 16 ships and planes on a 16- x 16-ft screen, representing a gaming area of 96 x 96 nautical miles. Later the number of projectors was increased to 25. Sixteen booths, simulating ship's bridges with positions for the Conning Officers, Tactical Officers, Communication Officers and Pilots, were provided. Eight booths have additional equipment for maneuvering either an airplane or a torpedo.

The device utilizes an electromechanical computer, an interesting feature of which is a series of special cams which can be interchanged to reprogram for different ships. The maintenance handbook writer (almost certainly employed by the device manufacturer) proudly proclaimed that these cams were designed to simulate *with extreme accuracy* the maneuvering characteristics of various types of ships!

In Device 1BZ2, enemy ships are portrayed on the screen as colored spots of light. When it is desired that the trainees see only the friendly forces, they are required to don colored goggles to "filter out" the enemy spots.

A degree of sophistication was introduced into the simulation through the computation of wind effects. Visual and radio communications are simulated. Future requirements were anticipated in the original design by allowing for aircraft speeds up to 600 knots!

Device 20A61–Maneuvering Tactics Trainer

A modern version of the Maneuvering Tactics Trainer is represented by Device 20A61, which was installed at Newport, Rhode Island in 1967. This device offers an interesting comparison with Device 1BZ2, a comparison which highlights the almost unbelievable advance in computer technology occurring in the less-than-twenty-year period between the development of the two trainers.

Device 20A61, consisting of 24 bridge mockups, eight Combat Information Center (CIC) mockups, and three Officer-in-Tactical-Command (OTC) rooms, is capable of training up to 200 personnel at a time, compared with 52 on the 1BZ2. Elements of the training problems which may be created with the device include radar display interpretation, helm operation, situation assessment, and communications.

Device 20A61 utilizes a general purpose digital computer for all computations, including the movements of up to 12 simulated vehicles in any training exercise. Vehicle position computation is maintained with an accuracy of 10 yards and course accuracy within a tenth of a degree. Unlike the 1BZ2, Device 20A61 does not require frequent adjustments and alinements to maintain its computational accuracy.

An electronic situation display is provided to allow trainees to observe the motion of their vehicle with respect to any other vehicle in the problem. This may take place over an area as great as 1,024 miles on a side. Alphanumerics and shaped electronic "images" are used to code the vehicles. This electronic situation display supplants the spotting projectors of Device 1BZ2, providing far greater informational content, but, perhaps, with some loss of the dramatic qualities of the "war room" atmosphere created by the projectors in the earlier device!

Three additional features of Device 20A61 distinguish it from its famous predecessor. Problems may be run in real time, or at rates corresponding to two, four, or eight times real time. This feature is used to shorten problem times on certain training exercises, with obvious economies. The device is further capable of

operating in four independent problem modes simultaneously, a feature which contributes greatly to its versatility. Finally, Device 20A61 makes provision for the insertion of ship malfunctions into the training problem by the instructor.

Device 20A62–Emergency Shiphandling Trainer

Another modern shiphandling trainer is Device 20A62, installed at the Fleet Training Center, San Diego, California in 1968. This device, described as an Emergency Shiphandling Trainer, provides ship bridge mockups, with each mockup containing all the standard controls required to maneuver a ship. In addition, each bridge mockup contains a radar PPI display, a TV monitor to present a situation display (not a part of the ship's equipment complement), and provisions for light and whistle communications. The motion characteristics of any one of three classes of naval vessels are simulated with reasonable fidelity. A training exercise involving as many as eighteen ships and buoys may be conducted with the device. All computations are accomplished digitally.

One of the features of Device 20A62, as in the case of Device 20A61, is the use of a closed circuit TV system to present situation displays to all of the trainees. In the 20A62 system, a display is first created on the face of a CRT. This display shows the location of all ships and buoys in the problem, together with their headings, identities, and type designations. Optically, a 35 mm slide picture depicting the shore lines of a harbor entrance is combined with the CRT display for viewing by the TV camera. The result is a composite image depicting the complete tactical situation. This image is displayed on a TV monitor at each of the four bridge mockups and in the instructor's room.

Another interesting feature for this device is a taped system test program, which can be run on the simulation computer to evaluate the device. With this program, test problems can be inserted and run quickly, with the results being observed on the radar indicators, TV monitors, and other indicators, dials, or instruments. The test problems are so constructed that errors of solution are readily observed visually.

Device 20A62 is providing valuable training in shiphandling techniques to naval officers. The training program, which has been structured to make optimum use of the device, is team-effort oriented and is designed to develop experience in dealing with a variety of ship maneuvers.

Device 16B13–Amphibious Operations Trainer

A rather unique training device, which perhaps can be grouped with shiphandling and tactical maneuvering trainers, is the Amphibious Operations Trainer, Device 16B13. In this device, which was built in 1966, model ships and aircraft are maneuvered on and over a terrain table 40 feet long by 10 feet wide by 30 inches high to provide an overall presentation of an amphibious assault landing. The trainer was designed to train both U.S. Navy and Marine Corps personnel. It is used to help develop an understanding of the coordination, communication, organization, and relative positions of all forces involved in an amphibious operation.

The sea portion of the terrain model enables maneuver simulation for seven transport ships in a circling formation; two boat waves of seven circling landing craft; four boat waves of seven landing craft, each simultaneously moving to the beach land area in successive in-line columns, V-formations and line abreast formations; four mine-sweepers moving on transverse course parallel to one another and the beach; four fire support destroyers circling on outboard platforms; one fixed position aircraft carrier; and two transport ships.

Maneuvering over the sea and land areas are various model aircraft, including three helicopters operating from the aircraft carrier, one observation aircraft, one strike aircraft, and one transport plane.

The entire training device is operated by one person from a control panel located at one end of the terrain stand. A slide projector, a 16 mm movie projector, and a view-graph are provided for auxiliary visual presentations. Also, a tape recorder and public address system are provided for the reproduction of special sound effects and amplification of vocal narration by two instructors, one from the Navy and the other from the Marine Corps.

ANTISUBMARINE WARFARE (ASW) TRAINERS

ASW represents a category of naval operations involving unusually demanding training requirements. It is perhaps in this area that the advantages accruing through the use of synthetic training devices have been most notable. The German submarine threat in World War II of course hastened the development of ASW tactics

trainers; the current threat posed by enemy submarines keeps in the forefront the need for these training systems.

Device RS8

An early ASW trainer, built by the NAVTRADEVCEN and put into service about 1950, is Device RS8. This fixed installation device is a trainer for enabling naval command officers to perfect the coordination of sea and air forces in locating enemy submarines during "hunter-killer" operations. It provides simulation of a task force consisting of nine surface craft, two heavier-than-air craft one lighter-than-air craft, four helicopters, and four enemy submarines, with all forces coordinated in a unit under complete supervision and control of an instructor. The gaming area is 100 miles square.

Two six-foot screens provide status display to both the instructor and to a large audience. The relative locations of friendly and enemy elements are displayed by projected spots of light one inch in diameter. Individual students control the 16 members of the friendly task force from individual rooms, each of which contains suitable control mockups and a status display. The four enemy submarines are under the direct control of the instructor. All movements are created by means of dead reckoning tracers properly scaled for compatibility with one another at the projection point. Provision is included for simulation of sonobuoys, which may be dropped where desired and whose simulated response signals, available to the students, are realistic to the point of including the effect of prop beat noise normal to sonobuoy functioning. Five channels of radio communications are included in the trainer, as are means of simulating the operation of MAD equipment in the submarine search operations. The master control for the instructor provides a radar screen displaying all craft except the sonobuoys, adjustable cursor for position measurement, switches for blanking each craft on the student's radar screens, submarine status control, synchro dials for speed and heading of all craft, intercommunication equipment, and miscellaneous controls for instructor's needs. There are 16 separate student rooms for simultaneous, but independent, instruction.

Computation is performed using analog simulation implemented by tube and relay circuits. The computer solves for the relative positions of all craft simulated, to provide for displays in each mockup appropriate to the surface ship, aircraft, or submarine represented in that mockup. The status display projectors are driven by two-phase a.c. motors. The unit was modified in 1957 to enhance its accuracy and performance.

Device 21B22—ASW Tactical Game Board

Another ASW trainer, which was put into operation at Key West in the first half of the 1950's, was Device 21B22, referred to as an ASW Projected Gameboard. It was intended for use by commanding officers, ASW officers and executive officers in screen orientation, hunter-killer search, patrol, and retiring search. It further was designed to train students in conning their own ships, accomplishing intership communications, and maintaining their own plots of the tactical situation as it developed.

The trainer, which is no longer in use, was constructed as a theater with projection screen and 13 projectors, to show the positions of eight destroyers, two submarines, two aircraft, and one convoy. Other equipments included were 13 dead-reckoning analyzers, eight dead-reckoning tracers, 13 course and speed helm units, and a communications network. The gaming area for simulated exercises was 40 x 80 nautical miles. The tracks of all vessels were plotted manually on the projection screen from the instantaneous position data afforded by the projectors.

Device 14A1—Action Speed Tactical Trainer

A "second generation" ASW tactical trainer is represented by the Action Speed Trainer, Device 14A1, which was first put into operation about 1957. This trainer differs from its predecessors in two major respects: (1) a vacuum-tube, analog computer system was used in lieu of an all-mechanical system; and (2) simulated radar PPI displays were provided. In concept, however, Device 14A1 is very similar to earlier ASW trainers.

The trainer originally provided for simulation of eight destroyers, one convoy, two submarines, and six aircraft, with provisions for adding 12 additional craft to the simulation. The instantaneous locations of all these craft in a 100 x 100-mile gaming area are indicated on a 9- x 9-foot screen by means of 17 optical projectors. Maps of properly scaled land masses and sonobuoy

locations are also presented in the display through the use of auxiliary projectors.

Plots are developed manually with colored grease pencils on the rear surface of the viewing screen. Also, provision is made for replotting on the front of the screen, using colored ultraviolet crayons to facilitate the analysis and critique of previously performed operations. Trainees control the destroyer movements from helm units located in eight mocked-up CIC rooms. Helm units for control of the convoy, two submarines, and six aircraft are provided at the instructors' stations in the problem and helo/air room.

Simulated radar azimuth and range indicators, one located in each CIC room, are provided to show the relative position of each craft in the training exercise with respect to the destroyer controlled by the CIC helm unit. Radar presentations are also provided at the instructor's master control console and in the helo/air room.

The limitations and disadvantages of Device 14A1 reflect the state-of-the-art of the time period in which it was developed. To maintain computational accuracy, it was necessary, among other things, to repeatedly balance tubes, and adjust helipot trim pots and gear trains. The only means provided for identifying a target or craft in the display was a switch to extinguish the projector for that craft! Greatly improved computational accuracy, enhanced reliability, simpler maintenance procedures, and displays with greater informational content, at this point, awaited the development of high speed, general purpose digital computers and associated CRT display systems.

Device 14A2–Surface Ship ASW Attack Team Trainer

The breakthrough of digital computation and problem control was first realized in an ASW Attack Trainer with the development of Device 14A2 in the late 1950's. This trainer is essentially an ASROC Weapon System Simulator; however, the simulation includes support units consisting of two surface and two subsurface units and three aircraft, making the Device indeed a multi-ship tactics trainer.

Working mockups of much of the actual equipment on an ASROC ship are provided in Device 14A2, including the Underwater Battery Plot, the Combat Information Center, the Launcher Captain's Control Station, and the Conning Station. Team training is accomplished utilizing the ASROC ship's normal ASW team, with three to 12 instructors and utilizing a 12-vehicle capability.

The importance of this device in the Navy's ASW training program may be inferred from the fact that units have been installed at six different locations: Newport, Rhode Island, Charleston, South Carolina; Key West, Florida, San Diego and Long Beach, California; and Pearl Harbor, Hawaii. Further, the device is to be upgraded in the near future through the addition of digital sonar simulation, which represents still another breakthrough in the simulation state-of-the-art.

Device 14A6A–ASW Coordinated Tactics Trainer Set

Perhaps the most modern and realistic means for team training in coordinated ASW operations is now provided by the ASW Coordinated Tactics Trainer Set, Device 14A6A, completed in 1967. The simulation provided by this device, which represents a modification of Device 14A5, is unusually extensive and includes the simultaneous and independent movement of 48 vehicles. These consist of 18 destroyers or submarines; 16 aircraft, either fixed wing or helicopter; one aircraft carrier; nine drone antisubmarine helicopters or weapons; and four instructor-controlled target submarines.

In addition, one flag plot and 64 sonobuoys are simulated. The sonobuoy types and techniques are: Echo ranging; CODAR N-S; CODAR E-W; JULIE; LOFAR; nondirectional passive; directional passive; and direction active.

Device 14A6A simulates the following sensors: active sonar; direct vision; electronic countermeasures; infrared; magnetic anomaly detection; passive detecting sonar; passive ranging sonar; radar; sonar intercept; and trail.

A total of 20 radio channels are available, and a 600-mile square ocean area may be used for maneuvering, with a maximum 2000-foot depth for submarines and a maximum 50,000-foot altitude for aircraft. Over 300 trainees may be involved in a single training exercise at the U.S. Naval ASW Tactical School, San Diego, California. A critique area, large enough to seat all of these trainees, is included in the building, which houses this training system.

Device 14A6A incorporates a problem display system which provides much greater informational content than the simple projector systems of

earlier devices. This system uses projectors capable of continuous plotting of vehicle tracks, and uses coded alphanumeric symbols to provide additional data. Thus the manual plotting used, for example, in Device 14A1 is replaced by fully automatic path recording. Another feature of this system is that the tracks developed during a training exercise are permanently etched on projector slides and can be reprojected at any time for critique purposes. Overall, this display system represents a second generation system providing, on a large screen for viewing by large audiences, displays not too unlike those created by today's computer-controlled CRT systems, albeit with considerably less flexibility and capacity.

SUBMARINE ATTACK TEACHERS

The effective use of submarines as weapons of attack requires highly specialized training of a type most feasibly provided by synthetic training systems.

Devices RS1B–Submarine Approach Trainer (MK 3) and 21A3–Submarine Attack Teacher (MK 7)

Several training devices in the category of submarine attack teachers were built during World War II and subsequently updated. Included in this category are Devices RS1B and 21A3. The purpose of these trainers is to provide team training of submarine fire control parties and conning tower and control room crews in tracking, approach and evasion tactics. Training is conducted through simulation for surfaced or submerged attack on single, slow or fast targets, on unescorted convoys or convoys escorted by one or more destroyers, or snorkling submarines; on evasion of ASW vessels; on long range radar attack; and on submerged sonar attack. Figure 1 shows one of the early submarine attack teachers.

These devices permit training against any one of five independent surface target models. Device 21A3 is an enlarged and improved version of the original RS1B trainer. The latter was installed at the Submarine School, New London, Connecticut, in 1944 and used almost continuously during the war. Typically, the trainer accommodates an average of eight, half-day classes per week, and provides training in six to eight simulated submarine attacks per class. The ASW vessel capability, now provided for one of the five targets, is the major operational difference between the earliest and the later devices.

Sonar simulator attachments for both Mark 3 and Mark 7 attack teachers were added in approximately 1950. This part of the system is designated Device 15R1.

On the lower floor of the Attack Teacher, a completely simulated conning tower is provided. This tower contains helmsman's station; two periscopes (one operative, one dummy); torpedo data computer; dead reckoning tracer for target vessel plot; a bearing and range indicator; surface search radar equipment; WFA sonar stack; torpedo ready light, battle order and firing panels; and intercommunication equipment.

The after end of the conning tower is open so that the instructor may view the actions of the conning officer and the fire control party. A panel at the instructor's station indicates course, speed, range, and bearing for each target. Just above the conning tower is a simulated submarine bridge with binoculars and target bearing transmitter for simulated night approach and attack. A simulated torpedo room on one side of the conning tower responds to commands to either the fore torpedo room or the aft torpedo room.

The periscope projects into the operating floor on the second deck of the trainer. On this floor, five model cars are maneuvered electromechanically in relative motion with respect to the periscope. Each car carries an accurate scale model of a target vessel. All models are interchangeable, and as many as five targets may be controlled simultaneously by an analog computer to simulate vessels either in convoy or proceeding independently.

The operating floor on which the cars move is designed so that the elevation drops off radially from the periscope in a scale to simulate the curvature of the earth. This gives distant target models a "hull down" appearance. A maximum optical range of 14,000 yards is simulated, allowing sufficient range for maneuvering the targets around the periscope in all directions. The gaming area of the device is 14,000 by 6,200 yards.

When in operation, the "submarine" is under control of the student officers in the conning tower and responds normally to the rudder controls. The submarine speed changes in response

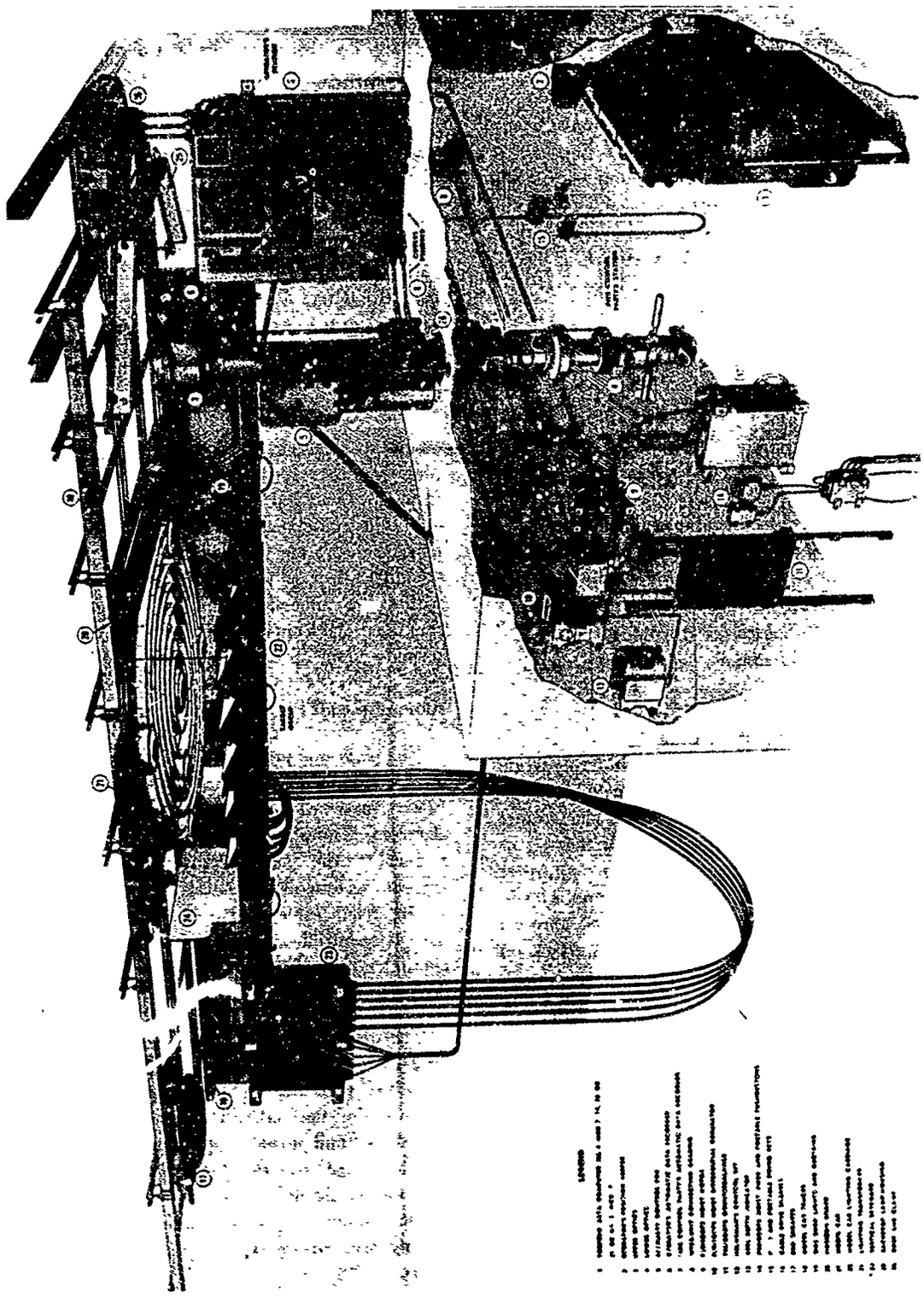


Figure 1. Early Submarine Attack Trainer.

to the engine order telegraph, with duplication of normal acceleration and deceleration characteristics. By means of an electromechanical analog computer, the changes in speed are transmitted to the model cars to provide the necessary changes in relative motion between the submarine and target vessels.

Submarine course changes are transmitted, via the computer, to the upper section of the periscope, which is rotated relative to the lower section to maintain the correct target bearing. The scale models viewed through the periscope appear on a simulated visual seascape to create the illusion of reality. Lighting of the operating floor may be controlled to simulate various periods of the day, from bright daylight to complete darkness.

The movements of the model cars are controlled by an operator who sets in course and speed changes to simulate evasive maneuvers of the target vessels.

The Submarine Approach Trainer is extremely versatile. It can be used for a wide variety of training problems, or in the evaluation of attack and evasive maneuvers. By simulating various attack problems, it is possible to evaluate attack procedures and establish operational methods, which finally can be tested at sea. The following types of problems may be worked out in the trainer either for training or evaluation of tactics:

1. Submerged attack on a single slow, or fast target.
2. Submerged attack on convoy escorted by one or more destroyers.
3. Night surface attack on any of the above targets.
4. Long range tracking and approach by periscope.
5. Long range tracking and approach by radar.
6. Submerged attack by sonar, unaided by periscope.
7. Evasion of antisubmarine vessels.

Implementation of these devices was completely accomplished by the use of analog computation components. Vacuum tubes were used for amplification. Servos using both two-phase induction a.c. motors and d.c. motors were employed. Synchros and resolvers were attached to the servos to generate command signals for the dials and indicators.

The target cars or "Crabs" bear the target model on a turn table and are propelled by three wheels which respond to speed and bearing synchro commands.

A fairly complex system of controls activates the lighting system to simulate day and night conditions. Also, some attempts were made in the lighting system to create the effects of sea motion and cloud conditions.

The sonar simulator attachment is compatible with the basic device. It uses what is basically a d.c. analog simulation. The sounds are completely artificially generated within this system; however, provision is made via a record player adaptor for introducing special noises and effects.

Device 21A38–Submarine ASW Training Facility

The U.S. Navy's newest and most sophisticated submarine antisubmarine warfare trainer is Device 21A38. This ASW attack teacher was officially introduced into service at the Fleet Submarine Training Facility, Pearl Harbor, on September 17, 1963. Providing realistic shorebased attack training, Device 21A38 fills a vital role in the training of U.S. Navy submariners. Through the use of target operators, operational equipment, and central simulation equipment, the essentials of the submarine seagoing environment are created.

Device 21A38 contains Skate, James Madison and Permit Class Submarine attack trainers, a war games complex, and a computer room. Each attack trainer contains a simulated submarine attack center and sonar room, a program operator station and a classroom. The war games complex provides overall program direction, control and observation. The computer room houses all simulation equipment and a digital computer. A communications system provides overall tie-in of the complete facility. Figure 2 shows the floor plan of the special building which houses the system.

The Skate attack center contains an MK 101 Fire Control System, plotting stations, sonar repeaters, and communications equipment. Trainees learn attack center procedures for all key phases of submarine warfare. Physically this attack center resembles an actual Skate attack center and the trainees use operational equipment to enhance the realism of the training. A periscope visual simulator, to be added at a future date, will further make the attack center a complete and realistic replica of its operational counterpart.

The Permit Attack Center, like the Skate, is a realistic replica of the operational attack center. It contains a fire control system, operational sonar, communications and the plotting station. In

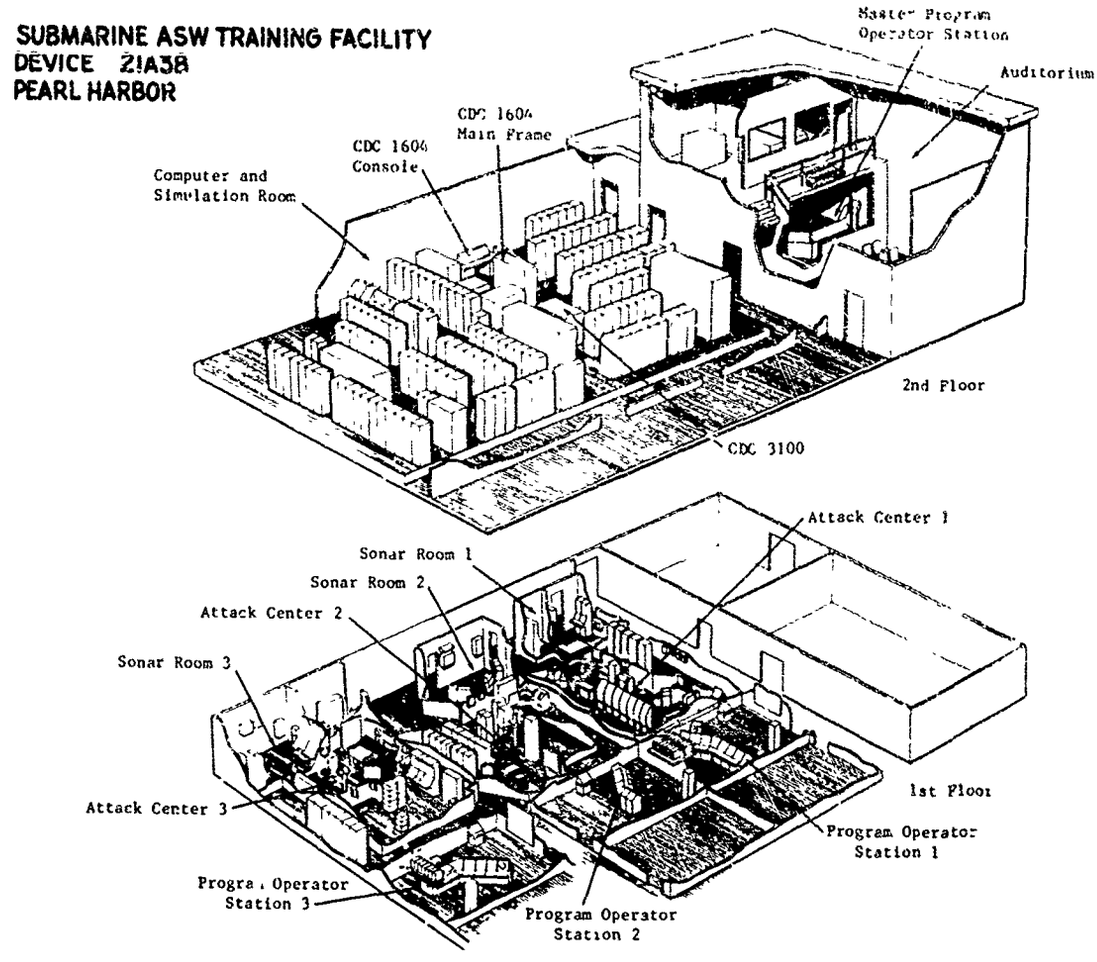


Figure 2. ASW Training Facility, Device 21A38, Pearl Harbor.

addition, this attack center contains a highly realistic periscope visual simulator. A ship's control panel, presently being developed and assembled, will enhance the realism of the attack center.

The James Madison Attack Center is quite similar to the Skate and Permit Attack Centers in capability. It presently lacks the periscope visual simulator capability present in the Permit Attack Center; however, equipment layout has been planned around the future addition of this capability. ECM simulation equipment is present but the necessary operational equipment to implement this feature has not yet been added to this attack center.

The sonar rooms of the attack trainer contain operational sonar systems, activated by realistic sounds generated by the simulation equipment. The resultant visual and audio indications are very nearly identical to those received under similar conditions at sea. Sonar simulation, wherein sonar inputs are applied to the fire control system directly from the computer, is also available in the three attack trainers. Operational radar equipment, originally provided in the attack trainers, has been removed, although the simulation equipment remains intact and this capability can readily be reinstated if required.

The program operator stations contain the controls and displays for the operators to act as helmsmen, torpedo room crews, and evaluators. Voice or signal commands from the attack center are entered into the computer, which change its outputs to the simulation equipment which, in turn, change the indications in the attack center. The program operator station also contains an

instructor's console which provides the instructor with range, speed, and bearing data on any selected target. A large picture window provides the operators and instructors with an unobstructed view of the attack center activity.

A projected display system, at the program operator stations, plots and projects onto a display screen color-coded tracks showing the courses of all vehicles and weapons active in a problem. Vehicle identification and time interval marks are included on each vehicle track. Other notations, such as initial sonar or radar contact, can be displayed. The screen area can represent an area of 10, 50, 250, or 500 miles square as determined by the program operator.

The master program operator station, part of the war games complex, includes the controls necessary for overall program direction. With these controls, the master program operator assigns targets to the program operators and, when necessary, assumes all or part of a program operator's duties.

The war games display system, using a 20-foot square screen, gives both the master program operator and the audience overall problem data. Loudspeakers allow the program operator to narrate into the auditorium the problem or project tactical communications, taking place in the attack centers. Problem status and a task time are furnished to aid the audience.

The computer room contains two general purpose digital computers and the bulk of the simulation equipment. This equipment provides data to the operational equipment as a result of inputs from the program operators and the fire control system. Figure 3 shows the main rack of one of these computers. Various modes of operation of Device 21A38 are possible, as follows:

1. A single attack trainer can be operated using from one to 12 targets.

2. Three attack trainers can be used independently, but simultaneously, dividing the 12 targets.

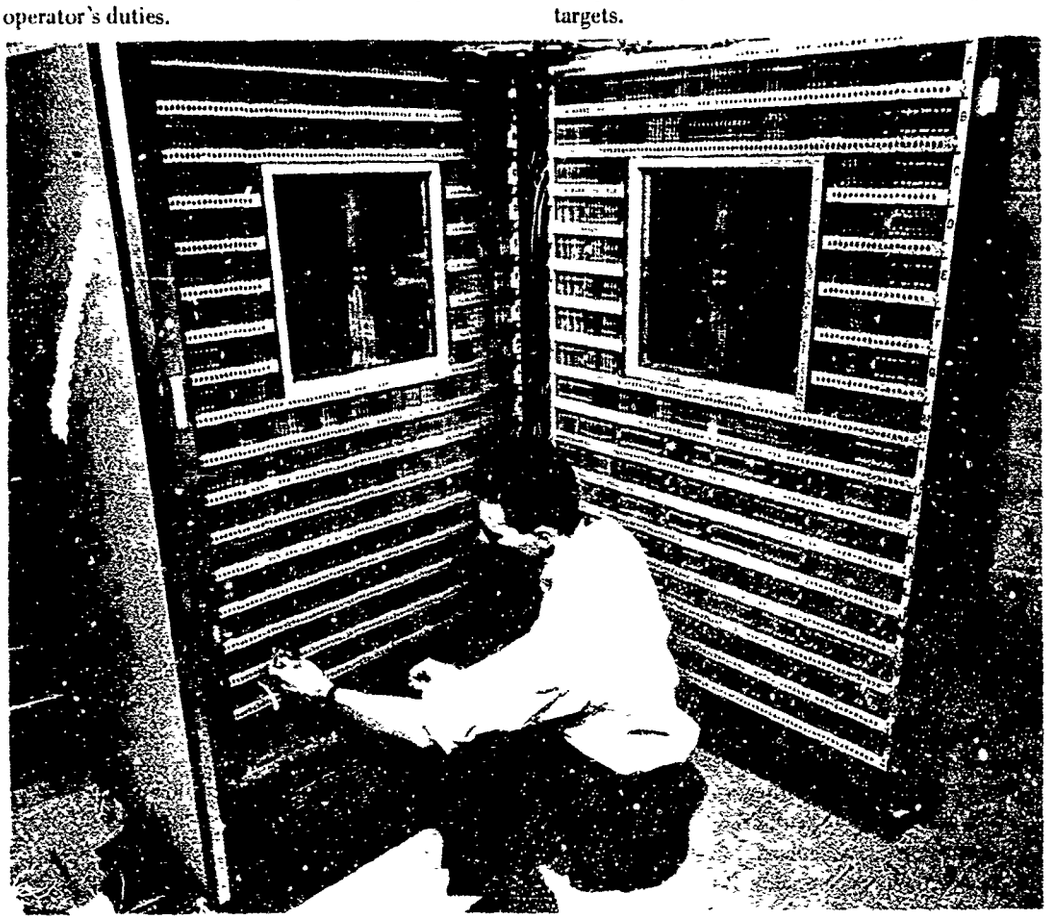


Figure 3. Computer Main Frame, Device 21A38.

3. Three attack trainers can be used in coordinated problems with the 12 targets available to each.
4. Attack trainers can be operated against one another.
5. All 12 targets can represent either submarines or surface vessels; one of the 12 may be an aircraft.
6. Training exercises can be recorded and played back for critique and evaluation. Playback can be at real time, two times real time, or four times real time.

The entire device is under control of the general purpose digital computer. Every attempt was made to use the digital signals directly, without the use of servos for providing signals to the output display devices. A to D and D to A converters are used. Synchro voltages are generated synthetically by digital to synchro converters. The trainer is transistorized, with the exception of some of the GFE operational components in the crew station mockups, which still use tubes.

Device 21A37 is a similar machine which was started before device 21A38, but put into service a year later. The same three attack center configurations are available in this machine, which is installed at New London, Connecticut.

COMBAT INFORMATION CENTER (CIC) TACTICS TRAINERS

Strictly speaking, nearly all of the trainers discussed in this article provide training in CIC tactics. There are two devices, however, especially designed for this function, which do not fit into any of the other categories of trainers and which, therefore, are presented in this section. These trainers are the Fleet Air Defense Trainer, Device RS12, and the CIC Tactics Trainer, Device 15F6.

Device RS12–Fleet Air Defense Simulator

Fleet Air Defense Simulator, Device RS12, is located in the operations building at the Fleet Air Defense Training Center, Dam Neck, Virginia and includes three portions: Search Phase, Fire Control Phase, and AEW Simulation Equipment.

The Search Phase equipment is designed to develop and maintain proficiency of personnel in CIC operations. Particularly, the Search Phase equipment trains personnel in the use of radar for search and acquisition of air and surface targets. The equipment provides simulated radar and synchro signals which are introduced into operational radar indicators in four simulated CIC rooms. In addition, the equipment provides synchro outputs of course and speed to operational indicators to provide for simulated ship movement.

The simulation equipment consists of target course generation equipment, relative motion computation equipment, and radar signal simulation equipment. The overall system provides four "Own Ships" which are freely maneuverable in an ocean area 240 miles square. Each "Own Ship" receives indications of the other three ships on the radar indicators in its mock-operational CIC room. In addition, there are eight other surface targets, consisting of two "Master Ships" each with three associated "Slave Ships" which can be observed by all four "Own Ships." There also are 18 air targets, each individually maneuverable within an area of 280 square miles. The air target maneuvering area is concentric with the surface target area. Each "Own Ship" can receive radar indications of the 18 air targets. Thus each "Own Ship" can observe 11 surface vessels and 18 air targets simultaneously. In addition, a simulated height finder radar set is installed in the CIC room of the CV and functions only with that "Own Ship."

The Fire Control Phase equipment develops and maintains proficiency of personnel in gun fire control director operations. Particularly, this equipment is used to train personnel in the use of gun fire control radar to acquire and track targets. The equipment provides simulated radar signals which are introduced into four individual gun fire control systems.

In effect, the simulation equipment allows the separate fire control systems to be switched onto any one of four simulated ships. Each fire control system then receives simulated target pulses of up to 18 air targets which can be acquired and tracked using the fire control radar. The simulation equipments consist of four systems, each one connected to a specific gun fire control radar, plus a switching network for transferring the independent systems to the different simulated ships.

The AEW Simulation Equipment was added to the device to develop and maintain proficiency of personnel in this class of CIC operations. The equipment provides simulated AEW radar target signals which are introduced into operational radar indicators in four CIC rooms.

The AEW Simulation Equipment consists of target course generation equipment, AEW relative motion computational equipment, and radar signal simulation equipment. The AEW system allows four of the original 18 air targets to become AEW aircraft. By means of a preselector switch, each of the four "Own Ship" CIC mockups in the trainer is capable of receiving any of the four AEW radar presentations in place of its own "surface" PPI picture. Any or all of the four AEW aircraft can thus become an "Own Ship" in the sense that the entire fleet, consisting of 12 surface vessels and 17 air targets, can be seen simultaneously on the PPI with respect to an AEW aircraft. The remaining three AEW aircraft become ordinary air targets when viewed on the PPI with respect to the fourth AEW.

Additional modifications have been made to the original RS12 simulator, particularly in the radar signal processing. A trigger and video distribution system and an IFF/SIF capability have been added to the device.

Because the operation of the device, since its initial construction, spans a decade and a half, the various subsystems are implemented in many different ways. The original computation equipment contains geared servos using a.c. motors and a.c. amplifiers. Synchros and resolvers are used in both the servos and in the instruments. Video generators provide pulses and noise signals and d.c. signals are used for some of the radar display computations. Some of the servo amplifiers are chopper stabilized, others use magnetic amplifiers. In general, the system uses tube circuits, except for the most recent addition of the IFF/SIF system in which transistors are used. All of the computation is based on analog methods.

Device 15F6 CIC Tactics Trainer

In the mid-1960's, a very major training system developed to NAVTRADEVCEN specifications was installed at the U.S. Naval Air Technical Training Center, Glynco, Georgia. This system, designated as Device 15F6 and known as a CIC Tactics Trainer, constitutes one of the most extensive environmental simulators ever produced for task force command and control training.

Broadly speaking, the device provides training to CIC officers in tactical situations encountered by various ships, such as ASW destroyers, cruisers, and guided-missile destroyers. Nine CIC mockups are connected to a central computing system. The gaming area for training exercises is 1,024 nautical miles square, with provisions for simulating aircraft to an altitude of 150,000 feet and submarines to a depth of 2,000 feet. A total of 128 separate targets can be generated. Fifty-five distinct interceptor consoles are provided, each for the realistic control of a simulated friendly interceptor aircraft and simulation of an equal number of "bogey" aircraft.

The true flexibility and utility of Device 15F6 can be appreciated better by considering the types of training exercises which may be conducted with the system. These include exercises for: CIC training, Airborne Early Warning (AEW) training—when integrated with Device 15F5, the E2A Aircraft Tactics Trainer; Air Intercept Controller (AIC) training; ECM training; IFF/SIF Equipment training; and Antisubmarine Warfare (ASW) training.

To provide all of these training exercises, Device 15F6 performs the functions of air-search, surface-search, and height-finder radar simulation; (13) "Own Ships" relative motion and characteristic generation; ECM simulation; IFF/SIF simulation; aircraft flight trajectory simulation; and target characteristic generation. These simulations provide inputs to operational equipment normally found in a shipboard CIC. These inputs provide the searching, navigation, detection, tracking, and identification-evaluation capabilities of nine CIC mockups. Up to nine separate problems can be conducted simultaneously using this CIC Tactics Trainer.

Device 15F6 takes full advantage of the power, computers. The computer used in the device is the computers. The computer used in the Device is the Univac 1230, which is a high-speed version of the original AN/USQ-20 computer used in the Navy Tactical Data System (NTDS) and the Airborne Tactical Data System (ATDS). Approximately 32K words of core memory are used by Device 15F6. It is doubtful, of course, that simulation on the scale afforded by this device would ever have been attempted without the development of the digital computer as a feasible unit for incorporation into training devices.

THE TACDEW TRAINING SYSTEM

Currently, comprehensive training systems are being implemented at the Fleet Anti-Air Warfare Training Centers, San Diego, California, and Dam

Neck, Virginia. These centers incorporate facilities for many varied facets of task force command and control training. These systems are known as the TACDEW (Tactical Advanced Combat Direction and Electronic Warfare) Systems. NAVTRADEVCEN, working with industry, is supplying training devices for these TACDEW systems.

Two features distinguish TACDEW from most prior training systems: (1) A comprehensive, multithreat environment is simulated, in contrast with the limited environments created by devices providing training in only a single area, such as ASW. In TACDEW, the total environment of ECM, anti-aircraft warfare (AAW), ASW, and surface threats and operations can be intermingled realistically to present the trainee with the world he will encounter in operational conditions. (2) The system can transmit its simulated environment via data link to NTDS-equipped ships in port or at sea. These ships can then train in their own surroundings, on independent exercises or as part of a training task force including TACDEW mockups.

These two features seem indicative of future trends in the development of training devices for task force command and control training.

The training capabilities of TACDEW are legion, and include: AAW training; ASW training; amphibious training for individual ships and task forces; surface tracking and tactics training; tactical data systems operator and team training; ECM/ECCM training; Air Intercept Controller training; Carrier Air Traffic Control training; E2A/E2B Team Training, using ATDS facilities; strike operations training; and shore bombardment team training.

Commanding officers and unit commanders, performing the functions of Officer in Tactical Command (OTC), Screen Commander, Force AAW Commander, or Commanding Officer, can actively participate in this shorebased training environment. Exercises can be specifically designed to fit the needs of individual commanders and their staffs in exercising and testing their command and control effectiveness.

TACDEW achieves its extensive capabilities through the integration of various simulation equipments with a central digital computer facility and the Naval Tactical Data System (NTDS), and through the preparation of simulation programs for a variety of training requirements. By category, some of the simulation devices are for radar, electronic warfare, airborne tactical data system (ATDS), weapons, and carrier-controlled approach. Specific devices procured by NAVTRADEVCEN for incorporation into TACDEW include the Electronic Warfare Trainer, Device 15E13; the Weapons System Simulator, Device 20C8; the Carrier Controlled Approach Trainer, Device 15G10; the ECCM Team Trainer, Device 15E28; and the SPN-42 CATCC Trainer, Device 15G17.

THE IMPACT OF ADVANCING TECHNOLOGIES ON TRAINING DEVICES IN THIS CLASS

Computers

The availability of computing capability directly determines the sophistication of the math model which represents the particular sequence of situations to be simulated by a training device. The math model defines the fidelity and scope of the features which can be included in the training environment. It has been the very remarkable advances in computer technology over the past 40 years that has multiplied the capability of simulating in detail (indistinguishable from the real world in some cases) the many components of an operational task force command and control environment. It is the purpose of this section to trace the technical art in the computational area from the 1930's to the 1970's.

The common factor in all the synthetic training devices in the multiship tactical area (as well as for many other trainers) is the ability to solve the dynamic motion problem for all the participants in the game (own ships, friends, enemies, targets, aircraft, submarines, torpedoes, missiles, etc.). The state-of-the-art has progressed far in this area from the Link trainer with its pneumatic computer and from the 1BZ2 Maneuvering Tactics Trainer and the Vernon Trainer which projected light spots and tracks based on mechanical integration and computation.

Because of its ability to solve the pertinent equations in real time, and because digital computers simply were not available, analog computation was the natural direction to take when simulating the motion of the various vehicles in a tactical situation. Several types of analog computer systems were developed and applied in the different simulators discussed earlier. The

earliest attempts at this analog computation involved mechanical integrators of the ball and disc types. Gears and differentials were often used. Later, the equations were mechanized by using "servos." These consisted of a motor, a feed-back tachometer, a servo amplifier, and a set of potentiometers for position feedback and function generation. A.c. and d.c. "servo" systems were developed. The a.c. type used a two-phase motor, an a.c. amplifier, and an a.c. tachometer. A.c. voltages were impressed across feedback and function pots. The d.c. type used d.c. components. In addition, a spectrum of hybrids was available. Typical of analog computer systems, and probably the most often used for all types of simulators, was the type in which all computation was done with d.c. and a magnetic amplifier was used inside the servo loop to convert the motor drive signal to a.c. The feedback and function pots were again d.c. to be summed at the d.c. input of the servo amplifiers. This type of unit was originally implemented using vacuum tubes, and later with transistors.

With the advent of digital machines, a review was made regarding the best way to provide complete solutions to the equations of motion in six degrees of freedom. The result was, again, a compromise. Some simulators used a hybrid approach consisting of both analog and digital computation. In most cases, it was found that approximations using binomials, exponentials, etc., were sufficiently accurate in the regions of interest for the equations of motion. This is particularly true in a tactics trainer involving many relatively slow-moving vehicles.

The digital computer, as a component of the training device, has expanded the computational capability horizon in several dimensions. First, it is inherently more accurate in nature. The use of 12 binary bits for describing locations and other functions is not uncommon; i.e., resolution of one part in 2^{12}. Most computers have 16 bit resolution; some have 32. Smaller word size machines are used with double precision to achieve almost any prescribed accuracy.

The second dimension in which the digital computer has grown is in the cost and space reduction of its memory elements. This makes it possible to store more data, i.e., divide the world into smaller pieces. More participants can be accounted for in a tactical maneuver, the gaming area can be made bigger, and the simulation of weapons and sensors of ever-increasing complexity becomes feasible.

Finally, the speed of the digital computer has increased tremendously in recent years. This makes it possible to perform more computations in the time required to update the displays without the trainee noticing that incremental changes are taking place, thus effecting more realistic simulation. The speed and memory increases have made it possible to simulate effects of the environment such as wind, weather, geographic effects on radar, etc., in great detail and to perform the necessary computations at a rate compatible with the requirements for presenting the tactical situation in real time.

Another effect of the high speed digital computer, not related to hardware, has been the advances made in simplifying the math model by the use of clever programing. Tradeoffs can be made in terms of computer time and memory requirements between storing a large volume of data and storing some scale factors and computing the data as often as required. This applies to such things as magnetic variations when simulating magnetic compasses, temperature and altitude effects and similar environmental conditions.

Although digital computers now form the "heart" of modern training devices for Task Force Command and Control Tactics, there are a certain number of analog computing elements which cannot be dispensed with. These are usually under control of the digital computer and serve to drive the various display devices such as radar scopes, sonar monitors, optical simulation equipments.

In addition to the central computer, a whole world of peripheral devices is now available. These operate under program control to enhance the capability of a training system. Typical devices are teletypewriters, lineprinters, magnetic tape units, disc memory units, graphic display terminals, etc. The minicomputer has found application in large scale training device systems. It can be used as a peripheral to the central computer, and be dedicated to perform subtasks in order to relieve the main computer memory requirements and/or to shorten its computing cycle. Examples of uses of dedicated minicomputers are the refreshing of a graphic display terminal or keeping track of the weather environment for a problem.

The effects of a "galloping computer technology" on the tactics training device can be summarized as follows:

1. Vehicles in the exercise have increased from several to hundreds.

2. Gaming areas have increased from a few square miles to more than 1,000 miles square, easily movable, if desired, to simulate any area in the world.
3. Many additional environmental effects can now be provided.
4. Great increases in computational accuracy can be obtained.
5. Improved and expanded provisions for scoring, monitoring, and even automated teaching can now be incorporated into the training devices.

The change in technology which has taken place over the past 40 years can best be illustrated by a review of the figures included herein. Figure 1 is a sketch of one of the earliest attack teachers. Computation was mostly mechanical, though motors and synchros were used from the earliest days. Figure 4 shows one of the integrator modules used in this device. Contrast these with the facility housing Device 21A38 depicted in figure 2 and the computer "main frame" used in Device 21A38 as shown in figure 3. This computer was installed in the early 1960's and therefore consists of all discrete solid state components mounted on printed circuit boards. Two more strides in the state-of-the-art have brought us to the minicomputer represented in figure 5.

Control, Scoring, and Monitoring Equipment

The state-of-the-art has advanced in the areas of problem control and scoring and monitoring in the same dramatic way as for the computational capability. The early training devices were controlled by an operator who also acted as an umpire. When a torpedo was fired, for example, the action was frozen and the instructor or operator determined whether a hit was scored. For this purpose, the situation display had an extra projector, which was used to establish range and bearing at the time of firing. Now, the digital computer has been put to use to establish hits and misses. Beyond that, it is possible to program scoring capabilities such that the actions and responses of the various crews are compared to a set of standards and/or to the performance of other crews. The events of a given exercise are recorded for real time or fast time replay during critique and evaluation periods. Permanent records and/or score cards can be made available via on-line or post-problem printout on teletype or line-printers.

Problem exercises can be preplanned and called from the computer memory for teaching certain types of problems. Further, the instructor now has available to him the ability to enter parameters into the problem, or alter preplanned problem conditions via teletype or interactive displays. He can request data that is not normally displayed. Recently, computer graphic terminals have been added to large training devices to provide ready access and control by the instructor-operator.

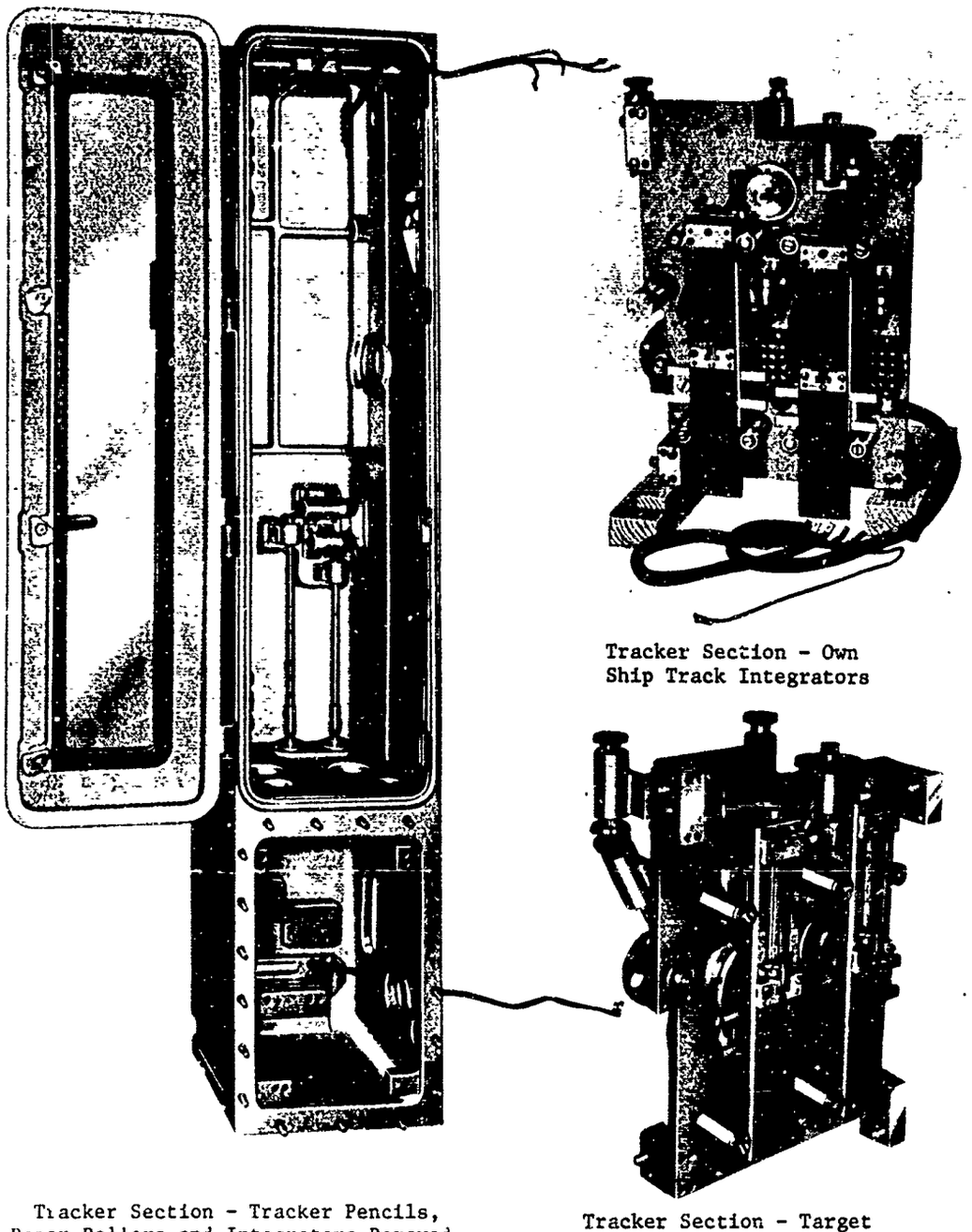
Scope of Feasible Simulation

The scope of the simulation, and the fidelity of the conditions simulated, has expanded with advances in the state-of-the-art. To illustrate this, we might consider the effects of wind. While early simulators might have considered the wind velocity and direction, the instructor had only one set of controls which set one wind for the entire gaming area. The use of high speed digital computers now has made it possible to specify the wind in several vertical as well as horizontal increments of whatever size is deemed necessary for realistic effects in the training device. The effects of these various winds are then included in the computation of weather patterns, sea states, aircraft velocity, etc.

It can be seen that the possibilities of simulating various conditions are limited only by the willingness to assign computer time and memory to a particular function. The use of magnetic discs for storage has even reduced the memory problem, making it necessary only to provide enough time to get the data on and off the disc.

In concluding this article, it is both interesting and impressive to list some of the environmental features and improved capabilities which can now be included in a tactics trainer for task force command and control. These include:

1. Increased number of combatants
2. Library of weapon types
3. Increased gaming areas
4. Effects of wind
5. Realistic radars
6. Realistic sonars
7. Countermeasures and CCM
8. IFF and SIF
9. Communications
10. Winds
11. Weather



Tracker Section - Own Ship Track Integrators

Tracker Section - Tracker Pencils, Paper Rollers and Integrators Removed

Tracker Section - Target Track Integrators

Figure 4. Early Mechanical Computing Components.

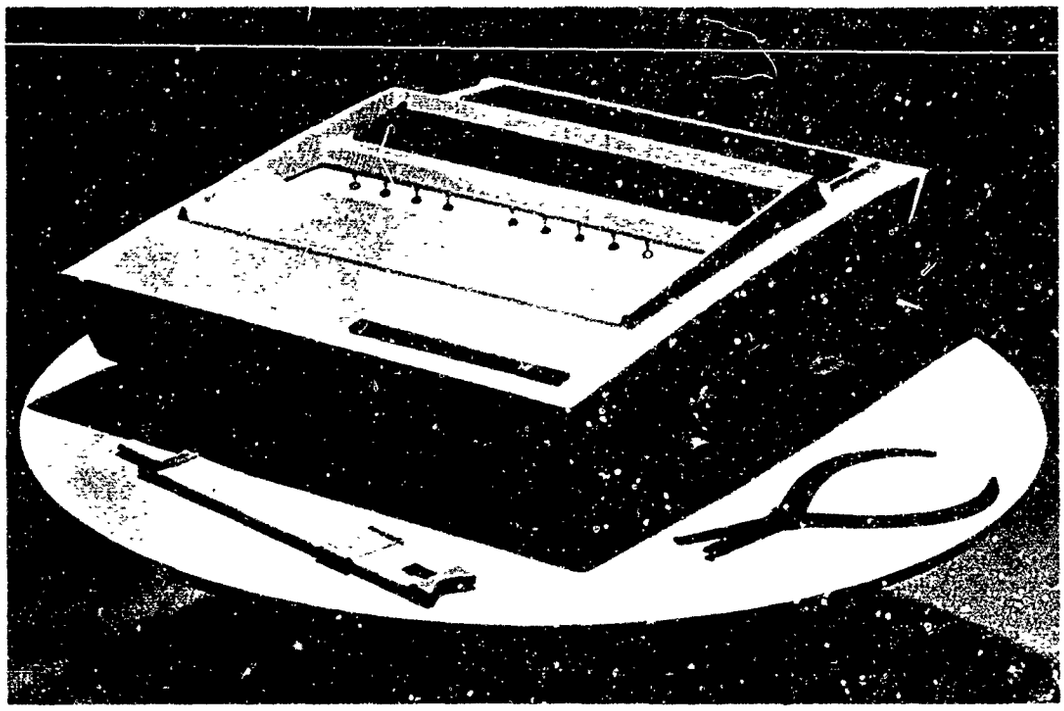


Figure 5. Modern Minicomputer.

12. Ocean currents

13. Visual displays in periscopes and similar devices

14. Landmass simulation

15. Magnetic maps

16. Geographic effects such as the effect of mountains on radar and radio, etc.

17. Navigation aids

18. Crew station motion.

The tools and simulation techniques available to the training device designer have multiplied with the advances in the state-of-the-art. The question to be answered in developing future tactics training systems will therefore no longer primarily concern the feasibility of creating a sufficiently realistic environment; rather the impact on the trainee must be considered and questions must be asked and answered regarding the extent of simulation necessary to enable him to learn and successfully transfer the abilities acquired to the ultimate task.

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Mr. Snyder holds a Master of Science degree in Physics from the University of Michigan, obtained in 1948. He started work in Training and Simulation in 1952 at the (then) Goodyear Aircraft Company and has worked continuously in this field since that time. He holds three patents for simulation devices and was co-author of a paper entitled "Four Hundred Cycle Computing Systems for Trainers and Simulators" presented at Naval Training Device Center (NAVTRADEVCEN) Symposium at Port Washington, New York, in 1955. He has worked closely with NAVTRADEVCEN personnel in the development of Devices 15V6, All-Weather Fighter Radar Simulator; 2F72 (Tactics), F8U2N Weapon System Trainer; 15C4 and 15C4A, Radar Scope Interpretation Trainer; 2F65, E2A Weapon System Trainer; and 15F5, E2A Tactics Trainer.

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Surface Ship ASW Trainer Development

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From the trainee's point of view, today's ASW trainer might look much the same as the trainer of the late 1950's; but on the other side of the operating panel there has been a dramatic change. In the earlier trainers simulation of at-sea exercises was accomplished with analog electronic circuits. This was followed by the development of special-purpose digital circuitry to control the analog devices. Then general-purpose digital computers were introduced and these have gradually replaced analog techniques in most simulators. Mathematical models describe the ocean environment, target-source noise generation, and the transfer function of the simulated operational equipment. Computers generate the actual audio and video presentation.

Result: Training simulation has reached a level of fidelity which was never before achievable. Significant improvements have been made in flexibility, reliability, and cost.

This paper deals with the advances in computer and digital system technology as they have developed in the area of Surface Ship ASW Trainers.

Advances in computer and digital system technology over the past decade have permitted rapid and extensive changes in many fields. This paper deals with those changes as they have developed in one particular area of training systems—that of Surface Ship ASW Trainers.

It is indeed fortunate that these technological advances have occurred, because during this same time frame a strong forcing function has also been developing. The forcing function has been the increasing need for greater training capability at lower absolute costs. The forcing function derives from three principal sources: increased complexity of operational systems; turnover of personnel; and fewer dollars available for training on operational platforms. It is unlikely that these sources forcing change will be materially altered in the near future.

Shorebased training systems can never be expected to completely replace "hands-on" training in the operational environment. However, increased use of high-fidelity, flexible training systems can greatly reduce the required at-sea training, while permitting the desired level of proficiency to be maintained.

It is difficult to make direct comparisons between at-sea training and shorebased training costs. However, an analysis of a typical training mission on a Device 14A2 (ASW team trainer), compared to at-sea exercises, was made by comparing costs of fuel and ordnance expended at sea to amortization and utilization costs of a Device 14A2.

This analysis indicated a cost advantage about 7:1 in favor of shore training as compared to at-sea training. This advantage can be maintained only if shorebased trainer acquisition and utilization costs are carefully controlled. This means we must take maximum advantage of those technologies that lead to increased capability without comparable increases in cost and complexity. Heavier utilization of all-digital computer-centered systems is one technology area that has demonstrated its ability to be effective in this important arena. The above cost advantages realized by the use of trainers do not take into consideration the elimination of hazards that personnel normally might experience while using operation vehicles for their training.

HISTORICAL OVERVIEW

The family of Surface Ship ASW Trainers has experienced many innovative advances during the course of its development. Changes in trainer approach and technique have closely followed the evolution of operational equipment and doctrine. The advancement in capability of ASW training systems has been made possible, in good part, by the growth of the technologies of hardware development. Within a mere 10-year span we have

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seen a whole generation of hardware techniques move from infancy to approaching obsolescence. Just a little more than 10 years ago, the discrete-component manually-designed transistor circuit was struggling to get on its feet; today this circuit is rapidly giving way to the computer-designed integrated circuit.

Further, a revolution has occurred in the whole philosophical and conceptual solution to the Surface Ship ASW training problem. Training systems composed of hard-wired, vacuum-tube circuitry and electromechanical servo systems, with their inherent design rigidity, accuracy compromises, and maintenance problems, were standard up to the early 1960's. The development of the economical general-purpose digital-computer has made accomplishments possible today that were unimaginable only a few years ago.

A short review of some of the ASW training techniques and trainers developed during the past 25 years provides a vivid demonstration of the tremendous advancement that has been achieved in this field.

At the end of World War II, the ASW weapons systems included searchlight-sonars as sensors, with depth charges (an early generation of acoustic torpedoes) and hedgehogs as the primary weapons. CIC had become an integral part of the ASW Attack Team. The Sangamo Attack Teacher QSA, which operated on an electronic photo-optical principle, served as the sonar and ASW team training device during the WW II period. An expanding arc of light simulated the transmission of acoustic energy through the water, and a photo sensor detected the optical coincidence between target position and the acoustic energy wave front. This triggered analog electronic circuitry that generated the appropriate audio simulation.

Various training devices to support the ASW surface training requirements had been developed under the Bureau of Ships. These were located at the various sound schools, shore stations, and on destroyer tenders.

During the post WW II period, with the introduction of scanning sonars, a new training device was developed by Sangamo Electric, under the direction of the Bureau of Ships. This was the AN/UQS-T1. This unit abandoned the electronic photo-optical principle, and used an electromechanical system to solve the problem. These units were modified each time a new sonar or fire-control system was introduced. The final unit of this series, the AN/UQS-T1E, is still in use at training activities to train students in sonar procedures. This unit includes the AN/SQS-4 Sonar and the Mk V Attack Director.

In 1951, the Special Devices Center (the forerunner of the Naval Training Device Center) developed several devices used for tactical group training. Among these were Devices RS6 (CRT Tactics Display System for ASW Tactical Evaluator) and RS8 (Undersea Warfare Tactical Trainer). In 1957, Devices 14A1 (Action Speed Tactical Trainer) and 21B22 (ASW Tactical Game Board) were introduced.

The need for a surface ship stand-off ASW weapon resulted in research and development on the Rocket Assisted Torpedo (RAT), an effort that eventually grew into the ASROC Development Program.

With the introduction of the ASROC weapon system and its nuclear warhead, the procedures for the handling, transfer, preparation, training, and operational use of the weapon became extremely precise. As a result, the Bureau of Ordnance established the requirement for a procedures and casualty-control training device. This resulted in the development of Device X14A2 (ASROC trainer) under technical guidance of the Naval Training Device Center (NAVTRADEVCEN). Primarily, this was a weapons employment training device.

DEVICE X14A2--ASROC WEAPON SYSTEM SIMULATOR

Device X14A2, installed at the Fleet Training Center, Navy Base Norfolk, in 1960, was designed to train and improve the proficiency of surface ship crews in the operation of ASROC and other antisubmarine warfare weapon systems.

Mathematically, the problems solved were rather gross approximations for vehicle motion, weapon ballistics and motion, and display generation. The equations were geometric, with vehicle course and speed resolved into rectangular coordinates of motion in the X-Y plane and added to initial positions to provide updated positions. Ballistic equations were solved for the effects of own-ship motion, target motion, and payload type on launcher aiming.

Device X14A2 employed a d.c. reference system for vehicle position generation, and a synchro transmission system for course and speed data.

Vehicle motion generation was by rate servos employing gear trains driven by tachometer-controlled motors to position the wiper arm of d.c.-referenced precision potentiometers. Fire-control computations within the simulated attack consoles also employed analog type computing servos and operational amplifier type computing circuits.

The progress of the problem was monitored by a projection type display, utilizing separate projectors for each vehicle or weapon being monitored. Vehicle position was manually plotted to provide a history for problem critique; however, no provisions were included for dynamic replay. All problem operation and control was performed manually. All the electronics employed vacuum-tube circuitry, as packaged solid-state amplifiers were not readily available when Device X14A2 was designed.

Although Device X14A2 successfully accomplished its long-term mission, it also pointed out, early, some significant shortcomings. Most notable were its extremely synthetic displays, cumbersome control, and frequent need for maintenance and adjustment. Gear trains employed in Device X14A2 require frequent cleaning; vacuum-tube amplifiers generate considerably more heat than solid-state amplifiers and are relatively more unstable.

DEVICE 14H4–ASW HELICOPTER TACTICAL TEAM TRAINER

Device 14H4, which was installed at the Naval Auxiliary Air Station Ream Field in 1966, was designed to provide ASW helicopter pilot and copilot instruction and proficiency training in navigation, ASW tactics and maneuvering, and procedural communications.

The math model approach for Device 14H4 was similar to that for Device X14A2. The same general hardware techniques were employed–the analog computer employing servomechanisms and operational amplifiers. This was one of the first ASW trainers to employ transistors. All problem operation and control was performed manually.

The training problem was monitored by a display system using separate projectors for each vehicle. The projectors had an automatic plotting capability using a technique of automatically scribing vehicle motion on opaque-coated glass slides. Analog-type stroke generators under digital control provided symbology for plotting of vehicle tracks, time marks, symbols, and alphanumeric coding. Again, no dynamic playback capability was provided.

As a result of the heavy utilization of transistor circuitry and packaged solid-state amplifiers, a significant improvement in performance, frequency of maintenance, and stability was achieved in this trainer.

DEVICE 14A2–SURFACE SHIP ASW ATTACK TRAINER

The Device 14A2 series was a major step in the use of digital techniques to solve the ASW training problem. The purpose of Device 14A2 was to train the ASW team in the following modes of operation:

Search–attempt to detect an enemy submarine

Classify–verify that the contact is a hostile submarine

Destroy–use the proper weapon system to neutralize the hostile submarine

Device 14A2 consisted of simulated UB Plot areas (including Mk 53, Mk 38, and Mk 143 fire-control equipment), CONN, CIC, and LCCP. In addition, an unattended equipment room (which housed the computer and computer interface equipment) and a critique room (which housed the instructor's console and projection equipment) comprised the remainder of the trainer complex. The computer controlled the vehicle and weapon motion, the ocean environment condition, and the automatic weapon hit evaluation–all of which were developed by the math model.

The generation of the sonar audio and video, radar video, and projector motion was accomplished by computer control of a number of analog, discrete-component circuits. Changes to the displays could be accomplished only with some hardware modifications. The fire-control system was implemented using traditional closed-loop servo techniques.

The use of the computer to control Device 14A2 resulted in significant advantages. First, the problem parameters could be rapidly fed into the computer and verified. Second, automatic "hit" evaluation and automatic vehicle plotting, coupled with instant replay capability, freed the instructor to perform more creative tasks. And finally, a reduced instructor load resulted in a favorable instructor/student ratio that reduced overall training cost.

DEVICE 14E19 AN/SQS-26 SONAR SIMULATOR

The introduction of the AN/SQS-26 Sonar to the fleet generated the requirement for a sophisticated trainer with sufficient fidelity for target classification. In response to this need, Device 14E19 was developed. Now the student could distinguish a submarine from biological targets such as a whale or a porpoise, and from deceptive targets such as ice or pinnacles

Device 14E19 is a simulation of the AN/SQS-26 Sonar, consisting of three manned operator consoles, plus an unattended passive receiver cabinet. The simulator has six CRT presentations and a passive receiver paper-recorder display. Each of these displays is computer generated and digitally controlled. In addition to the video displays there are three sonar audio channels which are also computer generated.

A key item in Device 14E19 has been the math model. The math model reduces the variabilities and anomalies of the ocean to a mathematical approximation that can be successfully implemented in a computer software program.

Recent advances in solid-state technology, primarily in the areas of low cost, low-power integrated circuits, and low-cost computer, have made possible complete digital generation of audio and video displays. The ability to generate the video and audio display in Device 14E19, rather than to merely control the video display, is a significant advance in trainer design. The primary advantage of digital generation is a tremendous flexibility in adjusting the qualitative subleties of an audio or video presentation as found in Device 14E19. In this manner the expertise of the user (e.g., fleet sonarman) can be an input into the computer's simulation equation. This combination of mathematical sophistication, plus qualitative inputs, results in a superior training device.

Digital generation has provided more advantages to Device 14E19 than merely flexibility. The advantages are increased reliability, high maintainability, lower life-cycle cost to users, and smaller physical volume.

This increased flexibility was vividly demonstrated in Device 14E19 during the final evaluation and testing operations. A group of sonar authorities from the Naval Underwater System Center New London and from NAVTRADEVCEN supplied new data to modify the overall appearance of the displays. The vast majority of these modifications were incorporated within hours; whereas, using previous trainer design philosophy, many of these display improvements could not have been made without significant hardware redesign.

Another advantage of the total digital concept has been the ability of Device 14E19 to function as an independent trainer (capable of providing sonar operator and sonar team training) and as a joint trainer (in conjunction with Device 14A2 to provide ASW team training with either the AN/SQS-23 or AN/SQS-26 as the sensing sonar).

The advent of the digitally generated displays has added a new level of flexibility and realism to trainers.

CHARACTERISTICS OF TODAY'S TRAINERS

Digital computational technology has provided great support for the growth of ASW training systems to their present capabilities. The incorporation of the general-purpose digital computer and special-purpose digital processors as the heart of the trainer permits in-depth simulation of real-world parameters.

The earlier approach of employing a digital computer to control analog circuitry has given way to the more advanced technique of maximized computer control and minimized analog processing. Today the computer directly commands trainer display and control functions. What does this mean? It means that math models can be prepared with much greater assurance that every significant detail will be reflected in the final design. It means that greater accuracy and complete repeatability are assured. Finally, built-in control of mathematical charactistics in software, rather than hardware control, provides a flexibility to readily modify characteristics to conform with newer and more advanced data as they become available

The fidelity and realism of ASW training equipment today is limited more by the limitations of our knowledge and ability to mathematically describe the real world than by the limitations of the hardware design.

ASW features that can be incorporated today are almost without limit. Recent examples include extensive simulation of the ocean environment and the generation of target-radiated noise (as they are understood today). The detail characteristics of operational equipment, particularly with regard to transfer functions, are readily synthesized.

Simulation of the ocean environment in recent trainers has included accurate simulation of detail features that were omitted or crudely approximated only a few years ago. One recent notable example was the inclusion of acoustic-ray trace paths to provide true real-world sonar range indication, rather than only simple slant range. Wakes and knuckles, two sonar simulation problems of long standing, are now available. Other important features that are now part of the modern ASW trainer repertoire include bathythermal characteristics, various bottom types and slopes, bottom returns, and convergence zones. Radiated noise features accomplished today include screw beats with accentuated blades and biological noises such as porpoise, whales, and shrimp.

The mathematical model, which provides the central control point of modern trainer design and includes mathematical expressions for real-world phenomena and descriptions of certain logical functions, is developed from many sources. The Navy's own research centers, such as the Naval Underwater System Center, provide some of the most valuable information—both theoretical and research type. Sometimes the manufacturer of operational equipment will make a contribution, which is especially important in those areas where it is essential that characteristics of the operational equipment (such as bandwidths, AGC action, motion characteristics, inherent noise, response times, etc.) be synthesized in the trainer. In those cases where specific data do not exist, a math model is specially developed for the trainer, based upon the best known information on the subject.

Once a math model has been prepared describing all mathematical considerations to be provided throughout the device, the computer program is prepared which directs the computer to automatically accomplish the required computations and order the logic of the trainer operation.

FUTURE TRENDS

The trend in the past decade has shown how the sophistication of computer techniques from analog to digital has had a far-reaching impact on the fidelity, effectiveness, flexibility, and cost of today's trainers. It is interesting to look back at the technical progress of the last decade, extrapolate that rate of progress into the next decade, and try to visualize what we can expect in the trainer of the 1980's. The prospects are exciting! Today we find ourselves limited by our ability to mathematically define the physical attributes of the real world in which we live and the operational machines we build, and to effectively communicate such mathematical models to trainer computers. In the next decade we will call upon the computer to help solve its own problems. Thus, a better understanding of the ocean environment, a better understanding of the transfer function of digital processors, and a better understanding of the acoustic energy components of an audio communication will be arrived at through computer analysis.

Computers will also be used to optimize the design of the digital logic, to lay out the electronic paths in large-scale integrated circuits, and to define the back panel wiring. Simplified diagnostic routines will ease the maintenance problems.

As we increase our knowledge of the human factors related to learning retention and transfer of training experience to operational capabilities, we will see a greater utilization of computer techniques in automatic student-scoring adaptive training. Problem difficulty will be computer-optimized to achieve a maximum learning rate. Since newer trainers have greater flexibility in software control, with minimum hardware limitations, these advantages can be incorporated without hardware redesign.

The foregoing techniques are certainly not restricted to ASW trainers. They are broadly applicable to all team trainers. We have already seen the technology used to digitally generate sonar video expand to video for electronic warfare presentations and radar landmass presentations. Digitally generated sonar audio has the flexibility to expand to any other audio presentation. The challenge here lies in generating a mathematical description of the acoustic intelligence that must be conveyed.

As problems are resolved in communicating the real world to computer memories, we will see physical models used for video and photographic memories give way to massive digital memories. Fortunately, developments in solid-state and laser optical memories are evolving in time to make such concepts feasible. Thus, in the next decade we may expect the forcing function of greater training capability at a lower absolute cost to lead us to a level of high-fidelity simulation of operational equipment with digital techniques of a simplicity unimaginable in the past decade.

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As Operations Manager of Honeywell Marine Systems Center/California, Mr. Klimke has complete authority and responsibility for the direction of all technical and administrative operations. A BSEE graduate from the University of Wisconsin, with graduate studies in advanced mathematics and physics at the University of Pittsburgh, Mr. Klimke has over 19 years experience with Honeywell and Westinghouse Electric. He started with MSC/C as Chief Engineer for the ASROC Weapon System program, later moving to Director of Engineering for the facility, a position he held for 4 years. Under Mr. Klimke's direction, the Marine Systems Center has become a leader in the fields of complex digital, computer-controlled training systems and ASW weapon systems.

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Mr. Baumgaertner has been with Honeywell for over 21 years, serving in various management capacities within the corporation. As Director of Engineering for MSC/C, he has overall responsibility for the total engineering effort at the facility. A graduate of St. Thomas College, St. Paul, Minnesota, with a BS in physics and mathematics, Mr. Baumgaertner completed graduate work in physics and electrical engineering at the University of Minnesota. Since assuming his position as Director of Engineering 4 years ago, he has been instrumental in the successful performance record established by MSC/C in the weapon systems and training and simulation systems fields.

The Fidelity Issue: How Much Like Operational Systems Should Their Training Device Counterparts Be?

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Knowledgeable, well meaning people believe different things about fidelity of simulation. This paper explores the meanings and the implications of the various positions on fidelity of simulation.

Discussed are three areas, relative to installing the environment in which training will be accomplished. These are: (1) the main issue, sufficient fidelity to ensure transfer of training; (2) levels of fidelity to device design; and (3) determining the fidelity requirements for training as a function of training purpose, task structure and trainer population.

Regarding simulation technology, key issues in training device design are explored.

It seems appropriate to begin this discussion by concentrating immediately on the question posed by the title of this chapter. The answer is straightforward, "it depends." What this means is that no given statement of fidelity serves as a standard or as a desirable operating practice for simulator design. To begin with, there are many classes of training devices, each class differing in purpose and complexity (there are no less than twenty classes of training devices designated in the Naval Training Device Center [NAVTRADEVCEN] inventory). The fidelity requirements vary substantially among these classes. Within each class are a number of training devices, currently in use, which also exhibit variations in fidelity requirements. One can readily appreciate the congeries of design issues generated by these quite diverse groupings of training devices, if only as to the magnitude of the problems. Thus, it is most appropriate to discuss levels of fidelity in training device design, any one of which may be useful in a specific training situation, depending on a number of considerations. These considerations include: the purpose of the training device; the tasks to be trained and the training objectives; the population of trainees and the training time allotted each; the monetary costs associated with various design alternatives; and, in certain instances, the engineering state-of-the-art. "It depends" also takes into account the fact that knowledgeable and well-meaning people believe different things about what constitutes fidelity, vis-a-vis the operational system and the training device counterpart. Certainly these differences in opinion are due in part to differing backgrounds, experience, and job assignments of people. But the differences are encouraged or augmented by the fact that no well-developed sets of standards and design guidelines are available for defining effective fidelity of simulation. Despite the current and growing sophistication in simulation engineering capability, there are still considerable weaknesses in design technique and in the data base needed for design and development. There are gaps in the simulation engineering technology.

Even more significant is the fact that training device evaluation and transfer of training data are meager and their impact on the design process leaves much to be desired. Consequently, the absence of good training effectiveness data forces a reliance on engineering facsimiles and unduly encourages design decisions based on experience and intuition, and on spotty research results which are not necessarily appropriate to the instructional requirements associated with complex training devices. Thus, the simple response to the question posed by the title of this paper figuratively opens a "Pandora's Box" so far as one is concerned with specifying the desirable design characteristics for simulating the environment in which training will be accomplished.

An examination of the differing and valid approaches to synthetic representation is the theme of this paper. A number of issues in trainee station design, which makes the answer "it

depends" quite reasonable, will be explored. Our emphasis centers on fidelity in terms of instructional strategy and capability, wherein training effectiveness is of paramount concern. In this context, fidelity has meaning in terms of the training process and the realism necessary to promote transfer of training. Defining the design characteristics for optimizing transfer of training from the synthetic to the operational environment revolves, essentially, about two interrelated questions: What or how much should be simulated to scope or "rough out" that piece of the operational universe to be represented?; and, how well should this be represented in terms of degree of physical correspondence to the operational environment? These two questions, plus the concern for incorporating training technology into design (integrating training process with engineering fidelity), circumscribe the approaches to fidelity of simulation. No direct attempt is made in this paper to organize a set of definitive statements about simulation fidelity and design; rather, it is hoped that the question posed by the title will be resolved during the course of the discussion on the issues in trainee station design. Also, no effort is made to describe the engineering means available for mechanizing the simulation requirements, nor to examining candidate engineering solutions for achieving fidelity. What follows is a discussion of the fidelity issues and the various approaches to achieving fidelity requirements in trainee station design. Specific design examples from current Navy training devices are provided to illustrate these approaches to fidelity.

THE ISSUE OF FIDELITY

Fidelity of simulation has been much considered during the time period revisited in this journal. Determining desirable design characteristics for maximizing transfer of training from the simulator to the operational system is a theme well represented in the literature. The sizeable research efforts have yielded an accumulation of knowledge and technique pertinent to design and have highlighted the weaknesses in simulation technology, ranging from conceptual disputes about simulation requirements to stubborn engineering difficulties in installing a desired environment for training. Suffice it to say that sizeable gains in simulation validity have been accomplished. But the story is not straightforward, nor complete. For in selected areas of design, simulation fidelity requirements have not been achieved satisfactorily. In some instances, the topic of fidelity has generated considerable controversy about simulation capability, design practices and training value. This is a complex and facinating story in itself (see, for example, the NATO AGARD conference on simulation, 1970; the Royal Aeronautical Society Symposium on Flight Training Simulators 1970; Smode, Hall and Meyer, 1966; Smode, 1971).

Ingenuity is required in assembling a synthetic representation of some portion of the real world in a way that will train a man to perform better in that real world. The view of the simulator as a training tool places a premium on transfer of training (via the selection of design alternatives which consider both cost and training technology). Historically, simulation design has been preoccupied with the problems of achieving maximum fidelity of simulation. This approach received support from the learning theory of identical elements which held that to maximize learning, the training environment should be equivalent to the real world. This quest for the ultimate in realism (i.e., physical correspondence to the operational environment) has often placed the development of a relevant training program and instructional strategies in a secondary design role. In fact, some of the design practices in the attempts to achieve this "real world" physical equivalence have at times increased costs with no corresponding increase in training value, and in some instances have actually interfered with realizing the full training potential of simulators.

The most efficient selection of degree of fidelity is based on the perceptual equivalence of the training situation to the operational environment. Good design should produce an environment in which the relevant skills and knowledges can be acquired most efficiently. Maximum engineering fidelity is specified to the extent that it facilitates the development of desired performances. However, simulators effectively designed for promoting learning also deviate deliberately from operational realism.

In principle, the design criterion is clear: it provides the minimum fidelity of simulation needed to develop and exercise the human performances required in the operational environment. The basis for achieving this is to examine the design implications (hardware orientation) in terms of the training requirements.

Ideally, engineering and human factors specialists interactively examine the information requirements (simulation parameters) that must be accounted for in design. They then determine the alternative technical approaches from which the optimum engineering solution is selected for satisfying the instructional expectancies (see Smode, 1971). However, translating behavioral information into device design is not a straightforward operation. It is difficult for several reasons: (1) As mentioned earlier, the state-of-the-art in training technology is not advanced to the position where transfer of training relationships are sufficiently understood, nor does a body of "training value" data exist that correlates well with design alternatives; (2) Synthetic representation (i.e., engineering capability) is not easily or completely achievable in every case. Compromises and less than desirable representation are used as the "best available" in certain areas; (3) Since complete fidelity is not always possible, nor in many instances desired, the extent of backing off from this and not sacrificing training value in both operational and motivational terms is crucial to effective instructional design; (4) There are alternative ways to "encourage" trainees to accept simulation as highly faithful to the operational world. Different tradeoff values are involved with each and the available design options must be identified and assessed carefully; and (5) The values of deliberate departures from realism (deviation in configuration/operation from the operational system being simulated) to enhance training effectiveness must be clearly understood and effectively implemented.

Thus, several approaches to fidelity must be considered interactively in design and played against the purpose and objectives of any contemplated training device. In principle, only that level of fidelity is needed to achieve the training purpose and the objectives of the device. This is a minimum cost philosophy that tacitly assumes a built-in flexibility in the utilization of the trainer, once it is on-line and operating. Flexibility is a key issue; the selected design options must be capable of handling revised or additional training objectives which may emerge over time. Compromising this flexibility is not cost-effective.

LEVELS OF FIDELITY OF SIMULATION

Four basic approaches or levels of fidelity pertinent to training device design can be conveniently identified. Each is useful in terms of satisfying defined training requirements. The intelligent choice from among these approaches is based on the support provided in the development of instructional strategies for maximizing the transfer of training from the simulator to the operational system. Of these four levels, three involve variations in fidelity on the engineering continuum: the fourth concerns special features of the training system and the desirability of deliberately deviating from the design of operational equipments (other than on the engineering continuum), to enhance transfer effects. Each of these basic approaches is described next. Specific design applications illustrative of these approaches are also shown, using selected current Navy training devices.

High-Fidelity Representation

This level of fidelity is defined by engineering precision in representing the operational situation (wherein the engineering state-of-the-art is adequate), the goal being a one-to-one correlation of the synthetic with the operational system counterpart. Providing a replica of the real world has advantages in a number of training situations. It is highly desirable in situations involving direct transfer of training from the training device to the operational system (e.g., antisubmarine warfare [ASW] team training in Device 14A2 for destroyer ASW personnel, or operational flight trainer [OFT] instruction for pilots transitioning to a given aircraft type). Practice in these devices should be highly realistic of actual vehicle operations; the system suites and critical equipments and all operating controls and indicators should be equivalent to those found in the vehicle and in similar configurations. Similarly, engineering precision is demanded in providing electromagnetic signal environments, such as signal signatures for airborne electronic warfare training. Also, advanced training situations benefit from exact physical simulation, as does training in emergency situations. It has been demonstrated, for example, that advanced casualty training in the submarine, involving emergency conditions, requires precise engineering simulation so that the student responses to the casualties become automatic (Goodyear 1966).

With increasingly abundant computer capacity, it appears quite useful not to "skimp" on high

fidelity as an approach to design (although this runs counter to a minimum initial cost design philosophy). At issue is the provision of maximum flexibility in trainer usage. For example, the inclusion of more than the minimum in simulation elements may heighten considerably the training capability and flexibility of the simulator (heightened engineering fidelity and complete representation may be extremely desirable in a number of subsystem areas). Careful consideration of increased capability and flexibility in design, with the attendant costs, may minimize later requirements for expensive modifications to a training device once it is on-line and training experience (hindsight) is obtained with it.

The advances in computer capabilities have solved some of the design problems of an earlier time (e.g., target characteristics, maneuverability, number of targets displayed, etc.), and excess computer capability can be used to minimize existing design problems. Hunt (1967) suggests that the substitution of an increasing computer capacity for expensive engineering ingenuity is inevitable. He suggests, for example, that the generation of an acceptable mathematical model for aerodynamic and engine performance can be considerably simplified by usage of large numbers of multivariable functions (requiring considerable computer capacity). Lavish computational power (e.g., extremely rapid computation) can be utilized to resolve some prominent and long-standing problems, in visual and in motion simulation, in realistic simulation of control forces throughout all operating conditions, in radar land-mass simulation (i.e., digital storage of the massive data file), and in realistic generation of ECM expendables (e.g., chaff bundles).

Several examples of high-fidelity simulation in trainee station configuration, equipment suites and control/display relations are shown below. The first depicts the Advanced Submerged Submarine Casualty Control Trainer, Device 21B20A. Advanced team training is provided in casualty recovery procedures (nuclear submarine). The device can simulate the submarine's reaction to flooding casualties, failures in the main ballast blow system and loss of diving planes. The reaction of the submarine to external environmental effects of sea state, changing bathymetric conditions, and depth is also

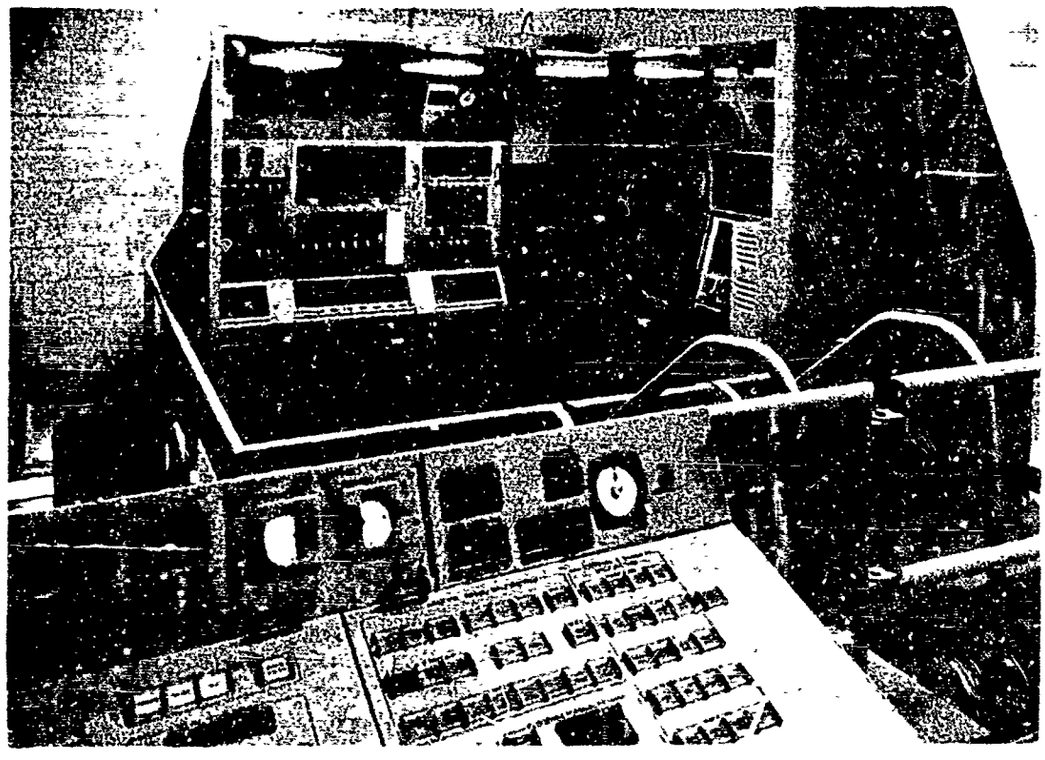


Figure 1. FLASHER Class (Nuclear) Submarine Control Cab, Device 21B20A (showing the instructor console in foreground).



Figure 2. Trainee Cockpit for A7E Aircraft, Device 2F84.

simulated. Figure 1 shows the layout and design of the FLASHER class (nuclear) submarine control cab, Device 21B20A.

Another example of high-fidelity simulation is the trainee cockpit in Device 2F84. The device simulates the A7E aircraft (flight and tactics portions) to provide training in aircraft and engine control, instrument procedures, emergency procedures and tactical mission operations. The training environment provides the same functions and operating characteristics as the A7E aircraft counterpart (all relevant controls, indicators and instruments are provided). Figure 2 shows the A7E cockpit.

A third example of high-fidelity replication is the Surface Ship ASW Attack Trainer, Device 14A2A. The training device duplicates the physical configuration of the major operational compartments and equipments of surface ship ASW attack weapons and simulates their operations and responses (i.e., target detection, fire-control solution, weapon launch and tracking). Figure 3 shows the Underwater Battery Plot (UBP) compartment in the device, containing sonar, fire-control and associated communications equipment.

A variation on the high-fidelity theme is represented in training devices which provide an exact physical simulation of the electromagnetic signal environment, but only generalized panel layouts and control operations. An example of this realistic signal environment (exact signatures), with functionally equivalent controls, is Device 15E18, Tactical ECM Trainer. Six trainee stations provide generalized system training in the basic characteristics and capabilities of aircraft ECM systems. This is accomplished in a real-time simulated electromagnetic environment, consisting of twenty-five hostile and friendly emitters (ten

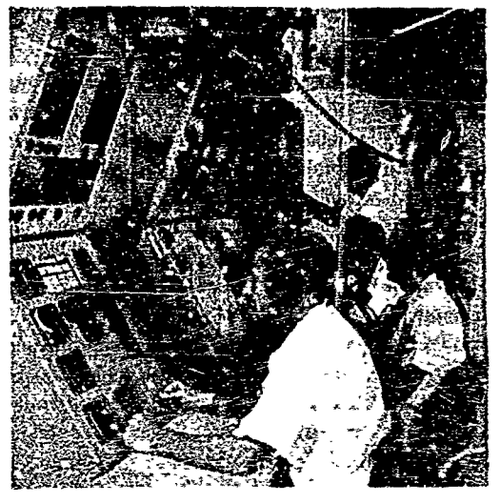


Figure 3. Underwater Battery Plot (UBP) Compartment, ASW Destroyer, Device 14A2A.

emitter types), of which five are airborne interceptors. The training environment provides high fidelity signal simulation and is typical for the aircraft ECM operator. All relevant control functions and performance of ECM equipments are simulated. The controls and displays however, are not identical to operational ECM equipments but, rather are representative of their intended use and performance. The simulated passive and active equipments are designed and arranged such that various combinations of panels functionally simulate different operational equipments and equipment configurations.

Similar in concept to Device 15E18 is the Air Force Simulator for Electronic Warfare Training (SEWT). This is a flexible trainer capable of synthesizing and presenting displays and aural presentations of the performance of electronic warfare equipments of the 1970's. The device provides controls and equipments which functionally represent five major flight missions (e.g., basic EW defensive missions, basic reconnaissance (ELINT) missions, WILD WEASEL, etc). No given aircraft is equipped to conduct all of these mission types. The signal signatures, however, are highly realistic of the operational electromagnetic environment and provide training appropriate to EW missions flown in many types of aircraft.

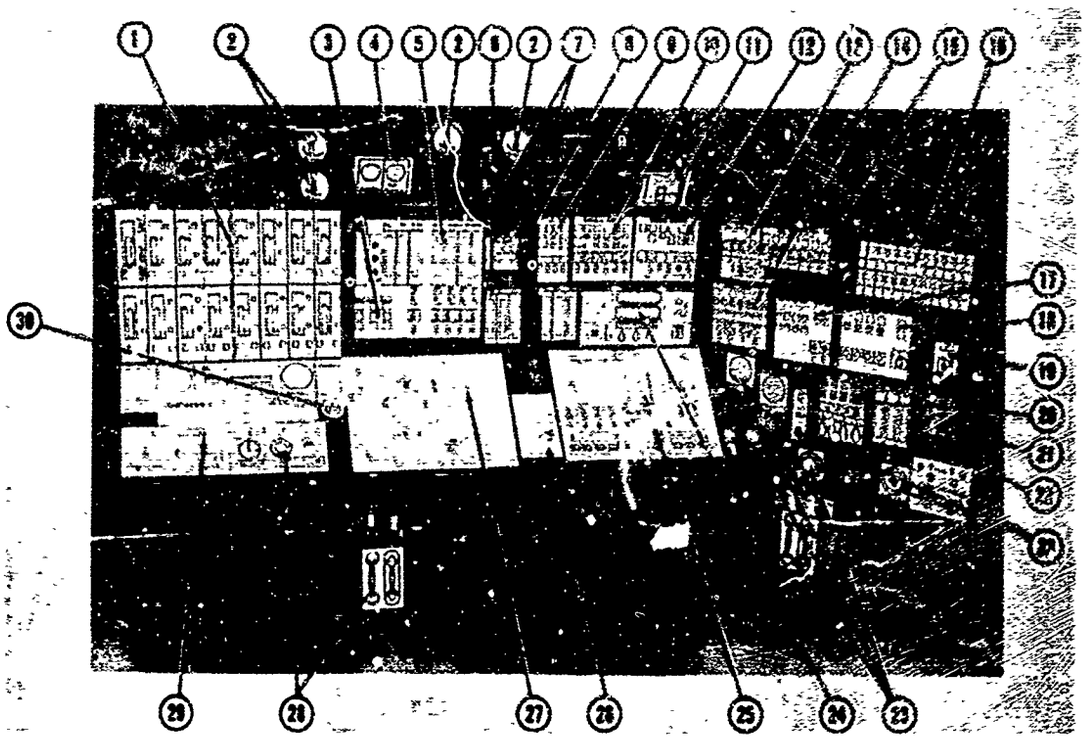
Deliberate Reduction in Fidelity Where the Engineering State-of-the-Art is Adequate

There are a respectable number of instances where the deliberate backing off from duplicating the characteristics of the operational situation is warranted in order to achieve cost economies without compromising training effectiveness. All other things being equal, reduced engineering fidelity, with attendant cost reductions, is desirable when it can be demonstrated that trainee performance is not significantly affected. For example, systematically reducing the level of aerodynamics simulation, while not compromising performance, introduces significant economies in computer hardware and associated software programing. Fogarty (1967) cites the strong tendency to include many terms in the equations of motion, since algebraic operations are accomplished easily with digital computation. The effect of many of these terms may be quite negligible in comparison with the accuracy of aerodynamic and engine data or with the accuracy of the numerical scheme used in solving the equations of motion. Research has attempted to determine acceptable levels of reduction in aerodynamics simulation (Wilkerson, et al., 1965, Ellis, et al., 1967), and simplified aerodynamic equations (omission of terms in the equation) are being developed for simulator design. Routine implementation of this approach as an option for training simulator design has not yet, however, been accepted.

The important question for design must consider how far one can back off from total fidelity and still achieve the purpose of training. Since training value data are lacking, the question of "nice to have" vs. "needed" in simulation is inexactly resolved. Quite often, as history has shown, solutions are based on "unusual" criteria. Related to this is the question of how far one must go in design to get the desired performance. Again, the question is tied in with training purpose and the objectives of training, but cost is an overriding feature. Unfortunately, more research issues than facts have been generated by these questions.

Another aspect of this reduction in fidelity approach concerns the decision to simulate generalized or universal functions in design to accomplish the desired training. A recent study (Lamb, Bertsche and Cary, 1970) has made a strong case for the feasibility of a generalized submarine advanced-casualty ship-control training device. Justification for such a device is found in the considerable evidence indicating the validity of training on generalized devices. The theme of the above study is based on the degree of similarity of instruments across classes of nuclear submarines. hence, the generalized device can accommodate training for a number of SSN and SSBN submarine classes without jeopardizing the transfer of training potential. Figure 4 shows the proposed Ballast Control Panel (BCP) design for the generalized trainer. The controls and indicators of the BCP are a best-fit composite for the following classes of the ALBACORE submarine: SSN.s 585, 594, 613, 637, and 671; and SSBN's 598 616 and 640.

A representative example of a generalized training system is Device 1D23, Air Navigation Trainer. This is a multiple-station trainer comprising 40 cockpits and six instructor stations. The device is generalizable to a variety of aircraft, but is not identical in layout, dimensions,



1. Missile Compensation System
2. Ship Alarms
3. List Angle & Control
4. Altitude & Hull Pressure Gage
5. High Pressure Air Banks
6. DCT 1, 2 & Sea Pressure Gages
7. Emergency Blow Controls
8. Power Ind.
9. Periscope Ind.
10. Antenna Masts
11. Bathythermograph
12. Snorkel System
13. Hull Openings
14. M.B.T. Vents
15. Rig for Dive
16. Common Alarm Panel
17. Emergency & Normal MBT Blow
18. Low Pressure Blow
19. Ground Detect System
20. Hydraulic Plant Pump Contrbls
21. Hydraulic Pressure Gages
22. Hydraulic Accumulator Contents
23. B.C.P. Operator Communications
24. Trim & Prime Pump Controls
25. Trim System
26. Status Board & Covered Neg. Tank
27. Depth Control System
28. Missile Operator Communications
29. Missile Away System
30. Missile Compensation Depth Controls

Figure 4. Proposed Ballast Control Panel (BCP) Design for a Generalized Submarine Advanced Casualty Ship Control Training Device (from Lamb, Bertsche and Carey, 1970).

equipment, etc., to any existing aircraft. Substantial simplification in the degree of fidelity is achieved, since only that information necessary for the navigator to effectively perform his functions is represented. This provides the trainee the opportunity to make the appropriate responses to stimuli which are characteristic of navigational problems. What is provided is common to many aircraft. Figure 5 is a proposed trainee station cockpit for Device 1D23.

A ground swell of sentiment is currently in effect for the development of low-fidelity generalized trainers for tactical decision-making training. Evidence from recent research is

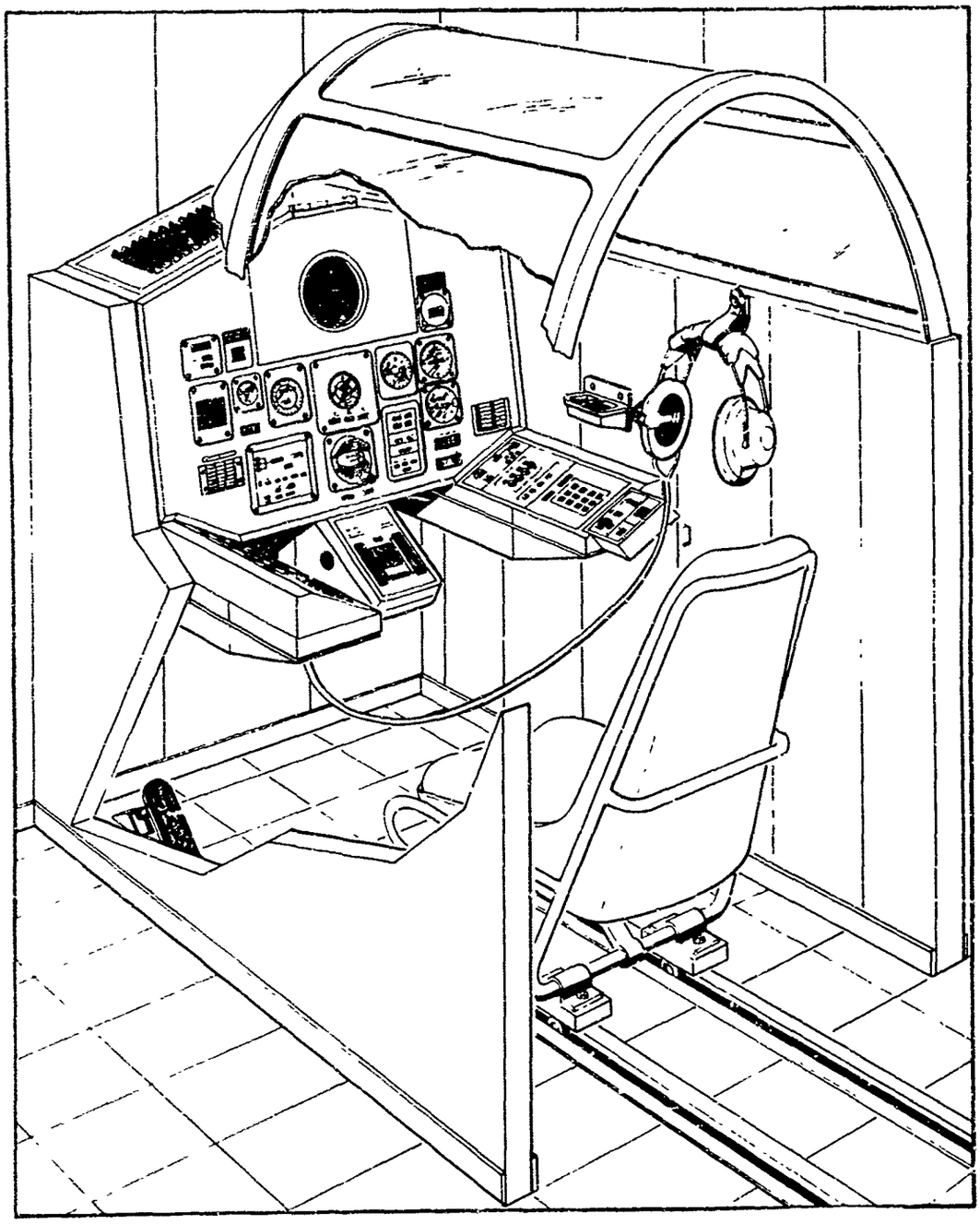


Figure 5. Proposed Trainee Station Cockpit for Air Navigation Trainer, Device 1D23 (from Bark, et al., 1969).

encouraging and indicates that this type of device will be forthcoming soon. The implication is that the equipment complexes associated with operational systems and the real-time requirements of the mission scenario need not be duplicated for effective training. Experimental studies suggest that the decision-making aspects in mission contexts can be installed for training without recourse to dynamic replication of antecedent and follow-on events. Sidorsky and Houseman (1966), for example, have found that the typically long period of time from initial detection to weapon launch need not be simulated in the training of tactical decision making for many ASW situations.

Another broad grouping within the deliberate reduction in fidelity approach is the use of part-task simulation to achieve training goals. Enough evidence has been assembled over the years to indicate that simplified part training for certain component skills and job situations is as efficient as training with complex high-fidelity simulation, and at much reduced costs (see, for example, Adams 1960). Part-task training devices are particularly appropriate in instructional situations which are defined by (1) the learning of procedures where the emphasis is on checklist operations rather than on control skills; (2) the learning of response sequences that are not performed in a concurrent time-shared relationship with other task requirements and, when learned, can be efficiently integrated into the total job requirement; and (3) maintaining proficiency in procedural sequences.

Examples of this level of fidelity abound in the NAVTRADEVCEN training device inventory. An idea of the profusion and diversity of these training means is depicted in the NAVTRADEVCEN publication, "Training Device Developments" (NAVTRADEV P-1300 series). A well-known example of this level of fidelity is the aircraft cockpit familiarization trainer. Device 2C23, shown in figure 6, is representative of this class. It simulates the interior cockpit area of the P3B aircraft. The aircraft interior is duplicated to the extent that the trainee encounters all the restricting dimensions and obstacles of the actual aircraft cockpit. The active components consist of trainee-actuated controls and annunciators which



Figure 6. P3B Aircraft Cockpit Familiarization Trainer, Device 2C23.

can be illuminated and extinguished by the instructor. The trainee-actuated controls include the wing flap handles, power levers, landing gear handles, switches and the components located on the electrical load center. Actuation of these components by the trainee imparts familiarization with the feel (adjustable), range or extent of movement, and the various detent positions, as well as the location of such controls. Illumination of the various annunciators by the instructor provides familiarization with the location, color, nomenclature, etc. Each annunciator is controlled by an appropriately identified switch. The passive components include all simulated control and instrument panels. The purpose of these controls is to create a training situation which familiarizes the trainees with the location, appearance, markings, ranges, and arrangements of all cockpit instruments, indicators and controls.

Reduction in Fidelity Tolerances When the Engineering State-of-the-Art is Less than Adequate

There are design situations where the engineering technology is not fully able to represent certain events with the realism required for effective instruction. The resultant design alternatives involve a reduction in tolerances in achieving the simulation requirements. The more prominent design problems here which provide demanding challenges to engineering include: visual simulation, vehicle motion simulation, the realistic correlation of visual and motion cues, radar landmass simulation, control loading systems, the generation of return from countermeasures expendables (e.g., chaff) and the generation of sonar classification cues.

Motion simulation exemplifies the difficulties in this level of simulation. As a case in point, the physical displacement limitations place serious constraints on both acceleration and frequency response. Displacement varies inversely as the square of the frequency for sinusoidal motion; the higher the frequency of the acceleration, the smaller the displacement. As frequencies fall below one cycle per second for a given acceleration level, the displacement requirements increase considerably; for example, an acceleration of $\pm 1g$ at 1 c.p.s. requires 10 inches displacement while an acceleration of $\pm 1g$ at 0.1 c.p.s. requires ± 85 feet. Because of the displacement limitations, techniques are required for deceiving the human with cues that have signal value and have relevance to the real-world counterpart. The design techniques currently employed in simulating g forces include the use of acceleration onset cues and washout acceleration, the scaling of acceleration and the use of signaling techniques such as inflatible seat cushions and seat belt tighteners. The solutions are less than desired, and design practices today rely more on empirical determinations since precise quantitative design information is lacking.

The design concern is to provide the needed motion cues rather than to completely duplicate the spectrum of aircraft motions. To achieve motion cues that are perceptually undistinguishable from those experienced in flight vehicles is a particularly taxing requirement because of limitations in the physical displacement of the simulator, less than continuously available power and the structural stiffness of the device. Further, the requirement is predicated upon how man combines visual, somesthetic and vestibular sensations into a perception of motion. However, sufficient data on this integration are yet unavailable to provide a body of information that can be used effectively in design. Specifications for any motion system include: the degrees of freedom required and, for each motion axis, the displacement (linear, angular) and maximum acceleration required. The parameters of displacement, acceleration, and velocity are interrelated; for example, a maximum velocity attainable is limited by a given displacement and maximum acceleration. Simulating the full six degrees of platform motion, wherein all axes are represented faithfully to the perceiver, cannot yet be satisfactorily achieved except for brief time durations, and design practice has settled for four or less axes (with pitch and roll mandatory in any system). Of concern are the multi-axis interactions, since the effective axis of acceleration in the operational environment seldom falls on any one orthogonal axis but is a vector with components of each. A prominent issue for design concerns the minimum in motion representation that is satisfactory to the trainee. This issue revolves around the priority of the motion axes, how many parameters to provide and the precision of representation for defined task situations. The coupling of visual and motion parameters in the flight simulator further compounds the problems in achieving acceptable tolerances for design.

In this whole simulation category, which is concerned with reductions in tolerance, human factors design must take into account the worrisome issue of instructional value (including the motivational component) resulting from the attenuation in fidelity which is the "best that can be achieved." Specific engineering design issues relative to this level of fidelity are discussed in other papers in this journal. They are also articulated in a number of published sources (see, for example, Hunt, 1967; Graham, 1968; Matheny and Wilkerson, 1966; Puig, 1970; Smode, 1971).

Deliberate Departures from Realism (Deviations in Configuration/Operation Associated with the Operational System Being Simulated)

A training simulator, by definition, represents some defined portion of a real situation and provides precise control over and planned variation of the training materials and sequences presented to the trainee. It also permits the deliberate omission of aspects of the operational situation in order to eliminate or reduce: natural variability and unpredictability; hazards; and elements not critical to task performance, not conducive to learning, or evidently not yielding sufficent advantage for the costs involved. A precise correspondence to a real job context is not necessarily a prerequisite for transfer of training. There is ample evidence that significant transfer of training accrues not only with low fidelity stimulus and control conditions, but even where there are significant alterations in equipment configurations or omissions of secondary cues found in the operational environment.

Thus, another approach to fidelity involves planned deviations in configuration or operation associated with the operational system being simulated. This differs from a cost-effective lowering of the engineering fidelity, or a reduction in fidelity tolerances where the engineering state-of-the-art is less than adequate, and is concerned primarily with the training process rather than with engineering fidelity. The intelligent use of this type of design option serves to enhance training effectiveness by providing conditions for learning to occur; it is also a prime means for motivating students to perform, since incentives which motivate man's activities come, in part, from the consequences of his own actions as they are understood. Representative design techniques include the following.

1. *Display enhancement.* Involved here are techniques which yield identifiable coding dimensions for enchancing the display of information to the trainee. The enhancing of signals insures detection and classification of events in cluttered displays and also the effective monitoring of signals in complex displays. The principle underlying this usage is simple. To provide guidance to delimit the frequency and severity of incorrect responses in performance. Proper use dictates that display enhancement be invoked during initial training with the response cues gradually withdrawn until the trainee eventually responds to the stimulus found in terminal performance. The means by which information display can be enhanced include: symbols, color, size, intensity, orientation and alphanumeric coding.

2. *Information Feedback via Training Equipment.* A desired design goal is to provide the capability in equipment for the student to know (as appropriate) how the results of his performance conform to expectations or norms. Much evidence has been assembled concerning the salutary effects of knowledge of results or information feedback on learning and on performance (see Bilodeau, 1966). For training device design, the interest centers on the display of augmented feedback to the trainee. This is a special case of information presentation in which the trainee is provided a signal immediately after his response which indicates the adequacy, correctness, or accuracy of his performance. This information is not available in the learning task *per se*. A number of design options are available for providing supplementary or augmented information feedback to the trainee. One means is to provide performance error information, as accrued, directly on a primary display (e.g., in alphanumeric form on a CRT). Variations on this theme include the use of pointers, indicator lights, digital readouts, etc., on instruments to show actual vs. desired values. Supplementary signals are also useful for augmenting the information feedback loop. Visual signals, overlaid on primary displays or peripherally positioned, serve to indicate that performance error has exceeded criterion limits, that the trend of performance is approaching an out-of-tolerance condition, or that a procedural error has occurred. Auditory signals are also useful (e.g., alerting sounds, pre-recorded words, computer-generated sounds based on voice synthesis).

3. *Guidance Supports.* In addition to information feedback (i.e., given during or immediately after performance), cues and prompts in equipment (i.e., information given prior to performance) serve an instructional purpose. Provision for a demonstration mode in the trainer is a prominent instructional guidance technique. One design technique involves the use of information displays which present future or predicted information based on trainee control performance of the moment. A predictor instrument, which provides a display of the response characteristic of the system in terms of predicted system output at some time in the immediate future, is a representative example. The control task can be simplified by providing the operator information relative to the future of the variable being controlled (see Kelley, 1960).

Related to this is a type of information display which provides an indication to the trainee of the immediate or successive actions required to maintain an in-tolerance condition. This approach can be implemented in various ways. One way is by means of miniature indicator lights imbedded in an instrument display which provide guidance information via a sequencing of the lights in the direction of the correction required. The rate of sequencing is proportional to the magnitude of the error. A specific application of this is a circular pattern of miniature lights built into the face of an aircraft instrument. The lights can be energized sequentially to give the sensation of a moving light in the direction of a required corrective action. The lights are not visible when performance is in tolerance (Faconti, Mortimer & Simpson, 1970).

Guidance may also be built directly into the controls operated by the student. Controls can be mechanized to describe a desired action; for example, a pilot trainee "following through" on an automated control stick sequence which demonstrates an ideal maneuver. Limits of movement can also be built into a control to ensure that a trainee does not exceed defined error boundaries.

4. *Extra-Mission Equipment.* Another means for optimizing training opportunity via design is the provision for "trainer peculiar" equipments in the trainee compartment. These refer to hardware and associated training functions which are not present in operator stations in the actual system. Their purpose is to provide the trainee useful performance information not available on the job and to enable trainee-initiated and paced instruction. These features, emphasizing the "training tool" characteristics of simulators, are becoming increasingly prevalent in the design specifications for new training devices.

In complex training environments, stimuli associated with various responses are not easily identified. This hampers the control of the instructional process. A way to minimize this problem is to provide means for presenting and monitoring specific stimuli. The Air Navigation Trainer, Device 1D23 (described earlier), offers a means of precise stimulus control for training and also provides immediate supplemental information to the trainee about the results of his performance. This is accomplished via an annunciator panel in the cockpit (Bark, et al., 1969). A number of programed questions are displayed to the student requesting certain information and specific types of behavior (e.g., calculate bingo fuel and time, calculate ETA to the next fly-to point). Each question is programed to be visually displayed at specified times in the mission cycle and remains "on" for at least 30 seconds during which latency of response is recorded up to 2 minutes. Failure of the student to respond (via keyboard entry) to the question in this time frame results in negative knowledge of results. In all cases, information feedback is given to the student, via the computer, immediately upon completion of response to each annunciator panel question. Figure 7 shows the annunciator panel and the performance status indicator (which provides knowledge of results to the student) on the proposed instrument panel for Device 1D23.

A performance measurement technique that also provides the trainee supplemental information about performance not available in the job context is the trainee monitoring system (TMS), designed for installation adjacent to the cockpit of OFT's (e.g., installed in Device 2F100 simulating the A7E aircraft). Procedures-following sequences (computer-monitored checklist events) involving both normal and emergency procedures in the mission cycle are displayed alphanumerically on a CRT in both the trainee and instructor stations. The trainee is provided information on the adequacy of his procedural performance as accrued (i.e., in-tolerance performance and errors of omission and commission in procedural checklist activities are depicted on the TMS display). This information is also recorded for performance measurement purposes.

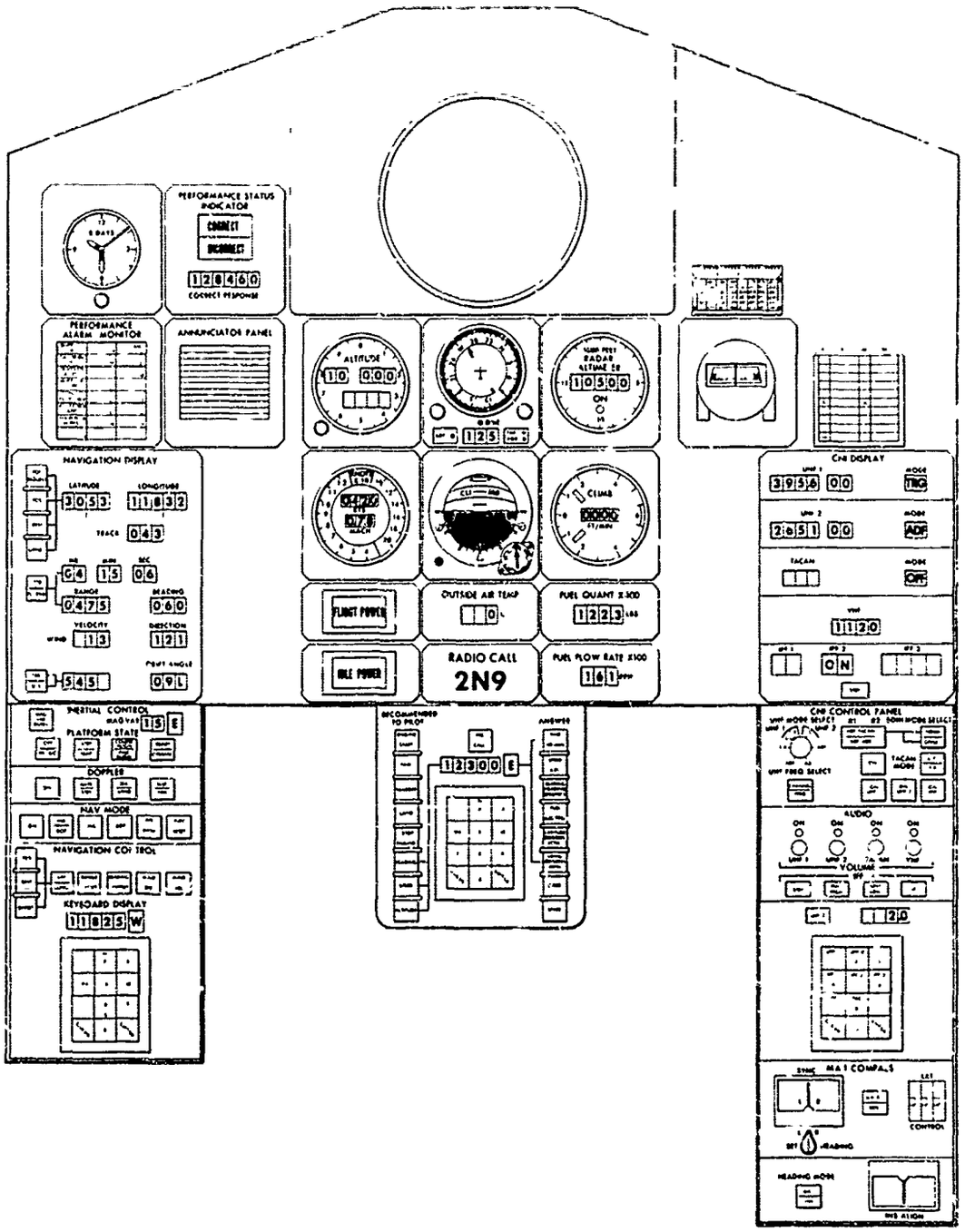


Figure 7. Trainee Station Instrument Panel Proposed for Air Navigation Trainer, Device 1D23 (from Bark, et al., 1969).

The recently developed Helicopter Instrument Flight Trainer, Device 2B24, possesses a number of instructional assists in the trainee cockpit. This device, designed within the Army's concept of a Synthetic Flight Training System (SFTS), consists of four UH-1 helicopter simulators and associated motion platforms, a general-purpose digital computer and an instructor station. The design goal is to provide realistic simulation of the helicopter pilot's task and to treat the

instructor simulator combination as a pilot production subsystem (Caro, 1969). Device 2B24 provides a capability for demonstrating training problem solutions in the cockpit. Upon the request of the trainee, demonstrations can be executed such that cockpit instruments and the motion module exhibit movements as actually flown. This may be in real time or slow time or combinations of both. A pre-recorded verbal explanation and commentary synchronized with the flight is provided. The demonstration emphasizes both instructional quality and technical accuracy to insure trainee understanding. The extra-mission equipments in the cockpit include: an information display panel which provides performance status and feedback information to the trainee, an automatic program control panel for initiating certain events such as demonstrations, training problems (in automatic mode), motion system operation, problem halt, etc.; a CRT monitor (monitored by the trainee for graphic data and for debriefing); and a CCTV camera (for instructor viewing of the engine and attitude instruments and the trainee manipulation of aircraft controls). Voice alerts are provided (via the intercom system) on parameters of flight which are outside acceptable tolerances for a given maneuver or flight condition. In addition, premission briefing is automated and provided to each trainee while seated in the cockpit. Figure 8 depicts the cockpit of the Helicopter Instrument Flight Trainer, Device 2B24, showing the trainee information display and the automatic program control panel. Not shown in the figure are the CRT monitor and the TV camera.

SUMMARY

1. Various levels of fidelity have utility for training device design. Selecting the appropriate design option is based on the training requirements analysis, the available candidate engineering solutions for achieving the simulation requirements, and the cost considerations.

2. High-fidelity physical correspondence to the operational environment is desirable in situations

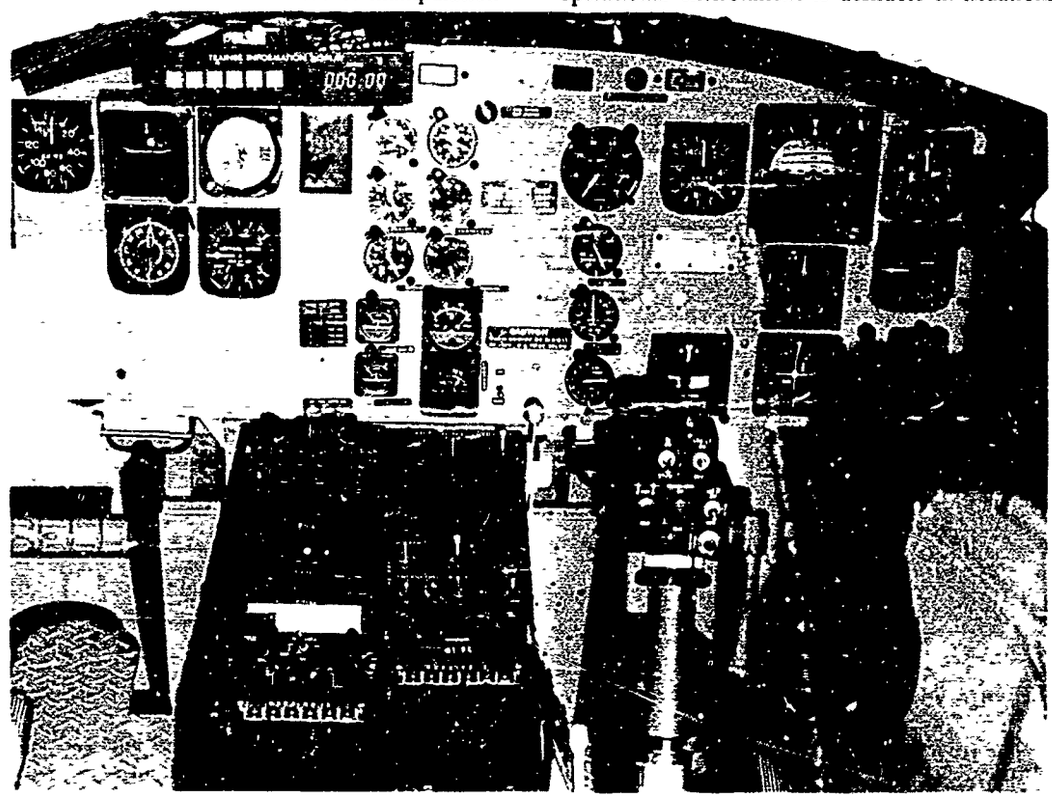


Figure 8. Trainee Cockpit of Helicopter Instrument Flight Trainer, Device 2B24 (the trainee information display and the automatic program control panel are shown).

demanding direct transfer of training from the device to the operational system, particularly in advanced instruction and in training involving emergency conditions. Advances in computer technology support the selection of this design option. Deliberately backing off from duplicating the characteristics of the operational situation is also a prevalent design option. The salient feature here is the cost economy achievable due to reductions in engineering fidelity without compromising training effectiveness. In design areas where the engineering state-of-the-art is less than adequate, considerable attention must be devoted to ensuring that the reductions in tolerances are the best achievable. Instructional advantage is forfeited when the resultant attenuations in fidelity are not perceived (both technically and motivationally) as valid by the trainee. Deliberate departments from realism reflect the incorporation of training technology into design. Training value is enhanced through design practices which integrate training process considerations with engineering fidelity. Using the simulator simply as a substitute for operational practice reduces its training advantage. The shaping of the desired behaviors is accomplished most effectively when the training device is designed as an instructional system.

3. Within the current state-of-the-art, advantage accrues from employing each of the approaches mentioned above; no given level of fidelity is uniformly preferred at the expense of other options. The selection from design alternatives depends on a number of considerations involving engineering capability, instructional advantage and costs. Several approaches may be incorporated effectively into a complex simulator to achieve the desired instructional capability.

4. Judgments concerning optimum design approaches must be based on an accumulating training effectiveness data base. This involves a reliance on transfer of training evidence obtained experimentally, wherein performances in the training device and in the operational system are compared systematically. From this foundation, design principles and operating practices can be recommended with some certainty.

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Some Current Issues in the Design of Flight Training Devices

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The value of the system engineering approach to training program development has become fairly well recognized. Not so well recognized, however, are the implications of the approach for training equipment design. Systems engineering of training focuses on the student and emphasizes the job for which training is to be given. All decisions concerning training should be made in favor of the student. The essential question is always, "How can he best be trained to perform the job he will be required to do?"

In selecting or designing training equipment, of whatever order of complexity, careful attention should be given to what the student needs to know and be able to do to perform successfully on the operational job. Care should be taken to ensure that the equipment provides the necessary information content and/or allows for the creation of appropriate job-relevant conditions for performance practice. Too often, though, emphasis is placed solely on duplication of the operational system. The result may be an excellent simulation, but a less-than-optimal trainer. Attention should also be given to the inclusion within design of features whose sole function is to facilitate the student's acquisition of knowledge and skill, features based on the laws and principles which govern human learning and retention. These features may represent deliberate departures from the real-world or operational system model underlying the usual high-fidelity simulation. The learning and performance characteristics of the device user, the student, must be paramount if simulators or trainers are to be maximally effective learning systems.

This paper develops the rationale described and examines several considerations relevant to training equipment design from the systems engineering standpoint. Suggested design features based on particular student learning needs and on student learning characteristics are presented. Training equipment design features for particular categories of training objectives and for levels of training (e.g., initial training of aviators vs. transition training) are considered. Also discussed is the criticality of the synthetic training program with respect to the total training engineering process.

An examination of the history of development of flight training devices would reveal a number of recurrent issues concerning their design. Generally, the issues that have been raised (e.g., is motion required? is a visual display required? what are the best mathematical solutions for representing aircraft performance?) have tended to center on how best to simulate dynamic operation of an aircraft in a flight environment. In short, the major concern has been, and continues to be, fidelity.

Many of the promised breakthroughs in simulation technology (e.g., unprogramed visual displays), however, appear still to be "just around the corner"—a condition they were in 20 and 30 years ago. Perhaps it is time to reconsider the position that the best training device is one that most faithfully simulates operational equipment performance. Let us consider ways of maximizing the value of the devices that we are capable of producing within our current technologies while we await the hoped-for developments in fidelity.

It is the contention of the authors that training device designers should modify their primary concern with aircraft fidelity issues somewhat, and focus their attention more heavily on the trainee, the instructing function, and the learning process. It is here that the most significant gains might well be made in the contribution that synthetic training equipment can make to the training process.

This is not to say that the problems of simulation engineering technology warrant no further attention. Certainly, simulators whose primary purpose is for engineering or operational research (e.g., tactics development) or for evaluation of flight crew performance require high levels of fidelity—the higher the better. Also, we are not saying that physical fidelity should not be of concern in devices to be used for training. The need for a particular level of fidelity in a given training device is not an issue. Numerous studies have demonstrated the relationship between physical fidelity and transfer of training (e.g., see Caro[1]). However, we are suggesting that the

emphasis should be on learning, and it should be noted that transfer and learning are not the same. The conditions that make for high transfer (i.e., stimulus/response equivalences), however, do not necessarily make trainee learning (i.e., his acquisition of desired skills) any easier or more efficient. If the aircraft is a poor learning environment--and for many flight related skills it is one of the poorest imaginable--then a ground-based duplicate of that environment will not necessarily be a better one in which to learn. There is evidence, for example, that skill structures change during training (Fleishman and Bartlett[2]). Thus, an exact duplication of an aircraft with fixed characteristics cannot be optimally suited for training if trainee skill structure does change over time.

Consider, if you will, that most synthetic trainers used today for military pilot training have been inappropriately designed. Ostensibly, trainers are procured to fulfill a *training* mission. In reality, they are most often nothing more than an approximation to a duplication of some sort of operational equipment, equipment which has a totally different mission than training. A visit to any large military pilot training school, and a look at the sundry, often home-made training aids and assorted devices, as well as the current user interest in learning centers, all suggest that the user has training needs which are not being met by the equipment supplied to him.

Have device designers fallen behind the user in failing to recognize his training needs and to design equipment to meet these needs? We, who may possibly be in a position to influence training equipment design or to devise ways of overcoming design limitations to meet training goals, should seriously consider altering the direction of device design. It is our contention that there is more to be gained at this point in time from applications of our present knowledge of learning and of techniques which facilitate learning than from seeking further increments in hardware fidelity. In short, we believe that device designers should design their products for *training* and not primarily for the creation of illusions. We should cease thinking so much about producing aircraft simulators (i.e., land locked aircraft) and begin thinking more about producing the most effective and efficient learning environments.

A number of steps have already been taken in this direction. Several characteristics of existing aircraft simulators and training devices can be identified that make them better suited for training than the aircraft they simulate. For example, simulators have a "freeze" capability which allows interruption of all simulated aircraft action during training activities; the simulated aircraft can be rapidly repositioned, thus decreasing the amount of relatively unproductive time required to perform approach maneuvers; and certain emergencies can be introduced and corrective procedures can be practiced in simulators more safely than in actual aircraft.

Characteristics such as these are important. Several of them provide sufficient economic justification for the acquisition and use of simulators by airlines, industry, military establishments, and educational organizations. Others are there solely to aid in the training process, and it is these features in which we are primarily interested.

The usual simulator design goal is to duplicate, within state-of-the-art limitations, a particular aircraft. But, the freeze and reposition capabilities do not contribute to this goal. They are features for which no counterparts exist in the aircraft, and they illustrate ways that the training value of a device can be enhanced through the inclusion of features which are there for training reasons rather than solely for engineering reasons.

The process of specifying those training features that should be included in simulator design is difficult to describe. Whatever the process may be, its output (i.e., design features) must be suitable for the development of relevant skills. The product need not faithfully reproduce in all respects the aircraft for which training is intended, although certain aircraft-specific stimuli must be included. Design features should be based upon those learning principles related to skill and knowledge acquisition. For example, we know that factors such as augmented feedback, reinforcement, and behavior shaping are important in skill acquisition. A simulator based upon design considerations such as these might be less like an aircraft than like a multimedia learning laboratory built around modern training concepts such as adaptive training, self-confrontation, and modeling. The overriding objective of training simulator design, however, should be to produce a learning environment in which relevant and aircraft-specific skills can be learned in the most efficient manner.

CURRENT TRENDS IN DESIGN FOR TRAINING

A survey (Caro and Prophet [3]) revealed a number of training-relevant features in their designs. These features fall into three broad categories. (1) automation of instructional functions; (2) aids to the instructor; and (3) trainee-controlled instruction. In the following section several design features which are related to the learning and instructional processes are discussed.

Automated Instructional Functions

Several recently developed training devices have attempted to improve the instructional process by assigning to the computer certain of the functions which have traditionally been performed by the instructor. For discussion of some of the specific considerations the reader is referred to Caro[4] and Faconti, Mortimer, and Simpson[5]. Some of the functions that can be automated, however, go beyond traditional instructor functions into new aids to the instructional process. Certain of these instructional design features have become feasible only because of the digital computer's great capabilities for data handling. They are examples of training device design features that are based on facilitation of the learning process. Descriptions of selected features and techniques involving computer-aided automation of instructional functions follow.

Performance Monitoring

One important function of the simulator instructor is the monitoring of trainee performance. This is necessary so that the instructor can provide appropriate feedback to the trainee and determine trainee proficiency. Many older training devices have repeater instruments for this purpose. Usually they are located at a remote instructing position, and the instructor obtains the necessary trainee-monitoring information from them. These instruments are basically the same as those designed for installation in actual aircraft where size and weight considerations were paramount. They were not optimized for displaying information needed by the instructor in a training application for use in ground-based trainers. Here is a very simple example where a training-oriented design concept would likely produce a different and more efficient item of equipment.

Training device instructor station display configuration is one design area which received early attention from personnel concerned primarily with training effectiveness. The instrument trainer of three decades ago reflected some concern for training in the design of instructor stations. The ground track plotter was developed during this period solely to monitor the track of the simulated aircraft. Some of the newer simulators incorporate other techniques for monitoring performance and show evidence of getting away from the duplicate instrument approach which still characterizes too many flight training devices.

Monitoring of aircraft tasks which are primarily procedural in nature often requires a great deal of the instructor's attention because of the necessity to keep track of time and sequence dependencies as well as task performance accuracies. Procedural tasks are relatively simple to monitor automatically. A number of training devices have greatly simplified the instructor's job in this area by presenting summary displays of procedural task performance.

The most difficult aspect of performance monitoring—whether in the aircraft or in a training device—has always been in connection with flight control tasks (i.e., the psychomotor skill area). Automatic or computer controlled monitoring of psychomotor task performance has been the subject of extensive recent investigation (e.g., Connelly, Schuler and Knoop[6]). Several approaches to automatic performance monitoring in the aircraft simulation situation are available. Each of these can determine trainee deviation from a desired model. Performances which are monitored automatically typically relate to total system output, such as deviation from preselected airspeed and altitude, rather than to direct trainee input such as control stick movement. The more sophisticated flight training device incorporating digital computers could monitor almost any system output or trainee input parameters that might be desired. Whatever the particular parameter to be monitored, however, it should be selected on the basis of task information developed through systems engineering studies, rather than on the basis of ease of measurement or some other non-training dependent consideration.

Malfunction Insertion

This function consists of using the digital computer to control the selection and insertion of simulated systems malfunctions during a training exercise. The trainee must respond by executing the appropriate emergency procedure sequence. Malfunction insertion in older devices is performed manually, commonly by having an instructor activate switches to introduce a system failure.

Variation of Task Difficulty

The capability to vary task difficulty automatically in response to trainee performance has commonly been called adaptive training. Application of this technique to flight training devices has attracted a good deal of interest recently. The general adaptive formulations of Kelley and Wargo[7] have attracted the most attention, although other approaches have been considered (e.g., Hudson[8]). Whatever the approach, adaptive training involves a deliberate departure from realism in aircraft simulation. It is an approach that has been found, in at least one flight trainer application, to contribute to training efficiency (Ellis, Lowes, Matheny, and Norman[9]). A discussion of considerations relevant to use of adaptive training techniques in training equipment design may be found in Caro[10].

Student Feedback and Guidance

In any training situation, one of the most demanding and critical activities of the instructor is that of providing feedback to students. Computers, which are integral to most modern simulations, can be used to analyze data rapidly and automatically provide the trainee with cues via feedback devices, supplemented possibly by summaries from the instructor. Automatic student feedback and guidance can relieve instructors of considerable feedback responsibility. Both aural and visual feedback devices are possible. Several are discussed elsewhere in this paper. In some applications, alerting or prompting cues may be automatically provided to the student if his performance approaches some specified tolerance limit. These cues may deliberately be quite different in form and frequency from those found in the real aircraft, if indeed they exist there at all.

Flight Demonstration

Flight demonstration is a teaching technique used in all pilot training programs. Several methods have been devised for programing a flight simulator to fly or demonstrate maneuvers under autopilot control while a prerecorded narrative highlights important or difficult performances. One objective of such a procedure is to assure presentation to all trainees of a standardized demonstration of each maneuver to be learned.

Sequencing of Maneuvers and Mission Segments

One of the principal benefits of the programed instruction approach has been the highlighting of the importance of the sequencing of instructional content and the development of bridging behaviors in skill development. Once the particular sequence that will produce optimum learning has been established for a specific set of tasks, it is possible, under computer control, to lead the trainee automatically from one training task to another in this predetermined sequence. Branching sequences are also possible.

Permanent Recording of Results

The rapid data storage and processing capability of computers associated with many modern training devices makes it possible to record trainee performance information for later analysis or for display of data summaries for use during subsequent training activities. Putting this function under computer control not only relieves the instructor of the distracting requirement to take notes "on-line" for subsequent debriefing or grading purposes, it also vastly extends the types and amounts of performance data that can be examined. Such data can be recorded in a form appropriate for direct input into computer analyses.

Instructor Aids

Three training device design features intended primarily to enhance instructor effectiveness have already been mentioned—the freeze and reposition capabilities and the ground track plotter. Applications of several modern technologies have made available a number of other tools that can be used to aid the instructor in his task of providing

feedback and guidance to the trainee. These aids can also let him make much more effective use of his time. Several of these are discussed below.

Performance Playback

To enable the instructor to confront the trainee with his errors, trainee performance (i.e., the performance of the simulated aircraft) may be recorded in real time for instant replay to the student. During playback of such recorded performance, the trainee may observe his own performance, errors and all. As with the original simulation, the playback may be "frozen" for detailed inspection. Additionally, it may be reviewed any number of times and even played back in non-real time for more detailed study by the instructor and the trainee of the performance which occurred. This provides an opportunity for performance review and corrective guidance from the instructor that cannot be provided in a real aircraft.

Audio and Video Recording

Another means of confronting trainees with their own performance is provided through audio and video recording techniques. Self-confrontation through such recordings has been used in other training settings (e.g., language laboratories, professional sports leadership development) and has been found to be useful in effecting behavior change.

Plotting Devices

In debriefing students, instructors have learned to make good use of the information contained in ground track plots. Other time plots of performance, such as airspeed and altitude, could also be used to advantage in the instructional process. When such plots are presented on CRT displays, rather than more "old-fashioned" plotting boards, the information they contain can be manipulated in various ways for rapid analysis of student problems. Location of plots, whether on CRT's or other media, in positions where they can be observed by trainees during or immediately following training (as opposed to having them located in some area remote from the trainee station) enables an instructor to provide feedback in a much more rapid and effective manner. While the point has not been previously discussed in this paper, the temporal contiguity of feedback to the performance of concern is extremely important as a factor affecting learning. Certainly, the temporal aspect of feedback is one of the most frequently and widely studied learning variables.

Instructor Displays and Controls

In older flight simulators, and in some instances even in current ones, instructor stations involve panels 25 to 50 feet in length consisting of plotting boards, pushbuttons, toggle switches, instruments, and various other displays and controls. Such designs require considerable physical movement of a team of instructors in order to control the training for one aircraft crew. The use of CRT's with special- and general-purpose keyboards and light pens in instructor station design has allowed great reductions in the size requirements of instructor stations. More importantly, it has given instructors much more positive control over training and has permitted better organization of their tasks. Being able to concentrate in a much smaller area, particularly the area represented by a CRT and its associated keyboard, enables the instructor to be alerted much more efficiently to parameters of training and trainee performance to which he should attend. The particular information which needs to be displayed to the instructor via CRT, or which the instructor needs to insert into the training problem through the keyboard and light pen, is a matter to be determined through systems analysis, not only of the training requirements, but of the instructional task as well.

For some training situations, hand-held remote control devices are being used by instructors as an aid in training. These devices, typically consisting of several general-purpose keys and a digital readout, permit the instructor to communicate with a remote instructor station while physically occupying a position beside the trainee—a position that may be determined to be necessary in the conduct of certain training activities.

Trainee Controlled Instruction

The requirement that a flight training device bear some physical resemblance to the vehicle it simulates has been recognized earlier in this paper. That requirement notwithstanding, the design of the trainee's compartment should be based upon fulfilling training requirements rather than solely

upon the physical characteristics of the vehicle simulated. It is quite possible, and perhaps desirable, that flight simulators designed for training might resemble multimedia learning laboratories more than the aircraft itself. Such an environment allows use of a variety of modern training concepts such as programed instruction, adaptive training, self-confrontation, functional context training, peer instruction, and performance modeling. In essence, such devices might be termed "fly ' learning centers. Obviously, the features and concepts used must not interfere with certain critical aircraft control tasks. However, a simulator designed for training would probably provide the trainee with a number of controls totally unrelated to operational flying tasks. Such controls might, for example, permit the trainee to initiate prerecorded demonstrations and exercises to freeze the simulation, to reposition himself, and to perform similar functions as directed by the training to be conducted. Displays not found in the aircraft itself might also be required to advise the instructor of certain administrative considerations, such as the condition of the motion system or that a prerecorded demonstration has been terminated and the trainee should again assume control of the simulator. If the performance monitoring functions have been automated to the extent that trainee performance can be scored against some external preprogramed performance criteria, evaluative information concerning his performance on prescribed exercises might also be displayed in the cockpit.

IMPLICATIONS

Design Considerations

What, then, are some of the principal implications for training device design implicit in this direction of development. The first is that training device design questions must be examined in a much broader frame of reference than has frequently been the case in the past. We believe that optimal efficiency and economy in training operations will come through the design of *training systems* in which all elements of the system are structured and organized in such a way as to enhance the student's acquisition and subsequent retention of the knowledges and skills that he must acquire. The central concern in design should be with questions such as: what does the student need to learn? how does he learn? what is the best way to organize and present information to him? what is the best way to teach complex skills?; and similar learner-oriented factors. The main point is that design should focus on the learner. This student-centered approach is the principal characteristic of the overall training system design process that has been designated as systems engineering of training. Thus, we are really talking about applying the systems engineering approach to training device design. It is in this sense that we contend that the frame of reference for evaluating device design alternatives and issues must be a much broader one; one based on the design of the whole training system. Systems engineering of training provides this mechanism and techniques for guiding these judgments.

Systems Engineering

Application of the systems engineering process to training system design is a still-emerging technology (Smith[11]). However, the systems approach to training requires that one first carefully define the specific skills and knowledges required for effective job performance. Only after this is done can training content relevant to training goal achievement be developed and organized. Procedures, including media selection and design, must then be developed for both the training and testing of students. The overall goal is to develop a structured set of experiences that will produce, in a cost-effective manner, graduates who can perform a given set of operations to defined standards on a specified job or mission.

Integration of Device Design with Training System Design

Within the area of aviator training, we usually find three distinct instructional components that are dedicated to the training process: an academic component, a synthetic training component, and a flight training component. Systems engineering concepts and principles may be applied independently to any one of these components, and indeed they should be applied, if we are to achieve efficiently the instructional goals established for each. But it is in this process of initially establishing goals for each training component that the *training system designer* makes his first contribution to training device

design. Each component has a specific role that it can play best in producing the final product—a pilot. Thus, rather than allowing the three components to exist as separately constituted parts of a whole, their establishment and existence should be founded on what each can best contribute to the total training process. Such supportive integration of training components to achieve the overall training objectives of a program sounds rather obvious, simple, and common-sensible. However, those familiar with aviation training know that this state has been all too seldom achieved. The reason is that training component design often proceeds down quite independent, and often antithetical, pathways, with only lip service paid to observance of training system design conceptions.

Often, it is determined from trade-off studies that synthetic training devices would be beneficial to an overall pilot training process. When this occurs, specific training objectives should be identified for achievement within the synthetic training component of the training system. The design of the device then should be based on the specific nature of the training to be conducted through its use. This consideration at least partially answers fidelity questions since it defines the training functional capabilities that should be included in the device. However, the training system designer and the device designer must then *jointly* return their focus to the student. It is at this point that they should consider features to facilitate the process of training and student learning within the device. This might involve specifying a number of design features similar to those we have already described. Creative design, though, will not stop with these. It will constantly seek new means of implementing the laws and principles of learning and the technology of training in specific devices.

Cost Effectiveness

This broadened context for developing device design makes the training device or simulator simply another competitor in the methods and media race. Design decisions must be justified on cost-effectiveness bases within the total training system context. Thus, the decisions are not primarily *whether* effective training can be conducted in a device or simulator—it is established that most flight training objectives can, at least theoretically, be accomplished in a simulator—but whether it can *best* be accomplished in the device. So, it is in this total training system context that tradeoffs and training function allocations must be made. As a result of such "competitive" training system design, we might, for example, see a greater stress on part-task trainers or lower-fidelity devices. In any event, the metric for such cost-effectiveness evaluations must be the trainee, the facilitation of his learning, and his ability to perform in the operational mission environment. With reference to the latter, it should be noted that the systems approach to training considers training only as a means to the end of job performance. Thus, the training system designer (and the device designer) must be concerned with long-term retention, operational-situation stress, recurrent training, and a host of other factors related to job performance in addition to those factors associated with the initial training program and its more proximal goals. As previously stated, it is our contention that concentration on design for training is the best means to achieve optimization of the training system in supporting the ultimate operational system.

Design Teamwork

The final implication of the position developed here relates to the composition of the design team and interactions of its members. As the reader has (hopefully) gathered, the authors contend that effective device design must be behaviorally oriented; i.e., toward the characteristics of the learner. It follows, then, that training specialists (whether they are training "engineers," psychologists, or whatever is not of concern; it is necessary merely that they have in-depth understanding of the human learning process) must play an active role in device design. They must challenge the device engineer to develop new means of implementing features to facilitate learning and the instructional process. Further, and perhaps most importantly, it is suggested that there must be full, free, and frequent communication and exchange of views between the training system designer and the device designer. Though they typically represent different organizations or agencies, they must truly form a team. To do less is to risk development of a non-integrated, overly expensive, and perhaps ineffective training system. User representation in

design is the key, and we must never lose sight of the ultimate user, the student.

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How Universal Should Universal Trainers Be?

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This paper develops the thesis that universal trainers can be highly efficient and cost-effective devices, when properly designed and employed, and that their use for both operational and maintenance training likely will increase significantly in future years. First, universal trainers are defined in detail, a distinction is made between within-family and across-family trainers, and the use of universal trainers is related to the present organization of naval schools. Next, a series of design and situational factors are identified that influence and determine the desired universality of training devices. These factors include the size and cost of parent electronic systems, the present training context, equipment standardization, modularization, functional packaging, general-purpose displays, automatic test equipment, life-cycle costing, total system design, and maintenance system design. Long-term trends in equipment design are described and related to training device requirements. Then, the effect of digital technology on the universality of training devices is discussed in detail. Finally, a series of conclusions and recommendations is made, including brief descriptions of some universal training devices likely to be required in the future.

Modern naval weapons and electronic systems are significantly more capable than their predecessors, but they must be properly operated and maintained for their full potential to be realized. Added system complexity has created many new skill and knowledge requirements placing greater demands on shipboard enlisted personnel than ever before. Training operators and technicians to the required standards of excellence is time-consuming and expensive. Universal trainers play an important role in the training process with respect to criteria of both cost and training effectiveness. This paper develops the universal trainer concept and discusses factors that determine the universality of trainers.

THE UNIVERSAL TRAINER CONCEPT

Universal trainers are those designed to serve the training requirements of groups of shipboard systems. Skill and knowledge elements required to operate and maintain complex systems are both common and unique—many requirements are common to several systems; others are unique to a single system. If two or more systems require common tasks, the possibility is opened that the tasks can be trained in the same classroom, trained using the same device, or both.

Electronic systems that are members of a "family" typically impose common operator and maintenance tasks. For example, many task requirements are common to virtually every radar system; they stem from "radar technology." Other operator and maintenance tasks are unique to a single radar set, often stemming from a unique operational feature, a unique construction practice of a given manufacturer, or a unique philosophy of maintenance and repair. Universal trainers capitalize on the commonality of skill requirements existing among a group of systems by stimulating common operational and maintenance situations.

The term "universal" is used typically to identify the type of training device described above: one that includes elements common to a group of systems. The term is used less commonly to describe a type of training device that includes all features of a group of systems. To make this distinction clear, consider the case of an aircraft cockpit trainer. A universal trainer by the first definition would be one used to train fledgling pilots in the fundamentals of cockpit control manipulation and instrument interpretation. By the second definition, the trainer would be one that could be set up differently for each aircraft to be simulated; that is, the pilot could be taught the techniques of flying a specific aircraft by changing the control dynamics and instrument configuration. The first type of universal trainer, sometimes called a "common core" trainer, is more typically used in the introductory phases of a training sequence; the second type of universal trainer is more typically used in the advanced or final phases of a training sequence. The second type of universal trainer does not depend on commonality among a group of parent systems or equipments, although such commonality may, in fact, exist.

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In recent years, the validity of the universal trainer concept has been established firmly. Several such devices have been built and are presently used at naval enlisted training schools. Experience gained with these devices has shown that enlisted trainees can successfully transfer skill and knowledge elements acquired using these devices to the parent systems. Experience also has shown them to be particularly well adapted for teaching the conceptual organization and function of "typical" systems laying the groundwork for learning the organization and operation of a specific system to which the technician/trainee (presumably) will be assigned upon graduation.

Universal trainers are particularly useful in teaching the basic concepts of electronic systems. All electronic devices, of course, derive from a common set of physical/electrical principles. All electronic components, because of their physical properties, exert known and predictable influences on the nature of electrical energy; in fact, the electronic designer uses these influences as tools to cause the form of electrical signals to be changed in some desired way. The nature of the change desired depends on the operational and functional objective to be served by the equipment under design which, in turn, stems from the basic purpose or mission of the equipment. Thus, to the extent that operational or functional requirements are similar, equipment features and task requirements are likely to be similar.

Task commonality can exist across families of electronic systems as well as within families. Greater task commonality exists between two digital systems that are members of different families than between a digital system and an analog system from the same family. In this case, commonality of maintenance tasks is directly and importantly determined by digital implementation, the maintenance philosophy that guided the system design, and the constructional techniques used to implement the design.

In recent years, techniques have been developed to identify skill and knowledge requirements for both operation and maintenance imposed by new naval weapons and electronic systems. Techniques also have been developed to establish the extent of commonality that exists among members of an equipment family, making it possible to determine in advance the feasibility and desirability of the universal trainer approach for the equipment group in question.

ORGANIZATION OF NAVAL SCHOOLS

The existence of both common and specific task requirements is clearly recognized by the Navy and reflected in the organization of naval schools. Class A schools offer beginning and intermediate-level instruction in the operation and/or repair of electronic systems on a family-by-family basis. For example, operation and repair of sonar equipment is taught at the sonar school. At the Class A level, training typically offered is not on specific equipment except when an older system is used as a training vehicle. In contrast, Class C schools offer instruction and laboratory practice on specific systems.

The training "pipeline" has changed significantly in recent years. Several years ago, trainees entering the Navy were processed through Class A school and then sent to a ship for on-the-job training on shipboard equipment. The objective of Class A schools was to equip the student with appropriate skills so that, when supplemented by proper on-the-job training, he could operate and/or maintain electronic systems. Following a period of shipboard apprenticeship, the trainee was sent ashore to attend Class C school to learn the details of a specific system installed aboard his ship. Class C schools were often poorly attended because ship commanders did not feel they could spare personnel from their watch bill to return to school.

Several years ago, the Advanced Electronic Fields (AEF) program was instituted. Under this program, qualified candidates entering service who enlist for a 6-year tour of duty are guaranteed both Class A training in an electronic field plus one selected Class C school, both before being assigned to shipboard duty for the first time. Upon successful completion of this sequence, a Naval Enlisted Classification (NEC) is assigned. In the past, technicians were assigned to individual ships on a "rate" basis; that is, a technician who had completed Class A training was assigned to any ship on which equipment was installed within the "family" for which he had been trained. For example, a graduate of sonar Class A school was assigned to any ship carrying a sonar system (although the training differed for surface ship sonar technicians and submarine sonar technicians).

Under the present scheme, operators and technicians are assigned to ships based on their

NEC. The Rating Control Officer in BUPERS assigns personnel to individual ships by NEC within most naval ratings, guaranteeing that technicians are assigned to ships carrying the exact equipment on which they have been trained.

A difficult problem in training technicians to repair and/or operate complicated electronic systems is that of bridging the gap between theory and practice. The technician/trainee must acquire knowledge of the basic principles of electronics and then must learn to apply these principles to the maintenance of complex systems. Operator/trainees must learn the basic principles of operation of equipment within a family, and then must learn to apply these principles to the operation of a specific system.

The basic organization of naval schools is important to universal trainer development; such trainers have been found to be most useful toward the end of Class A training when student trainees are starting to assemble the bits and pieces of their education into a logical whole; they are assembling basic building blocks into a complete "technology." Universal trainers are particularly useful at this point because they illustrate and simulate the basic principles of operation and/or maintenance of complex systems without burdening the student with the specific details of a particular system that often interfere with the effectiveness of the basic training process. But it must be clearly borne in mind that the basic premise underlying the development of universal trainers is that skill and knowledge elements acquired using the device will transfer to any of a variety of parent systems. The extent to which transfer can be expected depends upon the degree of similarity between the trainer and the parent system. It is important, therefore, to identify the factors that influence and determine the degree of commonality existing among parent systems and thus the universality of training devices.

FACTORS THAT DETERMINE THE UNIVERSALITY OF TRAINERS

The single most important factor influencing the universality of training devices is the extent of commonality of operator/maintainer task requirements that can be established among a group of electronic systems or weapons. In addition, the following factors are important: (1) the number of system or weapon types in the parent group, (2) the size and cost of each of the parent systems, and (3) the number of units of each of the parent systems installed aboard ship or naval shore facilities.

The number of parent systems is important because a Class C training course typically exists for each specific equipment in the group. To the extent that requirements currently covered by Class C training are common and can be taught at the Class A level, the duration and consequent cost of Class C training can be reduced.

The size of the parent system is important because larger systems typically require a greater proportion of unique skills related only to that system. Size generally is related to complexity, and complexity is important because large systems often require special installations, special sources of power, special cooling, and even special secure facilities—requirements that can be obviated by using a universal trainer.

The cost of the parent systems is important because it is always possible to use the parent system itself as a training device. There may, of course, be overriding considerations dictating the use of a universal trainer rather than the parent system. For example, the parent system may be packaged too densely for training purposes. Or, the power required by the parent system may exceed the power available in the designated classroom area. In general, however, the greater the cost of the parent systems, the easier it is to justify the cost of building a universal trainer.

The total number of units of the parent systems to be produced is important because it determines directly the overall required manning level and thus the number of technicians/operators to be trained. This factor, in turn, determines the potential level of utilization of the trainer. There are, for example, several complex command and control systems currently being designed for installation aboard large ships that will create formidable operational and maintenance loads for the technicians assigned. However, there are only a handful of such systems planned for production, perhaps on the order of six to 10. Since the entire complement of maintenance technicians is small, it would probably not be cost effective to design and build a universal trainer. Rather, training using the actual system would be indicated.

THE INFLUENCE OF CHANGING TECHNOLOGY

There are a series of technological changes occurring at present that act to influence and determine the desired universality of training devices: (1) solid-state circuitry, (2) modularization, (3) standardization, (4) functional packaging, (5) multipurpose displays, (6) computer availability, (7) automatic test equipment, and (8) total weapon systems design.

Solid-State Circuitry

Undoubtedly, the single most important change in electronics in recent years has been the gradual evolution from vacuum tubes to transistors to integrated circuits to medium-scale integration to large-scale integration. These developments significantly affect training because the smallest replaceable unit of hardware now lies above the "circuit" level, that is, the detailed principles of operation of individual circuits are no longer at issue in fault localization and equipment repair. The development of integrated circuits waived the requirement to understand the operation of individual components, requiring only that maintenance personnel deal with the input-output characteristics of the circuits. It is likely that no new training requirements will be created in the future as the size and complexity of the integrated block increases, because the technician will still deal with the input-output characteristics of the unit, regardless of size.

Modularization

Modularization has had a significant impact on training for maintenance activities, and thus on the desired universality of devices for maintenance training. Many new systems not only are modularized but, in addition, have a throw-away maintenance philosophy, one in which the isolation and repair of individual components is not required. Spare modules are kept aboard ship, often furnished and packaged as part of the original equipment. Of course, new skill requirements are created (isolating malfunctioning modules and replacing them with good ones), but older requirements are eliminated, particularly those associated with understanding the principles of operation of the circuits mounted on the module.

Standardization

Essentially, standardization increases the physical and constructional similarity of electronic systems. As systems become more standardized, the commonality of both maintenance and operator tasks increases, thereby increasing the transfer of learning from one system to the next and decreasing the diversity of specific skills required for operation and maintenance of different systems.

Quite recently, the Navy has become "serious" about standardization. The Components/Equipment Standardization program had its origin when VCNO directed the Chief of Naval Material to establish a standardization program extending to the concept formulation, contract definition, acquisition, and operational phases of developing and procuring naval electronic systems. By direction, standardization was to extend to materials, processes, services, and parts. The Chief of Naval Material, in response to the direction cited above, directed each of the Systems Commands and Program Managers to develop a standardization program covering all equipment under their administrative cognizance. Specific guidelines were provided and specific contents suggested. Such plans were developed and currently are being implemented.

It will likely be two or more years before the major impact of this standardization program is felt. But, it can safely be predicted that the proliferation of separate electronic devices and systems which characterized naval hardware development during the 50's and 60's will give way to fewer, more comprehensive procurement programs, including many items of standardized hardware. The impact of this program on universal device development will be to increase the commonality existing among electronic systems and to reduce the diversity of operator and maintenance skills required.

The Standard Hardware Program is a module standardization effort that will make available to electronic designers a wide selection of standardized plug-in modules. These modules will serve as building blocks from which systems engineers can construct a variety of complex systems. Since this program began, it has progressed to the point where over 300

standardized modules of known reliability now are available to industry. The modules are in use in over 20 major electronic systems. It is predicted that over 5,000,000 modules will be in service in the fleet within three years.

Management of the Standard Hardware Program recently has been transferred to Naval Electronic Systems Command (NAVELECSYSCOM). The Chief of Naval Material has instructed NAVELECSYSCOM to work with all Systems Commands and Program Managers to initiate the use of standard modules in all new programs, except when substantive evidence exists that the approach is not applicable to the equipment being procured. Thus far, Program Managers have responded by specifying standard techniques for many new procurements. If the trend continues, and there is every reason to believe that it will, the proliferation of diverse types of naval systems will decrease, creating a vast base of identical operator and maintenance requirements for many types of electronic systems. This development is so important that it may force a reexamination of the present naval rating and training structure, and will certainly force a critical examination of trainer construction techniques.

Functional Packaging

Functional packaging is an interesting and important design trend in which individual circuit elements are combined and physically packaged along functional lines; that is, each block of electronic hardware represents an identifiable function which is, in every case, relatable to both its role within the parent equipment and to the purpose/mission of the parent system. The functional package is the smallest replaceable unit but, unlike standard modules that are identical in size, functional modules vary according to the complexity of the function represented. Essentially, each unique, definable function performed by the equipment is given an analog in hardware. Since functions are similar among equipments designed to fulfill the same purpose/mission requirements, the commonality is increased of circuitry and of operation.

Multipurpose Displays

In the last few years, at least 15 multipurpose display systems have been developed by Navy laboratories and electronic manufacturing concerns. In general, the displays have been designed to operate with a computer system but, at the same time, they usually have a buffer memory or associated buffer computer used to develop alternative, selectable display formats. The operator can select from among these formats based on the tactical and environmental conditions.

Multipurpose displays presently are being developed for sonar systems, fire-control systems, command and control systems, navigation systems, acoustic warfare and countermeasure systems, and guided-missile control and direction systems. The surprising thing about all such displays is their design commonality; in many aspects they are identical to one another.

The operator and maintenance requirements generated by multipurpose displays are highly similar. Future trainers for operation or maintenance of electronic systems will unquestionably contain general-purpose, computer-driven displays as an integral part of their design. It is probably safe to predict that five years from now virtually all major electronic systems installed aboard naval ships or in naval shore installations will include one, and likely several, general-purpose displays. As the similarity of such displays increases, the commonality of maintenance and operator tasks will increase, and the desirability of the universal trainer approach will increase.

Computer Availability

The increasing availability of computer power is one of the most important influences on the universality of training devices. At the heart of virtually every new weapons system there is a digital computer designed to organize and process large amounts of information from the systems that feed it. Computer power substantially improves the capability of the individual sensor and weapons system to receive, process, and distribute information.

Computers can be used to store incoming sensor information in real time, up to an amount of time determined by available memory capacity. Then, sequences of events can be called out onto the general-purpose display, so that the operator can make a time-dependent assessment of the presence and nature of intruding targets. As a result, operators can observe sequences of events instead of single events. Operator tasks associated with these activities are common among

equipments of a family and across equipment families.

Computer power is used in many new systems for the "housekeeping" function—tagging, tracking, identifying, and sorting target events. Computers are used to keep track of the modes of operation selected, the status of important controls, information on expected environmental conditions, and other data that operators need to perform their jobs. Again, a family of operator requirements is associated with these activities. Such requirements are common both among and across families of equipment.

Computer power is used to conduct target motion analyses to determine the course, speed, and depth/height of targets contacted. This function is typically accomplished by tracking; that is, by superimposing an electronic cursor over an indicated target position on a display. Then, the computer assesses the location of the cursor in real time and computes the desired output quantities in accordance with stored formulas for processing target information. This mode of operation is characteristic of modern fire-control systems, whether coupled to radar inputs for surface-to-air missile direction, or to sonar inputs for underwater battery control. As in the cases described above, a family of activities is associated with target motion analysis and tracking.

These examples of computer aiding are but a few of the many typical uses of computer power in new naval systems. It can safely be predicted that both the amount of computer power available and the extent of computer aiding will increase significantly in the next few years, increasing the commonality of operator tasks, and increasing the desirability of the univeral trainer approach.

Automatic Test Equipment

Most new electronic systems and weapons being designed incorporate automatic systems for fault localization, often integrated with or driven by the shipboard computer. These automatic systems are capable of localizing faults down to the level of some fixed number of modules, 20 to 50 at present. In the future, localization to an individual module is likely to become feasible.

Automatic faultfinding systems are important because they can provide significant reduction in maintenance manpower requirements. They also reduce the requirement for training in fault localization using logical reasoning.

Total Weapons Systems Design

Until recent years, major combat systems have been designed and procured in pieces; separate suppliers have been responsible for various components of the total system. The Navy has been responsible for system integration. This practice had inevitably led to a number of system interface design problems as well as communications problems among suppliers. In contrast, total weapons system design places responsibility for an entire system on one supplier. The separate subsystems are purchased from different contractors, but the prime contractor is held responsible by the Navy for the performance of his subcontractors. The prime contractor also assumes responsibility for weapons system integration. To establish consistency among system components, the prime contractor typically sets criteria and standards to which subcontractors must perform, decreasing the probability of diverse task requirements and divergent equipment practices.

The 10 factors discussed in the paragraphs above operate during the research/development/production cycle of weapons systems and electronic equipment to increase the commonality of maintenance and operator tasks performed by enlisted technicians. It can safely be predicted that the commonality of both operator and maintainer tasks will increase substantially in future years, and that the importance of the role played by universal trainers will increase commensurately.

THE INFLUENCE OF DIGITAL TECHNOLOGY

The advent of digital technology has produced two primary effects: (1) it has created a need for training in digital logic and in the organization and maintenance of digital equipment, and (2) it has increased the commonality of circuitry and thus of maintenance requirements across and within families of electronic equipment. A shift register in a sonar set operates identically and creates identical maintenance requirements as a shift register in a fire-control system. The expected extent of transfer of skill and knowledge elements from one digital system to another is very high since basic logic and design elements are shared. The development of digital technology will be

responsible, in large measure, for the predicted reduction in diverse knowledge requirements for electronics maintenance of all naval equipment.

Courses of instruction in digital technology currently are being added to the existing curriculum at many naval schools. At the present time, personnel from many different rates are being taught basically the same information, but at different physical facilities. It is considered likely that training in digital technology will soon be made a part of "common core" training of all enlisted technicians, rather than being rate-specific training. The impact of these trends is important because it suggests the need for generalized training in digital technology and for universal training devices to support such training.

CONCLUSIONS

This is a period of very rapid change in the design and construction of naval weapons and electronic systems. Many, if not most, electronic systems now being installed in the fleet use digital techniques. Major new requirements are being created for training in digital logic and digital systems technology. A major training device development effort is likely required to adequately meet the training needs created by the new systems.

In a period of rapid technological change, training device characteristics must be based on timely and accurate forecasts of operational and maintenance requirements that will exist when the training device is ready. If training device characteristics are based on the needs generated by present shipboard equipment, they are less likely to serve adequately the requirements of the newer systems, particularly those now being designed.

The commonality of task requirements is increasing among individual systems that are members of the same family of electronic equipment and also among systems that are members of different families. The increase in commonality is generated by the swing to digital technology and by the incorporation of many advanced electronic features and techniques that are tending to increase the similarity among all electronic systems.

The task requirements created by newer digital systems are highly similar for both operation and maintenance. Computer systems and sensor systems are beginning to share more common task elements as they gradually are converted to digital technology.

The Navy's standardization efforts are beginning to pay off. Standardization, particularly as represented by the Standard Hardware Program, will have a major impact on both system design and training device design. The diversity of unique circuit elements and unique features is being gradually reduced. Standardizing on a group of predesigned modules will force a greater similarity in maintenance techniques as time progresses.

Important changes are predicted in the organization of naval schools and in the structure of naval ratings. There appears to be increasing evidence that members of the Data Systems Technician rate can more adequately maintain digital sonar, radar, and fire-control equipment than can members of the rate trained specifically for that duty. This is a function of the similarity between computer systems and digital sensor systems of modern design.

The usefulness of universal training devices has increased in the last several years; there is evidence that the increase will continue through the foreseeable future. It is concluded that requirements will soon exist for new universal training devices designed to teach digital logic, digital systems technology, and digital systems repair. Other devices will be required to teach operation of digital sensor systems, display/operator interaction with multipurpose displays, and computer programing. It is concluded that universal trainers should be as universal as possible, at least to the extent that common task requirements for operation and maintenance can be established among the systems to be served by the training device. The extent of such universality in the near future will be very high indeed.

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Some Current and Future Aspects of the Part-Task Trainer

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The definitional difficulty and some theoretical problem areas are explored in regard to part-task devices within the training system, together with a discussion of operational and cost factors which are affecting present and future use of these devices.

The first prehistoric man who aimed his bow and arrow at a clump of grass (practicing a critical element of the whole-task of food gathering) probably developed his concept, not as a result of vigorous analysis, but in sheer desperation in missing his dinner on several occasions. Having passed target acquisition, tracking, stalking, and other hunting part-tasks with honor, he probably found the need to practice a skill which could not be exercised in the actual situation to maintain the required proficiency for survival.

Perhaps the first influential recommendation on part-task trainers was by Wolfe and Garman (1956) in a report for the Scientific Advisory Board of the U.S. Air Force. They stated that merely because flying is a complex job comprising many subtasks, it did not necessarily mean that all of the parts should be necessarily practiced together at all stages of training. Whole task practice, either in an operational flight trainer or in an aircraft, is costly and expensive, and important dollar savings and training benefits might be expected to be derived from a judicial use of relatively low-cost part-task simulators. Bray (1954), in a presentation to the USAF World-Wide Simulator Symposium, pointed out that athletic coaches in training their athletes in their complex skills make extensive use of part-task techniques. Thus, a football coach does not use all of the practice time in scrimmaging the whole team, often giving attention to the component skills of blocking, punting, passing, and the intellectual "skull practice" of plays and signals. The first "four-minute mile" would have been unattainable without the careful, sequential pacing elements used in training the proponent in the tactics for each phase of effort.

THE PROBLEM OF DEFINITION

But actual evaluation and prediction of the role of part-task trainers in both civilian and military applications has been constantly bedeviled by the difficulty of definition.

Miller (1960) defines part-task training as ". . .Practice on any aspect, phase or dimension of a task, procedure or work-cycle which is independent of the rest of the work content. . .any training that does not demand total work-content inputs or work-content outputs." In his view, total task training ". . .can only occur in the operational situation or in a complete simulator." Miller points out, however, his difficulty in defining a "task."

A definitive statement by Briggs, *et al.* (1962) noted that the choice of a whole or other technique is dependent upon the complexity and the degree of organization (the interdependence among components) so that:

"a. A task which is quite complex and highly organized will be learned more quickly under whole-task training method.

"b. A task which is quite complex but not organized (the task components being essentially independent and non-interacting) will be learned more quickly under some form of the progressive-part method.

"c. A task of low complexity will be learned more quickly by the whole method regardless of the level of task organization."

Briggs (1962) preferred to separate a number of categories of training "condition" which, it is presumed, can be carried over to the system or devices used:

Whole task, in which the trainee ". . .practices all the components of the complete task and does not experience training on fractionations."

Pure part, where the trainee ". . .practices the several components of the task, one component at a time."

Progressive part-task, where the trainee ". . .practices the several task components separately and then trains on different combinations of the parts, up to total or whole-task training;" and,

Simplified training, which is whole-task training using a simplified version of the whole task for which he is training.

Briggs is surprised when, having split multidimensional simultaneous tracking into part-task elements for separate teaching, his action is unsupported by the professional evidence concerning performance in this mode, thus forcing him to treat tracking as an exception.

These two sources are representative of the definitional difficulty. Lack of firm definition, of course, also makes it difficult to establish if "part-task" training is relatively effective to whatever else. Miller, however, allows us a clearer picture in the negative sense in telling us the conditions negating "part-task." Skills learned in the part-task way may have to be relearned due to time separation (forgetting) or because of oversimplification of the stimulus-response conditions. Further, he suggests too great a degree of and overpreoccupation with the part-task may interfere with whole performance. He also suggests a taxonomy for trainer types:

Familiarization Trainers

1. Demonstrators. These attempt to develop through displays and words a conceptualization of the purposes of the man-machine system, its linkages and process continuities.
2. Nomenclature and locations trainers. These try to train the ability to name an object or signal when presented, or to identify objects and signals when given their names; further, to locate elements in the work environment.

Instructed-Response Trainers

1. Detection-of-conditions trainers attempt to improve the noticing of signal presence.
2. Identification-of-conditions trainers practice analysis and synthesis of displayed elements and learning the meaning of grouped elements.
3. Problem-solving and decision-making trainers require a decision process to develop from (2).
4. Instructed-response trainers for procedures are discrete-response devices which allow practice of control-display feedback activities out of total context, even when there are time-shared activities in the total context.

Automatized Skill Trainers

1. Tracking task trainers are aimed at nondiscrete activities for continuously changing stimulus conditions using dynamic control-display combinations.
2. Job segment trainers and simulators provide "realistic" simulation of a time-defined element of the full task requiring "total" performance of all work elements in that segment.

THE QUESTION OF REALISM

Running through all these classifications and definitions is a thread where the ubiquitous question of fidelity reoccurs, be it in the "realism" of a whole-task "mission" simulator or the degree of "simplication" of a behaviorally or temporally partitioned device. This point should be considered early because it conditions and clouds definitional lines. It has sometimes been somewhat cynically said that manufacturers of training devices aim at high fidelity of "realistic" designs because they must cost more, and that the procurers of these equipments encourage the increased cost because the greater the gross, the more important they become in their organization. Though there may be more than an element of truth in this, in some cases, the ostensive and overt reasons given are often that the additional realism will help "motivate" the students and thus increase the trainer's value. Flexman (1950) summarized this position:

"Fidelity of simulation can operate as a motivational variable. If the simulator looks, acts and sounds like. . ." (the real thing) ". . .then the trainee is more likely to be convinced that practice

in the device will be beneficial to him. The problem is to determine the extent to which varying degrees of simulation yield varying degrees of motivations."

As his research on training continued in both civilian and military contexts, Flexman began to suspect that his position should be reexamined. In discussions with Matheny and Dougherty (1951) at the University of Illinois, the problem became defined as, "What is the relationship between motivational variables in general and simulator training and the transfer to the operational system?" Solarz, *et al.* (1953) conducted an unpublished study which has been quoted by Muckler (1959). "This experiment attempted to induce, experimentally, negative attitude in one group of subjects and positive attitude in a second group toward the P1 trainer. It is important to note that the induction techniques rested primarily on the lack of fidelity of simulation between the P1 trainer and the AT-6 aircraft. In the negative attitude group, differences in fidelity were strongly emphasized with the implicit and explicit inference that lack of complete fidelity of simulation obviated any training value the simulator may have. In the positive attitude group, these same fidelity differences were pointed out, but it was stated that such differences were inescapable, and if carefully noted, would not deter training value to any important degree. An attitude scale. . .showed the induction techniques were quite successful. Both groups trained for a standard flight maneuver in the trainer and then were transferred to the same flight task in the AT-6 aircraft. The data showed high positive transfer for both groups from trainer to the aircraft, . . .the trend of the data was that the existence of a negative attitude toward the trainer did *not* affect transfer from simulator to aircraft."

Though this experiment had certain limitations, it is sufficient notice to the designer to consider fidelity separately from both motivational and partitioning factors in his choices of strategy.

THEORETICAL AND OPERATIONAL ASPECTS

The definitional and classification issues point to baseline theoretic problems in training strategy. Certainly, the independence of elements either from each other or from the whole is one issue. Another is the complexity of the whole or the element. The stochastic nature of the whole must condition both these matters. One would hope that some model could be derived, perhaps like the suggestions of Bush (1960) which extend Hullian concepts into situations of the sort we are discussing. Certainly, element complexity, time dependence and interaction are dealt with in these treatments, and predictions of the gains we have seen in adaptive techniques are apparent. But even simple concepts seem not to emerge in our training design; for example, "Hick's Law" (Hick, 1952), showing a near logarithmic relationship between number of choice responses and latency of individual response. should guide us in a cut-off point in segmenting a task. Bekey's work (1959) gave some clear indications to a choice between Miller's training devices: "Following the receipt of the signal, the individual turns his attention first to the task of translation and processing the perceived information and secondly to the performance of the required task. Not until these activities are underway is he free to sample the input signals again."

But the issues (apart from the part V whole learning issue) which appear time and again seem to be (Muckler, 1959):

1. The effect of transfer of the relative amount of "load" on the subject in both the initial and final task.
2. The cost-per-unit of transferred training.
3. The availability for use of whole task simulators against operational equipment.

Especially in the flight situation, the question of the amount of load on the operator in the transfer of procedural skills is closely related to the part-whole problem. Taking "load" for one case, to mean additional requirements to be met while performing a procedural task, while the latter is quite precisely definable as a "package," independence of the prime element becomes compromised in either a pure part or part-sequential approach. For example, the problem of transitioning a pilot from an A4 to an A7 aircraft is one where the aircraft operates in similar flight regimes but cockpit procedures and individual subsystems to be manipulated are significantly different.

If it is felt that dynamics have little effect on procedures, the designer may choose a simple procedural device, implying that he feels that it is possible to transit without dynamic load: this is the least expensive solution. If he feels that lack of

dynamics will affect transfer, he will introduce them. The loading question is often confused with the question of fidelity; when the designer makes the second choice, he may now design his dynamic load for extreme fidelity. Williams and Adelson (1954), in their case for part-task devices, suggest that the policy of striving for maximum fidelity may, in fact, be inefficient because it may not insure minimum cost-per-unit of training transferred to the operating job. A conclusion is that if an estimate can be made of transfer from a device to a job, then one can be made of the maximum amount its use should cost, given the cost of training using the operational equipment. This implies that a partial device should not include a training capability for those elements which can be learned less expensively on a whole-task device or the operational equipment itself.

Another operational point is that design information requirements and development time often make part task devices available for use earlier in a program than the more complex whole devices. They can also be modified more quickly and easily as configurations change and effectivity is determined. In many cases, time and cost point to the use of a partial device or nothing at all.

A MATTER OF MEASUREMENT

Though we may spend considerable time and effort on the determination of dependent variables appropriate to the operational situation and to the training device, in some "professional" areas there is a trend toward nonmeasurement or very limited evaluation. For example, it was once suggested that training toward "specific behavioral objectives" in a flying task (that is, temporally or system procedure partitioned behavioral elements) should be evaluated by an instructor choosing a random number of these out of a total and asking the trainee to perform them, subjectively evaluating the result. Both subjective evaluation and partial measurement of element performance tend to push toward extremely high fidelity whole-task devices. The "professional" point of view in many fields, which says that only the initiated and experienced can judge proficiency and that only subjectively, is sometimes a mixture of genuine belief and more mundane factors, such as the protection of a seniority system or limiting supply. In any case, objective measures of performance and thus of transfer from devices to the operational situation are deleted or diluted The designer is then bereft of any argument which points to partial devices with transfer capability of so much and must, in sheer self-defense, design to imitate the operating system as closely as possible. This has, in some cases, reached a stage where the training device is more expensive in all ways than the operational equipment, the saving grace being that it cannot be destroyed by an unsafe act of the trainee. The future of partial devices is most certainly a matter of determining in these "professional" instances if true objective measures exist, and then solving the problem of getting them accepted

FORMALITIES

Many of the problems discussed here can be made less difficult with an insistence upon the formalities of training system design. It is surprising how often these are glossed over, even in military systems where requirements are rigidly defined. There is always a tendency to avoid the decided drudge of task and mission analysis and to downgrade its importance, especially in the "professionally" influenced case. The choice of the full mission to small, pure part elements may only be properly made if the drudgery is done in full, before design is commenced and by competent personnel with access at a high level. There is perhaps a case for a new law of entropy applied to training devices which says, the less formal analysis preceding design, the more the resultant devices will approach one, high-fidelity, whole-mission simulator. The more, however, detailed analysis from total mission down to individual behavioral elements and groups, the more possible is effective and rational partitioning and the more meaningful and applicable are rules such as that of Miller Within this analysis, of course, should be estimations of hazardous conditions. Safety, taken with cost, may say that there is very little point in training on a device when the behavior can be learned in the operational situation with no danger to the trainee and with perhaps fewer trails. In the same way, accurate identification of necessary perceptual cues through early experiment and analysis (for example, accelerative and kinesthetic stimuli) may allow the designer to apply "just enough" cues for effective recognition and response, to be

reinforced in the operational situation.

A much neglected formality is the determination of the skills possessed by the trainee prior to training. Again, if we take the transitioning pilot, in many cases he might be sufficiently familiar with the mission and similar dynamics that he can perform safely on the new aircraft. His need is a detailed familiarity with the operating procedures for the new aircraft, including normal, abnormal, and emergency operation of the new systems. With thorough training on these, with limited procedural devices, he can devote his attention in the aircraft to the difference in handling qualities, some of which may be subtle and which would require an extremely high-fidelity dynamic simulation.

Analysis also allows a clearer view of values, if all the cards are laid in order on the table. For example, in a study sponsored by NAVTRADEVCEN (Adams, 1960), two groups were compared in a toss-bombing maneuver. One group had separate training and the other concurrent training in flight control and procedural tasks in a device. When both groups performed the whole task, both groups performed similarly after one trial showing differences. Predicting where partitioned elements join in the operational task is essential data. Hammerton (1967) emphasized this in a discussion of transfer, suggesting the categories of "savings" and "first-shot" measures. "Savings" measures, as the name implies, answers the question, "How much time (or, how many trials) on the real equipment is saved by using a training device of any order?" "First-shot" measure asks, "How well will a trainee cope with the real equipment the first time he uses it, after simulator training?" It is important to know which question must be asked. It is small comfort to know that 90% in training time can be achieved if the new operator is liable to be killed during his first run on the real thing. On the other hand, if economy in the use of equipment is the only consideration, very poor first-shot transfer can be tolerated so long as the savings measure is high.

CONCLUSIONS

From many points of view it seems evident that part-task trainers are becoming more acceptable to the discriminating system designer, performing as critical elements of the better training systems. While whole-task practice requirements cannot be ignored, in many learning situations these have become extremely vulnerable to such factors as equipment cost and availability. This point has been summarized:

"The cost, complexity, and unavailability of parent equipment led to the development of simulators. In a similar manner, the increasing cost and complexity of simulators leads to the development of trainers for trainers—devices designed to give procedural instruction or practice in basic skills, and to prepare students for practice on such devices as simulators or navigation trainers." Wolfle and Garman made this point about twenty years ago.

However, in some cases it seems that we are approaching the point where *part-task* devices are evoking dangerously high costs and may share the same fate of the whole-task systems. There is some hope, however, if we make proper use of the analytical tools available. We must insure that the total training problem is properly analyzed and that inappropriate interests do not bias the derived options. Even so, the costs of such part-task trainers (e.g., crew procedures trainers for commercial jet transports) have reached the point where efficient use demands that trainees are very carefully prepared for the time they spend in them. Houston (1968) reports on one approach to this problem by American Airlines which might be a trend indicator.

"Programed instruction techniques are also being applied to flight training by means of a slide-tape system with student response capability. This is still an experimental program at American, but it appears to have promise for teaching flight maneuvers and techniques. Flight instructors trained in programed instruction techniques considered the training well worthwhile." This approach evolved from a fiscal analysis of training programs and systematic determinations of how, and on what equipment, the various skills required of their operators should be taught for minimum cost-per-unit of training transferred to the operating job. This type of cost-conscious thinking is perhaps a key to future strategy and design.

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Dry Land Submarines

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The development of submarine steering and diving simulators is traced from the starting point of the Universal Submarine Simulator, Device 21B20, in 1956. The rationale and development of the submarine equations of motion and the coefficients used in the pioneer "EBDR-1," which served as the basis for the programing of the Universal Submarine Simulator, are discussed. Improvements in verisimilitude of training deriving from use of such submarine improvements as the "Joystick" Control, the Combined Instrument Panel, and the Conalog Display are described as they are introduced into various trainer models. The incorporation of the Ballast Control Panel and the effects of ballast changes in trainers is treated. As a result of the casualty to THRESHER, a reevaluation of the fidelity of simulation was conducted and much effort and urgency was placed upon casualty recovery simulation and training. This effort, along with its implications on trainer design, is discussed.

The theory of simulation as a training method, the role of the instructor, and the use of preprogramed casualties and hazardous situations are briefly discussed.

Finally, the improvements possible with the introduction of the digital computer are discussed, and some predictions of future trends in submarine steering and diving simulators are made.

To go to sea on dry land is by now an experience familiar to tens of thousands of officers and men. The degree of training afforded by providing controls and displays that will be used on shipboard, and having the station respond to use of those controls in the same way that a ship at sea would respond is so well appreciated today that it hardly needs mention, much less justification of the technique. The young enlisted man when first exposed to the sophisticated 21B56C submarine trainer, probably does not pause to wonder why the device he operates responds just as a submarine does. When he does go to sea, he finds that the submarine is remarkably similar to the trainer in the way it behaves. We are so accustomed to the whole training process that it is difficult to remember that thirty years ago there was no such thing as a submarine steering and diving trainer. How, and why, did we get where we are today?

Submarine steering and diving trainers in use today and, in fact, their lineal ancestors are designed on three fundamental principles:

1. It is possible to represent, by a mathematical model, the behavior of the submarine in response to the forces of the sea acting on it and its control surfaces, and in response to changes in its buoyancy and trim.
2. Using this mathematical model, a computer can be programed to provide force commands and sensory indications which can be translated mechanically, electrically, or hydraulically into platform motion in at least two degrees of motion (roll and pitch), simulating that of a given submarine, as well as displays (dials, gages, cathode ray tubes) of submarine status.
3. Training effectiveness is facilitated by the use, to the extent possible, of the actual physical controls (wheels, joystick, levers) and displays that are used on shipboard.

The art of design of submarine simulators has consisted in a determination of how closely each of these principles must be followed to provide the requisite training. For the first, it is a question of how closely the hydrodynamic equations of motion of the submarine should be represented; that is, what terms can, or should, be neglected in the interests of reducing cost and complexity. For the second, it is a question of how the needed forces can most readily and simply be provided, and whether some motions, for the purpose intended, can be safely omitted. In practice today, the motions of translation in the X_o, Y_o and Z_o planes and the yaw motion are not provided by the trainer, although their effects are represented on displays. For the third, there is the ever present question of whether stimuli are best provided by replicas of material which will be used, or alternatively, can be provided by some artificial means.

Simulation of the effects of the sea on ships has been a recognized tool in the shipbuilding industry for many years. From the time of Froude (in the latter half of the nineteenth century), models of ships have been towed in tanks to determine how they will behave in varying conditions. From the

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time of Prandtl (about 1910), the previously parallel development of the practical art of "hydraulics" and the science of "hydrodynamics" has been fused. During the period between the two world wars, submarine equations of motion began to be developed, but they were in relatively crude form until the late 1940's.

At about that time the needs of the submarine service began to change: The TRIGGER Class (SS-564), which was capable of higher speed, was designed; and a decision was reached to design and build the experimental submarine ALBACORE (AGSS-569) with a revolutionary "whale" shape. It became evident that the new submarines would be capable of operation in three dimensions, that new and more sophisticated means of controlling them in depth and heading would be required, and that special measures would have to be developed to train the submarine steering and diving party.

An obvious first step was to gain an understanding of the submarine's equations of motion, and the Bureau of Ships, working through the David Taylor Model Basin, undertook to do this. Under contract to the Model Basin, the Stevens Institute of Technology developed a set of equations of motion for submarines together with a series of constants and coefficients for various submarine designs.

The use of submarine diving trainers antedated the development of these equations. Shortly before World War II, the Askania Company, which had long been active in the design and construction of training devices, built diving trainers, more properly called submarine motion trainers, which provided platform motion These were put into service in about 1940 at the U.S. Naval Submarine Base, New London. These trainers employ a mechanical computer that operates on compressed air; the servomechanisms are controlled by a jet pipe unit, a type of feedback controller that consists of two jets of air blowing on each side of a flapper vane. Only motion in the diving mode (pitch) is provided. The motions of the platform in response to movements of the controls are empirical (rather than exact), and to the extent feasible represent the motions of a submarine. In effect, the knowledge of experienced submariners was brought to bear so that the trainer responded about the same as a fleet submarine would be expected to respond. With the relatively slow speeds, small excursions, and limited maneuvers attempted, this was sufficient at least for training purposes. The development of evasion tactics, "hydrobatics" and higher-order maneuvers was left for post-graduate, at-sea work by daring and innovative submarine commanders.

In the early 1950's, procurement of a new trainer providing for greater capabilities than those in existence was initiated. The Naval Training Device Center (then, Special Devices Center) requested proposals on the design and construction of the Universal Submarine Simulator, Device 21B20. This trainer was intended to be able to simulate any of a number of classes of submarines then in existence, or to be developed, insofar as its responses were concerned. The USS TRIGGER (SS-564) was used as the model for development of the hydrodynamic equations of motion, which was recognized as needed.

The Electric Boat Division of General Dynamics was the successful bidder on this procurement. The company immediately set out to develop submarine equations of motion which would be suitable to represent the actual motions of the submarines simulated to the degree needed to provide requisite training. Using: Sir Horace Lamb's classic treatise, "Hydrodynamics," a basic paper; "Nomenclature for Treating the Motion of a Submerged Body Through a Fluid," Technical and Research Bulletin No. 1-5, published by the Society of Naval Architects and Marine Engineers in April 1950; and the work done by the Stevens Institute hydrodynamicists, David Taylor Model Basin personnel and other researchers; along with results of sea trials of TROUT and ODAX, a comprehensive set of equations was derived. The result, which was embodied in an Electric Boat Division report called "EBDR-1" of 11 September 1954, was a complete descriptior of the submarine equations of motion needed to model the USS TRIGGER for the simulator.

The equations were developed on the basis of "providing a submarine simulator trainer which will provide the kinesthetic simulation of a submarine in operation." Particular care was taken to provide close simulation in pitch and roll, and to provide close readings of the depth of submergence. As was pointed out by the designers at the time, although there is no feeling of depth of submergence on the part of the crew of a submarine (this was true at least until truly deep diving submarines were developed), precision of depth gage readings is desirable for the purpose of training in operations which are vitally

reproduction of the submarine equations of motion and hence more complexity.

By the mid 1960's trainer development had reached the point where it seemed appropriate to replace the analog computers in these trainers with digital computers. The primary purpose in so doing was to provide greater flexibility in programing and to eliminate time-consuming changes in patchboards or wiring. A secondary purpose was to provide smaller and more compact computer facilities, with less maintenance, replacement and upkeep of parts. In 1967, Hydrosystems, Incorporated replaced the d.c. analog computer associated with the 21B20/21B20A with a digital computer, a Honeywell DDP-124, which contains a 16,000 24-bit word core memory. This computer is capable of simultaneously driving both platforms at once. It is programed with the full set of Naval Ship Research and Development Center coefficients.

Following the successful introduction of the digital computer in the Universal Submarine Simulator, trainers for both FBM and attack submarines were procured. The first of these was Device 21C5, Advanced Submerged Control Trainer, built by Hydrosystems, Incorporated, which simulates the Sturgeon Class submarine. It also uses the DDP-124 computer. Roughly in parallel, but somewhat later in time, digital computers (Honeywell 316) were being procured by the Special Projects Office to replace the solid state analog computers on three FBM Ship Control Center Trainers at Charleston, New London, and Pearl Harbor, simulating the LAFAYETTE, JAMES MADISON and BENJAMIN FRANKLIN, respectively.

Completing the cycle back to sophistication in representing the motions and responses of the submarine, the Training Device Center, in 1969, began the refurbishing of the existing 21B56A. This consisted of replacing the analog computer with a DDP-124 computer, providing instrumentation, and simulation of a generalized attack submarine of the SSN 594 and 637 Classes. This new version was called the 21B56C, and Electric Boat Division was awarded the contract to accomplish the modification and refurbishing. Both the Combined Instrument Panel and "Conalog" displays were provided on the platform, along with Ballast Control Panel and a versatile Instructor's Console. It was also possible to program the trainer to simulate the new SSN-668 Class submarine. The two cabs are driven by a single DDP-124 computer with an Electric Boat Division designed computer interface, and uses the existing hydraulic plant. The first 21B56C (figure 4) was accepted by the Naval Training Device Center at the U.S. Naval Submarine School, New London, in July 1971.

What of the future? It seems clearly established that relatively sophisticated steering and diving trainers are required with fairly close fidelity in submarine response and motion. Further, this fidelity can be provided with precision, flexibility and requisite range and accuracy of the variables in the equations of motion by the use of a digital computer of moderate capacity. Also, it has been established that through means such as time sharing, digital computers can drive more than one cab, providing a significant savings in electronic equipment. From the points of view of verisimilitude in simulation and costeffectiveness of equipment, it would appear that today's computers are quite mature. This is borne out by experience in their operation over the past few years; improvements in efficiency have been made, but principally by introduction of improvements in the training process. This includes the publication of an Instructor's Handbook for Advanced Submerged Control Training on the 21C/21C5 and 21B20A devices. This handbook was used primarily to train diving teams in advanced casualty control skills, and contained a number of training exercises as well as diagnostic exercises designed to evaluate the proficiency of a diving team before and after training.

The principal area of concern today in submarine steering and diving training is casualty control training. The basic high-speed submarine trainers do their job well, as do the advanced submerged control trainers, as indicated above. From exploratory research conducted recently at Electric Boat Division for the Training Device Center, it appears that there is a need for a generalized casualty control training device capable of providing multiclass emergency ship control training. Further, this research indicates that it is possible to provide an "optimal" set of ship control and ballast control instrumentation which will adequately represent the equipment on all classes of nuclear submarines. Programs can be written and taped to simulate various classes of submarines, and the trainer can be made to represent different submarines by a simple substitution of tape program. Alternatively, sets of

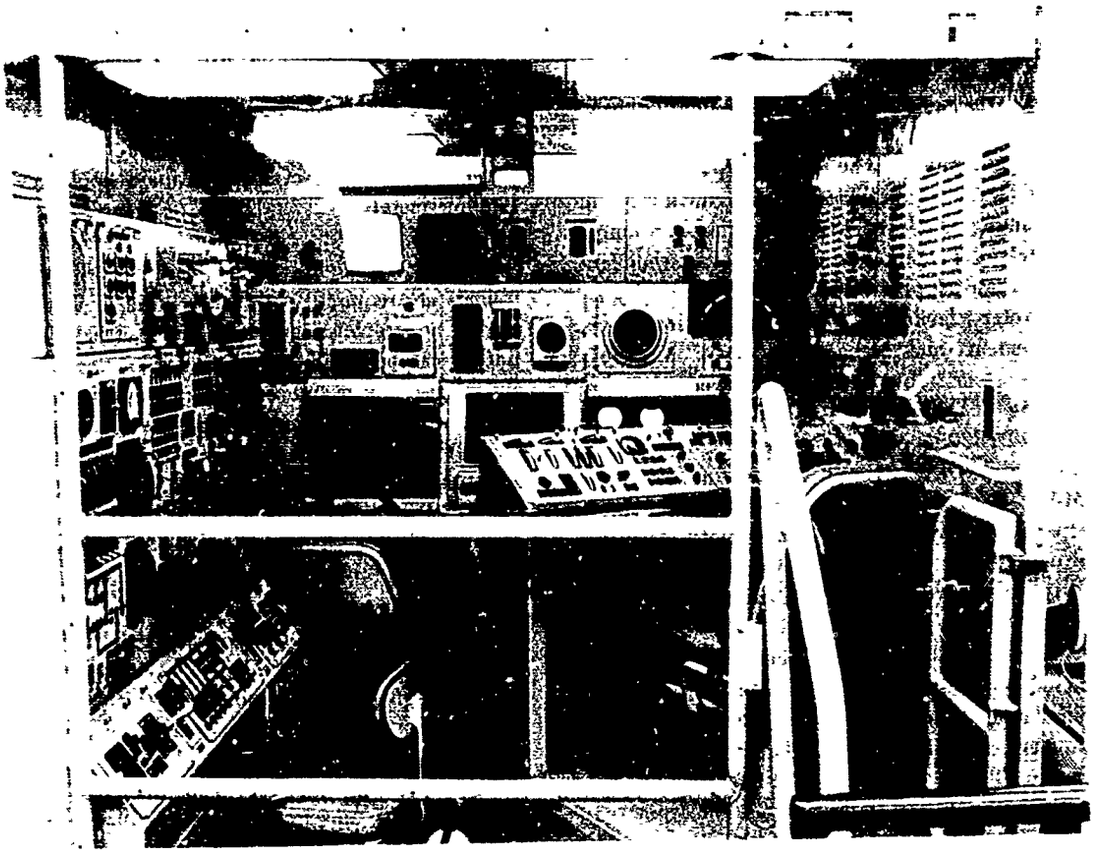


Figure 4. Submarine Steering and Diving Trainer, Device 21B56C.

coefficients could be stored in a core memory for use as desired. The theory is that a few, perhaps only three, such trainers could be used in conjunction with existing attack or FBM diving trainers to provide advanced training. It is estimated that use of the new devices and their associated training courses would make possible an increase in the amount of formal training for diving teams from the current range of 20-80 percent to a range of 95-100 percent. With time at sea as precious as it is today, it seems inevitable that devices of this type will be procured, if only to meet training needs now known.

What of new submarine types? Studies are being made of an Undersea Long Range Missile System, whereby the missile would be carried by submarines considerably larger than the BEN FRANKLIN Class. Studies are also being made of advanced attack submarines and cruise missile carrying submarines. Already, the Navy has developed and launched the Deep Submergence Rescue Vehicle (DSRV), designed to recover personnel in distress from downed submarines. The special tactical and maneuvering requirements of these types, or of submarines operating with the DSRV for example, may impose new training requirements. It is a truism that we cannot predict what the future may bring. But it seems safe to say that the groundwork established so painstakingly over the past twenty years of development of submarine steering and diving trainers (also referred to as Ship Control Trainers) will provide a sound basis for adaptation of trainers. It is even possible that new trainers offering additional motion cues will be developed and that the officers and men who are trained on them will be able to execute their missions confidently and effectively when they go to sea.

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Large Screen Display System Developments

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Early large screen display systems of the late 1940's and 1950's utilized for training devices, provided tactical displays for large numbers of trainees and were generally of the spotting or scribing projector type. Spotting projectors show a target's present position heading (by rotation of target symbol, usually shaped as an isosceles triangle) and its identification (friendly, hostile, unidentified, surface, subsurface, etc.) by color selection. Scribing projectors provide present position (as the head of a track), past history (as the remainder of the track) and identification by color selection. The early spotting and scribing projector systems were driven by mechanical or electrical analog computers and many are still in operation.

The durability of these technologies is due in part to the difficulty of providing electronic systems capable of adequately serving large screen areas (several hundred square feet); and in part to the availability of alphanumeric/graphic cathode ray tube displays, which can provide each user with his own display. The applications where large screen displays are actually required and cannot be served by individual displays are relatively few when subjected to close scrutiny. Initially, where tactical displays were required, the economics of spotting/scribing technologies available dictated a single large screen display which was viewed by all users. Therefore, in many cases, the requirements were modified by the technology available. Since any tactical display system may require both individual and group displays, careful system analysis is necessary to provide the optimum mix within existing technology limitations.

Emerging technologies, such as liquid crystal, plasma, light emitting diodes, laser, etc., may offer future solutions in the large screen display area, but current technologies are limited primarily to techniques which have related commercial applications. Representative of these are projection cathode ray tubes, with reflective or refractive optics, and television projectors of the light valve type. Performance and operating cost of some of these has been and may still remain unsatisfactory, but the impetus of commercial application has provided a continuity of development effort which has resulted in new and improved products in this area.

Both existing and emerging large screen display technologies require evaluation but should not be utilized to fill a need better served by individual displays.

It is the intent of this paper to treat large screen display system developments in the context of their place in the overall scheme of display system design rather than as a collection of individual techniques. Specific display technologies will be discussed as they relate to historical applications and to currently available and possible future technologies. But the main thrust of the paper is to discuss large screen displays relative to the needs which they serve, the needs which may be better served by other technologies and the integration of these diverse needs into a single cost-effective overall design. The hardware emphasis of the paper will be on commercially available large and small screen display devices and appropriate display generation techniques for these devices. Finally, the paper attempts to emphasize the need for the user to consider display needs in terms of requirements only and not in terms of preconceived hardware configurations.

Large screen display systems must be discussed in terms of their size, the nature of their information content, and their intended use.

Generally, large screen displays may be defined as those which are a minimum of 30-inches square and may be as large as 20-feet square.

The information content of a large screen display may consist of data in alphanumeric text or tabular form, or as a graph with data presented with respect to ordinate and abscissa. A symbolic plan view display depicting geographic boundaries and symbols representing moving vehicles or fixed objects of interest represents a fourth and major type, generally referred to as a tactical display.

In all cases, at least a portion of the data displayed should be changing as a function of time. The rate at which time-varying data is changed is referred to as the update rate. Where the display presentation is subject to decay in intensity with time, it must be rewritten at a rate fast enough to avoid flicker and to provide the

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appearance of uniform intensity. This rate is referred to as the refresh rate.

The major uses of a large screen display may be defined as belonging to one of two general categories. The first is that of providing general information to a homogeneous group of viewers usually of an audience size such that its members will assimilate the information thus provided, but will not be required to take positive action in response to the information presented. The second category is related to providing information to a more limited group of viewers who must assimilate the information presented, make decisions, and take appropriate action. For convenience, let us call the first category Information Displays, and the second category Interactive Displays. Generally, viewers of Information Displays require an overall view with less information content than do viewers of Interactive Displays. In fact, supplementary displays (normally small screen cathode ray tube displays) are often provided in Interactive Display systems to supply the additional information needed.

Early large screen display systems used in training device applications were primarily used for tactical displays, and were restricted by available technology to either spotting projector or scribing projector systems.

Spotting projectors operate by projecting light through a reticle containing a shaped symbol and onto a large screen. The symbol thus formed represents an air, surface or subsurface vehicle and is positioned on the screen by servo movement of the reticle vertically and horizontally relative to the light source. Vehicle heading may be shown by servo rotation of the symbol reticle.

Scribing projectors operate by use of a fixed light source and opaque coated slide whose coating is scribed away by a servo controlled stylus moving vertically, horizontally and transversely (to bring the stylus into contrast with the slide). The opaque material is scribed away as a function of vehicle position versus time and light passing through the clear area and through a color filter is projected onto a large screen where it is seen as a vehicle track.

It is possible with the scribing system to multiplex several tracks on a single slide, thus providing systems capable of providing 30 or 40 targets in four separate colors with four projectors.

It is important to discuss the relative capabilities of the scribing and spotting projector systems, as they illustrate the types of information content necessary in tactical displays for which these systems are most generally used. The scribing system can be used for alphanumeric display by scribing characters on the opaque slide, but a complete new slide must be generated when any change is required. As a result alphanumerics on scribing system tactical displays are generally limited to track identification and other supplementary uses.

TABLE I. COMPARISON OF SPOTTING PROJECTOR AND SCRIBING PROJECTOR SYSTEM CHARACTERISTICS

	Spotting Projector	Scribing Projector
Alphanumerics (Text)	No	Yes
Present Position	Yes	Yes
Track History	No	Yes
Vehicles Heading	Explicit	Implicit*
Multiple Vehicles/ Projector	No	Yes
Vehicle Identification	At Present Position	At One Position On Track (or by Color Coding)
Light Output Required	Function of Symbol Size	Function of Screen Size

*Based on recent track history information

Table I compares the performance capabilities of the two types of systems where significant differences in system capabilities are seen in the specific area of track history, vehicle heading, vehicle identifications and multiplexing capabilities. As a result, spotting projectors and scribing projectors are often combined in a single system. It should be noted that maintaining accurate position registration of a large number of spotting projectors is difficult and that multiplexed scribing projectors suffer increased maintenance due to the rapid slewing necessary to update the position of multiple vehicles. It is apparent that a system is required that can provide the functions listed in table I with maximum flexibility and minimum consumables.

Other systems have been devised in the past for tactical displays, but they have not achieved

general use. This is due to either unacceptably high consumables cost or high maintenance cost.

Scribing and spotting projector systems are practical for a large screen display for audience viewing and have been used in this fashion. However, in interactive systems, where multiple instructors viewed the same display, these systems lack the flexibility of allowing individual instructors to change display scale or scale center to examine a particular tactical area of interest in greater detail.

This lack of flexibility can be overcome in current technology by providing an overall tactical large screen display and by providing individual instructors with consoles containing graphic display terminals capable of tactical display with scale and scale center change (and capable of displaying supplementary alphanumeric text displays). This combination provides for both an interactive display for instructors and an information display for a general audience. It is also apparent that if an information display for a general audience is not required, interactive display requirements may be served by individual console displays.

However, the impact of earlier systems built before the advent of low cost graphic display terminals has tended to make the terms "tactical display" and "large screen display" synonomous when, in fact, they are not. It must be kept in mind that the size of a display is not properly measured in inches or feet, but rather in terms of the angle subtended at a viewer's eye by the height and width of the display. For example, a 12-foot square display viewed at 30 feet subtends an angle of approximately 23° horizontally and vertically, as does a 12-inch square display viewed on a console from a normal 30-inch viewing distance. Also, the number of symbols (alphanumerics, etc.) which can be placed upon the display is no greater since a symbol, to be recognizable, must subtend a given angle (10 to 20 arc minutes depending upon symbol quality, contrast, etc.) at the viewer's eye. In the above mentioned example, where each display subtended a total of 23° vertically and horizontally, and where 15 arc minutes per character width plus 5 arc-minute spaces are allowed between characters, a maximum of 69 characters could be written across either display [(23°)x(60 minutes/degree)/(20 minutes/character)].

For those current applications where a large screen display is requred, the technology to be utilized must be determined. The spotting and scribing projector systems are still available and for certain applications may be appropriate. However, it must be noted that these are mature technologies which lack adequate speed and flexibility for many applications.

There are also many new techniques which may provide useful display technologies in the relatively near future. Representative of these are, nematic liquid crystal, ionized gas discharge (plasma), light-emitting diodes (LED's) solid state light valves laser systems and others. For the present, however, the greatest potential for satisfactory large screen displays is in those technologies in general commercial use which can be upgraded in performance to meet system objectives.

The use of standard or upgraded commercial large screen display devices does not represent an ideal solution, but rather a realistic choice to satisfy a need. The "ideal" large screen display does not exist and any choice represents only the most satisfactory available solution considering the import of overall life cycle logistics needs. It should be emphasized that any available candidate technique may be most appropriate for a particular application, and each application should be carefully evaluated to determine the most cost-effective technique.

The commercial large screen display devices generally consist of some form of television large screen projector, though some of the devices may be designed for use in a random-write mode rather than a strictly television raster mode.

Projection cathode ray tube devices are available with reflective (Schmidt) or conventional refractive optics in either random write or raster type systems. Light output of these systems generally range from 100 to 300 lumens. For higher light outputs, from 300 to 4000 lumens, the oil film light valve is an appropriate candidate. The light valve produces an image on an oil film deformed through deposition of the electrostatic charge from an electron gun. The image contained in the deformed oil film is illuminated by a high intensity light source projected onto a screen through Schlieren optics. It is the combination of oil film deformation pattern and Schlieren optics that serve to modulate the high intensity light and give meaning to the term light valve. This represents a complex solution with some maintenance and consumables cost, but one which is currently in third or fourth generation design,

having benefitted by much past development. Examples are available of both American and foreign manufacture.

Current alphanumeric and graphic display systems, used primarily for cathode ray tube console type displays but applicable to driving large screen displays, fall generally into one or two generic types. These may be called stroke writing (or random writing) system and the digital television (or precision video raster) system. Of the two, the digital television represents the newer technology with both advantages and disadvantages relative to the random writing system.

Generally, the stroke writing system reads stored digital data, interprets the data and "strokes out" on a cathode ray tube the characters, symbols, vector segment, etc., to be written. When all the digital data has been read and the proper information written in the designated locations on the cathode ray tube, one "refresh cycle" is said to have been completed (usually in about 1/30 of a second). The procedure is then repeated continuously. Normally, the digital data is modified approximately once per second to update the information contained on the display. Since a specific amount of time is required to write each character, symbol, etc., the amount of data which may be written and refreshed at a given rate is limited. Any attempt to increase the data density of a specific system must be accomplished at a sacrifice in refresh rate (limited to the rate at which flicker occurs), or by increasing the writing rate (which is usually fixed by the design and not practical to change). For large screen displays, this type system may be used with a random writing projection cathode ray tube for applications where 300 lumens will suffice for the required large screen display. Scan conversion techniques may be used to make the system amenable to use of the television raster light valve projector. This is usually not desirable due to the resolution loss attendant to scanning one source of information by another pickup device.

The digital television system operates by reading stored digital data, interpreting the data and generating in a random access digital memory, generally called the display assembly memory, an "analog" of the television raster display to be generated. For example, the memory may consist of 480 "lines" of core, each containing 600 bits of information per line, or a total of nearly 300,000 bits of "picture" information. Characters and symbols are generated by transferring dot-matrix information from a symbol library (or read-only memory) into the proper position in the display assembly memory. Vectors are generated by computing which row and column bit positions will be "set" to display a given vector segment. Once the "picture" is assembled in the display assembly memory, it is transferred to a display refresh memory where it is "read" in synchronism with the television sync signals. The "set" bits provide video signals to modulate the electron beam of a cathode ray tube, turning its beam "on," in conjunction with the digital information in the refresh memory. Approximately 0.1 second is required to generate a display in the display assembly memory and transfer that display to the refresh memory. If a one-second update rate is used, it is possible to generate and transfer to refresh memory 10 independent displays. During the next second, all 10 displays may be recalled into the display assembly memory and selectively modified. Since updating requires less time than required to generate a display, it is possible to update as many as 20 displays within one second. It should be noted that the refresh rate is controlled by the television system and not degraded, regardless of data density. Update rate is a function of data density with the time between updates directly proportioned to total display data on all displays. This degradation could, for example, increase the time between updates from once per second to once per two seconds.

The digital television system can drive any of the raster type projection CRT devices or the light valve devices.

Since many of the current display systems require multiple console displays as well as one or more large screen displays, it is highly desirable that only one display generating system be required for both large screen and console displays. This approach will minimize software and hardware costs and make all display formats available to both large screen and console displays.

In summary, system needs must be evaluated to determine whether or not a large screen display is required, or whether console displays alone would provide an adequate or even more flexible system. Where both console displays and one or more large screen displays are required, a single display system capable of driving both the console displays and the large screen display should be considered in the interest of lower cost, improved maintenance and increased flexibility. Where a

large screen display is required, its capabilities should be carefully matched to needs. Generally, information density and display resolution may be lower for an Information Display than for an Interactive Display. One critical area is the amount of light output available from the projector. The light needed is a function of the overall design and includes considerations of audience size, viewing angles, front or rear projection, screen size, etc. No rule of thumb can be generally applied, but a rough order of magnitude of required light output may be projected on the basis of 5 to 10 lumens of light output per square foot of screen area. For example, a 5-foot by 5-foot screen would require 125 to 250 lumens; and, a 12-foot by 16-foot screen would require approximately 1600 to 2000 lumens.

In conclusion, any display system design must be accomplished as an integrated system design and that design must be based upon system needs and not predicated upon predetermined hardware configurations.

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A graduate of the University of Florida in 1957, Mr. Palmer was employed for six years as a design and development engineer at Honeywell Inertial Guidance Center, where he worked in the areas of inertial guidance system platform electronics and control/display. In 1963 Mr. Palmer joined the National Aeronautics and Space Administration Manned Spacecraft Center at Houston, Texas, where he was Head of the Display Systems Section, which was responsible for all display and control equipment in the Mission Control Center.

Since joining the Naval Training Device Center, Mr. Palmer has been concerned with system design work in Instructor Control/Display Consoles, Tactical Large Screen Display Systems and Visual Simulation Systems.

Advancements in Instructor Station Design

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In the early days of simulation, the responsibilities of the instructor were identical to what they are today although the manner of meeting them has changed over the years. The instructor created training exercises, controlled the exercises, monitored performance, determined progress, and graded the trainee. The training exercises and the simulation equipment in the early days were simple and the instructor's functions were readily accomplished. Technological advances, more sophisticated weapon systems, and the advent of the digital computer forced evolution of succeeding generations of instructor stations, each designed to permit the instructor to perform his functions despite the increasing complexity of both hardware and mission. This paper will trace that evolution through present day state-of-the-art and, based on current technology, will predict future instructor station evolutionary trends.

It is difficult to state with any degree of certainty when simulation for training purposes began. A research of historical data indicates that when it came to training, man's first endeavors most always included prime system hardware. That is not surprising, since it was the most logical approach—the hardware was available and technologically speaking was relatively simple in nature. World War II provided the impetus for rapid technological advancement, particularly in the art of making war, and the increasing growth of weapons systems, both in terms of cost and complexity, forced attention on simulation as a cost-effective and efficient means of training. Thus, the mid-1940's mark the first time simulation began to evolve as an art in itself.

Inherent in the training situation intself is the need for an instructor. The role of the instructor is to teach. He teaches by formulating training exercises, controlling the exercises, monitoring trainee performance, and grading the trainee. One of the prime considerations in any simulator is to provide capability for the instructor to perform those functions. Instructor station design and configuration from the beginning were influenced primarily by the role of the instructor. To monitor trainee performance, duplicate sets of trainee indicators were incorporated at the instructor station along with indicator lights to indicate trainee switch positions and actions. To control the training exercise, the necessary switches and controls were made available to alter the basic parameters of the training problem. To grade the trainee, some means of measuring and recording performance were included. In effect, the instructor station became a duplicate trainee station, with the added capability for controlling, monitoring, and grading.

The instructor station of Device 2F1, the PBM Mariner Operational Flight Trainer is shown in figure 1. It typifies instructor stations of the late 1940's and early 1950's and embodies the influence of the instructor's role on instructor station design. The repeater flight and engine instruments are shown along with the indicator lights. The controls necessary for introducing wind from any direction up to 60 miles per hour, for changing weight and center of gravity, both longitudinally and laterally, for introducing the effects of wing ice and rough air, and for failing some of the electrical subsystems which were packaged in a drawer in front of the instructor. A flight path "crab" recorder provided a standard for grading purposes and an intercom enabled the instructor to talk to the trainee. The hardware may look crude by today's standards but at the time it was an effective instruction station.

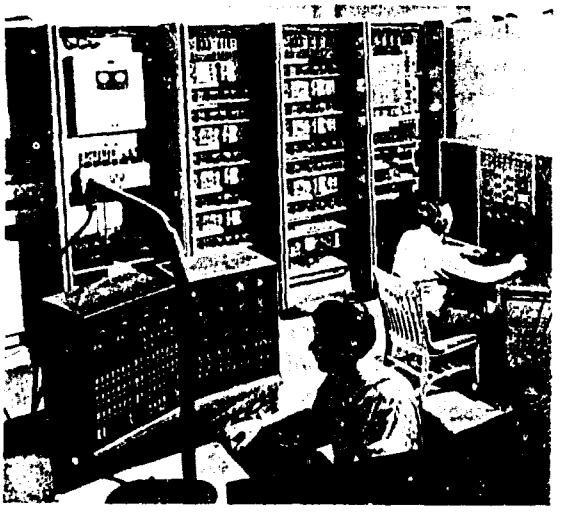


Figure 1. Instructor's Station, Device 2F1.

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There was little in the way of simulation in those early training devices. The prime system technology and hardware served the requirements of trainer technology and hardware. Three distinct advantages were realized from the similarity of instructor station and trainee station, and from the use of prime system hardware. The trainer was less costly to maintain; the instruction station could serve as an introductory trainee station; there was little necessity for formal training to train the instructor in how to operate the trainer. The second of these advantages was perhaps the most significant. While a trainee performed at the trainee station, another student or students observed the repeater dials at the instructor station and received introductory training. The observer students learned the relative positions of the instruments and controls and what constituted a good or bad trainee performance. The use of the instructor station for introductory training reduced actual training time and was the forerunner of the multiple station trainer.

The increasing complexity and sophistication of prime systems forced the trainers to grow apace, particularly the instructor's station. For each new system added to the trainee station, its counterpart must be added at the instructor station with associated controls, indicators, and recording equipment. The result is that there is roughly a two-to-one physical growth rate at the instructor station for each new system in the operational equipment. The advent of the analog computer accelerated the rapid growth. It also marked the first real departure from the use of prime systems hardware and into simulation. The effects at the instructor station were significant. The indicators were simulated. The on-off toggle switches, so prevalent in previous generation training devices, were replaced by multipurpose lenticular switches. The "crab" recorder was replaced by the x-y plotter. The capability of the analog computer to perform different functions automatically and simultaneously gave the instructor increased capabiltiy of altering training exercise parameters, which further necessitated additional control switches and indicators.

The rapid growth of instructor capabilities, and the attendant growth of controls and indicators, focused attention on the human engineering aspects of the instructor station. Throughout the 1950's, continuing research was conducted to find the optimum configuration for optimum instructor performance. Design engineers, who heretofore had neglected or paid minimal attention to human factors in formulating the design, now found human factors to be one of the overriding design considerations. In the late 1950's, instructor stations had reached a fairly standard configuration. The station was segmented into clearly defined blocks by function and their position on the console, or consoles, was determined by the frequency of use. The controls and indicators of those functions most often performed were directly in front of the instructor. The controls and indicators of other functions were arranged in descending frequency of use out to the right and left, the least frequently used being farthest from the instructor's normal operating position. The instructor's station of Device 2F79, F-4C trainer, is shown in figure 2. It shows the clearly defined functional groups of controls and indicators and the relative positions of each from the center out based on human engineering dictates. It vividly portrays the large physical size of the instructor station and the growth in complexity. Figure 2 typifies instructor stations of the late 1950's and early 1960's.

There were several major disadvantages associated with those analog instructor stations. They were too large for efficient one-man operation. Any change in operational hardware almost always necessitated a hardware change at the instructor station with attendant cost and loss of training time. Training is usually accomplished in stages starting with simple task and progressing to the complex. The effect of this progression is that during training missions large segments of instructor station hardware are utilized only briefly and in terms of utilization is far from being costeffective. The digital computer replaced the analog computer in the early 1960's and relieved some of those major problems. The use of the general-purpose digital computer allowed operational equipment changes to be translated into software program changes in the trainer. The digital computer performed automatically functions heretofore performed by the instructor, thus relieving the instructor workload. Information required by the instructor could be printed out when required reducing the need for indicators. The controls necessary to conduct a training mission were simpler with the digital computer, further reducing the need for bulky hardware. The reduction in size at the instructor station was offset by the ever-increasing complexity of the prime systems and by the great

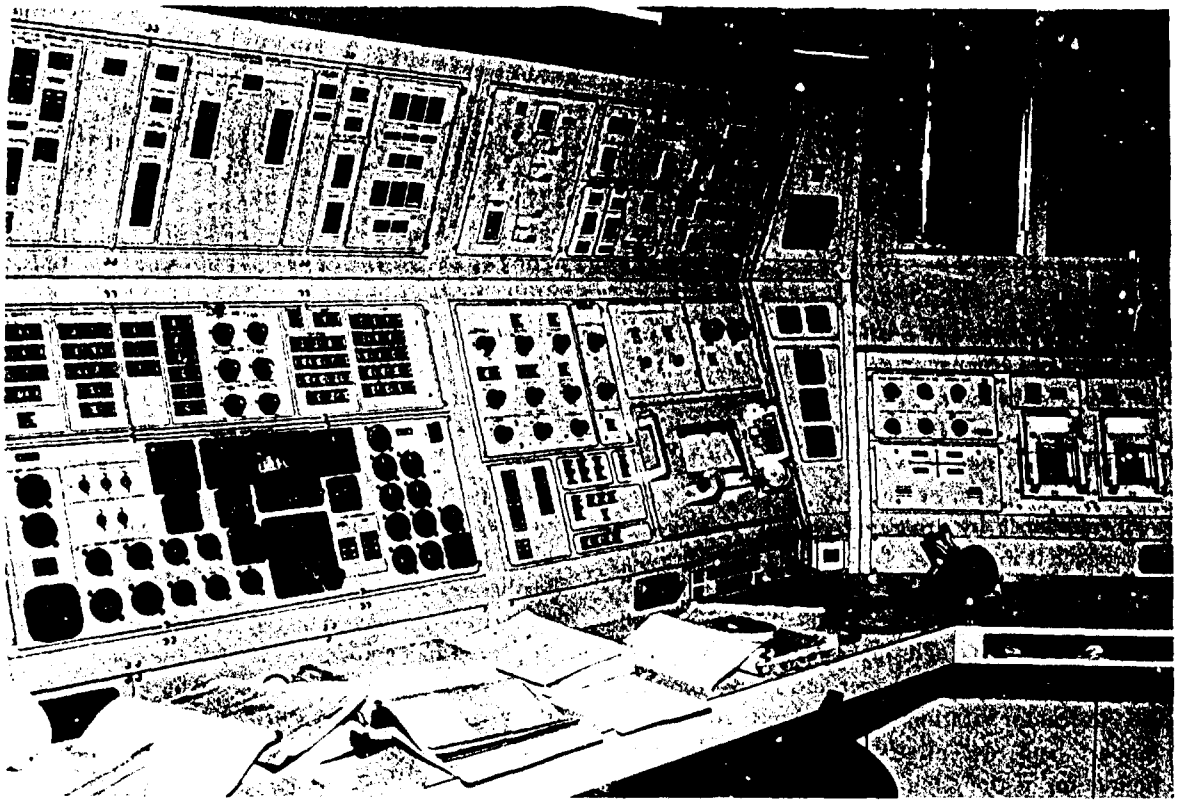


Figure 2. Instructor's Station, Device 2F79, F-4C Trainer.

flexibility of the digital computer, which enabled inclusion not alone of prime systems parameters themselves, but also of operating environment parameters. A new dimension was added at the instructor station which further increased the physical size of the instructor station. The digital computer allowed the instructor a record/replay, or freeze capability, which greatly enhanced the debriefing phase of the training problem. The net result was that even with digital computers, the instructor station remained large and complex. Device 2F88, F-4J Weapons System Trainer, figure 3, embodies all that was good and bad in instructor stations of the late 1960's. The enormous physical size is readily apparent and some estimate of the functional capability may be gleaned from the numerous controls and indicators. A rigorous formal instructor training course to optimize effective use of the great flexibility available was necessary. From a cost-effective point of view in terms of utilization, reliability, and maintainability, the great bulk of hardware left something to be desired. What was clearly needed was some means to allow the instructor rapid data entry and retrieval to and from the computer without the need for bulky controls and indicators. That need was recognized in the late 1960's, and technology created the computer display terminal system which shaped, and is continuing to shape, the configuration of present generation instructor stations.

The computer display terminal consists of: (1) an interface controller, (2) display electronics cabinets, and (3) display cathode ray tubes with keyboard entries. The cathode ray tube display unit has the capability to display graphics and alphanumerics. The instructor may input the display unit by means of a control keyboard, a light pen, or a pushbutton-actuated graphic cursor. The keyboard usually has a number of fixed and variable function keys. The fixed keys provide standard operator controls such as clear, enter, erase, retrieve, etc. The variable function keys permit the instructor to select program-specified functions such as call-up of another display or deletion of a line on a graphic display. Because the display unit has its own associated memory, the instructor can use it as a scratch pad without bothering the main computer. This capability permits the instructor to accomplish data formating and editing. Data is entered from the

keyboard. The data is stored in the refresh memory and displayed on the CRT. The instructor reviews his total entry and, using his edit keys such as "character delete," "line delete," or "insert in display," can modify and manipulate the data. When he is satisfied with the data, he can transmit them to the central processor. This edit capability is usually used with a split screen capability allowing the instructor to view a series of status displays on one portion of a display, while at the same time processing a mission request on another. When several display terminals are netted to a central computer, each one can operate independently, displaying and acting upon the particular data necessary for that station. New or changed data can be automatically cross-referenced by program to all other categories with which it interfaces.

The development of the computer display terminal drastically altered the appearance of instructor stations. Throughout the 1950's and early 1960's they grew larger and more complex. The instructor stations being built today are compact and deceptively simple looking. The elimination of the familiar repeaters, controls and indicators (by use of the computer display terminal) has resulted in greatly diminished physical size and has simplified the external human engineering aspects of instructor station configuration. The Naval Training Device Center recently accepted a four-cockpit UH-1H Helicopter Flight Trainer for the United States Army Aviation School at Fort Rucker, Alabama. The trainer designated Device 2B24, Synthetic Flight Training System, embodies all that is current in instructor station design. The Device 2B24 instructor station is shown in figure 4 and features six CRT display terminals. Four of the six are capable of displaying both graphic and alphanumeric data and are assigned to the four cockpit stations. The four stations are color coded and the CRT display associated with each has its bezel painted a matching color. The remaining two displays, an auxiliary information display and an air traffic control display, present only alphanumeric data. These two units have segmented display areas which permit data to be displayed in a color that matches the color code of the associated trainee station. The upper half of the two displays are vertically divided into four 4-in. x 6-in. sectors; characters displayed appear in red, blue, yellow, or green according to which station the data pertains. A cockpit indicator display is mounted atop the two center

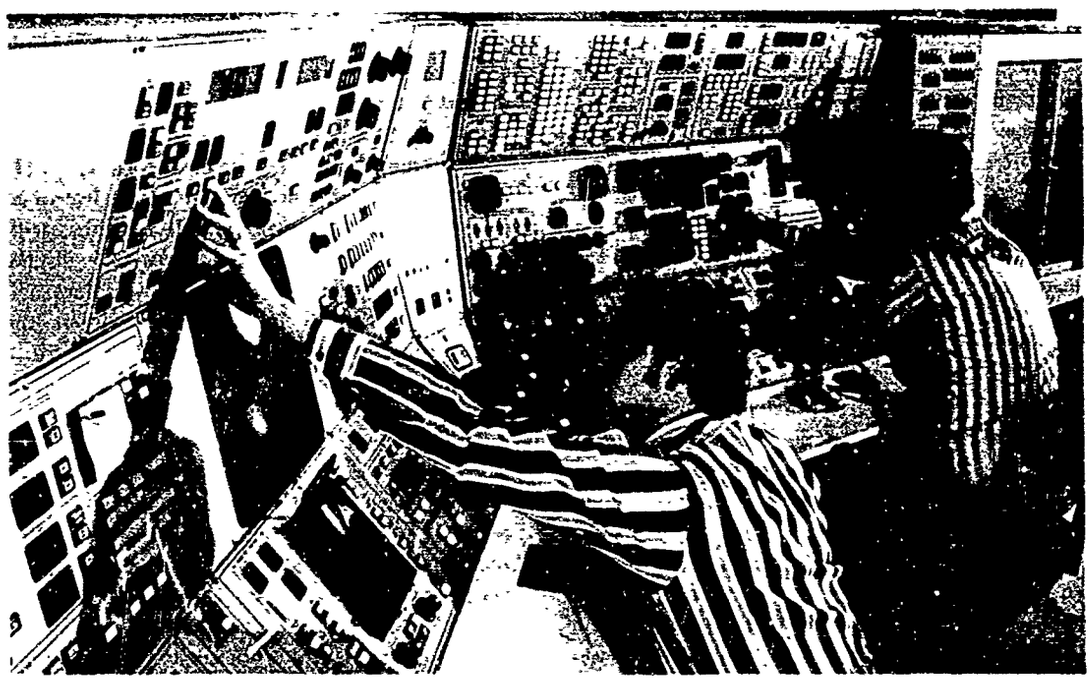


Figure 3. Instructor's Station, Device 2F88, F-4J WST.

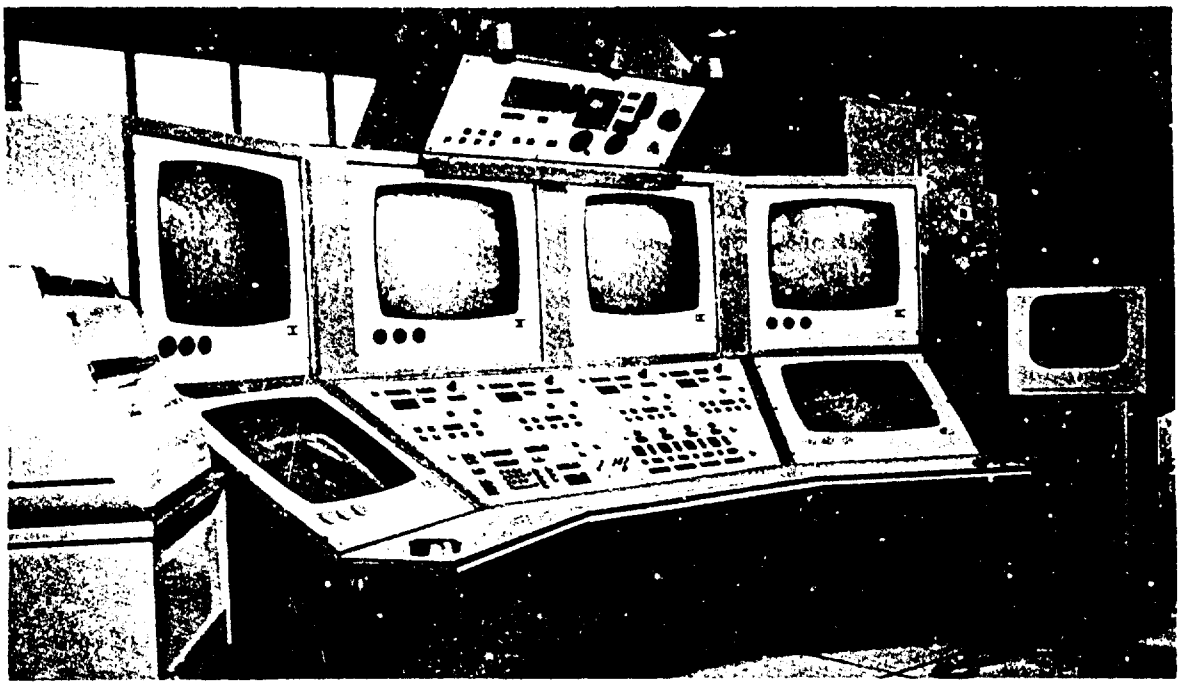


Figure 4. Instructor's Station, Device 2B24.

CRT's and titled for easy viewing. This is probably one of the last instructor stations to have such a display. In future designs, the cockpit displays will be graphically displayed on the CRT display terminals, thus eliminating the need for repeater instruments. Considering that Device 2B24 is a four-station device, each station capable of independent operation, the picture vividly depicts the reduction in physical size possible through the use of computer display terminals.

Technology never solves problems without creating new ones and the new instuctor stations are no exception. The most serious problems center around the instructor machine interface. The physical configuration of previous generation stations with their functional groupings and labeled indicators made instructor/operator training a relatively simple matter. The greater flexibility and multimode operation of present generation instructor stations require a more rigorous formal training course to teach instructors the flexibility and operational scope of the devices. In the old generation stations, data was displayed whether it was needed or not and the instructor selectively monitored that which he needed at the moment. In the current stations only that data which the instructor selects is displayed. CRT's in current use in computer display terminals have a maximum viewing area of 12 in. x 12 in. Because of the small viewing area, the format and the amount of information that can be displayed for efficient assimilation by the instructor becomes of paramount importance. The information available and capable of being displayed is vast. A small increment of it would clutter the viewing area beyond interpretation. The question to be resolved is that of what to display and when. The answer is difficult inasmuch as all the information required to be displayed is useful at some point in the training mission. The result is that the instructor must be thoroughly familiar with the now and the future of the training problem in order to select in time, and in correct sequence that information which is required for the efficient conduct of the problem. What is the correct sequence in view of the fact a given training problem can be conducted in a number of ways? To answer such questions, and to investigate man/machine interface problems created by the new generation computer display terminals, the Naval Training Device Center recently installed a computer-generated display system in conjunction with a Sigma 7 Computer for research in development of instructor station applications.

One possible solution to many of the instructor/machine problems is to relieve the instructor by allowing the computer to perform

more of the instructor's functions. This possibility has recently created a flurry of activity in adaptive training techniques. Adaptive training is a technique whereby the complexity and/or difficulty of a task is adapted to the skill level of a trainee. As the trainee acquired more skill at a given task, the task becomes more difficult until the difficulty level approximates or exceeds that of the operational task. Until now the adaption was under the control of the instructor. He intervened in a training exercise and varied parameters to improve the skill of the trainee. The intervention up to now was largely subjective and the variation of parameters was not necessarily in correct order for optimum training. The problem for the psychologists to enable implementation of adaptive training techniques in trainers is to quantify adaptive variables in terms of relative difficulty and determine the relationship between them. When one considers the complex nature of the learning process in individuals, the task is formidable, but a start has been made in Device 2B24. The University of Illinois designed the adaptive training system for the 2B24. The adaptive system consists of groups of automated training tasks executed by the trainee in response to computer-controlled instructions, performance measurement, and scoring. The specific application of the adaptive training provided is based on the premise that instrument flying is a composite of skills which can be learned individually. In practicing a newly introduced skill the study must use those skills already mastered until he can maintain criterion error rate on the parameters directly reflecting all the skills involved. For example, as the student progresses from the simple task of controlling airspeed by reference to the pitch altitude, shown on the Altitude Indicator, to making climbing and descending turns by reference to flight instruments, he is expected to control his airspeed as well as he did when that was his only task. The adaptive variables used in Device 2B24 are control damping, turbulence, and horizontal wind. Control damping is used to reduce task difficulty in the early training period. Turbulence and horizontal wind are used to increase task difficulty. The task is scaled in terms of relative difficulty based on the control settings of the adaptive variables. At the present time, the scale is predicated on a linear relationship between variables; however, as more research defines the interaction between variables, the computer programs can be changed. Student performance is measured by sampling various parameters and noting the time out of tolerance. The parameters sampled and the respective tolerances are listed below.

Performance Parameters	*Acceptable Tolerance*
Altitude	± 100 feet
Airspeed	± 10 knots
Heading	± 5°
Vertical Speed	± 200 fpm
Rate of Turn	± 1°/sec
Ball Position	± 1/4 ball
Pitch Attitude	± 4°
Roll Attitude	± 5°
Course Deviation	± 1 dot
Glide Slope Deviation	± 1 dot
Torque Pressure	± 4 lb/in^2

The list may not be complete in terms of optimum training, since parameters more relevant to the task may have been omitted. It emphasizes the difficulties facing psychologists in defining an adaptive program even for a relatively simple task. The computer notes the time out of tolerance of the various parameters and, if within acceptable limits, steps to a higher level of difficulty by automatically changing the adaptive variables in a preprogramed fashion. If the time out of tolerance is not acceptable, the computer automatically steps to a lesser level of difficulty. Performance feedback to the student is accomplished by verbal prompts which are prerecorded and automatically played to the student when a measured parameter exceeds acceptable tolerance and by displaying a training score on a panel in the trainer cockpit. If a student achieves a preset minimum difficulty level of performance, the computer allows him one cycle through his task to step to the next difficulty level and, if he fails, the computer freezes his cockpit. In the automatic training mode, the instructor is free to turn his total attention to student performance without having to concern himself with parameter variation or fault insertion.

The implementation of adaptive training in Device 2B24 highlights the problems associated with adaptive training techniques. To use the computer to measure and score the trainee and to free the instructor from routine control presupposes a complete knowledge of training methods and performance measurement. Such is

not the case, nor is it likely to be in the immediate future. The order of priority of task parameters, the interaction between various trainee skills, the effect of adaptive training techniques on the role of the instructor, the learning process itself—these are areas which are only now being researched in the laboratory. Recently a study was conducted jointly by the Naval Training Device Center and Manned Systems Sciences, Inc., utilizing the TRADEC simulation facility. The study was designed to identify, develop, and demonstrate the analytic and empirical steps necessary to apply the existing body of knowledge concerning training and machine control technology to a complex team training task. The results indicate that the development of an automated trainer is feasible, but only after extensive research refines and extends performance measurement, and quantifies adaptive training parameters and the interaction between them as related to individual trainee skills.

The effect of this continued research will have little impact on the external configuration of instructor stations. While vast changes are taking place in software and behind the exterior, the outward appearance should vary little at least throughout the early 1970's. The CRT display terminals and the keyboard entries will become standard at the instructor station. The next major configuration change will be in the result of developing display techniques. The CRT has the disadvantages of being bulky and requiring high power consumption. Recently, flat tubes have been developed which overcome these disadvantages and will probably replace CRT's in computer display terminals. Instead of an electron gun, the flat tube has a flat cathode with a control grid for diffusing the electron beam and making it planar. A series of thin metalized glass plates provide switching mechanism for beam focusing and the target screen is phosphor-coated as in a CRT. All the components are sandwiched in a structure about 1-in. thick. The tube can display graphic or alphanumeric data in color and can also incorporate its own storage memory. The beam can be randomly scanned over the target screen and is not restricted to the raster scan of a television-type CRT. Currently the tubes have a 3-in. × 5-in. active screen area but the technology exists to build 12-in. × 12-in. tubes. The flat tubes will probably replace CRT's in instructor station consoles in the mid-1970's.

Two other areas of emerging development that will shape the configuration of future instructor stations are holography and liquid crystal imaging. In the laboratory holography and light beam deflection have been combined to produce time-varying displays. The holographic recording process preserves phase as well as intensity information, and complex three-dimensional displays can be recorded on high-resolution photographic film for use with light beam deflection to produce moving three-dimensional displays. The need for such a display is immediate in the requirement for an aircraft landing display that exhibits a time-varying perspective. Recently in the laboratory, the light scattering phenomena of liquid crystals subjected to electric fields have been used in conjunction with matrices of electrodes to display pictures. Liquid crystals reflect light; they do not generate it. This characteristic permits an image to be viewed under a broad range of lighting conditions and requires very little power. Images can be stored or erased so that the crystals constitute a reusable recording medium. The sensitivity is much better than that of many reusable materials in current use. It is several orders of magnitude greater than that of photocromic films and is particularly suitable for project display systems such as large screen situation displays.

The evaluation of instructor stations between 1940 and 1960 was slow and relatively invariant. They grew larger parallelling the growth in complexity of operational hardware but techniques and concepts relative to training and instruction remained much the same. The human factors aspects of instructor stations were dominated by the optimum placement of controls and displays for ready access rather than the optimization of the instructor. The introduction of the digital computer caused the focus to concentrate on instructor optimization and the transfer of knowledge process itself. The development of the CRT terminal display and the implementation of adaptive training techniques, even if minimal, indicates that progress is being made. Behind the instructor stations of the late 1970's, hardware design will be dominated by the trend toward computer-controlled training. Up front the instructor station configuration of the late 1970's will be largely determined by the emerging image/data display and recording techniques such as flat-tube holography and liquid crystal imaging.

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Gerard L. Murphy was born in Roscommon, Ireland in 1932. He emigrated to the U.S.A. in 1953 and, after military service in the Army, attended the University of Illinois, graduating with a BSEE in 1960. He joined Martin-Marietta Corporation, after graduation, and worked as a Guidance and Control Engineer on the Titan II booster for the Gemini program. In 1961, he went to work for the Foreign Technology Division of the U.S. Air Force, and in 1966 joined the Naval Training Device Center. He received his Masters Degree in Commercial Science from Rollins College in 1968. Currently, Mr. Murphy is the Project Engineer on the F-14A Missile Control Officer Trainer being built by Hughes Aircraft Company.

Factors That Influence the Use and Acceptance of Training Devices

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The use and acceptance of training devices by military personnel are dependent on a number of interrelated factors: (1) adequacy of simulation of vehicles, sensors, environment, controls, communications, displays and weapons capability; (2) training convenience as reflected by ease and flexibility of problem setup, adequacy of software, provisions for feedback and evaluation, and equipment reliability; (3) the opportunity to practice critical procedures that can rarely be practiced in the operating environment because of cost or safety considerations; and (4) the user's concept of what the trainer's capabilities are, particularly in relation to his own felt level of expertise in that area of operations.

The influence of the factors outlined above was studied in a survey of the acceptance and use of 16 complex training devices used by the Navy. The attitudes of students, instructors, administrators, and maintenance personnel were measured.

Acceptance profiles were developed for each trainer that reflected the users' evaluations of its simulation features, training effectiveness features, and the role of situational factors. The profiles were shown to be highly diagnostic of the superior qualities and felt inadequacies of each trainer.

Problems of acceptance were by no means associated exclusively with design features of the trainers. The manner in which a trainer was used and the users' concept of the trainer's role in the overall training system were critically important. The need for qualified "trainer advocates" to deal with the latter problems is discussed.

The critical role of training devices in developing and maintaining the skills of Navy personnel is accepted by virtually everyone. Recognition of the need for a training device, however, does not automatically insure a high level of acceptance of the device by its users. Many factors operate, some perhaps obvious and some quite subtle, to determine the level of acceptance and method of use of training devices by military personnel. In extreme cases, strong patterns of rejection can develop that can defeat the very best of intentions and large-scale investments in training systems.

The problem is not peculiar to training devices. The Navy has become increasingly concerned about the potential degradation of systems performance associated with non-acceptance of various kinds of operational equipment by the personnel who must maintain and use it. Several studies have shown that, in the hands of the users, new equipment often fails to achieve its full potential performance capability. It is obviously in the interest of all to identify the factors that operate in the acceptance or rejection of Navy hardware systems and to try to develop techniques whereby acceptance can be maximized.

It was the objective of the study reported here to (1) identify the factors leading to the acceptance (or rejection) of training devices by their users; and (2) to determine the extent to which these acceptance factors were present in "effective" and "ineffective" training devices.

SOME BACKGROUND CONCERNING THE PROCESS OF ACCEPTANCE

The processes of acceptance and rejection have long been studied from the academic viewpoint by the social scientists concerned with attitude formation and change. The appropriate literature was carefully reviewed in an effort to develop hypotheses that might be pertinent to the acceptance of training devices. In the more practical world, the process of acceptance has been a major concern of every manufacturer of consumer goods—how does one gain acceptance on the part of the public to which he wishes to sell his product? In the marketplace, the consequences of consumer resistance are immediate and economically severe. In the military, where there

usually is no competition (i.e., the user has no choice), the consequences are more subtle but very likely just as serious.

There were also a small number of studies within the literature directly concerned with the acceptance of hardware developments by Navy personnel. In one of the earliest such studies, Simpson and Parker (18) performed a field study of the ASPECT sonar system by fleet personnel. The investigation was concerned both with the operational use of this equipment and the degree to which it had been maintained in good operational order. It was found that the equipment on board over half of the ships visited was either incapable of producing target signals at all, produced signals of very poor quality, or was so severely miscalibrated that proper operation was impossible. Simpson and Parker suggested that the principal problem lay in the fact that a *lack of understanding of the purpose and operation* of the device had engendered biases against it. These biases led to insufficient maintenance, thus reducing potential operational effectiveness, which in turn further strengthened the biases, and so on, in a never-ending cycle.

A number of investigators have stressed the importance of first hand personal experience, in contrast to the simple presentation of factual information, in promoting the acceptance of new equipment. Berger *et al.* (1) suggested that the importance of personal trial was the result of the opportunity to overcome negative attitudes based on unfamiliarity, to compare one's own performance using the new equipment with that using older equipment, to build confidence in how to use the equipment, and finally to provide an opportunity to communicate attitudes and ideas about the equipment to one's peers.

An important incidental finding of Berger's study was that attitudes towards new equipment may change over time without any additional firsthand experience, as a result of informal communication. A period of initial resistance to innovations may well be overcome, in time, provided that the proper provisions for trial have been made. If not, negative attitudes become stabilized and possibly increase in strength with time.

There is little objective documentation of user acceptance problems with respect to training devices. However, in an earlier Naval Training Device Center (NAVTRADEVCEN) study (20) a committee of engineers, training specialists, and maintenance personnel investigated the use of two operational flight trainers. The trainers were studied from the viewpoint of how effectively they were utilized by both training commands and the fleet. These investigators identified significant differences between design capability and the manner in which the trainers were actually used. They found that neither of the operational flight trainers was in a condition that permitted use of all of its capabilities, either in a single problem, or in a series of problems. It was found that despite their other capabilities, the OFT's were used almost exclusively for cockpit familiarization training in normal and emergency procedures. They reported that squadron training officers for the most part had little confidence in the trainers, and did not as a rule make OFT instruction a part of the training syllabus. It appeared that some pilots had a "generalized dislike" for simulators as a result of early negative experiences. It was concluded that the problem of OFT utilization might be principally one of educating the users.

In many respects, the problem of optimizing the utilization of a training device is similar to that of maximizing the demand for a consumer product. The ultimate user of a trainer must be convinced of its worth, and educated concerning its capabilities and limitations. Apathetic acceptance may result in poor utilization which, in turn, may eventually result in actual rejection of the training device. The latter can also result from overselling or misinformation concerning a trainer's capabilities.

In a recent study of the acceptance of Navy equipment, Mechanikoff and Mackie (11) showed that the effects of design deficiencies can become accentuated through personality dynamics. One of the most important dynamic reactions that clearly lead to rejection was the "not invented here" phenomenon. This refers to the formation of negative attitudes that can result from the absence of personal involvement in a technical innovation in one's own area of expertise. Any deficiency in the design of the innovation may be magnified in importance by the "not invented here" reaction.

Another factor identified in this study as important to the acceptance process has been clearly emphasized in the extensive literature on attitude formation and change. Attitudes toward new equipment or other innovations are critically determined by the "change advocate" -some individual who functions formally or informally, in the role of initial communicator concerning the

advantages and capabilities of the device to the potential users. The qualifications and other characteristics of the change advocate, real or perceived, are critically important to the development of acceptance, particularly if the innovation is in an area where the potential users consider themselves experts. Such factors as the change advocate's credibility, prestige, perceived motivation, relationship to the users, apparent impartiality, intent to influence, methods of handling criticism, etc., are factors that significantly affect his success in promoting the acceptance of new equipment.

While the importance of the change advocate has been known to social scientists for many years, it is apparent that there has been no systematic attempt to employ well-qualified advocates for the introduction of new equipment into the Navy, whether that equipment be operational or training equipment. In fact, in many cases, the role of change advocate is never filled at all, with the not unpredictable consequence of disuse or misuse of the equipment. In some cases, the role of change advocate falls by default on petty officers whose primary responsibility toward the training device is its operation and maintenance. In a few instances, the role of change advocate has been unofficially assumed by some highly motivated individual who recognizes the need to solve a training problem and is willing to do something about it, however sophisticated his approach may be. But in many cases there is no qualified advocate at all, official or otherwise.

When a new training device is designed, the designers make judgments and decisions based on *their* understanding of important parameters of the total situation. These hopefully include:

1. The deficiencies of present devices (procedures or systems).
2. How learning occurs.
3. How the device will fit into an existing curriculum and what changes in curriculum may be required.
4. The range of usefulness of the device (specifically what it is intended to accomplish and what it is not intended to accomplish).

It seems likely that the designers themselves may not be fully aware of the extent to which they are making such decisions; certainly, the assumption is doubtful that the eventual users understand all of these factors *in the same way that the designer does*, or that the hardware itself will somehow convey its purposes.

McClelland (10), in his extensive analysis of the processes of effecting change, has identified a number of fallacious propositions that clearly appear to be pertinent to the introduction of training devices to military personnel:

1. *A good product will succeed on its own merits.* (Don't you believe it.)
2. *The introduction of a new device is a final act. No further attention is required.* (In the absence of a formula for maintenance and feedback, many training innovations are gathering dust, and teachers and managers have reverted to former practices.)
3. *There is an orderly process from research to development to use.* (The fallacy of this proposition has been emphasized by numerous investigators.)

Quesada (15) has identified five criteria that appear to play significant roles in the acceptance of innovations. These have been paraphrased with reference to training devices.

1. *Relative Advantage.* The degree to which the training device is perceived as being superior to the one it succeeds.
2. *Compatibility.* The degree to which the device is perceived as consistent with operational requirements, equipment, and past experience.
3. *Complexity.* The degree to which the device is relatively difficult or easy to understand and use.
4. *Visibility.* The degree to which the results of using the device may be transmitted to others in a way that is easily seen or demonstrated.
5. *Divisibility.* The degree to which the device may be tried on a limited basis to gain firsthand personal experience.

It seems likely that all of these criteria apply, in one way or another, in determining the user's acceptance of Navy equipment and training devices.

Quesada also distinguishes between three types of decisions in the acceptance process. An "authority decision" results when those high in the power structure require utilization of a device. A "contingent decision" permits the individual to adopt or reject the device but only after an enabling decision is made by the organization. Finally, a "collective decision" occurs when individuals in a particular group participate in the verdict concerning a given innovation. Decisions of all these types may be made in connection with an individual's use of a training device. They need not be mutually exclusive. An authority decision may

be made that requires periodic use of the device, but this in no way prevents independent individual or group decisions concerning the value of using the device.

Clearly true acceptance must be a function of the "collective decision," for it is the decision at the user level that eventually determines whether the device is used effectively or not.

SOME SPECIFIC HYPOTHESES CONCERNING ACCEPTANCE

In their study of attitudinal factors influencing the acceptance of new equipment in the Navy, Mecherikoff and Mackie (op. cit.) attempted to summarize all of the influencing factors that appear to operate in the pattern of acceptance or rejection. They relate in part to the hardware, in part to the processes of introducing and promoting the device (advocacy). Not all of the factors were considered equally important or even applicable in every case. However, the list appears fairly exhaustive of the factors that should be considered in the course of introducing any new equipment. In the reproduction of this list, the statements have been paraphrased as they might apply specifically to training devices.

HARDWARE OR SYSTEM FACTORS

Conceptual

1. Agreement on definition of the need or requirement for a particular training device.
2. Various engineering approaches to device design.

Physical Factors

1. Equipment reliability and maintainability.
2. Problems of mismatch with the operating environment.
3. Problems of mismatch with the capabilities of user personnel.
4. Possibilities of mismatch with other elements of the training system.

Psychological Factors

1. Reaction to the appearance of the training device.
2. Perception of its "fit" into the training environment.
3. Reactions to delays in delivery (the device itself, components, spare parts, software).
4. Opinions formed on the basis of hearsay and rumor.
5. Opinions formed on the basis of limited experience with the device.

Support

1. Documentation of the purposes and functions of the device.
2. Documentation on how the device should be operated.
3. Documentation of technical specifications and maintenance data.

ADVOCACY FACTORS

Consideration of:

1. What different kinds of persons or groups will use the device and what are their relevant characteristics.
2. What communication channels were provided for user inputs during the design phases.
3. What means were provided to detect and resolve differences in approach or philosophy concerning the design of the device.
4. What users likely will want to know about the device.
   a. Overall purpose.
   b. Direct and indirect benefits to themselves.
   c. Benefits to the Navy.
   d. Data on reliability.
   e. Real or apparent drawbacks compared with earlier trainers.
   f. Real or apparent advantages compared with earlier trainers.
   g. Adjustments that must be made in the user's behavior patterns.
   h. How these adjustments will be achieved (formal retraining, assumption of personal responsibility, etc.).
   i. New responsibilities that are entailed.
   j. Present responsibilities that are to be reassigned to others.
   k. Who these other persons are and what preparation will be given for carrying them out.
   l. How those in the chain of command will be made aware that these responsibilities have been met.

5. Who is to be in charge of promoting usage of the trainer (trainer advocate).
6. What are the credentials and authority of the trainer advocate.
7. What threats might the new device present.
   a. Physical.
   b. Threat to current confidence with respect to operating skills.
   c. Threat to other aspects of the user's self-image, prestige, etc.
8. What does the trainer advocate expect of the potential users, and what do the users expect of him. Are the two sets of expectations explicit and agreed upon by both parties.
9. What provisions are there for direct experience with the new devices.
the users.
10. Have the introduction communications (both oral and written) been designed for maximum appropriateness considering the characteristics of the users.

A simple listing of factors, however, is not enough to describe the *process* of acceptance or rejection. Clearly, this process is dynamic and many of the factors operate in an interactive way. Figure 1 represents an attempt to model these interrelationships and to describe the way in which the process of acceptance (rejection) may develop over time.

A SPECIFIC STUDY OF TRAINING DEVICE ACCEPTANCE

In a study sponsored by the Human Factors Laboratory of NAVTRADEVCEN, an attempt was made to take into account as many of the factors shown in figure 1 as possible by considering them as hypothetically related to trainer acceptance or rejection.

The study was particularly concerned with five major sources of influence:
1. *The Training Situation.* Particularly the level and uniformity of skill development in the fleet; the opportunities for training certain functions in the operational environment; various characteristics of the equipment and environment that influence the opportunity to exercise particular skills; and the training time available in contrast to operating and administrative demands.
2. *Trainer Characteristics.* These were considered in two broad areas: (a) simulation factors; (b) training effectiveness and situational factors, including convenience, location, availability, and reliability.
3. *Understanding of the Trainer.* The user's comprehension of the trainer's capabilities, limitations, and purpose; knowledge of the trainer through both formal and informal communications and through direct personal use.

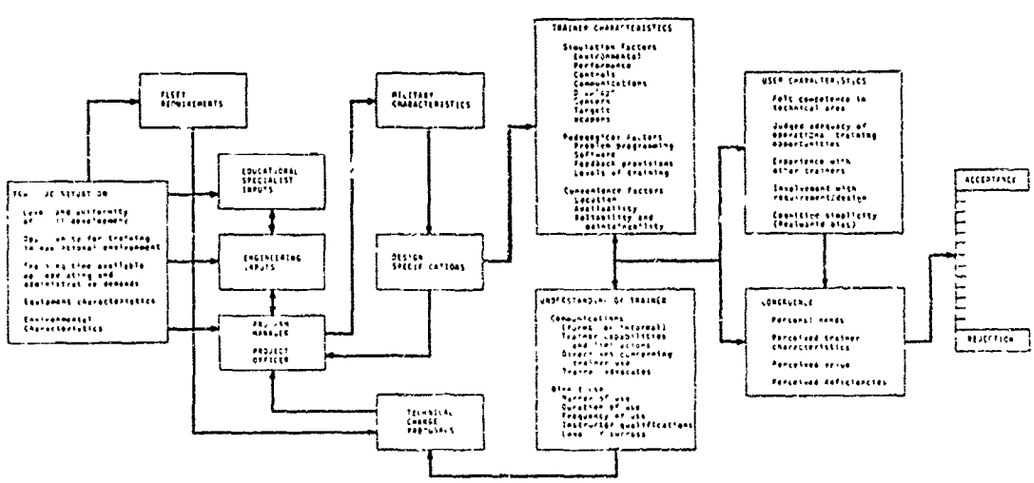


Figure 1. Factors Hypothesized to Influence Acceptance of Training Devices.

4. *User Characteristics.* The user's felt level of confidence in the technical area represented by the trainer; his experience with other similar trainers his personal involvement with the design or successful use of the trainer; his assessment of the training need, etc.

5. *Congruence.* This was defined as the degree of conformity between (1) physical characteristics of the trainer; (2) the user's understanding of its capabilities and limitations; and (3) how he perceived his own training needs and that of other Navy personnel.

Study Methodology

The investigation required the development of a means to obtain scaled judgments of all trainer and user characteristics hypothesized to exert major influences on the acceptance process. It was desired to develop definitive profiles of different trainers that, on the basis of various operational criteria, could be shown to be differentially "accepted" or "rejected," "effective" or "ineffective."

To accomplish these objectives, the following procedures were followed:

1. Specially designed quantitative rating scales were developed that could be used to rate training devices on 10 areas of simulation and 12 training effectiveness and situational factors.
2. A structured questionnaire was developed to provide detailed information that might amplify the ratings.
3. A group of training devices was identified whose members were thought to reflect significant differences in level of acceptance as well as various kinds of operational training.
4. Qualified groups of users were identified, contacted, and interviewed using the rating scales and structured questionnaires. To insure that various viewpoints were adequately represented, the user sample was carefully selected from administrative, instructor, student, and maintenance personnel associated with each trainer.
5. An operational definition of acceptance (rejection) had to be developed that reflected, in some logical way, all available objective and subjective data. In addition to opinion data, objective indices were included, such as percent utilization and the ratio of trainer time requested to time actually accommodated.
6. A technique was developed whereby some of the more subtle factors, such as felt level of competence, and the perceived importance of various characteristics of the trainer, could be conveniently identified and quantified.

The sample of 16 training devices selected for the study is listed in table 1. It will be evident that the trainers were very heterogeneous in nature, involving surface, subsurface, and airborne operations, and including devices intended for part-task training of individual operators up through some of the most complex coordinated tactics trainers ever developed.

A description of the 326 participants in the study is contained in table 2. They varied greatly in rank and in personal experience in the area of operations represented by the trainer. However, most had had considerable experience with the trainer they were called upon to rate. The participants were further considered as having low, medium, or high experience in the area of operations represented by the trainer, in accordance with the distribution of self-ratings of experience shown in table 2. Fifty-five percent of the respondents knew the trainer in the role of student; the remaining 45% was comprised of instructors, maintenance personnel, and administrators.

The Trainer Rating Factors

Each training device was rated on each of the following factors by each participant:

Simulation Factors

SM-1 Simulation of the Internal Operating Environment. This factor was concerned with the adequacy of simulation of such characteristics of the internal operating environment as the type and location of equipment, arrangement of displays and controls, illumination, noise, motion, temperature, vibration, and other internal features that might be considered critical for training.

SM-2 Simulation of the External Environment. This included consideration of such factors as the visual scene, auditory stimuli or noise from the external environment, and ambient temperature, pressure, atmospheric or water conditions that might affect equipment or personnel performance.

SM-3 Simulation of Vehicle Equipment Performance. This factor was concerned with how well the performance characteristics of the vehicle

TABLE I. SAMPLE OF TRAINING DEVICES

Designator		Type	Location (Of Unit Studied)
Weapons Systems Trainers			
	2F65	S-2E aircrew	North Island
	2F66A	S-2E aircrew (pilots only)	Quonset Point
	2F55B	F-4B aircrew	Miramar
	2F65	E-2B aircrew	North Island
	2F69A	P-3 aircrew	Barber's Point
	2F67B	P-3 aircrew	Moffett Field
	21A38	SS(N) S/M crew	Pearl Harbor
Flight Trainers			
	2F64B	SH-3D helicopter	Quonset Point
	2B21	T-28 instrument trainer	Pensacola
	2H87	Carrier approach landing	Pensacola
Tactical Team Trainers			
	14A2	ASW team trainer	San Diego
	14A6A	Coordinated ASW tactics	San Diego
Sensor Operator Trainers			
	14B35	JULIE/JEZ operations	Moffett Field
	14B40	Radar/MAD operations	Pax River
	15E16	Electronic countermeasures	Moffett Field
Emergency Procedures Trainer			
	21C5	Submarine casualty control	Pearl Harbor

TABLE 2. DESCRIPTION OF STUDY PARTICIPANTS

N = 326

A. Relationship to Trainer

	N	%
Trainee	181	55.5
Instructor	57	17.7
Maintenance	58	17.8
Administrative	30	9.2

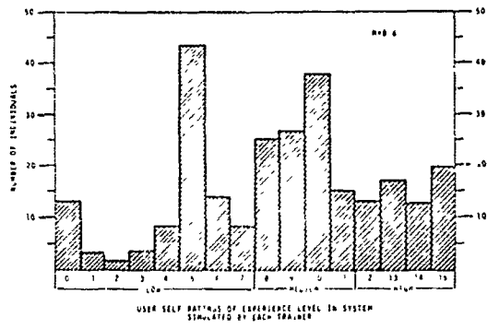
B. Rank or Rate

	N	%
LCDR or above	44	13.5
LT.	38	11.7
LT.(j.g.) or ENS	51	15.6
CPO or PO1	89	27.3
PO2	26	8.0
PO3 or below	59	18.1
Civilian	15	4.6
Not determined	4	1.2
	326	

C. Times Used Trainer (As Trainee)

	N	%
1 or 2	16	8
3 6	54	26
more than 6	138	66
	208	100

D. Personal Experience in this Area of Operations



or equipment were simulated. In the case of vehicles, consideration was to be given to maneuverability, response time, and range of operation, in the case of equipment, consideration centered on accuracy of operation, limits of operational effectiveness, typical operating difficulties, etc.

SM-4 Simulation of Controls. Control effects were to be considered from the standpoint of the "feel" of the simulated vehicle and the effects of control manipulations on how the system operated or how various information was developed and displayed.

SM-5 Simulation of Communication Procedures. This was concerned with the various communication links and procedures in the trainer with respect to communications both within and between operational units.

SM-6 Simulation of Communication Problems. Consideration was to be given to such problems as environmental noise that might interfere with communications, faulty equipment, and various other sources of interference with the communicated information.

SM-7 Simulation of Information Displays. This was concerned with the fidelity of the display information on scopes, plots, dials, and status boards that was critical to the operation. Both video and audio displays were to be considered.

SM-8 Simulation of Sensor Performance. Consideration was to be given to such factors as physical representation of objects or conditions in the environment as sensed through the equipment; the number and variety of objects simulated, how detectable the objects were as a function of environmental conditions, etc. If applicable, consideration was to be given to the different classes of targets that were simulated.

SM-9 Target Evasion For trainers that included target simulation, consideration was given to how realistically the target employed evasive tactics, aggressive tactics, and countermeasures.

SM-10 Simulation of Weapon Firing and Control. For trainers that involved the firing or control of weapons, consideration was to be given to the simulation of target tracking, localization, solution to the fire-control problem, choice of weapon, weapon launching procedures, and realism of the results of the attack in terms of typical weapon effectiveness.

Training Effectiveness and Situational Factors

Although the adequacy of simulation is of undoubted importance in the acceptance and use of training devices, it is clear that a variety and pedagogical and situational factors also influence user acceptance. Consequently, the participants were asked to rate each trainer on the following factors:

TSF-1 Problem Setup. Within the purpose for which the trainer was designed, how readily can a variety of operational problems be set up on the trainer? Consideration was to be given to representativeness and scope of problems in relation to operational requirements, and the relative ease or difficulty of setting up the problem for execution.

TSF-2 Software. Consideration was to be given to the thoroughness, effectiveness, and sophistication of the utilization guides and other training materials associated with the trainer. The question was asked, "How effectively could the trainer be used if *only* the information contained in these guides were used to program and operate it?" (Technical and maintenance manuals were not to be included in this factor.)

TSF-3 Completeness of Performance Evaluation. Consideration was to be given to the trainer's provisions for providing information to individual students concerning all important elements of their performance.

TSF-4 Immediacy of Performance Evaluation. The trainer's provisions for *immediate* feedback were to be considered in contrast to situations where there is feedback only after extensive delay.

TSF-5 Reliability and Maintainability. Consideration was to be given to the amount of down time and the level of effort required to keep the trainer operational. How readily can it be kept operational by the *average* training device technician?

TSF-6 Level of Training. Consideration was to be given to whether the trainer was suitable mainly for basic training and familiarization, or whether it could be used effectively for advanced or refresher training as well.

TSF-7 Training Opportunities. The respondent was to consider the skills developed by the trainer in relation to the opportunity for acquiring and maintaining those same skills in the operational environment.

TSF-8 Comprehensiveness of Training. The trainer was to be evaluated considering *all* of the skills that must be acquired for effective performance in a selected area of Navy operations. Are there any critical skills that receive insufficient emphasis?

TSF-9 Value of Time in the Trainer. In considering all the activities that occur in the trainer, the respondent was asked to judge what proportion of the time was spent in actually acquiring or improving essential skills.

TSF-10 Use of the Trainer vs. Operational Equipment. One of the recognized advantages of trainers is that they permit training on activities that are either impractical, too costly, or too dangerous to perform on actual equipment. However, the trainer may differ in some significant way from actual operational gear. The respondent was to consider how much advantage there is to using the trainer as configured vs. using actual operational equipment for training at shorebased schools.

TSF-11 Repeated Use of the Trainer. When a trainer is used on some regular basis, some of the skills may already be well trained. Consideration was to be given to how useful the trainer is for repeated use in maintaining or refreshing the essential skills.

TSF-12 Comparison with Similar Trainers. From an overall training viewpoint, the respondent was to compare the trainer in sophistication and effectiveness with other trainers that simulated similar Navy systems.

Results

The results of the study have been summarized in descriptive profiles of each trainer. Two types of profiles were prepared, one reflecting the 10 simulation factors, and the other the 12 situational and training effectiveness factors.

The profiles permit easy analysis of the judged capabilities and limitations of each trainer and how each trainer compared with all others in the study. In addition, they reflect how *important* the participants considered a particular feature to be

and whether the trainer measured up to their expectations on each factor. Space does not permit complete reporting of these profiles here.* However, examples are given of the differential profiles of a highly accepted trainer and one that is experiencing serious problems of rejection.

Two trainers have been selected for comparison that are directed toward somewhat similar training objectives in that each is designed to train operator in the P-3 ASW patrol aircraft. The 15E16 is a passive ECM operator trainer designed to train operators in equipment familiarization, "knobology," and the recognition and analysis of radar signals. It is designed for use by both enlisted and officer personnel having a wide range of background in ECM operations.

The 14B35 is a JULIE/JEZEBEL trainer. It was designed to train ASW tactical crew members, both enlisted and officer, in the detection, classification, and localization of targets sensed through sonobuoy systems. Unlike the 15E16, which is installed only at fixed shore stations, the 14B35 is portable, having the capability of being carried in the aircraft and injecting simulated signals into the operational displays. Or, it can be used in the hangar to provide training while the aircraft is on the ground.

Comparison of Acceptance Profiles for the 14B35 and 15E16 Trainers

Simulation Factors. Figure 2 shows the profiles of the two trainers on simulation factors as well as the average rating assigned to all trainers on each factor. The large differences between the two trainers are clearly evident. The 15E16 was rated distinctly superior to the 14B35 in all but two areas of simulation—communication procedures and communication problems. On those features, the 14B35 enjoyed a slight advantage.

It is clear that the 14B35 was considered below the average of *all* trainers in simulation of displayed information, sensor performance, and target reactions. In contrast, the 15E16 was rated superior to *all* trainers on six of the nine applicable simulation factors.

Although relative scores are informative, they do not provide a fully satisfactory answer with respect to whether or not a trainer is "acceptable" or "unacceptable" to the user. Clearly, a trainer may be seen to have some deficiencies and yet may be regarded as acceptable in a general sense. In an effort to more clearly identify the user's felt consequences of various simulation factors, each participant was also asked to rate the "importance" of each area of simulation. By subtracting the value of the rating assigned each trainer on each characteristic from the rating of the importance of that characteristic, a score was developed that has been called the "importance differential." Where these scores were negative, it was interpreted to mean that the user felt the characteristic was insufficiently well-simulated in relation to its importance.

"Importance differentials" were calculated for each simulation factor for the 14B35 and 15E16. It is clear (table 3) that the 14B35 received a large deficiency score, while that of the 15E16 was very small. Not only was the absolute sum of negative scores for the 14B35 very large, but it was given a deficiency rating in eight of the nine applicable simulation areas. It is again evident that the most severe deficiencies were felt to be in the areas of displayed information, sensor performance, and target reactions. Incidentally, personnel with extensive experience in sonobuoy systems systematically rated the 14B35 lower than did less experienced personnel. In contrast, there was no difference in the ratings assigned the 15E16 as a result of the amount of operational experience.

Training Effectiveness and Situational Factors

In figure 3, the ratings assigned to the 14B35 and the 15E16 are compared for training effectiveness and situational factors. The general superiority of the 15E16 again is evident. Both trainers were rated about the same on adequacy of software, and both were rated somewhat below average on immediacy of performance evaluation. The 15E16 was considered superior in all other respects, however, particularly on problem setup, reliability, level of training, comprehensiveness of training, value of time in the trainer, use of trainer vs. operational equipment, and in overall comparison with similar trainers.

The diagnostic quality of the ratings is to be noted. Although the 15E16 was a highly accepted trainer, the profile nevertheless reflected areas in which the users felt that improvement was possible or desirable. For example, negative importance differentials were obtained on simulation of equipment performance, communication procedures, and displayed information. With

*For detailed results, see Mackie, *et al.* [8].

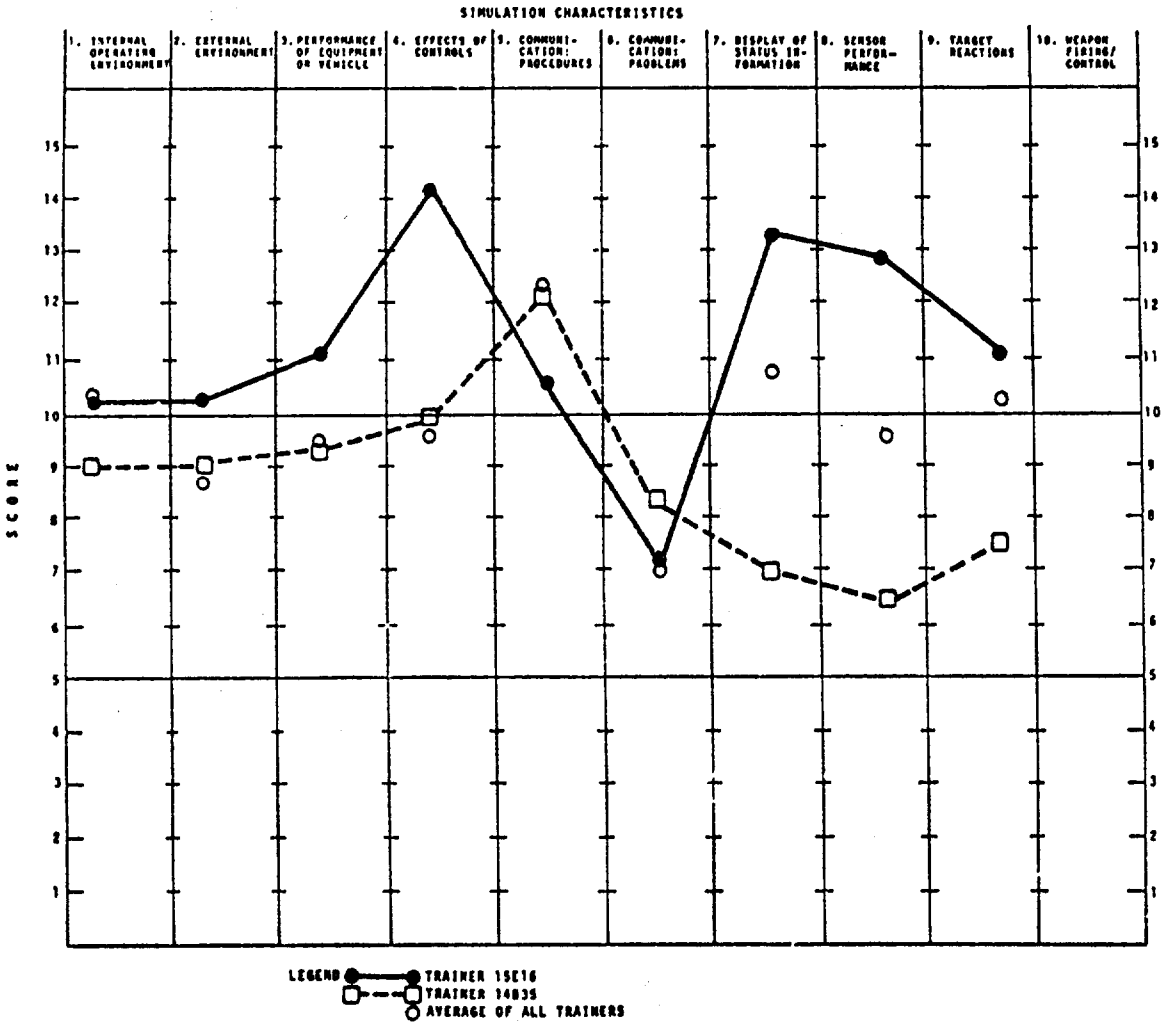


Figure 2. Comparison of Profiles of the 15E16 and 14B35 on Simulation Factors.

respect to training factors, the 15E16 was rated only average on completeness of performance evaluation, and somewhat below average on immediacy of performance evaluation. The 14B35, although suffering from considerable rejection, was nevertheless rated average or better on five of nine simulation factors and above average on software.

The acceptance profiling technique provides for a quick and comprehensive picture of user opinion concerning the merits and deficiencies associated with any complex training device. Although the profiles are intuitively convincing, the question might be raised as to how one can be sure the profiles are a true reflection of acceptance. Such a question is difficult to answer definitively. It was possible, however, to provide some additional evidence by correlating various scores from the profiles with a number of external criteria. These are shown in table 4.

Criteria such as percent utilization and ratio of requested-to-accommodated training are themselves very fallible measures of trainer acceptance for a variety of administrative reasons. The substantial size of many of the correlations shown in table 4 are, therefore, regarded as additional convincing evidence of the meaningfulness of the acceptance profiles.

It will be recalled that interview data were also collected and that particular attention was directed toward any low ratings that had been given. This procedure often provided insight into the reasons why various acceptance problems had developed. In many cases, design and procedural

TABLE 3. COMPARISON OF "IMPORTANCE DIFFERENTIALS" FOR 14B35 AND 15E16 TRAINERS

Simulation Factor	Differential (Rating Scale Units)	
	14B35	15E16
1. Internal operating environment	-3.0	+0.4
2. External environment	-2.7	+2.1
3 Equipment performance	-2.7	-2.0
4. Control effects	-1.3	0.0
5. Communication procedures	+0.1	-2.0
6. Communication problems	-2.0	+1.1
7. Displayed information	-5.9	-1.6
8. Sensor performance	-6.3	-1.1
9. Target reactions	-4.6	-0.7
10. Weapon firing	(not applicable)	
TOTAL	-28.4	-3.8

problems were identified that could either be corrected or at least anticipated when new trainers of these general types are developed. However, the problems of acceptance were by no means exclusively associated with the *design* of the training devices, frequently, they were associated with the *manner* in which the device was being used and the extent to which its *proper role* in the overall training system was appreciated by the users. Acceptance of training devices not only depends on basic engineering adequacy, effective software support, and on competent instructor and maintenance personnel, but on the promotional effort of some individual or administrative group that may be considered to be the *trainer advocate*. The role to be fulfilled is very similar to that of the "change advocate," who has been found to be so important in the process of promoting attitude change and acceptance of innovations. The role is primarily an educational one.

Military personnel are generally far too busy with operating demands and administrative chores to educate themselves concerning the capabilities, limitations, and various roles that can be played by training devices. Because of the Navy's practice of encouraging operational personnel to specify their own training requirements when they schedule use of a trainer, the full capabilities of the trainer, as well as its intended limitations, are not always recognized. The problem is compounded by the fact that operational personnel are assumed to be qualified instructors, which they frequently are not. Further, the trainer operators often are not experts in the subject matter area of the trainer. All of this can result in a less than optimum use

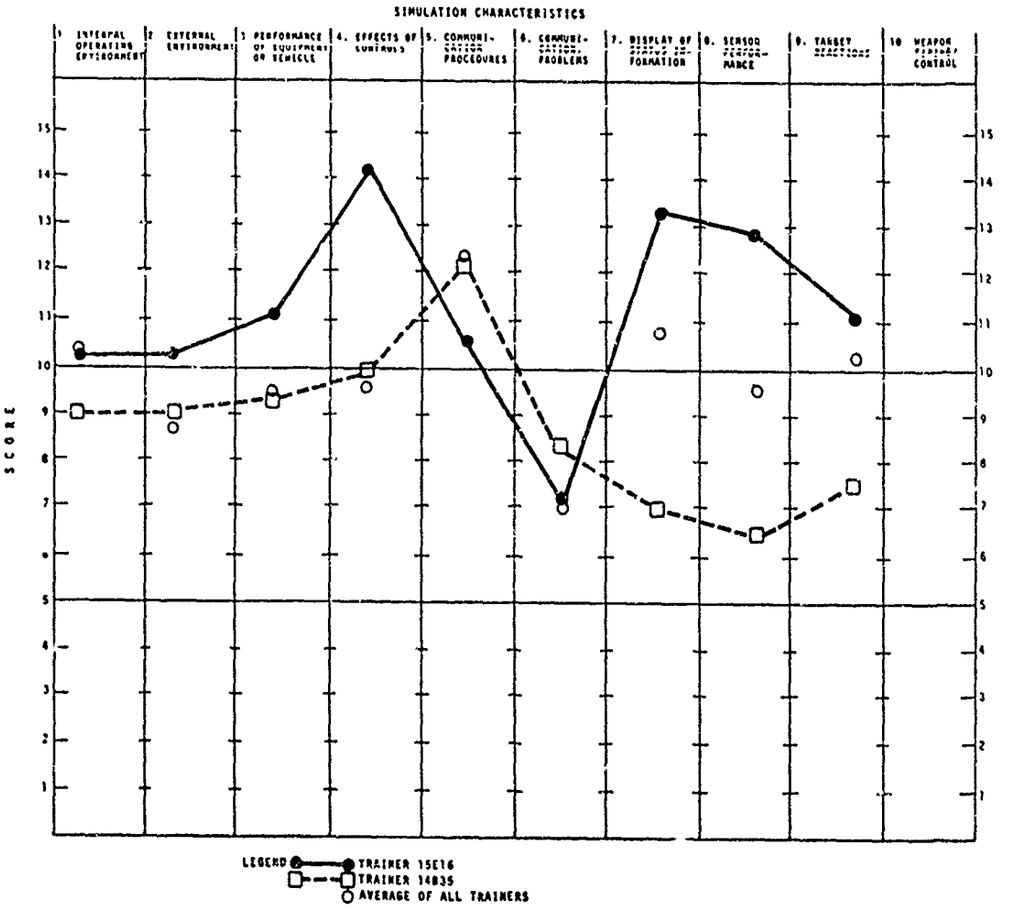


Figure 2. Comparison of Profiles of the 15E16 and 14B35 on Simulation Factors.

respect to training factors, the 15E16 was rated only average on completeness of performance evaluation, and somewhat below average on immediacy of performance evaluation. The 14B35, although suffering from considerable rejection, was nevertheless rated average or better on five of nine simulation factors and above average on software.

The acceptance profiling technique provides for a quick and comprehensive picture of user opinion concerning the merits and deficiencies associated with any complex training device. Although the profiles are intuitively convincing, the question might be raised as to how one can be sure the profiles are a true reflection of acceptance. Such a question is difficult to answer definitively. It was possible, however, to provide some additional evidence by correlating various scores from the profiles with a number of external criteria. These are shown in table 4.

Criteria such as percent utilization and ratio of requested-to-accommodated training are themselves very fallible measures of trainer acceptance for a variety of administrative reasons. The substantial size of many of the correlations shown in table 4 are, therefore, regarded as additional convincing evidence of the meaningfulness of the acceptance profiles.

It will be recalled that interview data were also collected and that particular attention was directed toward any low ratings that had been given. This procedure often provided insight into the reasons why various acceptance problems had developed. In many cases, design and procedural

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20. *Use of the Operational Flight Trainer.* NAVTRADEVCEN Tech. Rept 1734-00-1, 1966

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Emerging Developments in Flight Training Performance Measurement

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This paper reviews critical examples of past and present performance measurement for flight training. Emerging concepts, methods, and techniques in training performance measurement are presented in the areas of: automated and adaptive training, abilities and task measurement, development of multidimensional algorithms, training state measures, utility analysis, and measurement technology.

In all training the role of measurement is to provide information so that the training process can be controlled. Without measurement there is no guarantee that the appropriate behaviors are being trained.

CURRENT TRAINING

The Need To Measure

A Department of Defense review of tactical jet readiness training across all services (ref. 11) concluded:

> "The key issue underlying effective pilot training is the capability for scoring and assessing performance. In essence, the effectiveness of training is dependent upon how well performance is measured and interpreted. . .Reliable measurement of pilot performance against validated standards is the keystone for determining how much instruction and practice is required to attain desired levels of skill."

The DoD review substantiated and often referenced the earlier work of Smode and Meyer (ref. 37), who studied Air Force combat crew training and made the following observations:

> ". . .measuring and describing performance continues to be the most persistent problem area in pilot training. . .In every unit visited, training personnel were concerned over the fact that they could not effectively assess performance."

Smode and Meyer further observed that all of the training organizations desired proficiency-based training where the progression of the student is based on demonstrated skill rather than a fixed curriculum.

A very recent survey (ref. 32) has revealed that the situation remains severe. No substantial improvement in the acquisition of objective performance measurement has been realized at operational training sites; yet, requirements for more efficient training have continued to mount.

For example, two decades ago fighter aircraft were assigned a specific role; however, today's multiple-mission aircraft require a fighter pilot to be trained, and maintain proficiency in a wide spectrum of operations. Current training must accomplish a great deal in spite of reduced budgets. The F-14 is even more complex than previous weapon systems, posing more severe challenges (ref. 35).

Training managers and operational commanders now have an urgent need for objective performance data. The training managers need information to increase the quality of their product and increase the efficiency of training. Operational commanders need data to know their unit proficiency for continuation training, personnel assignment and upgrade, and for combat commitment. Given such information in the form of performance measurement, these managers should be able to exert more effective control of the training systems.

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Subjective Measurement

Most performance measurement in current training is provided through subjective judgments made by qualified instructors. While the reliability of such measurement has been questioned, such difficulties have been circumvented in specific cases. For example, in a development by HumRRO for Army helicopter training (ref. 14, 24), correlations between instructor and checkpilot grades were increased from r = .09 to r = .51. Even if reliability of measurement can be achieved, the training system designer may wish to incorporate machine-derived performance scores to relieve the instructor, and to provide data when the instructor is unable to make observations.

TRAINING TECHNOLOGY

Instructional System Development

A systems engineering approach is currently being applied to military flight training systems. The approach requires extensive analysis of the specific training to be accomplished, the behavioral objectives for each task to be trained, and the level of proficiency required. The goal is to assure that the proper level of training results, and to attempt only the necessary training in the most efficient manner. In particular, training of unnecessary tasks is expected to be eliminated through the application of systems engineering principles.

It should be noted that the systems approach to training provides specifications for performance measurement as a natural output. Measurement development should, therefore, be directed toward assessing the extent to which each behavioral objective is achieved. Measurement is then a direct consequence of such analytical approaches to training. However, the success of this method remains to be seen, as the feasibility of generating measurement depends on whether the manner in which training objectives are defined lead to usable metrics.

Automated Training

Modern training device technology paves the way for unprecedented manipulation of training course content, information presentation, and performance assessment. Developments of partially automated or adaptive devices are underway (ref. 7, 24, 29) with improved instructor-student and instructor-device interfaces, and improved performance measurement capability.

An automated, adaptive trainer is one that adjusts the problem or task being presented to the student as a function of his measured performance (ref. 17, 24). Its operation is not unlike that of a good instructor who observes performance and adjusts the presentation of material accordingly. The adaptive trainer must contain a performance measurement subsystem and an adaptive logic subsystem. The measurement subsystem determines the performance level of the student. Based on this information, the adaptive logic chooses the next problem, or adjusts the difficulty of the problem.

An adaptive trainer may be considered a control system in which specific objectives are reached through a feedback system based on particular observations or measurements. Each significant state of the control system must be included in the feedback control loops, but often it is difficult to obtain information about each system state variable. This problem is termed "incomplete observability" in control theory, and can be a major obstacle to the construction of effective control systems, since the available information may be insufficient to determine proper control actions. Analogously, an adaptive training system must be "completely observable"; i.e., permit measurement of each facet of performance affected by the training process, in order for the training control system to effectively reach specified training goals. In short, our ability to provide automatic training devices may well depend upon the measurement state-of-the-art.

It has been shown that there is a critical relationship between the measurement and adaptive logic in such systems (i.e., a monotonic relation) (ref. 42). It follows that the designer of the adaptive training system must know this relationship. As a hypothetical example, if the designer assumes that altitude error will become greater as turbulence is increased and designs a device on this assumption, he may find that the system does not work because altitude error may not increase monotonically with turbulence. It is possible to determine these relationships early in design and it is also necessary to do so.

TRAINING MEASUREMENT CONCEPTS

Introduction

Training performance measurement may be arbitrarily arranged into five classes: (1) measurement of human abilities which are necessary for the accomplishment of desired tasks; (2) measurement of operational tasks which are required for a given system mission; (3) measurement based on the multidimensional character of human and man-machine system performance, necessary for the development of metrics for the guidance of training decisions; (4) measurement of training progress and training effectiveness; (5) measurement of the utility of specific combinations of information and information-providing systems. This scheme of classification was found to be convenient for the purposes of organizing this paper.

The selection of appropriate measurement, of course, depends on the corresponding events to be measured. A discussion of measurement for use in training systems would therefore involve analysis of each possible measurement application—much too large a task to attempt here. Instead, the current emphasis will be on the nature of the mathematical tools to be considered in the implementation of measurement. The tools for putting human and system events in correspondence (i.e., "map") with quantitative scales will be noted, together with selected implications to training theory and training system design.

Abilities Measurement

Abilities and Task Performance. Today's training environments generally teach system-specific tasks, procedures, and maneuvers. Presumably, however, there are certain basic human abilities that underly human operator task proficiency (refs. 12, 12, 21). It has been reported (ref. 39), for example, that radar intercept officers reaching the fleet do not have sufficient proficiency in "spatial visualization," which is possibly a fundamental perceptual ability essential to successful task performance.

The psychological and human performance literature over the past half-century abounds with studies of and predictive tests of human abilities. In a review of the literature, some 72 basic abilities have been identified which fall into the following categories (ref. 12): (1) general body movement; (2) conceptual thinking, including verbal abilities; (3) psychomotor performance; (4) perceptual-cognitive processes; (5) memory; and (6) personality and group composition variables.

One point of view is that training should be oriented around human abilities rather than system-specific training. Depending upon which approach one takes to the design of a training system, very different measurement techniques may be required. However, it is possible that both types of measures may be useful. For example, if a radar intercept officer misses an intercept, what he did can be shown in exhaustive detail through task measurement (ref. 42). It is relatively easy for an instructor to look at performance data and point out where the student went awry But, there is currently no direct way to determine from system performance data if his problem was "spatial visualization," or any other ability dimension.

Little work has been done to transform information available in the behavioral domain (where tests can measure human abilities) into the task domain (where system performance information is available). Thorough research to define the relationships between task performance and underlying abilities is sparse. Rules for mapping between the two measurement domains have not been found. Once they have been defined, lawful relationships should permit identification of deficiencies in basic abilities based on system performance measures.

Current Research. Work relative to, and motivated by, a human abilities point of view is underway in many current programs.

1. Fleishman (ref. 13) and his associates have studied the structure of human abilities in task performance for several years. Two general points have been established. First, the measurement of abilities can account for much (60-80 percent) of the performance that is achieved. Second, the composition of abilities shift as a function of training. For example, in one study, performance variability due to spatial relations decreased with training, but variability associated with response time increased. Their methods and measures tend to reveal changes in performance strategies as the operator learns to become more proficient.

Locke, Zavala, and Fleishman (ref. 21) have related pilot helicopter performance to task and

maneuvering factors. They found that performance scores tended to form task factors rather than maneuver factors. Measurement of a given task in the context of one maneuver was correlated strongly to performance of that same task in another maneuver. It was suggested also that basic human abilities (such as spatial abilities) could be mapped into task factors (such as line and angle of descent). This type of finding has strong implications for the identification of training units, the construction of training plans, and measurement of training performance.

2. Senders, Kristofferson, Levinson, Detrich and Ward (ref. 36) have developed a model and a method for studying the perceptual-cognitive and memory dimensions involved in automobile driving. Their prime interest is in the "attentional demand" or "perceptual workload" aspects of complex vehicle control. It can be hypothesized that: (1) human controllers vary in their ability to extract from the visual environment the information they need to control vehicles; and (2) measurement of this ability can discriminate between individuals when system performance measures show no difference. Measures of the amount of time to look and frequency of looking were shown to be the major parameters for a human information processing model. And these measures were shown to discriminate between individual abilities when system performance criteria (e.g., lane following) did not show performance differences. Senders is continuing this basic abilities research at NAVTRADEVCEN, using a more complex psychomotor task (the captive helicopter) as a test bed.

3. Matheny and Norman (ref. 23) have hypothesized a measure, the effective time constant, which they feel reflects perceptual abilities that are essential to man-vehicle control training. The effective time constant is the speed (time) with which the operator can detect a vehicle change after a control input. The effective time constant is a psychological parameter characterizing the human operator and presumably directly relatable to his abilities. This approach implies that measurement should key on this type of parameter rather than system performance measurement. Such a measure for training would be indicative of the students' stage of proficiency and diagnostic with respect to training performance deficiency.

Task Measurement

Time Domain. In the flight environment most system states change in value over time. Measures of those system states change in amplitude over time. The fundamental measure from which all other measures are constructed is the time history. The familiar pen recorders which trace signal amplitudes over time offer a graphic example of a time history. Time history measures show what happened in time and are quite useful in systems that are repeatable. With human operator performance, however, it is necessary to summarize the characteristics of the time history so that information can be statistically manipulated. The following measures simply reflect different ways of summarizing the time history.

Amplitude Domain. The time history can be summarized using the average value (the mean), the variability (standard deviation), or the range (peak deviations) of the parameter over a specific time interval. It is frequently most informative to describe summary data in terms of error from the desired value. Therefore, measures of average error, average absolute error, root-mean-squared error, and error standard deviation can be constructed (ref. 31). In tracking studies, the root-mean-square (RMS) score is most frequently used. These measures are frequently referred to as integrated error scores.

The interpretation of measures depends on the specific raw data used for calculation. Using an inflight approach and landing program as an example, average profile performance can be described as integrated error scores or variability at successive points in the profile (ref. 40). The integrated error scores provide information on accrued error over the entire profile, while the profile measures reflect error at different points in the profile. Frequently, terminal performance provides sufficient information about the task which would reduce the requirement to measure the entire profile. One study (ref. 41) found that touchdown performance measures led to the same conclusions as the more elaborate integrated error and profile error scores during the approach.

Another common method used to reduce and summarize time history data has been to construct tolerance bands and to measure time within tolerance, number and time of out-of-tolerance conditions, and similar treatments of measures based on successive tolerance bands. These data

treatments are directly applicable to system performance where operational error criteria (such as instrument flight) can be specified.

Frequency Domain. Vehicular parameters are usually dynamic in nature; they change in value over time. The result is that time histories frequently plot as "wiggly lines." Such oscillatory characteristics are measurable and offer another avenue of information.

At perhaps the simplest level of description, the number of times that a parameter reverses its direction (reversals) or crosses a fixed amplitude (usually zero crossings) can provide valuable information. Recently, the steering wheel reversal patterns of truck drivers have been related to operator alertness (ref. 33).

Most oscillations of time histories, although they appear quite irregular, can be described as the simple summation of known regular oscillations. Fourier analysis techniques provide a method of describing irregular, continuous wiggly lines as a weighted sum of sine waves of known frequency.

Use of these techniques form the power spectral density function (ref. 4), which shows the relative power (or contribution) of each frequency in the spectrum from the lowest tested frequency to the highest. With human response data, the frequency spectrum is often limited to the range of zero to about 6 radians per second because most human control activities lie in this bandwidth.

As a practical example, frequency content information can be used to determine how often one needs to sample a parameter to fully capture all significant changes. Studies of this nature conducted on flight data recordings have provided a sound basis for reducing the sampling rate (how often one measures).

Practical use of power spectral density function measurement in training systems is somewhat limited because these measures are difficult to obtain in real-time and their derivation requires computational rigor, time and memory. A recent implementation by Norman (ref. 30) in studies at NAVTRADEVCEN offers a partial solution to the computational problem. Norman implemented a set of second order, low-pass filters and, in real-time, was able to proportion the average amount of stick deflection energy attributable to inputs below 2 radians per second and inputs below 6 radians per second. Arithmetic operations showed the relative proportion high- and low-frequency inputs, and the shifts that occurred during training and transfer tasks. His method circumvents the processing requirements and the rigor required of the classical techniques.

Transfer Functions. Transfer function measurements of human pilots using engineering servo control methods have been used successfully for the design of real systems (ref. 26, 28, 31). In situations where the pilot input is known (such as from a command steering display), measures which relate the input to the pilot and his subsequent output in the frequency domain can describe his dynamic control characteristics quite well.

The principal measures of pilot dynamic response are the effective time delay, and the gain and phase differences. Gain and phase measures are taken, usually, at specific points across the power spectrum. Gain is the ratio of the output to the input (the amount of control deflection vs. the amount of display error). Phase is the time or angle difference between the output and the input.

As an illustrative example, as the frequency of the input disturbance increases, the input errors increase, but the pilot is able to respond with countering control inputs of proportionately equal magnitude; his gain remains relatively constant (up to a point). As the frequency content of the input disturbance increases more, the pilot will typically fail to "keep-up" with the input: the time between input and output will increase, therefore becoming more and more "out of phase," and his gain may reduce. Finally, there is a point where the pilot lags the input so badly that he is 180° out of phase with what he should be doing. Unless his gain is reduced to insignificant levels, his control actions will destabilize rather than stabilize the system. Such pilot-induced oscillations (PIO) are a fact of life in high performance aircraft in critical flight regions.

Although earlier studies have shown no differences in single dimension tracking performance during training (ref. 19), very recent work (ref. 15) shows significant differences in gain and phase measures of pilots at three stages of training.

Transient response measurement on the TRADEC simulator at NAVTRADEVCEN has been useful in determining pilot-vehicle responses to radar intercept officer (RIO) verbal commands during air-to-air intercept training (ref. 42). Measures of response time, rise time, overshoot amplitude and damping revealed that for moderate bank commands the pilot-vehicle acted as a second-order control system; a transport delay,

gain and damping term would describe performance. The measures changed as a function of the magnitude of bank, the level of adaptive variable being administered, and as a consequence of training.

Multidimensional Algorithms

No single parameter can describe adequately the multidimensional aspects of flight performance. For example, a current study of combat crew training performance measurement (ref. 32) has identified over 100 measurement parameters. Candidate measurement sets have been defined for the following phases of training: transition, instruments, formation, air-to-air intercept, basic flight and air combat maneuvering, air refueling, ground attack, airdrop, and radar navigator/bombing. Measurement sets which are sensitive to the multidimensionality of operator skill have been constructed.

It is not sufficient to just measure independent dimensions. Practical measurement requires the combination in some form and relative weighting of the entire measurement set. In particular, all future automated training will require the development of multidimensional measurement algorithms.

Examination of the current literature shows an embarrassing richness of methods for developing multidimensional algorithms. Over the past decade, there has been a strong theoretical and empirical interest in developing multidimensional models of human performance from which multidimensional performance algorithms are specifically derived. In the area of manual control theory, for example, there are available multidimensional approaches from the describing function (ref. 26), sampled-data (ref. 2), multiple loop (ref. 25), and hierarchical (ref. 3) points of view. In the following paragraphs, eight different methods are illustrated from the current literature which have been developed within varying contexts of training performance measurement.

Factor Analysis. The previously described work of Fleishman (ref. 13), Locke, Zavala and Fleishman (ref. 21), and Booth and Berkshire (ref. 5), represents the current state-of-the-art of flight performance measurement using factor analytic techniques. Mention has already been made of the possible implications for training measurement that can result from these studies.

Multiple Discriminate Analysis. More recently, Hill and Goebel (ref. 15) performed a multiple discrimination analysis of a set of 266 summary measures which were taken throughout a flight profile. Using a GAT-1 trainer and 30 subjects, they found a set of 27 measures which uniquely separated pilots into three different skill groups: beginning, intermediate, and advanced. The measures consisted of means, standard deviations and correlations of flight parameters in addition to pilot gains and phase shifts. A single criterion variable, the linear weighted sum of these measures, was suggested as an overall measure of proficiency. It was noted that measures which were most sensitive to individual differences were standard deviations and means. The next most sensitive measures were gains and phase shifts. Intercorrelations between parameters were the least sensitive.

Linear, Weighted Algorithm. As a part of the development of an adaptive, automated GCA trainer at NAVTRADEVCEN, Charles and Johnson (ref. 8) developed a multidimensional measurement algorithm for the ground controlled approach (GCA) task. The algorithm measured wheel, flaps and speedbrake positions, sampled heading and heading rate, angle-of-attack and angle-of-attack rate, lateral and vertical displacement from the approach path/course, and the turbulence adaptive variable difficulty factor. Data were sampled down the approach profile and at a terminal "gate" position (100-ft. altitude and 1/4 mile). The algorithm formed an approach score based on a linearly weighted sum of the performance measures. The score successfully controlled automatic progression through 38 incrementally more difficult steps of the adaptive variables in the training course.

Non-Linear (Threshold) Model In studies of pilot-system bank control performance during variations of three adaptive variables, Vreuls and Obermayer (ref. 42) found that monotonic relationships did not exist between the adaptive variables, the variations in bank command and the measurement set. A linear, weighted summation of measurements did not appear practical over the entire range of the tasks and adaptive variables, especially when the pilot was operating close to the aircraft performance limits. The most straightforward solution to the problem was to place tolerance bands on each measure of the set, and use binary out-of-tolerance data as information for the adaptive logic. The tolerance

bands were selected on the basis of measured relationships between adaptive variables and the measurement set. The resulting out-of-tolerance data appeared to have the required monotonic properties, but the method requires further verification.

Energy Maneuverability. The science of air combat maneuvering has evolved recently due to the development of energy maneuverability concepts. The energy maneuverability model (ref. 38) in its simplest form provides a numeric statement of aircraft energy potential under given conditions of thrust, fuel state, weight, altitude and airspeed. Energy dissipation caused by maneuvering is multidimensional, but predictable. Thus, families of energy maneuvering envelopes have been defined. Partial verification of model validity is derived from the fact that analytically derived "optimum" maneuvers closely resemble maneuvers that are employed by highly experienced fighter pilots. Energy level performance is a strong candidate for air combat maneuvering measurement sets.

Time Demand. Faced with the problem of specifying objective measures of training aircraft effectiveness, Kusewitt (ref. 20) found it necessary to develop a singular measure of training difficulty. The measure had to be sensitive to changes in aircraft cockpit configuration, instrumentation and avionics, and handling qualities in various speed envelopes. At the subtask level, human time and deviation terms were identified for each of the procedural tasks. Engineering control analyses determined the amount of attention to control (in time) would be required for various aircraft configurations and maneuvers. Analytically derived times required to control were brought together with times required to perform procedural tasks. The resulting model of training difficulty was given the name, "time demand." It assumed that training difficulty would increase as the time to perform activities approached (or exceeded) the time available to do them. The time to perform was the unifying dimension of the model.

Recursion Models. Connelly, Schuler, and Knoop (ref. 10) have derived a set of models which adaptively organize measured pilot performance in a simulator based on instructor grades. The model teaches itself the rules for collecting and weighting performance data sets so that its grade matches the instructor grade. Grade inputs from several instructors are used. Once the system has been tested with a number of students and instructors, the model parameters should reveal analogies of the performance assessment strategies used by instructors. If the model does converge on repeatable characteristics, those parameters can be fixed, and an "automatic" performance assessment system will result. The concept awaits critical testing.

Empirical Curve Fit. The system performance measurement for co-speed, co-altitude, stern conversion air-to-air intercept has been suggested as an elementary model of the radar observer-system (ref. 42). The spatial-dynamics relationships of the interceptor and the target aircraft can be fitted to a family of hyperbolic curves based on target aspect angle and range. Mathematical description of RIO-System efforts to approximate or parallel the central member of the family (ideal intercept) of curves, plus or minus a reasonable tolerance, appears tractable. This model requires further development and testing.

Training State

Adaptive Variable. Historic measures of the state of training of any particular student have been his position in the syllabus and the level of performance exhibited. In an adaptive trainer, the adaptive variable may change to affect the task so that the student continuously performs at a fixed level of performance. No differences in performance measures can be detected during training. The remaining parameter which does change as the student progresses is the adaptive variable.

Incremental Transfer Effectiveness Ratio. The appropriate metric for the control of training effectiveness has been the amount of transfer of training (1) from one unit of instruction to the next; (2) from training in devices to vehicle training; or (3) from training environments to the operational environment. Classically, the time to train to criterion performance level has been used as the measure.

A new metric, called the incremental transfer effectiveness ratio, has been proposed by Roscoe (ref. 1). The technique assumes that performance generally reaches an asymptote; equal time increments tend to produce smaller improvements in performance on any given training unit. Further, it assumes that some transfer exists from one unit to the next; for example, level flight control will continue to improve even though the

student is practicing turns. Therefore, there is a point at which it is more effective to transfer to the next unit, rather than to continue training on the existing unit. The incremental transfer effectiveness ratio provides a basis for selecting the optimal time to train each unit.

Utility Analysis

Because of the complexity of human performance and the ever-increasing technology available for performance measurement, it is possible in every application to generate enormous quantities of raw data. Measurement logic and practical reality, however, dictate that everything that moves should not necessarily be measured. Logic and empirical findings have continually shown that because parameters may be measured it does not follow that the measures are automatically meaningful and/or useful. Further, measurement sets invariably must be reduced to manageable proportions for at least two very practical reasons: (1) Constraints on storage and processing media; and (2) human limitations in the amount of information that any instructor, training manager, or analyst can assimilate.

A singularly important consideration is the cost of generating information through performance measurement. Analytic methods of rationally reducing measurement to those sets which provide adequate and sufficient training information relative to the cost of obtaining that information must be developed. For example, Cronbach, and Gleser (ref. 9) have developed a utility model that requires evaluation of expected payoff of information vs. the cost of that information. Their model shows clearly that it is possible to collect too much information, and, better, just what and how much information actually is useful. The development of such utility models in training performance measurement should be explored.

MEASUREMENT TECHNOLOGY

Requirements

It is too early to know what the total flight training measurement requirements will be. Based on work thus far (ref. 32), it can be estimated that 100-200 parameters should be capable of describing most flight-training situations. At any given phase of training, however, the measure set reduces considerably. Generally, the parameters fall into groups that can be sensed electrically, optically, and from auditory data.

In simulation environments, the organization of the software will be the key to successful implementation. Performance monitor subsystems simular to those developed by Knoop (ref. 18) will be required. The same software could be applied to airborne data recordings.

The most important data processing requirements are display format and speed. Data must be formated in such a way that instructors can use them easily and naturally; data must be available during or at the conclusion of a logical lesson. Any delay seriously degrades the training utility of the data. For example, a 5-minute delay might be tolerable, a 30-minute delay would be irksome, and a 12-hour delay might totally destroy the utility of the information for training

Data will require labeling, formating, storage and access for many purposes of instruction, and for training quality control. Software, hardware, and personnel systems for efficient and timely data processing need specification and development.

Finally, the algorithms (especially those used for human performance measures) must be constructed in such a way that they can be changed through iterative test. Current analytic methods fail to predict all of the idiosyncratic behavior of humans; consequently, they must be developed through an iterative procedure of development, test, and revision. Tests of algorithms throughout the full range of tasks are required to insure validity.

Components

Input/output devices found in any modern digital computer center, such as CRT displays, plotters, line printers, card readers, tape transports, disc packs, and typewriter terminals are sufficient to meet measurement requirements for the simulation environment, and processing portions of the flight environment data. Good measurement is constrained more by software organization, storage and memory requirements than by input-output devices.

Measurement systems, however, should not be "added-on" after the design is completed. For adaptive trainers it is mandatory that the measurement systems form part of the design.

Measurement in the flight environment is more challenging, but technologically possible. Digital magnetic tape recorders are an excellent storage medium, and will be common even on commercial aircraft using Mark II area navigation systems. Recently, for example, the Air Force Human Resources Laboratory has instrumented a T-37 aircraft for flight recording of up to 34 parameters. The calibration and data processing procedures are well developed.

Camera records have been difficult to use for training because of everyday problems of film identification, processing delays, and quality control. Gun and scope cameras have been in use since World War II. A recent application of camera time-lapse recording has been successfully reported in helicopters (ref. 16). Improvement in picture quality control and elimination of processing delays have been reported by the Air Force Human Resources Laboratory, Flying Training Division, through the use of a video camera and recorder installation on an A-7D aircraft.

A need for voice track data has been indicated by measurement requirement analyses. Audio recording devices must provide a means for synchronization with other data.

ACMR

The Navy Air Combat Maneuvering Range (ACMR) (ref. 27) will be located outside Yuma, Arizona, with a real-time data link to Naval Air Station, Miramar. The ACMR will be able to determine the positions of up to 16 aircraft, simultaneously, with an initially requested accuracy of 25 ft. and altitude to within 10 ft. for four aircraft. Detachable-pod aircraft instrumentation subsystems will sense aircraft and fire-control system parameters, and data-link information to ground-tracking sites. The sites will transmit data to a control and computing subsystem. On-line (real-time) display of the fight as well as off-line processing capabilities will be provided.

The fascinating fact about the ACMR is that it is designed as a measurement system; yet it is destined to become one of the more viable training systems. Thus, measurement components, when put together in a system, have become a new training device concept.

DEVELOPMENT CHALLENGES

Airborne Equipment

In the airborne environment, the cost of instrumentation, the accurate determination of aircraft position, and real-time control of data acquisition are major considerations. Instrumentation costs can be high and might be a limiting factor; although storage media are relatively inexpensive, the cost of retrofit, installation of sensors, wiring the aircraft, and proper formating of data are far more costly. The accuracy of aircraft position needed depends on the specific aircraft mission and the position accuracy required for training objectives. On-board navigation systems may not be adequate, requiring use of ground-based ranging systems. Control of data acquisition during a flight may require use of complex systems to avoid imposing these tasks on the crew and thereby interfering with their training tasks.

Simulator Equipment

Newer digital simulators may have measurement subsystems that can be adapted to additional new requirements, or they may have spare memory and cycle time within which some measurement capability can reside. Retrofit tends to be a problem. When a system is patched to do something that it was not designed to do, undesirable constraints can result. It is difficult to generalize because much depends on the software organization, the amount of processing time needed, and the amount of input-output required. In any case, modifying a simulator to obtain basic data is less challenging than determining the proper measurement algorithms to enhance control of the training process.

Data Processing

The primary problems in the data processing environment are data synchronization and logistics. Information from many sources will have to be synchronized, labeled, and formated. Different data forms (i.e., auditory and electrical) will require collective processing. The logistical aspects of the problem will require careful system analysis, design, and development. Again, the basic criterion is the ability of the measurement system

to provide useful information to the training community.

Training Utility

A system for performance measurement must provide timely information in a form useful to training personnel. Acceptance of performance information by training personnel will be a function of how well it answers their needs, and how well the information is displayed. Ultimately, use of the system may be a function of these factors. If the system does not provide the proper information, in a timely manner, in an understandable form, and in a form permitting convenient operation by training personnel, then the measurement provided will have little utility.

SUMMARY

Developments in current training, training technology, training measurement concepts, and measurement technology have an impact on the future development of training performance measurement.

Current Training

A review of current training reveals that there is an urgent need for better measurement to control training; a lot of subjective measurement is taking place, but the current need is for improved objective performance measurement.

Training Technology

Two developments in training technology are important to performance measurement. First, detailed descriptions of the process and an end goal of training are being sought by instructional system development teams. Measurement directly follows from the specification of behavioral objectives. Second, the emergence of adaptive training demands precise measurement, without better measurement, adaptive training is not possible.

Training Measurement Concepts

Training performance measurement methods are evolving from research in five areas.

Abilities Measurement. Measurement of the abilities that underly task performance is felt by some investigators to be the key to training. However, the future utility of this concept will require more precise definition of the relationships between abilities and tasks.

Task Measurement. Most training is task oriented, and most measurement capability in the past has been available at the subsystem level where tasks can be measured. Measurement concepts in the task domain have been more fully developed than abilities measurement. Numerous examples of past approaches can guide the measurement analyst.

Multidimensional Algorithms. Multidimensional methods are required to adequately describe the many facets of human performance for training control. The number of tools that are available offers evidence of creative efforts in this area.

Training State Measures. Measurement of the state of training is evolving. Adaptive training devices permit the use of the adaptive variable as a measure of training state. Training effectiveness measures, the transfer-of-training, may be expressed in terms of changes in performance, rather than the classic time to train.

Utility Analyses. Utility analyses will be necessary and vital for the determination of practical performance measurement since complete measurement is generally undesirable. System cost tradeoffs should be based on the expected payoff of training information relative to the cost of obtaining that information.

Measurement Technology

Measurement technology was briefly reviewed. The hardware necessary to acquire performance data is available. Extensive software technology is required for practical processing of performance data. Although, the implementation of measurement systems may present significant user-interface design issues, these are best resolved through thorough systems development programs.

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The Evaluation of Training Systems

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How can we know when a training device is doing the job it was designed to do? We have to measure the extent of transfer from training on the device to performance in an operational situation in the Fleet.

This article traces the history of the Naval Training Device Center's concern with the evaluation of its products from the first evaluation of a training device in the late 1940's to its current program of training effectiveness evaluation.

Emphasis is on the development of a methodology for conducting field evaluations of the effectiveness of training devices from the standpoint of transfer of training.

HOW ARE WE DOING?

The Naval Training Device Center (NAVTRADEVCEN) has always wanted to know how good a job its training devices are doing. This is as it should be. There is no sense in carrying out training without being able to account for its effectiveness. Actually, there is no justification for not determining the effectiveness of a training system.

In any training situation, it is reasonable (and prudent) to ask to what extent the training system has resulted in improvement in skill in the operational situation, whether it is at-sea or in an aircraft flight. In this regard, the NAVTRADEVCEN position is comparable to that of the trainee. That is, in order to make progress, the trainee must receive feedback (evaluative information) on how well he has succeeded in what he is trying to do. For example, in learning to use a rifle, there is little value in firing at a target if the trainee cannot tell where the rounds hit. His skill will not improve much unless he receives feedback on where the rounds went; the NAVTRADEVCEN has a similar necessity for evaluative feedback.

There is relatively little value in using a training system without attempting to evaluate its effectiveness. With this evaluative information, it is possible to decide how to make appropriate modifications in training device design, patterns of utilization and associated syllabus. Furthermore, such effectiveness evaluation provides a closed-loop training system.

WHAT IS EVALUATION?

The title of this article, "The Evaluation of Training Systems," can have a number of meanings, such as the determination of whether a device meets specifications, is reliable in operation, easy to maintain, or is acceptable to instructors and trainees. All of the different concepts of evaluation, some of which can be determined by simple observation, are important. Obviously, though, such data alone tell little about the effectiveness of the device in accomplishing the desired training. The word "evaluation" will be used in this article to refer to the determination of training effectiveness.

WHAT IS TRAINING EFFECTIVENESS?

The training effectiveness of a trainer is usually expressed as a measure of transfer of training. Transfer of training refers to the degree to which practice in a trainer carries over to (or affects) performance in an operational situation, as compared to trainees who received no practice in the trainer. In other words, training effectiveness is the difference between a performance measurement on an operational task after practice on the device, and performance on the operational task without practice on the training device. (Trainees who receive practice in a training device are usually referred to as the experimental group; trainees who receive no practice in the trainer are referred to as the control group.)

Most measures of training effectiveness are measures of transfer of training. Many different formulas exist for expressing the amount of transfer. Some of these formulas appear in one of the first articles describing such formulas, namely, the NAVTRADEVCEN technical report by Gagne, Foster, and Crowley (1947).

EVALUATION OF TRAINING EFFECTIVENESS

Although there is value in various forms and levels of evaluation (this will be demonstrated later in examples for which transfer data were not obtainable for various administrative reasons), transfer of training is the ultimate and crucial test of training effectiveness. Unless time and effort spent in the trainer have a positive influence on performance in the operational situation, training was not beneficial. It is even possible that negative transfer will make a trainee less effective in the operational situation than if he had not experienced the training (for example, if the trainee learned to attend to cues in the training situation that either are not available or are the wrong ones to attend to in the operational situation). Generally, however, the skills acquired in the training situation are transferred, in some positive degree, to the operational situation.

Training devices do not have a single training effectiveness value, so for research purposes questions (hypotheses) should be stated analytically. For example: what are the effects of certain amounts or methods of training on transfer to an operational task? Or, for which tasks or stages of training will the trainer produce positive transfer of training? These types of questions will result not only in a statement that the trainer is or is not effective, but also in recommendations for optimal use of the device for effective training and appropriate syllabus revisions.

HISTORICAL SURVEY OF NAVTRADEVCEN EVALUATIONS

From the start, the NAVTRADEVCEN has been interested in knowing how well its training devices were doing. To demonstrate this interest, the history of its evaluations will be traced. Included will be only those studies which experimentally sought to determine the training effectiveness of a device by comparing the effect of using and not using the device. Excluded will be evaluations consisting of surveys of how trainers are used, evaluations of trainer design from the standpoint of human engineering principles, investigations of the percentage of time a device is utilized, or comparisons of the effectiveness of training aids such as transparencies or paper-and-pencil trainer-testers.

In the first year of the NAVTRADEVCEN's existence, evaluations were conducted on four aerial gunnery training devices, namely, Devices 3A2, 3A35, 3A40, and 3E7. Experiments were conducted on tracking training to determine the effectiveness of various training procedures and to obtain answers to such questions as: (1) What is the limit of skill attainable?; (2) What amount of practice is required to reach this limit?; (3) What is the nature and shape of the learning curve?; and (4) What is the optimal length and spacing of practice sessions to use in training personnel on each of the devices?

Some of the findings for the Mark 18 Sight Coordination Trainer, Device 3A40, were: (1) ranging, tracking and hit scores improved rapidly through five trials and more slowly to the 20th trial; (2) training on a variety of target cycles produced more gradual and long-continued improvement than training on one target cycle; and (3) training transferred in a high degree to new target courses (Crook, 1946a, 1946b, 1946c).

Studies on aerial gunnery Devices 3A2 and 3A35 found the following: (1) five different training methods showed no differences, mainly because of the large variability of scores from gunner to gunner; (2) trainees improved significantly with practice; (3) the ceiling on performance is reached early in training, but the data suggest that further training might result in higher final levels of performance, especially using the on-target lights which function as feedback (Knauft, 1946a; Knauft, 1946b, Knauft and Buxton, 1946).

In 1947, two more studies were conducted on the 3A2 and 3A35. The experimenters found that: (1) the learning curves took the form of fairly well defined S-shaped curves; (2) approximately 25 to 30 practice sessions were required to attain maximum level of performance; (3) there was a low consistency in day-to-day performance which was explained both by variation in the sensitivity of the scoring equipment and variation in individual performance; and (4) with new and different target speeds and direction, the trainees'

performance transferred to some extent. There was a tendency for the trainees to memorize the individual attacks and make use of this memory in anticipating the course of the target. Nevertheless, there was evidence that there was some learning of the general principles of position firing (Knauft, Hamilton, and Spence, 1947).

On the Ranging, Tracking, Aiming-point Assessor, Device 3E7, it was found that most of the meter scores relating to gun-pointing (e.g., right and left elevation) were unreliable. The graphic records available, however, showed that there was a rapid improvement of performance on early trials for azimuth, elevation and range curves. In other respects, the curves differed. For azimuth, none of the subjects improved after the 18th trial. In elevation there was gradual improvement even at the 48th trial. In ranging, there was great variability in the curves of all trainees (Gottsdanker and Armington, 1947).

These studies resulted in discovering ways to modify the devices and in recommendations for improving training. However, the primary concern of the experimenters was to obtain basic data on the learning of tracking skills. The evaluations of the training devices, *per se*, were in the nature of a secondary fallout. That is, for the transfer experiments used in this series of studies, no attempt was made to obtain transfer measures in an operational situation. Instead, transfer consisted of trainees being given test trials on the trainer with unfamiliar target speeds and courses.

It was not until 1953 (Weigandt, Bishop and Channell) that the Mark 18 Gunsight Trainer, Device 3A40B, was evaluated by determining the effect of training on performance in an operational situation. (It is interesting to note that the researchers state that this study contains the only data available on the effectiveness of Device 3A40.) The results showed that neither training in the air or on Device 3A40B resulted in improved performance on tracking or ranging tasks separately. However, both types of training resulted in better performance in coordinating these tasks than when no training was given.

During the years 1948 to 1954, a series of evaluations was conducted in the area of aviation training. The experimenters were interested in the effectiveness of the trainer on performance in an actual flight. A number of transfer of training experiments were conducted to investigate whether flight trainers can be used to reduce actual flight time. These experiments, which compared the effects of simulator versus no simulator training on subsequent flying performance, follow:

Mahler and Channell (1948) and Mahler and Bennett (1949) evaluated three flight trainers at Pensacola for the Naval Air Training Command; the 12BK1 landing trainer, the C-3 Link trainer, and the SNJ Link trainer. A control group and a group who had previous solo flight time received no synthetic training. Roughly equivalent results were obtained from the three different training devices. Accidents were reduced by 40 percent and flight failures were reduced by one-third. A very slight reduction, one-half hour per student, in amount of actual flight time, was found among those given synthetic training. The differences in average check-flight grades between experimental and control students were negligible.

Williams and Flexman in 1949 evaluated the Link SNJ operational flight trainer (OFT), with a modified cyclorama, as an aid in contact flight training. The trainer group performed maneuvers both in the SNJ OFT and in the SNJ-5 aircraft. The control group performed maneuvers in the aircraft only. The conclusions of this experiment were: (1) training in the SNJ OFT resulted in saving flight training time in the aircraft; (2) the saving in time averaged 7 hours and 14 minutes per student for the syllabus used; and (3) the saving in training time for the entire population of such trainees lies somewhere within the limits of 4 hours and 47 minutes and 8 hours and 47 minutes.

Mahler and Bennett (1950) evaluated the PBM (two-engine seaplane) and the PB4Y (four-engine land plane) OFT's at the Naval Air Advanced Training Command at Corpus Christi. The findings showed: (1) with regard to flight time, there were no savings during the familiarization stage, but during the instrument stage, some flight instruction time can be saved; and (2) OFT training resulted in few serious errors (deviations from tolerances that increase the possibilities of accidents) and fewer total errors on most maneuvers in the familiarization and instrument stages.

Brown, Matheny and Flexman (1950) gave two groups of trainees, with no previous flight experience either a minimum of 2 hours of practice landings in the School Link (experimental group) or no training on the synthetic flight trainer (control group). Both groups received 3 hours of instruction and practice on airwork maneuvers, not including landings, in the Aeronca

7-AC. The findings indicate that errors made while learning to land a light aircraft can be reduced significantly as a result of previous practice in the School Link. The initial landing trials of the experimental group were much better than those of the control group. The trainees who received training in the School Link showed improvement during their first three landings, but little further improvement during the following 12. Apparently they had learned in the trainer most of the skills employed in landing a light aircraft. The control group trainees made a relatively large number of errors on their initial landing trials and showed no improvement during their first three landings. During their next three landings they improved at a rapid rate, but even on their 15th landings had not caught up with the trainees who had practiced in the trainer. (The attempts of this study to evaluate the effects of simulator training on forced landings and pylon eights resulted in data that could not be statistically treated and were not reported. The inadequate data were due to the small number of trainees, incomplete record sheets and lack of a valid record sheet, problems which apparently assumed more importance in connection with the more complicated maneuvers.)

Payne and others (1954) performed a study to test the effectiveness of the Cycloramic Link Trainer. The subjects in the experiment were primary flight students learning to make their first approaches in the SNJ aircraft. The Modified Cycloramic Link Trainer display was a closed-loop projection system, and the runway image projected on the screen showed changes of the simulator with respect to the runway image. The experimental group qualified on approaches in the trainer first and then went on to the aircraft. The control group used only the aircraft. The students who used the device: (a) required 61 percent fewer trials in the aircraft and made 74 percent fewer errors than the students who did not use the device; and (b) showed an oberall superior ability to handle the aircraft in both approach and landing.

Wilcoxon, Davy and Webster (1954) conducted research at Corry Field, Pensacola and found that both the SNJ OFT and NAV BIT (1CA1), a Navy trainer for basic instrument and radio range practice, are effective aids for instrument flight training. The students who had no synthetic training required 22 hours of flight and still did not reach the proficiency level of students who had 18 hours of synthetic training.

Dougherty, Houston and Nicklas (1957) evaluated the training effectiveness of four training devices for teaching a large series of procedural and flight maneuvers. The training devices were: (1) an SNJ OFT with modified cyclorama; (2) the SNJ OFT with the flight system disconnected, but with engine, electrical and hydraulic systems operating normally, to make it a procedures trainer; (3) a life-size photographic mockup of the SNJ cockpit; and (4) the SNJ trainer in the procedures trainer configuration, but with the added task of maintaining level flight on the altitude indicator (as a tracking task). The four groups then transferred to the SNJ aircraft and their performance was compared to a control group which received only inflight training. The subjects, who were private pilots transitioning to the SNJ aircraft, were given five learning trials on normal and emergency procedures on one of the situations. All trainer groups performed significantly better (i.e., fewer errors) on the first air trial than the control group.

The groups who trained on the procedures trainers and the OFT showed the highest degree of transfer to the first air trial. In fact, they performed as well as the group which practiced in the aircraft for five trials. By the third air trial, no difference could be observed as a result of training with the different methods. The conclusion was that both normal and emergency procedures could be taught to transitioning pilots in a variety of ways and that, for practical purposes, differences in performance disappeared after the first air trial. Another finding was that procedures could be learned as effectively on the ground as in the air.

Although most of the experimental work described above has been done on simple aircraft and trainers, the experiments show that substantial amounts of flight time can be substituted for by training device time. It is clear that training devices are best for procedural and instrument flying tasks and for providing an environment where the trainee can integrate his skills and receive different kinds of evaluative feedback on an individualized basis. Procedures, in fact, can be learned 100 percent in training devices and can be taught in a variety of ways. Complex maneuvers, however, have not been learned as well with the past state-of-the-art simulation.

CURRENT EVALUATION PROGRAM

Since the studies on aviation trainers in the early 1950's, very little systematic effort has been conducted on evaluating the effectiveness of training systems from the viewpoint of their effect on on-the-job performance in an operational situation.

Presently, the NAVTRADEVCEN has activated an accelerated effort on the evaluation of training devices. A new division, called the Training Effectiveness Division, was added to the Human Factors Laboratory to initiate and implement a program of evaluation of training effectiveness.

One goal of this program is to provide specific information: (1) to the using activities concerned; (2) to cognizant NAVTRADEVCEN personnel; and (3) to improve present evaluative techniques. A more important goal is to develop validated procedures, techniques and measures in a form which can be used by Navy-wide training activities to evaluate the training effectiveness of their own training systems. Now in its second year, considerable progress has been made in both developing assessment methods and applying these methods in the evaluation of training devices in the field.

Emphasis during the first year was placed on developing measures of trainee performance which are sensitive and accurate enough to provide a reliable picture of the transferable learning (or lack of it) taking place in training devices. In addition, complex, multi-individual trainers have been studied since they represent the major investments. Emphasis during the current year is on conducting transfer of training studies.

A prototype handbook for use by qualified human factors personnel has been developed (Jeantheau, 1971). It features a description of four levels of assessment, three of which allow for obtaining useful evaluative information without the need for those transfer of training measures (requiring data on the performance of personnel in operational, e.g., at-sea settings) frequently unobtainable in quantitative terms. A brief summary of these levels follows.

Evaluation is conducted at one or more of several levels. Each level provides successively more information about the training situation. The methods are organized into four levels of increasing "rigor," where "rigor" reflects the power of the statement that can be made about training value.

Level I–Qualitative Assessment

This is a minimum step that should be performed even when much more is possible. This first level of evaluation attempts to validate the content and procedures of instruction. A questionnaire is developed to determine answers about items related to the relevance of the content to the operational situation, monitoring and measurement features, and curriculum guidelines. These data about the device and its utilization can lead to inferences about the effectiveness of the training system. The rationale behind this is that we know something about the effectiveness of the training when we know whether or not there are specified training objectives, proper monitoring, exercise feedback, and adapting of training based on measurement of performance. An end product of this level of evaluation would be statements as to the positive features and deficiencies in design and utilization with recommendations for improvement where needed. However, the data collected on this basis are based on judgment, so the conclusions that could be made are limited.

Level II–Non-Comparative Measurement

Measurement requires another level of evaluation, namely, quantitative evaluation. The simplest test has been called non-comparative measurement, because it measures what occurs only in the current training situation. No comparison with alternate methods of training or with the operational situation is made. It obtains pretest and posttest scores. The difference in scores indicates the amount of learning that has occurred. The effectiveness of the training, however, is a function of the extent to which the content of the training can be judged to be related to the behaviors required in the operational situation. If the content can be judged relevant, then improved performance can be a reflection of training that would be effective on the job.

The measures of performance that might be used to indicate changes in trainee proficiency are: length of time or number of exercises to reach a specified level of proficiency; number (or types) of errors before reaching a specified proficiency level; final difficulty level reached; or pretraining and posttraining comparisons.

Level III–Comparative Measurement

Each of the two previously mentioned levels of evaluation can be accomplished on a "not-to-interfere-with-training basis." All that is needed is to observe training in process or to record measurements of proficiency. However, if we want to compare the training with alternate methods of training, or with performance in the operational situation, in order to obtain data based not on logical bases but instead on actual comparisons, difficulties arise. For example, for a comparison of two methods (such as using or not using measured training performance, or the use of a series of exercises graded in difficulty), control must be exercised. This might mean inserting standard exercises at the beginning, during, and at the end of training. As the alternate methods proposed may require instructor involvement, considerable cooperation will be needed. Such details must be worked out with the staff of each trainer.

Level IV–Transfer of Training

The final level of evaluation is the crucial and ultimate one. This is the test for transfer of training. It is the objective of training evaluation to determine whether training devices train the skills that they claim to train, and the extent to which those skills are trained. Training may be considered effective to the extent that on-the-job performance in the operational situation is improved.

To obtain information on the extent to which skills learned in the trainer transfer to the operational situation, a transfer of training experiment is carried out. In the operational situation, the performance of a group of trainees who received training on the trainer is compared with a group of trainees, who received no training on the training device.

The measurement of transfer of training is a comparison of the training group with the operational (or control) group on the levels of performance shown in the operational situation. Three kinds of transfer effects may be found: positive transfer, negative transfer, or no effect. Both the kind and degree of transfer effect must be determined to evaluate training effectiveness.

An evaluation has been completed of the skill retention of those trained on the ASROC trainer (Schrenk, Daniels and Alden, 1969). In this project, performance changes by members of ASROC teams undergoing training at Norfolk were measured, and their skills reevaluated at periods ranging from 8 to 32 weeks after training. Two rather straightforward conclusions were reached. One is that the trainees do in fact learn in the ASROC trainer. The other is that they rapidly forget what they have learned when they go to sea. It was concluded that shorebased team training should be made a regular part of the operating schedule of ASROC-equipped ships. The consensus expressed was that Device X14A2 practice was as good or better than at-sea practice, since it allows for multiunit problems and unexpected contingencies. Despite these findings, only four of 12 teams, with convenient access to the training device, had utilized it more than once during the year preceding this study. Problem exercises developed for this study are available and could be included in any Device 14A2 training program.

The evaluation of the Fleet Ballistic Missile Attack Trainer, Device 21A39/1, found that approximately 50 percent of the teams tested showed evidence of improvement in training, through the use of this device (Jeantheau, 1970). The interpretation of the results is dependent upon the purpose of refresher training. This training is sometimes directed at cross-training and attempts at new techniques. If the purpose is that of proficiency maintenance, it is not expected that the crews will build substantially to a new level, since they are already near a plateau level of proficiency when they enter refresher training. The improvement found for 50 percent of the teams may therefore be a conservative estimate, with the training effectiveness of this device being actually much higher than that implied by these results.

A study of submarine diving trainer effectiveness was recently completed (Kramm and Buffardi, 1970). The effects on training during a five week Student Officer Indoctrination Course, which used the Advanced Submerged Control Trainer for the SSN 611 (Flasher) Class Submarine (Device 21B20A) and a Diving Trainer for the SSBN 627 Class (James Madison) FBM Submarine, were investigated. The results showed that for the tasks of attaining ordered depth and maintaining depth during speed changes, trainee proficiency reached almost 90 percent of the performance of experienced crews. In the task of regaining ordered depth during buoyancy, the trainees attained only approximately 40 percent of the experienced crew

performance. Further, evidence was found of negative transfer effects resulting from the substitution of a trainer for the SSN 594 (Permit) Class (Device 21B56A) when Device 21B20A (Flasher Class) was being repaired. Since receiving this information, the instructional staff no longer uses Device 21B56A as a substitute trainer for Device 21B20A.

The evaluation of the S-2E Weapon System Trainer (Device 2F66A) conducted by Meister, Sullivan and Thompson, found the following:

1. No. 4 Operator (Julie-Jezebel) showed substantial learning; No. 3 Operator (MAD, ECM radar and navigation computer) and the TACCO showed minor improvement.
2. Differences resulted from location; i.e., San Diego students gained more than Key West students.
3. The trainer is normally used as an individual, rather than a team, trainer. (When it is first used as a team trainer, performance decreases, but then improves.)
4. Instructor evaluations of the trainer, via questionnaire, showed criticism of equipment reliability and lack of realism of aircraft simulation inputs. San Diego instructors rated the trainer highly; Key West instructors did not.

The Tactical ECM Trainer (Device 15E18) evaluation found that trainees rapidly reach performance levels required by instructors, due to experience on operational equipment, both in flights and on the ground, prior to receiving trainer experience. The device was not utilized to its full training capability (and purpose). Recommendations for more effective use were given to the user and to personnel involved with the design of a related trainer. For example, one of the recommendations resulting from the evaluation of Device 15E18 was to change the current procedure of spending 10 hours on operational AN/APR-9 equipment, in preparing students for tasks to be performed during training flights which are made prior to, or interspersed with, training on Device 15E18. It was recommended that scheduling device time first, then a short session with AN/APR-9 equipment, followed by training in flight would be a more effective sequence. If Device 15E18 training transfers, there should be the possibility of omitting the AN/APR-9 operational equipment used in the aircraft.

A study currently underway is investigating the undergraduate pilot training program conducted by the Chief of Naval Air Training (CNATRA). This study is addressing the issue of substitution of in-flight time with trainer time. An analysis was conducted to identify flight training areas in which proficiency can be achieved through increased emphasis on the use of ground training equipment. For example, a proposed full visual, 6 degrees of freedom motion simulator for the TA-4 training aircraft could substitute from 22 percent of the formation stage to 82 percent of the instrument navigation stage. The overall substitution for all stages is estimated to be 55 percent.

Because of the time and costs involved and the difficulties of obtaining Fleet assistance to arrange operational transfer tasks, the above-mentioned current evaluations did not obtain transfer data. The following on-going studies are obtaining transfer data:

The TA-4J OFT (Device 2F90) evaluation is measuring transfer of training from the simulated situation (the trainer) to the operational situation (the aircraft). This is being accomplished by giving one group training only on the "B" Stage flight syllabus, another group the identical syllabus on the trainer and a third group only academic training on the related principles of the "B" Stage. All three groups will then be given a checkride flight. This evaluation on the 2F90 has the full cooperation of CNATRA.

The P-3B Weapon System Trainer (Device 2F69B) at Patuxent River is being evaluated using Training Squadron VP-30 ASW crews. Individual and crew performance measures are being taken in the trainer. Then, the extent of transfer of training will be determined using at-sea measurements with live surface ships (the current training procedure). In addition, an attempt is being made to obtain live submarine targets for transfer tasks, though the administrative hurdles seem formidable.

After training on the Tracked Vehicle Driving Trainer (Device 3A105), Marine Corps trainees were transferred to the operational M48A3 tank. Preliminary data analysis indicates that there is a one-to-one substitution for time spent on the trainer and for time spent on the operational equipment.

Transfer data collection is currently underway on the U.S.S. CONSTELLATION and the U.S.S. MIDWAY for personnel previously trained on the Carrier Air Traffic Control Center Portion of a large Tactical Advanced Combat Direction and Electronic Warfare (TACDEW) System. Preliminary data analysis indicates that increasing

the time spent in the trainer from 4 to 8 days results in increased performance at sea.

PLANS FOR THE FUTURE

The current evaluation of the TA-4J OFT (Device 2F90) described above will provide data on the extent of transfer of training from the trainer to actual flights in the TA-4J. However, the research design approved by Chief of Naval Air Advanced Training (CNAVANTRA) and CNATRA will not provide information on transfer effectiveness ratios, i.e., the ratio of simulator time that can be substituted for flight time. If positive transfer of training is demonstrated by the current experiment, an experimental design to obtain substitution ratios will be submitted for consideration to OP-553, CNAVANTRA, and CNATRA.

It is also hoped that experimentation can be conducted on Device 2F90 to determine the effect of training with simulator motion versus no motion on an in-flight checkride, and a checkride on the trainer itself.

For future evaluations, it would be very desirable to conduct task analyses to determine specific training objectives for the training situations. Fleet training and missions should be analyzed. In addition, criterion-based performance measures should be developed based on fleet performance standards (such as Operational Readiness Inspections). Further, syllabi based on the training objectives should be developed for academics, training devices and aircraft flights.

With the above three elements developed, i.e., training objectives, syllabi and performance measures, a very meaningful experimental program could be performed. In fact, such a program is being planned for the Surface Ship ASW Attack Trainer (Device 14A2), for which such materials as just mentioned have already been prepared. Additional resources, however, are still necessary. Among these are the Fleet-assists necessary: (1) to obtain the crews and target submarines when and where needed to measure transfer; and (2) to evaluate laboratory-developed techniques that show promise.

CONCLUSION

The greatest single gain in improving training should come from proper use of training devices in the instructional process. Logically, the case for simulation is clear. The increasing complexity of military jobs will demand the flexibility, control and practice opportunities given by simulators. Also, advances in the state-of-the-art of educational technology (for example, automated data systems, adaptive training, and increasing psychological fidelity [which is related to transfer of training from the simulator to the operational equipment, vice engineering simulation which duplicates the physical characteristics of the operational equipment within very close tolerance specifications]) will increase the value of simulators for training.

Unfortunately, the training effectiveness of training devices is not well documented, nor have training devices been fully exploited. Essentially, the data available today indicate that simulation is useful in the acquisition of skills but the usefulness is understood only in qualitative terms. Quantitative relationships are not precisely known. Further, research has not systematically uncovered the conditions accounting for the optimal use of training devices for increasing training effectiveness.

The issue of substitution of simulators for time in the operational situation is very frustrating. In some cases, simulators are praised far beyond what is justified from the results. In other cases they have been unjustly maligned. There is no question but that simulation is a key factor in the training of military personnel, and knowledgable people look to it as an important solution for many of the present and future training problems.

HOW ARE WE DOING?

The NAVTRADEVCEN is taking part in an accelerating effort of formal evaluations of the training usefulness of training devices. Ideally, both the designers of training systems and the users will welcome this. In addition, they will realize that long-term routine operation of training devices, in conjunction with formal evaluations, should result in modifications to the equipment and in its utilization. This realization, and its implementation, can tremendously improve the quality of a training system.

How are we doing? This is a question that can never be completely answered. It is also a question that we must do our best to answer continuously.

Hopefully, the idea of the evaluation of training systems will expand.

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Training Devices Computing Systems

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There is a frequent requirement in trainers to represent equations of motions and complicated physical and military environments. This necessitates the use of computers which have the requisite mathematical and logical capability and permit adjustment to the exigencies of training. Originally, such trainers were activated by analog procedures, but the need to adjust the trainer to changes in the design of the original weapons system, and the need for greater logical flexibility, required the use of digital computers with software programing. Recognizing this need well in advance of the time when digital computers were capable of satisfying trainer requirements in respect to reliability, computing capability and storage, the Naval Training Device Center sponsored the development of the Universal Digital Operational Flight Trainer Tool to provide an orderly evolution of digital trainer activation. Improvements in reliability and in general capability of digital computers have greatly expanded the possibilities for trainer applications, but there is still a potential for useful improvements in data processing beyond the present state of the art. There is also a need for overall control and standardization of the design of computer-activated trainers to reduce lead time, cost, complexity and maintenance.

The purpose of a training device is to permit simulated experience in order to obtain skill and understanding in regard to an actual situation. The actual situation may be dangerous to the trainee or others if he lacks training, or it may simply be expensive.

In the case of a weapon or vehicle, one may utilize a substitute device of limited operational capability in an appropriate environment. The most obvious examples are "wooden rifles" for parade drill, flight training aircraft, torpedoes and bombs with no warhead or with substitute warheads.

But the use of the actual environment has a number of objectionable features. It is expensive and the danger element is never eliminated. Instructional supervision is limited in any actual environment. Furthermore, to the extent that they are used, operational equipments, such as ships or planes or guns, are demoted from combat readiness—at least by location, and probably by personnel factors. The "exercises" of military and naval forces are, of course, training procedures, but these are the peak of training. Maximum effectiveness for armed forces in regard to readiness and capability presupposes a considerable base of more elementary training.

These considerations indicate the desirability of training devices for weapon systems which simulate not only the weapon but also the environment.

TRAINER TYPES

There is an extremely varied range of trainers and training objectives for which a simulation involving the environment is appropriate. The most obvious training objective is the development of skills from the elementary level. This is represented by flight trainers, submarine trainers, radar operator trainers and docking trainers. In these trainers, the operator is in a mock version of the operational equipment; for example, an airplane cockpit. He views instruments activated by the simulation, operates the controls of the device and may even receive a sensation of motion.

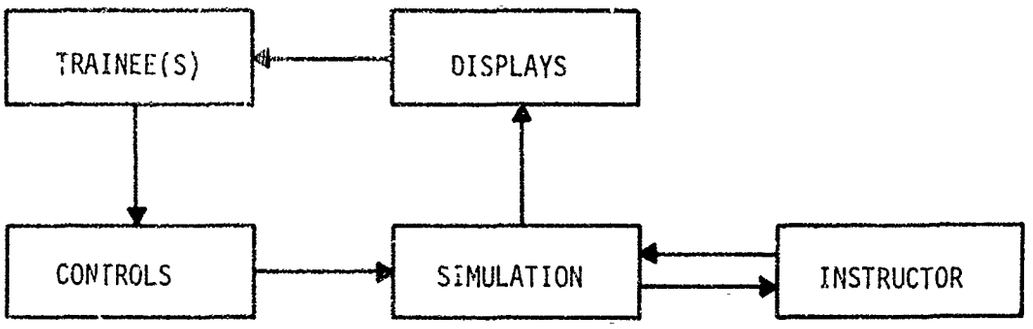
One objective for such a device is training skill, in which the advantages relative to safety and expense are quite obvious. After all, one cannot use up one cruiser or one dock per training exercise.

Training devices can also be used for "familiarization." For example, a skilled pilot can use a flight trainer to become familiar with a different type of aircraft.

In addition to trainers for operational skills, there is another class of trainers intended for the development of team cooperation and command capability. These require a simulation of the military environment, including the various elements of hostile forces. Examples are trainers for complete anitaircraft defense or fleet trainers for antisubmarine warfare.

A trainer involving an environment simulation can be represented by a block diagram as follows:

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This diagram indicates a rather obvious counterclockwise flow of information, with the simulation subject to instructor control.

SIMULATION AND MATH MODEL

For the simulation itself, there are three major possible alternatives: (1) a scale model; (2) a physical analog, mathematically equivalent to the situation; or (3) a purely mathematical description.. These alternatives are by no means mutually exclusive and many trainers correspond to a compromise between these three methods of simulation. Thus, scale models may be incorporated into a simulation because they represent the most appropriate method of activating a display; for example, that of a periscope. In the case of a radar trainer, scale models may represent the only available method of handling complex environmental data. Mathematical analog computation may be appropriate for linking the simulation with the controls or displays. On the other hand, the mathematical and logical flexibility of a mathematical simulation is frequently essential for handling the myriad problems of trainer development, and the tendency has been for the purely mathematical element to become more and more important.

Let us now consider the various elements of a simulation from a purely logical point of view. These are: (1) the geometrical relations between the weapon system and the environment as functions of time, i.e., the "equations of motion." These may be purely "kinetic," i.e., given directly as functions of the time when the actions of the trainee does not affect them. But if the action of the trainee changes the motion, the forces which result from his actions must be computed. The equations of motion are then "dynamically" given as differential equations; (2) the coupling of the trainee with the simulation, i.e., the "Input-Output." The information concerning the control movements must be introduced into the simulation, and information from the simulation must be displayed to the trainee, either as instrument readings, sensor displays, such as radar or periscope displays, or by sensations such as trainer movement; (3) the production of the environmental and other information which is required by the training. This information includes the actions of hostile forces, guidance clues and background information from the natural environment and the effect of malfunctions; (4) the control of the simulation for training purposes either by programing in the general sense of the term or by the intervention of the instructor. Training normally involves a series of exercises of increasing difficulty, an evaluation of the progress of the trainee and actions by the instructor, such as introducing malfunctions to develop trainee response.

These four elements constitute logical requirements for a trainer involving an environmental simulation. The precise description of how these requirements are to be met is usually referred to as the "math model"; i.e., the equations of motion, the input-output data processing, the production of information and the control of training. An analysis of the training situation which produces the math model is of course the first step in the development of a trainer. An appreciation of the nature of the math model is also necessary to understand the relation of the trainer with computation. It is extremely desirable to appreciate that the logical requirements of the math model are essentially

more complex than, say, just a realization of the equations of motion.

EQUATIONS OF MOTION

Nevertheless the equations of motion of an aircraft, ship or submarine in the dynamic form are essential and primary elements in a trainer simulation. In the case of aircraft, one would anticipate that such equations of motion would be available from design simulations. Actually, design simulations were resolved into three two-dimensional problems; for example, one two-dimensional system involves linear motion and pitch. The adjustment required by the "cross coupling" of the two-dimensional simulations was done on a simplified basis.

On the other hand, the simulation of a flight trainer seems to require a full three-dimensional approach to avoid certain negative training characteristics. Thus, it was necessary for the Naval Training Device Center (NAVTRADEVCEN) to pioneer in the development of complete dynamical simulations. These simulations are based on Newton's Laws but, because of the form in which aerodynamical data is available from wind tunnels, these laws must be expressed relative to a combination of moving non inertial coordinate systems. This pioneer development was reflected in design procedures.

The early development of the equations of motion involved work by Bell Laboratories, the Cyclone Laboratory at Reeves Instrument Corporation and at MIT. This is effectively summarized by Mark E. Connelly of MIT in the technical report, "Simulation of Aircraft," February 1958, (NAVTRADEVCEN 7591-R-1). Work on helicopter equations of motion was reported as early as October 1952, and a complete system of helicopter equations was developed for NAVTRADEVCEN Device 2F54 by Melpar in 1957.

The development of the equations of motion for submarines was sponsored by NAVTRADEVCEN at the Naval Ship Research and Development Center (Washington, D.C., Report 2510, June 1967), at Oceanics (Report 63-05, December 1963), and at Hydrosystems (December 1967). The motion of hydrofoils was studied at Boeing, Seattle, Washington, December 1966 NAVTRADEVCEN Technical Report 1630-3), and the motion of assault boats at Oceanics (September 1969).

As mentioned above, the equations of motion correspond to Newton's Laws expressed in a complex of moving coordinate systems. The mathematical description of the forces and moments, either aerodynamical or hydrodynamical, is essentially empirical and is based on the measurement of models in wind tunnels or towing tanks.

SYNTHETIC TRAINING: INITIAL CONCEPTS

The initial development of flight training devices for military purposes was based on pre-World War II German and British experience. British training, which culminated in the Battle of Britain, established the value of synthetic training devices that could save not only time and money, but also lives. These developments were described by Commander Luis de Florez, who visited England in October 1941, in his "Report on British Synthetic Training." This report was highly significant and influenced the establishing of the Special Devices Divisions of BUAER during World War II.

Early simulations were based on a rather close analogy. Thus the "Link Instrument Trainer," which was available before World War II, involved a cockpit with instruments which sensed the position of the cockpit. The cockpit was mounted on a universal joint and activated by a vacuum system which responded to the motions of the controls.

Another example of direct analogy was Device 12BK1, a landing and takeoff trainer, which was available in 1947. The trainee had remote control of a model airplane which was mounted on a boom and could land on and take off from a rotating canvas mat. It was controlled in the air by the effect of the slip stream from its propeller. Still another example is a docking trainer for submarines, (Device 1DA2), which involved a radio-controlled model.

An important analog concept was the simulation of airborne radar by sonic propagation in a water tank whose bottom was configured to simulate terrain. In a number of trainers, the relative position of aircraft, surface vessels and so forth was simulated by "electrical crabs" on a large flat surface corresponding to an ocean area.

The motion of the "crabs" integrated electrical signals which corresponded to velocity components. Such a crab could be used with a Link Instrument Trainer to indicate a total flight path.

ANALOG SIMULATION CONCEPTS

The period immediately preceding and during World War II witnessed the development of many concepts which permitted more mathematical and scientifically precise simulations for training purposes. These concepts included analog differential analyzers for the solution of systems of differential equations, electronic and mechanical amplifications in the form of servomechanisms and the remote control of motion by synchro-systems. Furthermore, fire control for anti-aircraft and naval artillery represented a developing application.

The 2F series of trainers, developed by Bell Laboratories and the Special Devices Division of BUAER in 1943 utilized an analog simulation of flight for operational flight cockpit training. This series was initiated with three types of trainers, but eventually at least seven types of aircraft were simulated. The typical block diagram contained blocks for cockpit, computer, and instructor station.

Projected optical displays, including cinema, were used in gunnery trainers. The use of electromechanical computation permitted the development of more complete trainers, based on the control of such displays by an analog simulation. For example, Device 1BZ2 (1953), the Maneuvering Tactics Trainer at the General Line School, Newport, consisted of 16 independent control booths. Each booth was designed for a conning officer, navigator and signal officer. In addition, each booth had a display, utilizing 25 light projectors, controlled from an electromechanical computer. These projectors yielded a visual simulation of a situation involving 16 maneuvering vessels, four aircraft, possibly four torpedoes, and background.

The electromechanical control of displays in accordance with a simulation had many applications including carrier approach training, channel pilot training and the use of periscope displays in which models were moved on "crabs." This concept also permitted the use of radar landmass trainers, using a complex of transparencies derived from actual aerial maps.

Cathode ray tube displays became of increasing importance in training, since radar and sonar displays required their use. This development favored the use of more mathematical simulation either in the analog or digital case. The use of cathode ray tube displays eliminated certain mechanical problems associated with optical projections.

During the 1950's as the use of more sophisticated mathematical analog simulations developed, these were utilized in fleet and submarin attack trainers. Targets, sensors, own ships and weapons were simulated mathematically in the analog computers, rather than by models in a scaled down version of actual areas or space. Mechanical complications involving considerable engineering were thus eliminated or replaced by computer-controlled arrangements. This paved the way for the later use of digital simulations with their improved resolution, which was extremely desirable in this type of simulation.

DIGITAL AND ANALOG TRAINERS

Analog computers are necessarily limited relative to the logical requirements for the complete mathematical model. Trainers, and in particular flight trainers, are often required when the operational equipment is first placed in service. During this time, the operational equipment design is frequently subject to change and, correspondingly, the trainer may require modification. Since an analog model is a piece of machinery, this modification may involve considerable engineering.

In a flight trainer, one does have a situation favorable to an analog; the flight equations, with the trainee, represent a feedback loop with a relatively short time constant. Thus, inaccuracies are normally not permitted to accumulate but are countered by the trainee, and slight computational errors may appear to correspond to variations in the original device. Thus, small-time scale simulations are appropriate for analog trainers.

On the other hand, in long-time scale simulations, analog errors and inaccuracies can accumulate to an objectionable extent. Also, there are difficulties in those simulations in which a change of scale is required. Another weakness of

analog computation is the presence of "dead spots."

Digital computation, on the other hand, seems to offer expanded logical possibilities for, say, the representation of malfunctions and training procedures. Variations in the math model, due to changes in the design of the operational equipment, presumably can be handled by programing rather than by engineering. Accuracy can be obtained on a far greater range of scales than is possible in the analog case.

UNIVERSAL DIGITAL OPERATIONAL FLIGHT TRAINER TOOL

The possibilities of digital computation for military purposes caused the Office of Naval Research (ONR) to initiate a diverse program of computer development. In the specific training area, the NAVTRADEVCEN sponsored studies by the University of Pennsylvania. These studies led to the development of the Universal Digital Operational Flight Trainer Tool (UDOFTT).

When this program was initiated in 1952, in many ways the state of the art in digital computation was inadequate for trainers. Since analog computation is in parallel, there is little limitation on the amount of computation available in an analog. One simply adds more equipment to increase the amount of computation-per-time interval. On the other hand, digital computation is serial, which means that all computation must go through the same set of registers, and the available speed of computation in the state of the art was inadequate for flight simulation. The types of storage available were also inadequate and the problem of dealing with the large number of trainer analog inputs and outputs was new and serious. But probably the most serious problem was in reliability, due to the limitations imposed by vacuum tubes.

Despite these limitations, the University of Pennsylvania produced a design adequate to initiate the digital activation of trainers. A number of specialized sequential procedures increased the available rate of computation. Core storage was used with separate modules for instructions and data. This permitted two parallel flows from storage. A system of multiplexing inputs and outputs was developed. Reliability was increased by the use of communication vacuum tubes, an expensive approach which also led to difficulties in procurement. The later development of solid state circuitry was of critical importance in regard to reliability for digital trainers.

Another important development involved the appropriate math models for digital activation of trainers. Procedures for establishing the stability of numerical methods for solving differential equations were formulated.

UDOFTT was constructed by Sylvania Electrical Projects Corporation and became operational in 1959. This device yielded a tremendous amount of practical experience. The essential advantages of digital computation in accuracy, flexibility and programing were realized.

DIGITAL COMPUTER DEVELOPMENTS

The developments in digital computers, many of which were foreshadowed by the UDOFTT design, greatly increased the potential for training application. The speed of access to core storage was increased, and the division of core storage into a number of independently accessible modules became a part of many commercial systems. The possibility of integrated circuit memories, which are faster and more flexible than cores, is a recent development.

Large-mass storage became available in the form of discs and related devices and the use of transistors greatly improved reliability and lessened air conditioning requirements. The design of the central processor was improved to permit the maximum parallel use of registers. There was also a considerable commercial development of analog-to-digital and digital-to-analog conversion equipment and multiplexing devices.

Computer systems were also designed to yield program control of input-output and flow of data. This permits a considerable development of display devices.

The NAVTRADEVCEN continued to monitor these developments, both in the expanded use of computers in trainers and in the in-house development of TRADEC, a modern experimental data processing system for trainer development.

The increased capability of modern computers has permitted the digital activation of flight trainers and has raised the possibility of helicopter trainers requiring more computation. Another possibility is the activation of a number of cockpits by the same computer. Multiprocessing is

also used in school training for combat center teams and teams for antiaircraft defense and antisubmarine warfare. Radar trainers, fleet tactics and submarine crew trainers also exist. These trainers, of course, require a complete math model with either dynamic or kinetic equations of motion, the representation of both hostile forces and the natural environment, and instructor control for training purposes. Modern training emphasizes the use of instruments and sensor displays such as radar or sonar rather than visual projected displays. These are more effectively activated by digital methods.

TRENDS

The potential for computer based trainers does not seem to be exhausted by the present possibilities. The simulation on which the trainer is based, i.e., the substitute for the actual situation, should be expressed in terms of information. Presumably this information is most effectively expressed in digital form. One can obtain a kernel of basic information and the rest can be logically derived.

Radar landmass data is an example where this information, while essentially simple in character, contains a tremendous amount of independent facts. Consequently, the data processing procedures required to activate displays at real time rates appear to be beyond the present state of the art. However, this problem is the subject of intensive effort at the moment. The basic independent information appears to be capable of condensation to an extent which will permit storage in modern equipment. On the other hand, one is then faced with a problem of processing and data traffic, presenting requirements which are, at present, beyond the art in the general-purpose computer. But these difficulties may be solvable with either special-purpose parallel digital circuitry or, conceivably, by hybrid circuitry.

The cost of computation on a unit operation basis goes down as the size of the computer increases, provided efficiency of use relative to the total capability of the computer is maintained. This trend has been extremely remarkable during the era in which automatic digital computers have been developed. It is difficult to get precise measures of the relative capabilities of different computers. The same is true, to a lesser degree, for the comparative cost of computation on different computers. However, it is reasonably clear that over the last 16 years, an increase in computation capability of about one thousand occurred and a decrease in cost-per-unit computation of about one hundred.

These trends are by no means exhausted. It seems clear that technological developments will produce computers with a hundred times the present capability, without resort to increasing logical complexity, i.e., more components. This would favor multiprocessing in the activation of trainers. One computer in a flight trainer might activate quite a number of cockpits. In other trainers, one computer might service a relatively large number of combat centers or team trainers.

TRAINERS AND COMPUTERS

It must be emphasized that their use in trainers represents a negligible fraction of computer marketing and trainer development. This probably should be adjusted to the commercial availability of computers. The situation is not equivalent to that of the past, where major technical problems actually limited applications. The situation, now, in many cases, is not a matter of feasibility but on economics, as far as the computer itself is concerned. The impetus to increase computer capability arises from very broad market characteristics, and the corresponding engineering effort requires tremendous resources. Resources for training development should be concentrated on such specific training areas as programing for trainers and input-output traffic controls and displays. Thus, if the computer business produces small computers of the requisite efficiency to justify individual cockpit activation, then this should be acceptable. Smaller units yield reliability by simply providing spare units, and engineering costs for a less complex unit are usually less. On the other hand, computer developments may indicate another direction as being most economically favorable. The tremendous costs for computer development make it inadvisable for one to get involved in computer development to meet trainer objectives. One can accept and adjust to general-purpose computer developments. Such a policy reduces the cost of engineering development and utilizes maintenance techniques which were developed in a broader field.

Trainer Philosophy

It is true that there are engineering and other technical difficulties in the present state of the art relative to trainers activated by computers. In general, these do not appear to be basic, but the appropriate application of effort, time and resources should yield progress.

The purely engineering technical potentiality for trainers is actually responsible for a fundamental difficulty in the present situation—the need to appropriately formulate training requirements from a sensible overall point of view. The fact that a trainer can be constructed with a large number of features certainly does not mean that it ought to be constructed with all of them. There is an even more painful version of this: after a trainer has reached a certain point in its development, a new feature is proposed and found to be technically feasible. It still may be undesirable to add it on.

What is needed is an overall training requirement philosophy which permits the adjustment of requirements to yield a maximum return for a given investment in resources. Training procedures, educational psychology, human engineering and, above all, common sense must be part of this philosophy. Is it desirable to develop a trainer which, in addition to a prescribed school training requirement, will permit the school training faculty to experiment in the tactics area? Devices of this character to design tactics can be constructed, but they are not training devices, and a device for both purposes is a major innovation which should be very explicitly required.

Programing Control

Not unrelated to this problem of requirement philosophy is the need to develop a certain amount of control over the programing part of trainer development. Consider for a moment the programing for a new computer. This is done now by the contractor as part of the engineering development and independently of the programing for previous computers. The previous programing experience for this type of computer may contain many practical procedures for handling the general programing problem and the specific subroutines. The independent new work will invariably involve new alternatives, and totally new debugging, and be more expensive than it would be if based on the previous work.

However, the main effect of this situation is long range. In the first instance, there is the loss of cumulative experience with the same line of programing. Furthermore, if later it becomes desirable to readjust the trainer, then a study of the original programing becomes necessary. It is not unusual to find in these circumstances that the experience and expertise with the program are no longer present, even in the original contractor's organization.

The problem of possible field readjustment of trainers to future variations of the operational equipment has led to the philosophy of using equipment from the operational equipment in trainers, i.e., GFE. Theoretically, if the operational equipment is changed, one can simply replace the associated equipment. In practice, the advantages of this procedure are highly illusory. Normally, the simulation will still have to be changed and consequently the programing. It is the study which must precede the changes that is the expensive element in the programing. There will also be engineering adjustments in any such changes. Basically, this philosophy is one of replacing programing by engineering, and the impetus is due to the lack of long range programing control. There is also the difficulty that, when new equipment for the operational equipment is first introduced, combat readiness may take precedence over training and the new equipment may not be available for trainers.

Trainer Standardization in Information Processing

One can of course consider programing standardization as only one aspect of a more general program of standardization of information processing in trainers, including input-output and data processing configurations. A standardized approach to information handling would minimize engineering development and consequently cost and lead time. The standard approach could be readily adjusted to state-of-the-art improvements.

There is the objection to standardization that it may limit technical improvements. However, in regard to information handling in computers, I am convinced that there is little value in ad hoc computer gadgetry. In the computer field, commercial equipment, where available, is most desirable. On the other hand, if a specialized development is required, a continued and consistent development should be followed in order to maximize the amount of relevant

experience; i.e., as part of the evolution of standardized requirements. Relative to training information, essential progress must be associated with a better scientific understanding of training requirements and procedures.

Input-Output Possibilities

If the training simulation can be made a matter of digital information handling, then the characteristics of a specific trainer appear in the controls and output displays, i.e., the inputs and outputs of the trainer. Apparently, this is the area in which significant engineering developments can be hoped for quite soon.

For example, voice communication from a computer to a trainee seems quite practical and is subject to actual experimentation at the moment. This development permits the trainee to practice instrument landings under simulated tower voice control. In general, it will permit teams to function under verbal commands which arise from the simulation.

The inverse communication from trainee to machine by voice is dependent on the general problem of pattern recognition, which is also involved in reading hard copy by the machine. There is a tremendous amount of experimental development and corresponding claims, but immediately available commercial equipment is extremely limited in its capabilities. The writer believes that emphasis on gadgetry in this general area befogs the basic situation; our presently available information theory and concepts are inadequate for the pattern recognition problem. The pattern recognition problem should be tackled with standard devices, such as the vidicon or orthicon, and the data processed by general-purpose digital computers until effective concepts of pattern recognition are available. Concepts can always be tried out and established in this fashion, even using artificial inputs. The gadgetry is inevitable, but should not be permitted to defocus the basic problem.

The really glamorous output possibility at the moment is three-dimensional video on a holographic basis. It would of course be very valuable for training but it has certainly not as yet technically arrived. On the other hand, integrated circuit modules are available and provide tremendous possibilities for interface procedures between the computer and displays and controls. Also, holographic techniques for "read only" memory may represent an extremely valuable increase in storage capability.

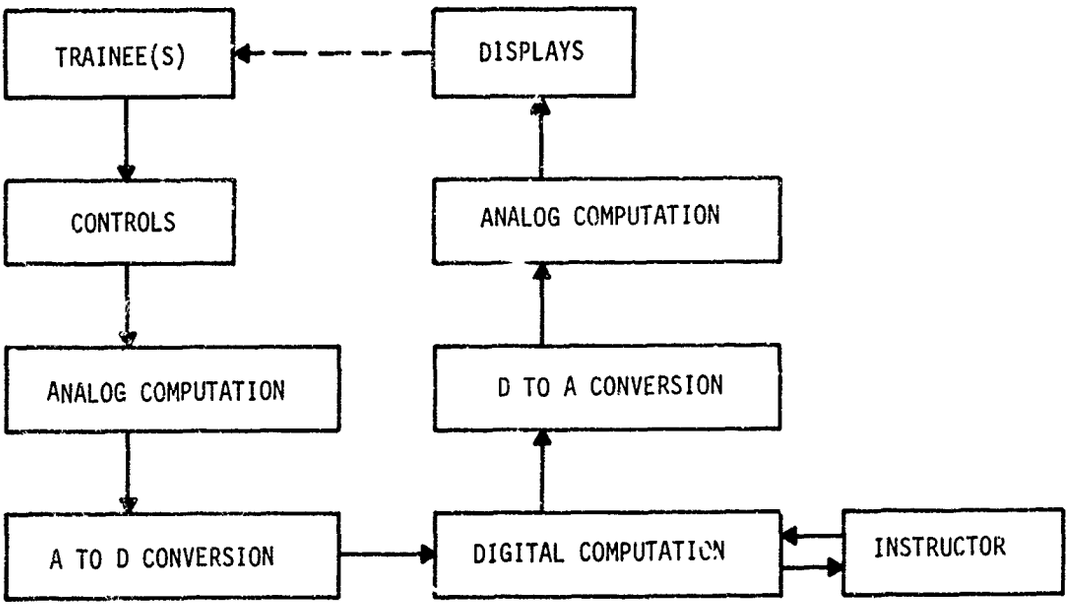
Hybrid Principles

A training device is usually a hybrid device in which one has both digital and analog computation and the need to convert between these. This means that the principles of hybrid computation should be understood. There is now a wealth of experience in this area which can be readily illustrated by examples. Let us consider a type of hybrid device which is successful. Suppose we are monitoring the data of an experiment or of an instrument of observation; for example, a seismograph or an instrument to measure the motion of an airplane in normal flight. For most of the time, the reading is of no interest. But when violent motion occurs, the reading is to be subject to considerable analysis. The information appears, in the first instance, in analog form. An analog test is used to eliminate the data of no interest. The remaining data is converted to digital form and may be subject to, say, Fourier analysis. A properly designed system of this type can readily be shown to provide the data processing at minimal cost.

The characteristic element here is the one-way flow of data and the corresponding trainer situation is represented by the following diagram. There are a number of possible reasons for inserting the analog computation in this loop: (1) to minimize the computation in the digital computer, e.g., control forces may be more readily computed in the analog form; (2) to minimize the amount of conversion between the two forms, analog and digital; or (3) to service the displays, which may require a large amount of very special computation. One may add that, with the availability of digital circuitry, special-purpose digital computers may be inserted in this loop on the digital side of the conversions.

There are a number of comments which can be made. Logically, complex general computation is best accomplished in general-purpose computers. A special-purpose computer, either analog or digital, can usually be justified only by its ability to do a very large amount of a fixed sequence of computation, such as display computation.

There have been, of course, efforts to produce "general-purpose hybrid computers," but the resources available for development are very slight compared to resources for general-purpose digital



development. Some of this effort is also based on a misconception among certain engineers that analog integration is superior to digital in accuracy. This is due, simply, to an ignorance of numerical analysis similar to that which produced the digital differential analyzer. There are quite a number of cases where systems were proposed and justified on this alleged superiority of analog integration, which ended in a very painful fashion for all concerned, including the taxpayer.

An optimal system may well involve, in addition to a general-purpose digital computer, special-purpose computers, either digital or analog, with a fixed sequence responsibility. For special-purpose computers, the choice between digital and analog is not always clear cut. The availability of digital circuit modules favors the digital as well as the logical and numerical precision of digital computation. The digital circuits do not need "adjustment" as do many analogs, and this adjustment complicates operation and maintenance. On the other hand, there are special-purpose analog devices—levers, cams, springs, tuned circuits, which are simple and inexpensive and difficult to replace economically. There is an empirical principle which states that one should minimize conversion between the two numerical forms, i.e., digital and analog.

Finally, there is the case where the information (and the problem) is so large that only analog forms such as photographs or parallel analog systems can handle it. Advances in speed in digital computation have, in general, eliminated the latter; i.e., the need for parallel analogs or, at least, produced digital competition—sometimes in parallel form. But there are still cases where analogs are used because of the amount of information or because the conversion of information from analog to usable digital form may have serious practical limitations.

Conclusions

It is clear that there are many engineering developments which would have significant impact on the applications of computer-activated trainers. For example, improved computational speed, improved input-output data traffic handling, and improved principles of pattern recognition. There is a clear need for programing control and an associated standardization of computer digital information systems.

But there may well be deeper policy problems involved. To indicate what I have in mind, let us recall Office of Naval Research (ONR) policy following World War II. At that time, the importance of digital computation, either for military or general affairs, had not been demonstrated. With ONR support, NAVTRADEVCEN embarked on a general program of computer development; i.e., the Big Winds (Cyclone, Whirlwind, Hurricane, Typhoon,

etc.). The first effect of these programs was general. But ultimately the general development led to a tremendous increase in capability in military affairs; for example, combat information centers, complex digitally based weapon systems and, of course, trainers.

As it served its purpose, this general NAVTRADEVCEN program was reduced and eventually eliminated. But the general situation today may require an entirely different broad policy unless one is willing to surrender the concept that military systems should be based on the best available science and technology. One may be willing to accept a second class scientific and technological status for military matters. If not, however, one simply must develop an adequate policy to counteract the current trends. University research is turning away from contact with military matters, and even commercial development may turn wary, with good reason. Thus, military development may well be denied the intellectual support on the deeper levels which it requires. A case in point, for instance, is the radar landmass study which required an information-theoretic study. This study was available from the University of Pennsylvania and one can quote similar situations in UDOFTT and situations where support was obtained from MIT and Columbia. These would probably not be available today.

This new required policy may well be complex. Surely, it is desirable to develop and increase in-house intellectual competence in scientific and technical areas. This intellectual competence must include the practical engineering end as well as the theoretical scientific aspect. But many other policies will probably have to be changed, too, since we seem to be dealing with a very general malaise of which the scientific and technical problems are only a symptom.

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Digital Flight Trainers and Radar Landmass Simulation

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The Naval Training Device Center (NAVTRADEVCEN) has been a leader in the development and application of digital computer systems for flight trainers and radar landmass simulation Trainers. The author has participated in this development since 1950, both at the Moore School of Electrical Engineering, University of Pennsylvania, and at Pennsylvania Research Associates, Inc. Beginning with a summary of the flight-trainer state-of-the-art 20 years ago, the paper traces the significant steps in developing digital computer techniques and devices for these real-time man-in-the-loop training systems.

The Naval Training Device Center formerly the Special Devices Center of the Office of Naval Research, has consistently been one of the leading pioneers in applying digital computers to the simulation of dynamically complex systems, and especially to digital real-time man-in-the-loop flight trainers and radar landmass simulators. Right after World War II, when the invention of the electronic digital computer was just being announced to the general public, the Special Devices Center sponsored a study at the Massachusetts Institute of Technology to determine whether their Whirlwind Computer "could be made to simulate the performance of an airplane so well, even including structural deformations in flight, that it could be used to a certain extent in place of actual experiments on pilot models."[1]

This was followed in 1950 with a detailed feasibility study at The Moore School of Electrical Engineering, University of Pennsylvania, directed to a highly specific goal, namely, to determine whether a digital computer could be used as a substitute for the analog computer in an ERCO operational flight trainer for the Grumman F9F subsonic airplane. The study led to the design of a rather unusual but general-purpose digital system, the Universal Digital Operational Flight Trainer Tool (UDOFTT), which not only proved powerful enough for the job but was readily extended to simulate the F100A supersonic flight plane as well.[2]

As was generally characteristic of NAVTRADEVCEN pioneering studies, the OFT study was aimed as much at determining the underlying criteria and requirements of digital simulator design as at procuring a specific device. Two problems were critical at that time: (1) no existing, or soon to be completed digital computer, could solve the given equations of a single airplane in real time; and (2) there was not *a priori* assurance that the methods of numerical integration then in common use could guarantee stable solution for each and every dynamically realizable flight maneuver that might be experienced in a training flight. Both problems were resolved; the first by designing a computer[2,3] with a ten-microsecond multiply time (in 1953, using vacuum tubes), and the second, by demonstrating mathematically through "stability charts"[4] that a mple open quadrature formula could be used iteratively, without closures, with assured stability and with acceptable accuracy for flight trainer simulation.

The investigation of digital radar landmass simulation began back in 1960 with a feasibility study sponsored by NAVTRADEVCEN, with the end goal of displaying radar returns from helicopters up to Mach 3 airplanes, and with 100-foot resolution out to 200-mile range. The target test area was to be 500-by 1200-nautical miles of real world. The mountainous area centered on Williamsport, Pennsylvania, was chosen for the purpose.

By this time, digital computers had advanced to the solid-state semi-conductor stage and arithmetic speed was no longer the bottleneck. The basic problem was the handling of massive amounts of data that need to be stored as well as transferred, processed, updated, and displayed in relatively short time intervals.

An easy calculation showed that simple storage of the hills and valleys of natural terrain at the required resolution over the specified minimum test area called for a multigigabit memory. Assuming seven bits to designate terrain height above sea level and two bits to designate terrain reflectance, about 2×10^{10} (twenty billion) bits were needed. This is substantial even for today's mass memories. Means for data compression without significant loss in resolution were clearly desirable.

It should be recalled that resolution and accuracy are separate and distinct terrain attributes. For example, it might be feasible to resolve two hilltops, 100 feet apart, while inaccurately placing them hundreds of feet from their true geographic positions. Or, alternatively feasible to place them with topographic accuracy but fail to resolve their separate identity. Moreover, the need for both accuracy and resolution, or even their relative needs, in an operational radar landmass trainer is an open question; only general subjective answers can be supplied until specific training missions have been identified for trainers being procured.

The resolution/accuracy considerations are significant also in designing the final video display. Early considerations[5] suggested that a digital display would require painting at least 1000x1000 points with at least eight shades of gray (3 bits) for each radar scan. Based on radar scan rates up to one per second (360-degree PPI display), the information display rate requirement is at least three million bits per second. The data transmission rate from the computer to the display must be equally fast or faster.

It was concluded from the first phase of the radar landmass simulator study (1962) that "digital terrain storage and processing were feasible in principle with digital devices but that the conversion to height profile vs. ground range and the reconstruction of radar video signals could be accomplished more efficiently by analog devices. The primary reason for the hybrid approach was the high frequency and low precision of radar-return information (on the order of megacycles per second) and the repetitive nature of the process for generating height profiles."[6]

In order to visualize these conclusions in proper perspective, it is well to examine the analog competition, namely, the factor transparency.[7] In the latter system, a photographic plate is used to represent the height at a point, another plate is used to represent the reflectivity of the terrain, and still other plates may be used to store other contributing factors.

A flying-spot scanner is used to illuminate the factor transparency(ies), and the transmitted light is picked up by a photoreceptor. The spot of the flying-spot scanner is moved along a path corresponding to the radar sweep along the ground. The resulting output of the photoreceptor is an analog waveform corresponding to the factor being scanned; e.g., height or reflectivity. The various waveforms generated via these transparencies are combined in a display computer to produce the "video" waveform which is displayed. The display computer incorporates various effects such as shadows and attenuation. It implements the features that are incorporated into the model of the return signal, limited to effects on the signal envelope (as distinguished from the modulated carrier).

The factor transparency simulation is restricted in several important respects, primarily due to optical problems and the difficulty of controlling the size and shape of the flying spot. For example, the radar sweeps an essentially constant angular beamwidth. This means that the shape of the spot should change as the range increases: the range resolution is constant, but the cross-range resolution varies considerably.

A basic problem of the factor transparency method is that the limiting resolution is tied directly to the size of the problem area. The combination of spot size, photographic grain size, and optics limits the resolution; i.e., in order to accommodate a sufficiently large problem area, the resolution of individual points is sacrificed, or else the size of the photographic plates would be excessive.

The factor transparency system can be designed to incorporate the primary contributing elements of the radar return, such as height, terrain gradient, reflectivity, and specularity. However, this would require one plate for height, two for terrain gradient, one for reflectivity, and three for specularity, for a total of seven plates to be synchronized and registered to within a few mils. The practical difficulties involved have limited factor transparency systems to the simulation of the basic radar return signal.

Further, a real radar does not see an average height, specularity value, etc. Rather, it sees an average return signal, composed of returns from

perhaps many separate reflectors, each of which has a controlling height, specularity, etc. Such nonlinearities cannot be simply reproduced in the factor transparency system.

In some applications the time and cost to prepare the precision photographic plates prohibit the use of such a simulator. Moving targets, structures that are destroyed and then rebuilt, weather, countermeasures, or any other dynamic effects must be sacrificed.

The approach taken in digital radar landmass simulation is conceptually the same as in factor transparency systems, except that the photographic analog storage of terrain data is replaced by digital storage in a mass memory, such as magnetic tape or disc. Instead of a flying spot sweep over a transparency, a search is made by computer through the memory, and data appropriate to the point in question is brought out in synchronism with the sweep. That data is converted to analog waveforms or profiles of the various factors, and then to radar return signal values.

One advantage of a digital simulator is that resolution is not directly related to the problem area; high resolution data may be used in areas with many features, and low resolution data may be used in monotonous regions. Similarly, coarse data may be used at far ranges and fine data at near ranges. This characteristic of digital storage allows the exploitation of inherent terrain redundancies not feasible in analog systems.

Furthermore, the problem area in a digital system need not be of fixed shape. The problem area can be patched out of several base maps with almost unlimited flexibility; for example, a very long, narrow corridor, with a larger operational or target area at the end. Patching of maps or incorporation of dynamic effects is done digitally under computer control and can be considered a field operation.

Although a digital simulator may have a higher first cost, it can accommodate a wide variety of radar effects with small incremental costs, resulting in a simulator which for a given high level of performance is less costly than is the equivalent factor transparency system.

As mentioned above, the primary problems of digital radar landmass simulation are due to the massive amounts of data that need to be handled. In radar video reconstruction, there are several sets of data to be generated. The primary data components are height, reflectivity, slope or gradient, and specularity. When properly generated and combined these data components produce the video signal. The data is generated in the form of profiles, which are synchronized with the display sweep as a function of ground range. The term "profile" is derived from the concept of height profiles, which represent the height as a function of range in any angular direction of the radar antenna pattern. The extension of this concept to include reflectivity profiles, terrain gradient profiles, etc., is quite natural.

A cursory solution of the problem based on straightforward use of large-scale digital computers (using direct enumeration of terrain data on a point-by-point basis) leads to a requirement for nanosecond computing and gigabit memories. In order to reduce the combined effects of memory size and speed, the inherent redundancies which exist in natural terrain can be exploited.

A specific simulator may be used to illustrate (figure 1). To obtain an optimal compromise between cost and performance, the simulator can be designed using analog, digital, and hybrid equipment organized into four major components. As shown in figure 2, these are the aircraft computer, terrain data generator, terrain function generator, and display computer.

The aircraft computer is digital, or a part of a digital computer; the terrain data generator is digital; the terrain function generator is hybrid; and, the display computer is analog. The aircraft computer is not a functionally important part of the radar landmass simulator; it is concerned with the simulation of those aspects of the aircraft which are important for radar landmass simulation, primarily aircraft position over the terrain, altitude, and attitude. The terrain data generator is functionally equivalent to the factor transparency, its positioning devices, and the flying-spot scanner and its controls.

The terrain function generator is equivalent to the photoreceptor of the factor transparency system; it is concerned with the generation of profiles. The display computer is completely equivalent to that of the display computer of a factor transparency system; in fact, the display computer of a complex factor transparency system and that of a simple digital simulator could be nearly identical.

The primary component of figure 2 of interest at this point is the terrain data generator. The main store consists of magnetic tape or disc units containing the total terrain data for the area

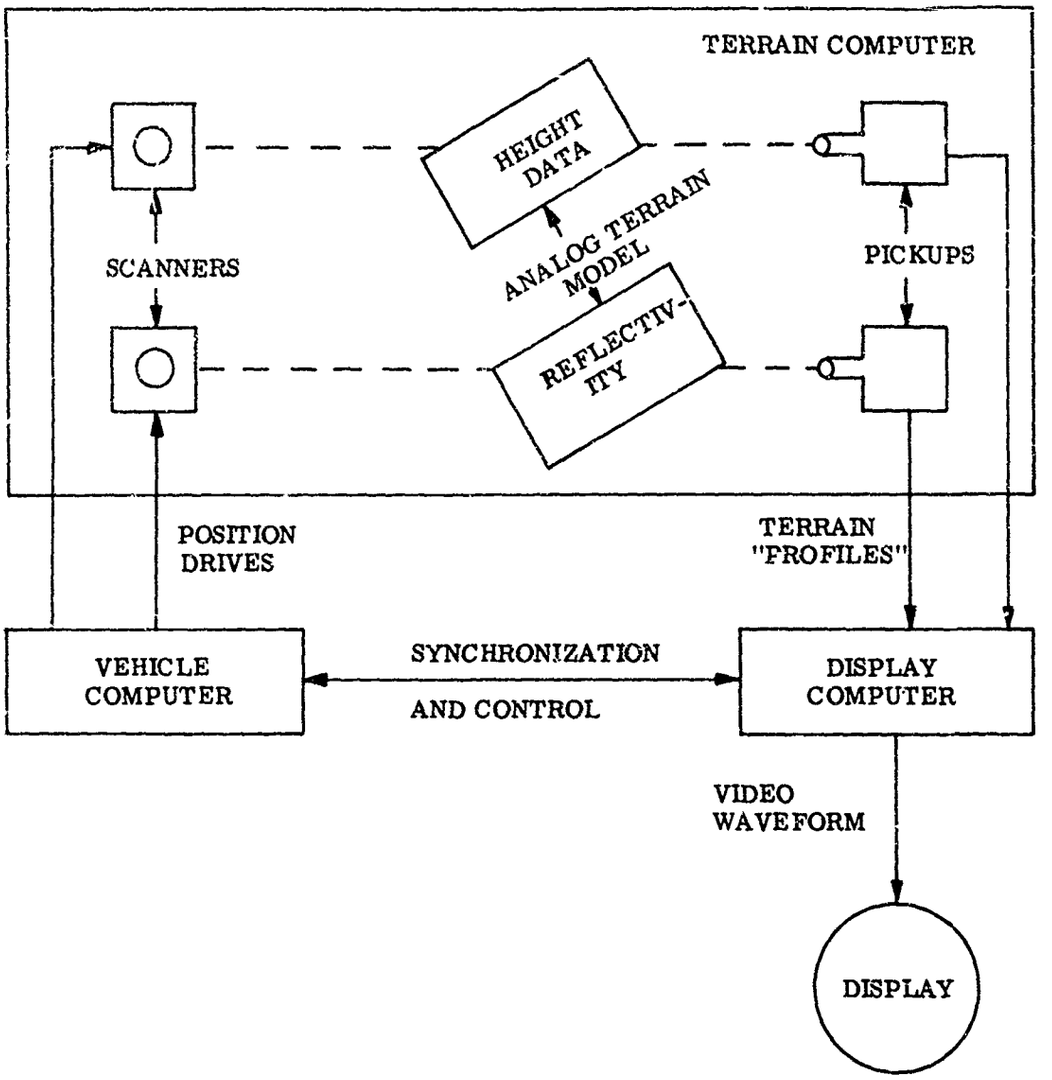


Figure 1. Analog Radar Landmass Simulator.

covered. The main store is followed in succession by two levels of core memory storage called the intermediate memory and the sector memory. The outputs of the sector memory are sent to the region memory employing flip-flop storage. Region memory outputs are transmitted to the terrain function generator for conversion to analog signals and generation of the range profiles.

This memory hierarchy illustrates the primary problem of digital radar landmass simulation. As data proceeds from main store to region memory, memories of increasing speed and decreasing size are encountered. The region memory stores data for a small portion of a radar sweep. The sector memory stores data for a complete radar scan, whereas the intermediate memory stores data for a set of successive scans within the maneuvering limits of the simulated aircraft. These memories are arranged in a buffering hierarchy, in which less and less data is accessed at a higher and higher speed.

Data is stored in such digital systems in discrete packages of a predetermined number of bits. For each group of data there is an address in memory. The act of accessing a block of data requires computation to determine where that data is stored (its address). If the basic package size is made small, relatively more time or hardware must

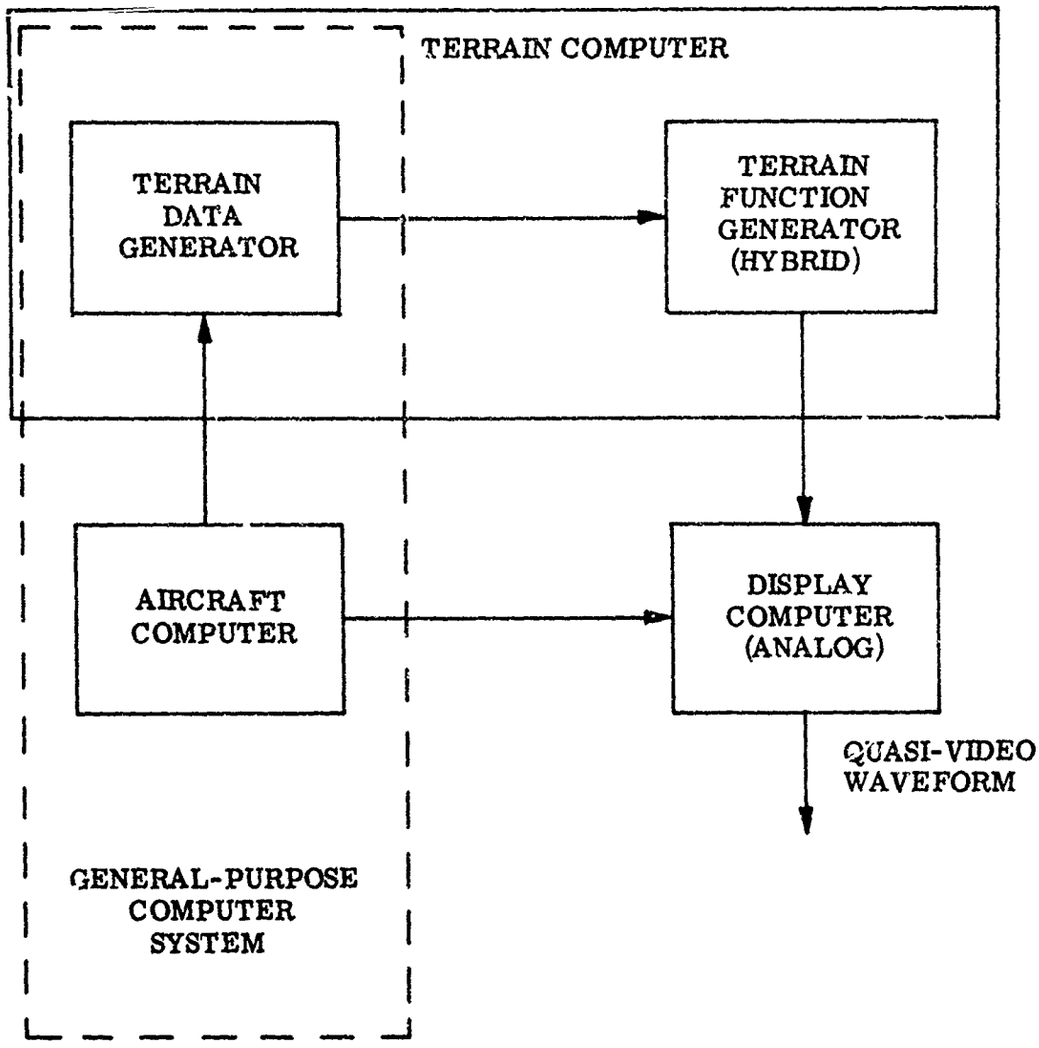


Figure 2. Major components of a Radar Landmass Simulator.

be devoted to the determination of the address and the accessing thereof. If the package is made large, more hardware must be devoted to the storage of data. The primary tradeoff in the design of a digital radar landmass simulator is the relation between data package size and speed of access and the hardware required to effect these functions.

The underlying consideration in establishing data package size is the required accuracy and resolution of the simulated terrain. Man-made objects such as buildings, highways, powerlines, etc., are handled separately since "cultural objects" have sharp boundaries and usually need to be positioned very accurately. Moreover, "culture" can be organized in any convenient way and it is simplest to package it in the same hierarchy of regions as the terrain. Search for an effective method of digitally representing natural terrain, to achieve a compression of data approaching the theoretically derived estimate, resulted in a new function approximation method which was based on a modified Lagrange polynomial.

From purely theoretical considerations making use of statistics on the distribution of terrain height and its derivatives, it was computed that no more than about 100 bits per square nautical mile were required to store map data. Thus, a problem area of 600,000 square miles comprised 60

megabits of data, which is well within the storage capacity of a single reel of magnetic tape. It was shown that a Lagrange polynomial of third degree, in two variables, was sufficient to achieve the theoretically derived estimate to the same accuracy as obtainable with contours at 100 foot intervals.

The height at any place within a particular region is generated from the polynomial specified to fit the height and associated derivatives at the four corners of the region. In an adjacent region a different polynomial is used with the same format and a different set of parametric values. This polynomial fits the data for the four corners of its own region On those corners which the two regions have in common the same data are used. The advantages of this approach as related to other possibilities are continuity of height and slope across region boundaries and significant compression of the amount of data required in storage. Boundary continuity and data compression requirements are discussed in detail in reference 8.

Figure 4 shows the nine different parameters stored at each regional corner in the so-called 2-2 version of the modified Lagrange polynomial which has

$$\frac{\delta^4 h}{\delta X^2\, \delta Y^2}$$

as the highest cross derivative.

The polynomial has the form

$$f(X,Y) = \sum_{i=0}^{1} \sum_{j=0}^{1} \sum_{p=0}^{2} \sum_{q=0}^{2} g_{ip} \left(\frac{X-X_3}{d}\right) g_{jq} \left(\frac{Y-Y_2}{d}\right) f_{i+3,j+2,p,q}$$

where

$f_{i+3,j+2,p,q}$ means the stored parametric value

$$\frac{\delta^{p+q} h}{\delta u^p\, \delta v^q}$$

at the point $u = 3+i$, $v = 2+j$;

and u and v are used instead of X and Y to normalize the values: and

$$g_{00}(z) = (1 - z)^3 (1 + 3z + 6z^2)$$

$$g_{01}(z) = (1 - z)^3 z(1 + 3z)$$

$$g_{02}(z) = \frac{1}{2}(1 - z)^3 z^2$$

$$g_{10}(z) = z^3 (6z^2 - 15z + 10)$$

$$g_{11}(z) = z^3 (1 - z)(3z - 4)$$

$$g_{12}(z) = \frac{1}{2} z^3 (1 - z)^2$$

A least-square fit over each region is used to generate the first approximations to the parametric values for the corners of that region. Since each corner is common to four regions, the values obtained from the four separate least-square fits are averaged to provide the final results. This can be shown to be equivalent to obtaining four separate approximations to the entire map and then averaging over the four map approximations.

The block diagram of figure 3 shows three major subsystems; namely, a general-purpose digital computer with associated memories, a special-purpose hybrid computer, and a special-purpose analog computer. The general-purpose digital computer performs those functions of the aircraft computer that are required for the simulator and the function of the terrain data generator. The hybrid computer thus serves as the terrain function generator, and the analog computer acts as the display computer.

The aircraft computer programs provide aircraft velocity, position, and orientation (or rather the antenna boresight) with respect to the terrain. The effects of wind on the position of the aircraft and the overall dynamic response of the system to the changes in aircraft position and orientation initiated by the pilot are also handled by the aircraft computer.

With aircraft position and orientation and the direction of the radar sweep with respect to the aircraft (antenna boresight angles) as input data, the terrain data generator provides data concerning the height, terrain gradient, reflectivity, specularity, and other factors for the portion of the terrain within the range setting of the radar. The terrain data generator as implemented in the general-purpose computer consists of a main store (tape or disc), some buffer memories, and controls (via program) for the interchange of data among these memories. The outputs of the terrain data

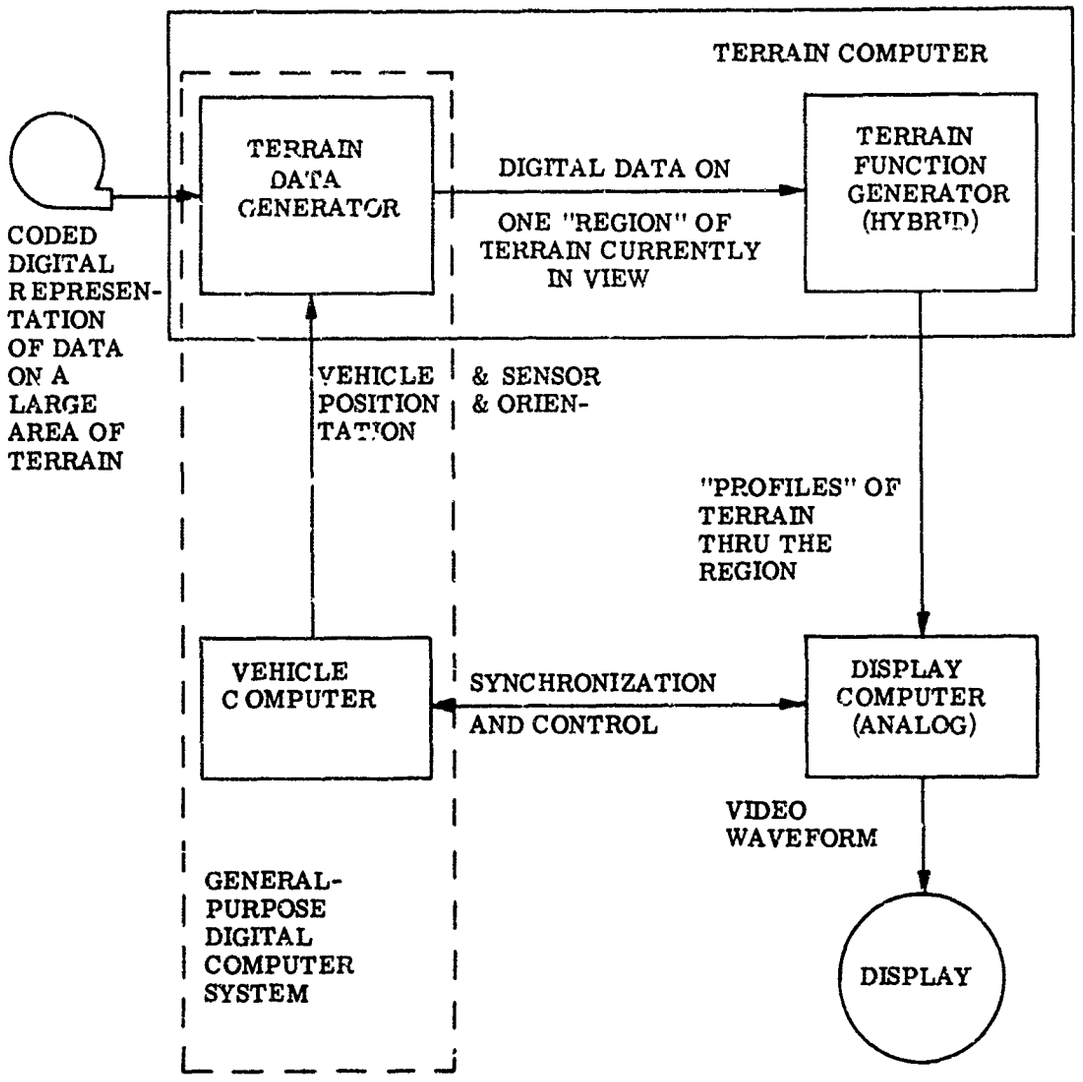


Figure 3. Radar Landmass Simulator Based on General-Purpose Digital Computer.

generator are presented to the terrain function generator, which converts the discrete digital data to continuous profiles.

The display computer modifies the data provided by the terrain function generator for final display. Its computations consist of those required for shadow determination, weather, noise, antenna pattern, and similar radar effects. The display computer also handles the weighting of data from calculations on regions of different sizes, scale factors, etc., to allow a smooth transition during the decrease in resolution from minimum to maximum range.

The terrain computer, consisting of the terrain data generator (general-purpose computer program) and the terrain function generator (hybrid special-purpose computer), does the actual reconstruction of the various profiles. Within the terrain computer there are three storage areas: main, district, and region memories. The main memory stores the data for the entire problem area and is implemented as a set of magnetic tapes or as a disc file. The district memory holds all of the data which can be seen with a nominal radar range of 200 miles within maneuvering limits of the aircraft. The district memory is implemented as an off-line auxiliary high-speed memory, controlled by the independent I/O controller of the computer.

For a problem area of 600x1200 nautical miles, the main store might consist of four magnetic tape transports. Three regions with different scale

factors are used in the data. Each region is a square of a fixed size; reasonable sizes of the various regions might be:

Region Type	Mod 1A System	Mod 1B System
A	10,000 ft.	7,000 ft.
B	40,000 ft.	28,000 ft.
C	160,000 ft.	112,000 ft.

The district memory is fed with data from the main store and includes only those regions whose resolutions correspond to the resolution required up to the maximum range possible for the radar. Functionally, the district memory consists of three levels of detail or resolution. Each of these memory areas is numerically equivalent to a east and west of the due north point, the district memory is fed with only B and C region data. At the extremes of the radar scan, where only low resolution data is required, only size C regions are taken from main store and placed into the district memory. The main store is organized so that the tape is moved only once in an east-west direction for the short-range A regions, intermediate-range B regions, and long-range C regions, the range being measured in a north-south direction.

For the Mod 1B system, data from the main store is examined at a rate of approximately 900 A regions per second, of which 64 are stored every 6.6 seconds. Thus, the tape problem consists toroid. As the aircraft moves, memory data is not shifted in the memory, but, instead, the central point of the memory is redefined. In effect, the torus is rotated about its axes. Information to be entered ahead of the aircraft is loaded into memory locations corresponding to points which are behind the aircraft, and the boundary between forward and rear data is redefined.

As the main store is serially accessed for sections in an east-west direction, those sections due north of the center of the district memory (the center corresponding to the aircraft position) are transferred from tape to the district memory with data at all three resolutions. Slightly to the primarily in finding the data to be entered, rather than entering it as such. A transfer rate of about 29,000 characters per second is needed if all data were transferred. These rates are well within the capabilities of commercially available low-cost magnetic tape transports.

The data required to establish a portion of the sweep being processed is accessed from the district memory and sent to the terrain function generator. The data are used as coefficients for the terrain profile polynomial. Sweep position is entered as another pair of parameters (x and y component of the sweep) resulting in the generation of the profile. The output profile is obtained with a frequency response approximating that of the video bandwidth of advanced airborne radars; i.e., several megacycles.

The output of the terrain function generator consists of a set of simultaneous profiles in height, reflectivity, terrain gradient, etc. The above discussion centered on the height profile; however, the same general approach (at a much lower rate) applies for the reflectivity, terrain gradients, and other factors. For example, it is possible to extract the gradient components at the same time, using much of the same equipment as is used in the reconstruction of the height profiles. Reflectivity is done partly with the polynomial representation and partly with cultural data representation.

The outputs of the terrain function generator are combined by the display computer which performs a ground-to-slant-range conversion, in addition to shadow computation and simulation of various radar effects.[9]

The calculated video profile is displayed on a scan conversion tube, and is not yet a real-time signal; i.e., it is painted on at various scales and rates and has many stops and starts. Of major importance is the fact that the sweep-to-sweep average is in real time. Several video profiles can be combined to simulate azimuthal beam spreading. The data which has been calculated, i.e., the several micro-sweeps which may make up a single displayed sweep, is stored in an intensity modulated form. The face of the scan converter is scanned electronically. The equivalent of the scanning aperture would be a rotating mirror and slit arrangement to yield an output proportional to the total illumination across a line on the scan converter tube face. The slit or filter in the scanner performs two functions; (1) its vertical profile approximates the azimuthal beam pattern, and (2) its horizontal profile approximates the transmitter pulse width. The scanned output is then the video signal which is presented to display system.

If required, at that point, the video may be modulated to an appropriate IF and injected in the actual radar receiver which performs the normal terrain avoidance or contour mapping presentation of the video signal. Processing, which is performed at RF in the real radar and which depends on wave optical effects (e.g., monopulse radar), cannot be

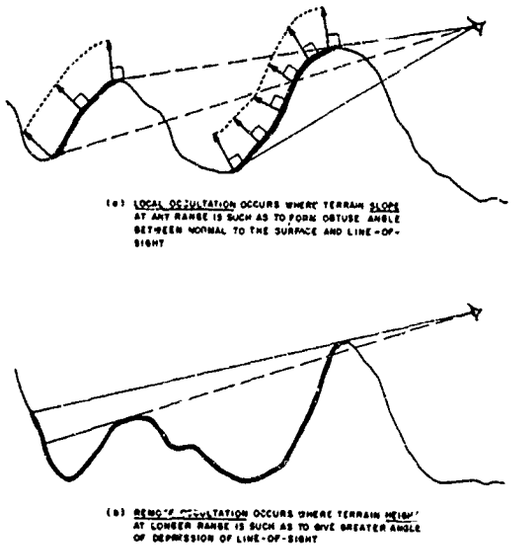


Figure 4. Local vs. Remote Occultation.

Remote occultation requires a knowledge of the terrain at points other than the point of interest. Figure 4 shows an area of remote occultation. A profile of the "landscape" is traced in the direction away from the observer, and a record is made of the largest elevation angle. When the elevation angle of a new point on the profile is smaller, the point is known to be occulted. Remote occultation depends only upon elevation angle and not upon terrain slope.

It can be appreciated that such occultation calculations are made on the height profile in direct correspondence to the deflection of a writing beam on the display. Thus, an indication that a resolvable picture element is occulted simply means that the writing beam of the display (or in a buffer memory) is blanked for the corresponding period of time. This proves to be a very effective way of deleting from the display objects that are not visible from the vantage point of the observer.

Exhibit A is a simulated radar picture, presented in the usual polar pattern of an airborne scanning radar. The area shown is centered on Williamsport, Pennsylvania, in the Allegheny Mountains. For this picture the computer situated the radar to the southwest of Williamsport (the bright city in the center) at 20,000 foot altitude with the range of 0-30 nautical miles.

The sinuous black line in the lower right is the Susquehanna River, which curves around below Williamsport. The river valley appears very wide in places due to shadowing by a long ridge running



Exhibit A. Radar Display Prepared by Digital Computer Simulation.

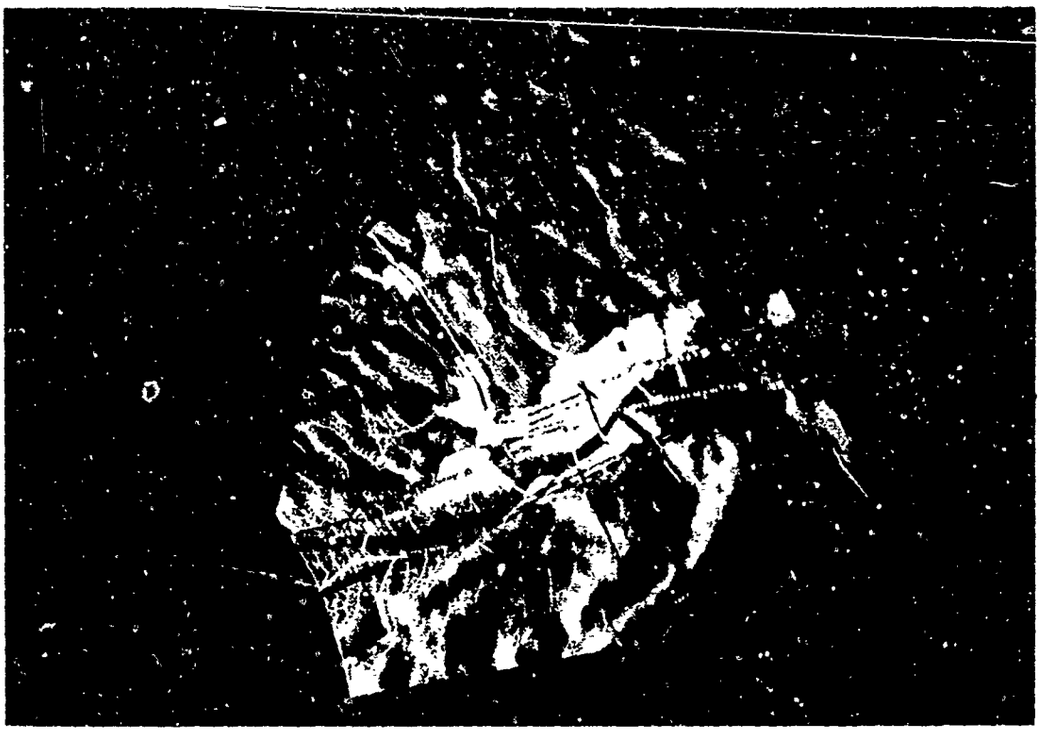


Exhibit B. Portion of Preceding Picture with Expanded Scale.

south of the river. This is the effect of calculating shadow and occultation as each profile is traced from ground-zero.

In Exhibit B, the radar has been flown to the northwest of the city, and the range scale has been expanded three times (showing 10-20 nautical miles). Here the city outline is distinct; the boundary of the built-up or highly reflective areas is delineated, although the lower reflectivity of streets and highways takes precedence where such features are found on the map.

The above radar pictures were synthesized by means of a CDC 6600 computer, which wrote a magnetic tape for driving an SC 4020 computer recorder. This is a device which intensifies individual spots on a cathode-ray tube, the image being focused on a frame of microfilm. The pictures were generated in a polar raster so as to simulate as faithfully as possible the equipment being designed to portray radar images in real time.

During the last two years the foresight of the Naval Training Device Center in sponsoring early work on digital radar landmass simulation has borne fruit. Four simulator manufacturers have constructed laboratory models of real-time landmass displays based partly or wholly on digital technology. Although the various systems differ for proprietary reasons, there are many common elements that may be recognized. The use of digital terrain and culture data storage, a mix of general-purpose and special-purpose equipment for system control, and high-speed digital/analog conversion are typical. The interface between digital and analog formats is moving away from the original data storage and toward the ultimate display instrument (CRT), in line with the increase in speed and decrease in costs of modern digital computing elements and circuit packaging techniques. A recent development that promises to have impetus on digital landmass simulation is the award of the Undergraduate Navigator Training Simulator (UNTS) by the Air Force, whose radar landmass simulation subsystem is specified to be based on the same digital technology that has been nurtured and developed by NAVTRADEVCEN and its contractors.

A large number of technical experts contributed to the successful development of radar landmass simulators. Some who come immediately to mind are Paul A.T. Wolfgang, Professor Albert Schild, Edward W. Veitch, Henry

L. Apfelbaum, Joseph C. McMenamin, and Dr. Boris Beizer. The contributions of Roger L. Boyell are particularly noteworthy since he contributed to these developments from the outset. The stimulation and guidance of Milton Fisher, Alfred Weinrauch and other members of NAVTRADEVCEN were vital in reaching today's accomplishments. Assistance by Professor Francis J. Murray, their consultant, in the development of the mathematical bases of radar landmass simulation is especially acknowledged.

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Professor, The Moore School of Electrical Engineering, Philadelphia, Pennsylvania

Dr. Rubinoff holds the B.A. degree in Mathematics and Physics, and the M.A. and Ph.D. degrees in Physics, all from the University of Toronto. Since 1946 he has been an active contributor to the field of digital computers including digital/hybrid real-time simulation, switching theory, and information storage and retrieval. Dr. Rubinoff has been a member of the faculty of the University of Pennsylvania since 1950, where he is now a full Professor of Electrical Engineering.

Dr. Rubinoff was first to demonstrate the feasibility of actuating flight trainers by digital computers. In 1952, he and his colleagues at the Moore School of Electrical Engineering developed a graphical presentation of the frequency range over which numerical solutions of differential equations were stable.

Dr. Rubinoff served as Chief Engineer for Computers for Philco Corporation from 1957 to 1959. He served on several government advisory boards, and on the editorial boards of several professional societies. He has written approximately 40 papers on real-time solution of differential equations, on logical and hardware design of digital computers, and on information storage and retrieval.

Since he formed Pennsylvania Research Associates, Incorporated in 1960, Dr. Rubinoff has been an active participant in projects dealing with radar landmass simulation and related work for the Naval Training Device Center and other sponsors.

Adaptive Vehicle Control Trainers

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It is traditional to make individual advancement contingent upon the acquisition of skill. In one sense, then, the demands made upon a man adapt to his ability to meet them. Within increased development of complex machines–aircraft, submarines and the like–there has developed a reliance upon training devices to provide the necessary skill. A training device is often, but need not always be, a faithful replica of whatever actual machine the training is to be directed.

The role of the instructor has been to monitor behavior and impose problems of increasing difficulty and increasing validity. The efficacy of training devices has been recognized to be a complex function of its design, the intrinsic difficulty of the task, and the sophistication of the instructor. The increased availability of computers (analog, and more recently digital) has provided increased knowledge of the mechanisms effecting training and increased communication between training psychologists and automatic control engineers to bring about the adaptive trainer.

An adaptive trainer is one which alters its task and vehicle characteristics in response to the variations in one or more quantitative aspects of performance. It is thus able to achieve high rates of skill acquisition by the student in a way which is unique to that student. As a simple example, a flight trainer might reduce its "excess" stability as the deviations around the desired flight path become smaller. For another example, the amount of visual noise in a display might increase toward values found in operational equipment as the student's detection rate increased and his decision time decreased. A skilled instructor would presumably have done this if the trainer design permitted. The adaptive trainer insures that it is done for each student in a way best suited to his rate of gain of skill.

One of the newest and most promising developments in the field of training devices is the Adaptive Vehicle Control Trainer. Vehicle Control Trainers have, in the past, tended to be simulators in which some aspects of the task were presented to the trainee with an opportunity for frequent repetition. It was frequently discovered by instructors that it was easier and quicker to train people for complex tasks (like air-to-air radar gunnery) by turning off part of the environment and part of the complication of the task in order that the student could grasp certain other parts. In general, as designer sophistication (and common sense) increased, part-task trainers were developed with the expectation that training on the components would simplify the whole task performance of the student when he put these components together in the more complicated whole task trainer. Such devices did work, of course, although they placed a heavy load at times on the instructors. However, there still was the tendency to assume that the best vehicle control trainer was that which came closest to the real equipment in all its aspects.

Between every trainer and the student using it, there was always an instructor. The instructor's task had many facets. One, of course, was to make sure that the training device was operating properly. Another was to interpret changes in student behavior, and in quantitative measures of behavior, and make suggestions to alter behavior. On a more informal basis, instructors have actually modified the equipment which was being used in order to meet some intuitively satisfying schedule of task difficulty. This is what teachers have always done when given the freedom to change curricula to meet the requirements of individual students. It is of interest to quote from a summary technical report of the National Defense Research Committee in 1946 (Volume IV, Records and Devices Developed for the Selection and Training of Sonar Personnel, page 7):

> "Next to the lack of trained administrators, the lack of trained instructors was probably the greatest weakness in the Navy training system. The majority of instructors were conscientious and hard-working, but they were not qualified teachers. Too often. . .good teachers were transferred and replaced by inexperienced men. Like administrators, instructors should be given special training or selected because they have had the necessary training."

The shortage of skilled instructors, as existed during WW II, is still a serious problem. There are good instructors and bad instructors, and the

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quality of training obtained by a student will vary according to his instructor and to the degree to which his behavior in learning and the attitudes of the instructor agree or conflict. The notion of adaptive training is the rationalization and mechanization of good instructor behavior.

Kelley has stated "Adaptive training is training in which the problem, the stimulus, or the task is (automatically) varied as a function of how well the trainee performs" (ref. 11). The importance of the word "automatically," he goes on to say, is great since virtually all training, in one sense or another is adaptive. In its simplest form, an adaptive trainer might be one in which the vehicle to be controlled was simulated but with greatly enhanced stability. The degree of extra stabilization might then be reduced until the student's errors increased above some preset level. When this occurred, the stability might increase. Thus the change of the system in the direction of stability or instability would be inversely related to the level of performance demonstrated by the student, depending on what the logic is, which relates error or rate of change of error to stability or rate of change of stability. The student's performance will be held at some constant error or constant error rate. A generalized diagram of adaptive training, as compared to fixed training, is shown in figures 1 and 2.

A way of considering the adaptive vehicle training problem is to imagine the task of training a novice to ride a unicycle. The traditional approach is to give the unicycle to the trainee and suggest that he use a friend or two to help balance until he learns to operate it. The adaptive technique would be to provide the unicycle with extendable balancing wheels like those used on a child's bicycle which in the beginning are in firm contact with the ground. Thus the operator would be pedalling a "pentacycle" through his center wheel. The balancing wheels would retract at some slow rate so that the amount of force which they exerted against the ground would diminish as a function of time. Then, if large forces were exerted, indicating that the trainee had lost balance, the wheels would extend and the process would be repeated until the trainee did not exert large forces, and thus was riding the unicycle as it was originally intended to be ridden.

Another alternative might be the stabilizing of the unicycle through sensing gyroscopes and a computer (hopefully mounted somewhere else), which would send appropriate signals and forces to the pedals to keep the machine in balance. Then, using a similar strategy to the one described before, the degree of added or external stabilization would diminish as a function of time, as long as the tilting of the machine remained within some acceptable limits. As a concept, it seems like a reasonable way to learn to ride a unicycle; whether, in fact, it would work in practice is another matter.

A third way, of course, would be to simulate a unicycle, thus freeing the trainee from the hazards involved by allowing a freer expression of his control activity to occur. The trainee would be provided with a saddle and pedals and a tilting shaft on which these would be mounted and a surround which would be moved appropriately to simulate both angle and movement. Under these conditions, far more parameters of the training situation could be varied and it would be possible to choose a number of alternative strategies by means of which to effect the training. Of course, there would still remain the question of whether the trainee would be able to ride a unicycle when he had successfully mastered the unicycle simulator. However, that is a question which is impossible to answer in the absence of experimental data.

Let us consider once more the simulated unicycle, and ask what parameters of unicycling we would measure, and how we would use these to vary the system. Merely to measure the angle of the shaft on which the seat and pedals were mounted would be sufficient only for the "hovering" task, since during acceleration and deceleration shaft angles are necessary if a tumble is to be avoided. In the simplest case, we might train unicyclists to hover by exerting appropriate body and pedal movements, with the goal of maintaining shaft angle within some designated limit. As long as the shaft angle remained within the designated limit, the degree of external stabilization or system damping would diminish. When the shaft angle exceeded the limit, the damping or stabilization would increase. This, operating as a feedback, would tend to hold the average error over short periods of time at whatever angle had been specified by the training supervisor until finally all external stabilization was removed and the trainee might then be able to reduce the angles to whatever level his skill would permit. Then, presumably, he would be ready to ride a unicycle since the control activity and the visual and kinesthetic stimulation would be

identical in both the simulated and in the real condition.

It is worthwhile to consider certain fundamental principles of learning, which generally conform to common sense and can safely be considered non-controversial. The first principle of learning is that of reinforcement. In simple terms, behavior can be strengthened or its probability increased by following the behavior immediately with some kind of event. Whether one is teaching a pigeon to peck at a key, or a child to write a word correctly, a pellet of food in the one case or candy in the other will serve as a reinforcement for the correct response. A corollary to the general principle of reinforcement is that the sooner the reinforcement comes the more it facilitates the learning.

The second principle may be stated as the principle of activity. One must elicit the desired behavior before it can be reinforced (although in some cases it is possible to give verbal instruction about later motor activity, but for the most part the motor activity itself must occur before it can be learned). The trainee has to be engaged in the task.

A third principle of learning is that of self-pacing. The learning proceeds most effectively when the pace of the work is set by the learner, or by his own behavior, rather than imposed from the outside. This is a consequence of individual differences in rate of learning.

A fourth principle (which stems to some large degree from the behavioral studies of Skinner and his followers) is that of approximation. Animal trainers reinforce as rapidly as possible any behavior which is in the general direction of the desired terminal behavior. If they want an animal to perform a complex act, they cannot wait until the complex act is performed before reinforcement is given, since the complex acts which are taught to animals, in general, will never be performed. The same is true, of course, in the teaching of children. Any activity may at first be reinforced in order to cause more activity to be done. Then gradual differentiation of the responses by the reinforcer will lead to progressive shaping of the behavior, until finally reinforcement is offered only for the desired behavior.

Let us consider how such principles can be applied to training devices in general and how they occur in adaptive training devices. Reinforcement in a training situation can occur either in the form of an external reward, a commendation from the training director, etc., or in the form of internally generated satisfactions. That is to say, the trainee has high motivation to succeed from some other source outside the training situation. Then, as he improves, he finds his reward in the improvement itself. This, of course, requires that some information be provided the subject about the nature of his response and the degree to which his response changes from training session to training session, or even within successive short periods of a single training session. That the behavior be elicited and the trainee engaged, of course follows ordinarily in any complex vehicle training session.

If the trainee falls asleep, he is not engaged, and this would become immediately apparent to the instructor. The two other principles, that of self-pacing and that of approximation, are necessarily a part of adaptive vehicle trainers. It is, in fact, the very nature of the adaptive principle that it is gaged to the pace at which each learner learns what to do, and by the principle of successive approximation, the desired task behavior is achieved by alterations in the system, which the trainee is controlling as he learns more and more how to control it. The trainee's perceptual-motor activity is determined almost entirely by the nature of the vehicle control trainer device. As it changes to become a better and better approximation of the actual vehicle, so will his control behavior change to become a

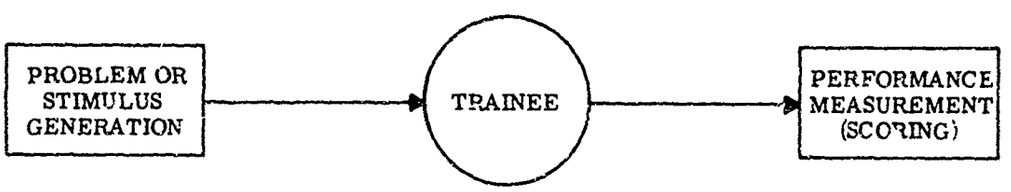


Figure 1. Fixed or Preprogramed Trainer (taken from ref. 11)

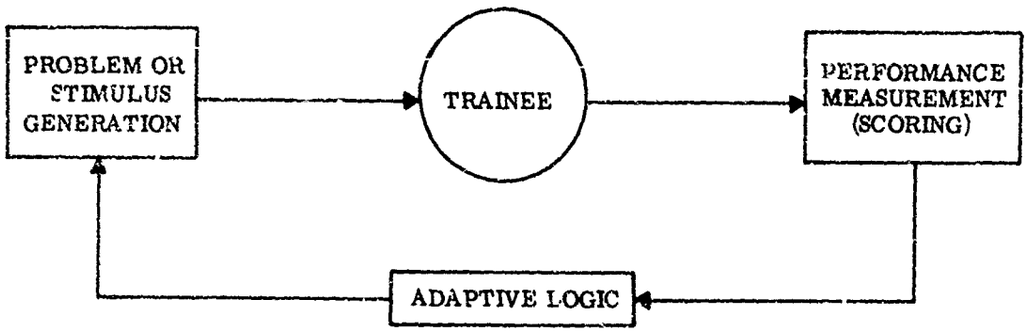


Figure 2. Adaptive Trainer (taken from ref. 11)

better and better approximation of correct control of that vehicle. The adaptive trainer, then, makes it possible to use the principle of self-pacing in a way which obviates continuous personal attention by an instructor.

The adaptive vehicle control trainer can be seen to be an extension of automated teaching, which has been used effectively in a variety of other fields not related to vehicle control.

There are three main sources in the United States of adaptive training studies: The Engineering Psychology Branch of the Naval Research Laboratory where Henry P. Birmingham and his associates developed so-called Equalization Teaching Machines (ref. 1), the Otis Elevator Company where E.M. Hudson conceived and created an adaptive tracking simulator (refs. 2, 3), and Dunlap Associates where C.R. Kelly has carried on the most extensive research program on adaptive simulation and adaptive training in this country (refs. 4-10). In England, Gordon Pask initiated research on teaching with adaptive machines prior to 1960 (refs. 12, 13). The ideas for such development almost simultaneously and quite spontaneously emerged in a number of places in the latter half of the decade of the 50's, and might be presumed to be the result of the increasing engineering sophistication of psychologists concerned with training and vehicle control problems, and with the increased availability of analog and digital computers. When it became clear that one could alter the characteristics of a simulated machine (or for that matter of a real one) on the basis of some measure of the behavior either of the machine or of its controller, the way to making adaptive simulations and adaptive training devices was open. The Office of Naval Research, initially, and later the Naval Training Device Center, have supported a long series of important studies by Kelley. A list of the publications coming out of this research program is included in the references.

Adaptive training is not necessarily good. It depends on how it is designed. If we go back to figure 1, we can expand the drawing to show in figure 2 an adaptive vehicle control trainer (taken from Kelley [ref. 11, page 13]). Kelley stated:

"Here is a diagram of an adaptive vehicle trainer that includes the displays, controls, and problem generator of the typical flight simulator. The trainer is made adaptive by superimposing an adaptive logic that connects the performance measurement equipment with any part of the system in a way that makes the task automatically harder or easier as a function of that performance."

Adaptive training, as stated, is related to the broader field of computer aided instruction. Some forms of computer aided instruction are indeed adaptive. Research has shown that in some cases the adaptive computer systems are no more effective in training than the conventional techniques, and that the presumed logic on which the program was designed in fact nad no basis in reality. That is to say, alterations in the program technique or the training technique gave as good results as that which was originally designed into the system. One way of looking at adaptive training is to consider figure 3. Figure 3 shows a typical learning curve. Such a curve is almost inevitably encountered when one places a trainee in a fixed simulation whose characteristics do not change with time. The trainee who has had, let us say, 10 trials and finds himself on point x on the learning curve, is in reality a different trainee from

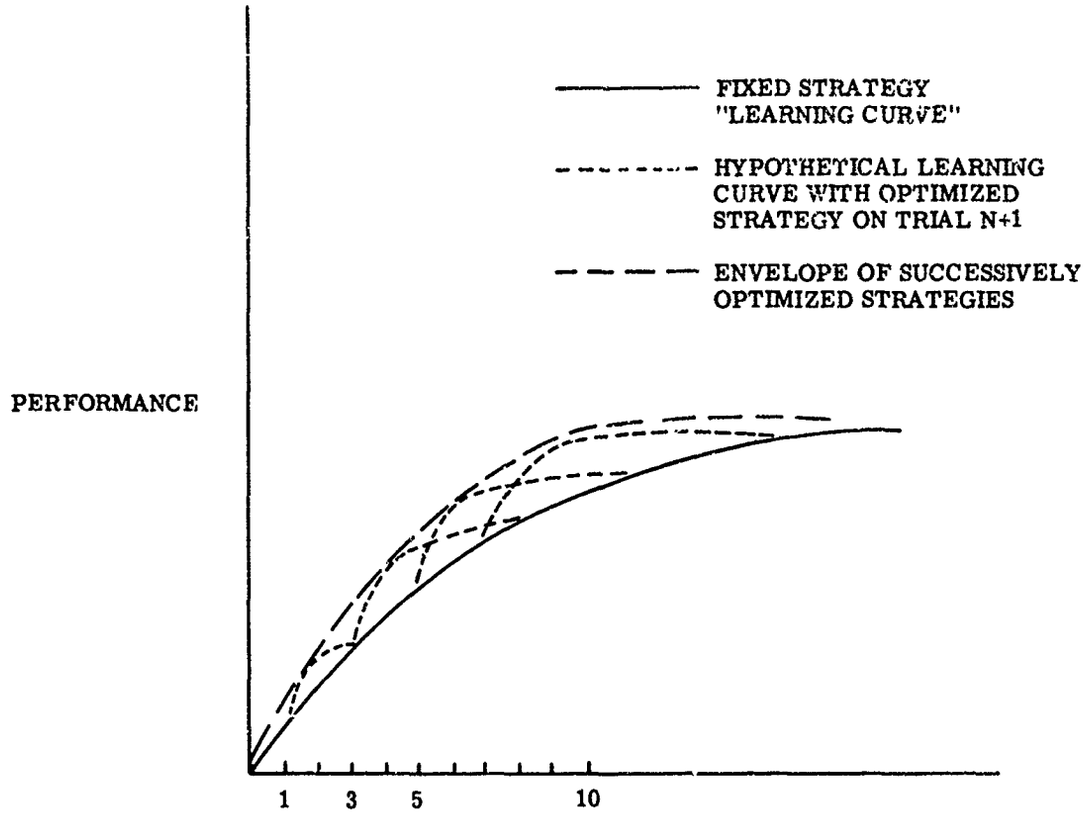


Figure 3. Hypothetical Learning Curves

the one at point y who has had only one trial. If then, there was an optimum strategy for training of the subject at y in order to steepen his improvement curve, there would be some other optimum strategy pertaining to the person at point x. By extension, we can imagine that at every point on a learning curve there is an optimum way of training this "different" organism from the ways which are appropriate for the organism at other stages of skill. The task for the designer of an adaptive system might be to formulate a technique which would, at every point on the performance curve, give the maximum increment for every unit of time spent in the training situation. In fact, to find such a curve might be difficult, and in some cases impossible, due to the limitations of repeatability of behavioral studies.

At a meeting at the University of Illinois (ref. 11) a number of workers in the field of adaptive training discussed the cases and situations where adaptive training is most appropriate. Kelley stated: "Adaptive training methods are called for when training is already adaptive but instructor controlled and when it is desirable for reasons of cost, standardization or when it can be demonstrated that training effectiveness results from mechanizing the instructor's adaptive function"...and "The criterion for using adaptive training should be cost effectiveness, broadly interpreted and applied." Mansfield stated: "The main reason for choosing adaptive versus fixed training methods is to arrive at a desired result in a complex training task at less cost by reducing the number of instructors and by reducing the trainee's total time in the training program, thereby increasing the trainee's and instructor's time that can be made available for performing the operational task as skilled personnel."

Knoop said: "The development of adaptive training methods is linked to the goal of automating many of the instructor functions (in flight simulation training, for example). One reason for doing this is not to replace the instructor but to relieve him of time-consuming

routine duties so that he could use his teaching skills more effectively. It is impossible or impractical to automate some instructor functions so let us not talk about getting rid of him." As Kelley points out, "It is undesirable for trainees to practice only on easy tasks and never on difficult tasks. At the same time you may not want them to perform sloppily and get them in the habit of doing so. The relation here is defined by the adaptive logic and it is very crucial. One difference between a good and a bad adaptive system can be the difference between the performance standards used."

The problem, then, seems to boil down to the question of whether one can sufficiently comprehend the nature of good instructor practice to specify it precisely enough that it can be programed in an automatic device. Some investigators, like Pask, have postulated that one can get around this difficulty by having what might be called an adaptive-adaptive trainer in which, if a particular strategy originally programed into the system proves less than adequate, the strategy itself can be altered. Figure 4 gives an example of how this may be done.

Let us imagine that an adaptive simulator to be used as a training device measures the smoothness of the vehicle performance and integrates this measure over a short time period to be used to vary the degree of stability augmentation provided. In this hypothetical example, if the student settled down at a particular comfortable level, then the system would be stabilized at some high level of stability augmentation. The failure of the augmentation system to change could itself be a stimulus through the second outer loop to alter the measurement from smoothness of flight to some other measurement; for example, amount of control stick movement. If this were done, then the situation would change to one in which the

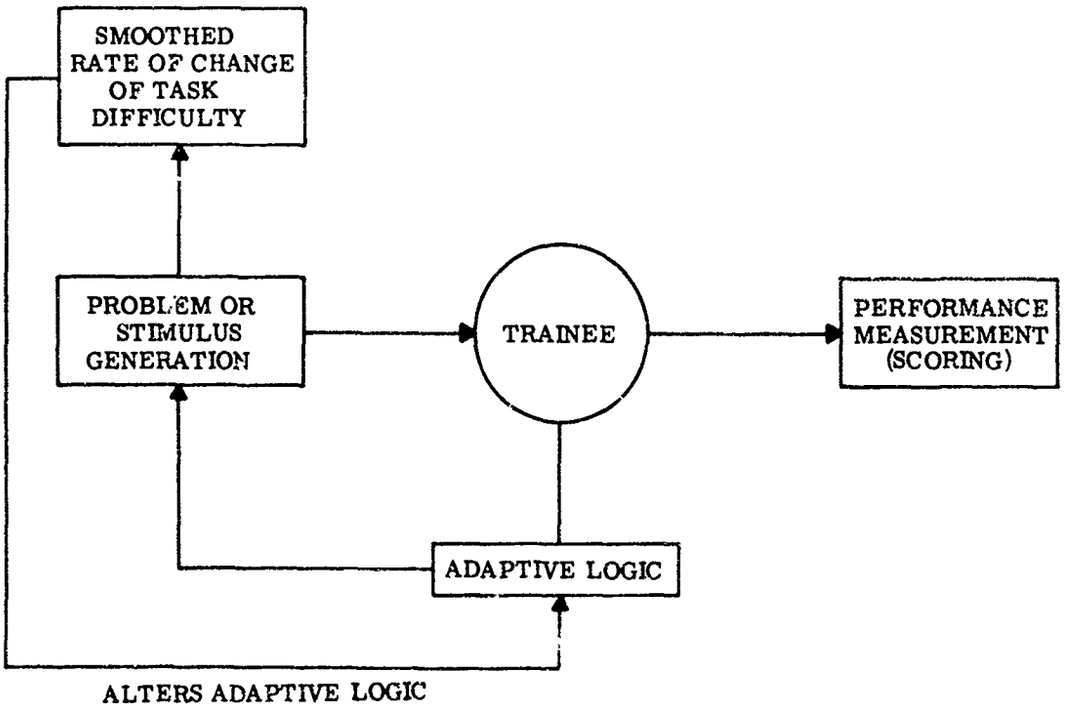


Figure 4. Adaptive Adaptive Trainer

subjects were being taught to minimize the control stick movement rather than to maximize smoothness of flight. The overall task of the system, of course, is to maintain some desired path in space, and it might probably be that the ultimate outer loop would be one which measured path deviations and chose various strategies of feedback in an effort to minimize these. The analogy might be drawn to training for non-vehicle situations where, if one reinforcement, say, lollipops or M&M's, fails to produce a desired improvement in behavior, then some other reinforcement such as money will be tried, only to be abandoned in turn as improvement ceases. Of course, if all conceived-of reinforcement failed to induce further improvement, then either a physiological limit or some psychological limit has been reached and the training program would be terminated.

Adaptive training, then, can be considered merely as a way of eliminating the necessity for human instructors to be constantly engaged in monitoring, interpreting, and exhorting in an effort to improve student performance. Since students are all different and the optimum reinforcement scheduling and training program for each will be somewhat different from that appropriate for any other student, the adaptive system can patiently attempt a variety of techniques until the appropriate one is found. The variations in system characteristic can be in any one or combination of measures. Ultimately, of course, the adaptive machine must find its way to a state at least as demanding as the operational equipment. It may, in fact, be desirable to have it exceed the operational equipment in the demand that it makes upon the student in the same way that swinging two baseball bats seem to facilitate batting with one.

Adaptive training may revolutionize vehicle control training; further experiments are still to be done.

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