# A NEW GENERATION OF TRAINERS FOR ACOUSTIC ANALYSIS

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ABSTRACT

The development of low-cost trainers for acoustic analysis (AA) is dictated by the need for both initial training and continuing refresher training in this volatile skill. The state-of-the-art in computers and graphics systems supports the development of trainers that produce the high resolution displays of operational equipment, support a computer-assisted instructional (CAI) system, and provide the portability and low cost for wide distribution to multiple fleet units and reserve components.

The key to an effective AA trainer for advanced and refresher training is a means of creating a realistic display of what the student would observe in the real world. Recordings of actual acoustic contacts provide a data base from which realistic displays can be created. Low-cost is achieved by performing the conversion from acoustic data into display data by an off-line process that is separate from the trainer.

This paper describes the development of the use of prestored data in a trainer, the signal processing necessary to create the data base, the proof-of-concept trainer that incorporates the use of prestored data, and the current research initiatives that will lead to improvements in low-cost trainers for AA.

## INTRODUCTION

Acoustic Analysis (AA) is a technique for detecting, identifying, tracking and localizing underwater targets. Acoustic energy generated by target vehicles is received by hydrophones and transmitted to an acoustic signal processor which transforms the audio signals from the time domain to the frequency domain for subsequent display. Figure 1 depicts the various sensor platforms in use by the fleet to detect the submarine radiated noise. Surface ships and submarines use hull-mounted arrays of hydrophones and towed arrays of hydrophones. Aircraft drop sonobuoys that transmit the acoustic signals present in the ocean to receivers in the aircraft. Helicopters use a dipping sonar attached to a cable. Although there are differences in the display formats used on various acoustic signal processors, the process is the same. The acoustic information is presented to the operator as an aural signal and is processed and presented to the operator as a visual display of the frequency spectrum of the signal being received. Using the techniques of passive acoustic analysis of the unique signatures produced by different types of targets, the acoustic operator is able to identify the target type and, utilizing other techniques, to pinpoint its location for tracking or prosecution.

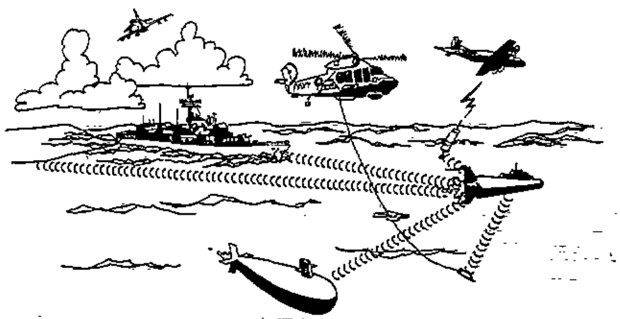

Figure 1. Antisubmarine Warfare Platforms.

AA has been identified by research studies and in Operational Requirements statements as a perishable skill that requires periodic refresher training. In particular, studies by the Navy Personnel Research and Development Center (NPRDC) have shown degradation in knowledge and skill in AA due to infrequent practice, inadequate feedback, and long periods of task nonutilization.[1,2] Systematic practice and performance testing for the air, surface, and subsurface communities is recommended.[1]

The development of a low-cost trainer for AA is in response to the documented need for AA training. The hardware state-of-the-art provides graphics systems that allow replication of operational displays, computers capable of both display generation and support of a computer-assisted instructional system, and large memories that can provide the extensive data base needed for producing realistic displays from prestored data. The compact size and low cost of the hardware now available makes possible a portable trainer that can be widely distributed to multiple fleet units and to reserve components.

DISPLAY GENERATION

The research effort in the development of low-cost AA trainers has concentrated upon training in the skills required to classify a target by its passive acoustic signature. The operator must analyze a display of the acoustic spectrum of the target to determine frequencies present and their harmonic relationship, then relate the frequencies to their sources in order to determine the type of target generating the signal. The most important component in a trainer to refresh experienced operators in performing this task is the presentation of a realistic display of what the operator would observe in the real world.

The key display used in passive acoustic analysis (PAA) is the lofargram, a graphic presentation of the time history of the frequency spectrum of the acoustic signal to be analyzed. The real-world situation that must be reproduced to create a lofargram is shown in Figure 2. The lofargram must include the effects of (1) the target-generated acoustic signature, (2) the propagation of the signature through the ocean, (3) ocean background noise, (4) dynamic effects such as relative motion between target and sensor, and (5) signal processing performed within the sonar set.

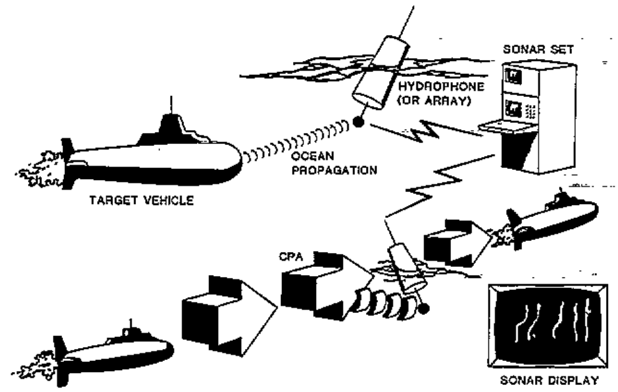


Figure 2. Components That Must Be Modeled.

Realistic Lofargrams

The method which creates the most realistic lofargram displays is the playback of acoustic recordings of actual sonar contacts into a sonar set. The lofargram produced by this technique is an exact replication of the real-world, but it has two disadvantages in application to trainers. First, the operational sonar sets are costly and are not portable, thereby limiting the use of operational equipment for training to use in situ or at a few training sites. Second, the operational equipment does not provide an instructional system or lend itself to the addition of an instructional system or a means of evaluating a student's performance. The design problem in implementing a low-cost trainer for AA is (1) to achieve the same degree of realism using less expensive equipment and (2) to provide an instructional system that can be used without the presence of an instructor.

The state-of-the-art in computers and graphics displays provides a means to provide such a low-cost system for AA training. The generation of realistic displays at low cost is achieved by effectively duplicating the display that is obtained by playing a taped acoustic contact into a sonar set. This process is shown in Figure 3. The taped acoustic signal is digitized and processed by a general-purpose computer which emulates the signal processing performed in the sonar set. The result is stored on a magnetic disk for later use by the AA trainer. Thus, the AA trainer does not model the real-world scenario, it uses a prestored lofargram that is an exact replica of the one produced on a sonar set.

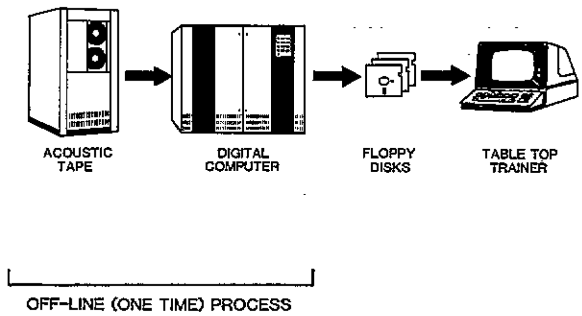


Figure 3. Preparation of Prestored Data.

Operator Aids

With the major part of the display-generation task reduced to retrieval and display of prestored data, the most computer-intensive part of the task becomes sensing of operator inputs and the generation of operator aids like those in a sonar set. The computer must accept inputs from a trackball and control pushbuttons and position cursor and reference marks in the appropriate position on the display screen. The primary operator aids are: (1) a frequency cursor which allows measurement of the frequencies of lines in the lofargram, (2) a multipoint cursor which allows determination of the harmonic relation of frequency lines in the lofargram, and (3) reference marks and annotations which the operator may add to the the lofargram display.

Synchronization with Aural Cues

AA training requires that the student be presented both a visual display of the processed acoustic signal and a synchronized aural signal. The aural signal is provided by playback of a copy of the original acoustic tape from which the visual display data have been derived. Synchronization of the visual display with the aural data is achieved by recording a two-channel version of the aural data tape, writing the aural data on one channel and a timing track on the other. The timing track is written under computer control by use of a modem, the device used for communication between computers via telephone line. The modem converts the data from the computer into an audio signal which is written on the timing track. Time codes are recorded at one-half second intervals, with each code sequence giving the time increment and the tape identifier. Thus, the timing track is used for both synchronization between the aural cues and the graphics display and for verification that the correct tape is being used.

## DATA PREPARATION

The preparation of prestored data for the trainer requires a hardware and software system capable of emulating the operations performed in a sonar set. The input to the preparation process is an analog recording of an acoustic contact in situ. The output from the data preparation process is (1) a copy of the analog recording to which a timing track is appended and (2) a data file containing the picture element by picture element intensity values needed to create a lofargram display.

### Signal Processing

The signal processing operations include the conversion of an acoustic signal presented in analog form into digital samples, simulation of the sonar signal processing operations in an sonar set to create frequency spectrum information, and quantizing of the data to represent intensity of individual elements on a CRT screen. Figure 4 shows a block diagram of these operations.

- Low Pass Filter. The analog signal is bandwidth limited in order to avoid aliasing.
- Digitize. The analog signal is converted into discrete samples for processing by the digital computer.
- Bandpass Filter. The digital signal is filtered to limit the signal to the frequency band of interest, and the sampling rate is reduced accordingly.

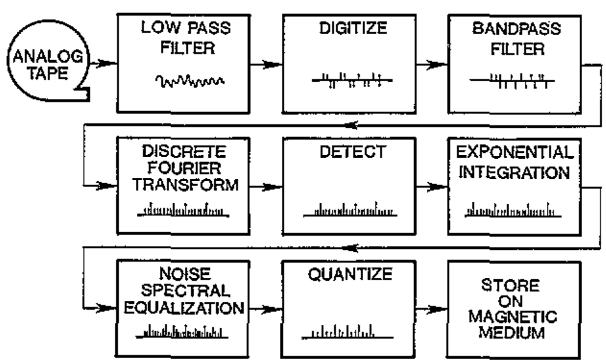


Figure 4. Signal Processing Functions.

- Discrete Fourier Transform. The Fast Fourier Transform (FFT) is used to convert the time domain sampled data into the frequency domain.
- Detect. The result from the FFT is detected by taking the sum of the squares of the real and imaginary parts of the Fourier transform (square-law detection) or by taking the square root of the sum of the squares (linear detection).
- Exponential Integration. The results of successive Fourier transforms are averaged to improve the signal-to-noise characteristics of the display.
- Noise Spectral Equalization. A local mean is determined for each frequency element, and the signal is normalized by dividing by the local mean.
- Quantize. The amplitude of the signal is quantized to eight levels simulate the operational equipment display characteristics.
- Store on Magnetic Medium. The result is saved on a disk file for use in the trainer.

### Hardware Implementation

The hardware for preparation of the prestored data base is that required to reproduce the acoustic input signal, convert the analog signal to digital form, and process the digital data to produce the PAA trainer data base. A block diagram of the signal processing hardware is shown in Figure 5.

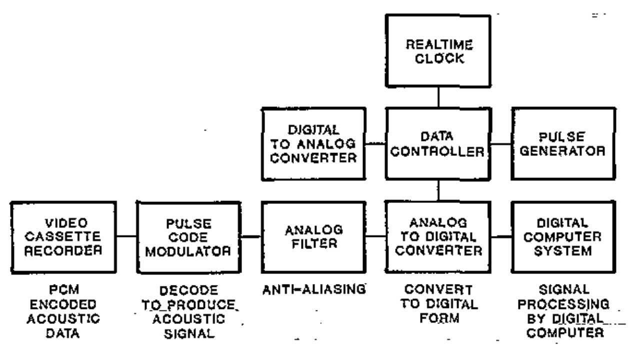


Figure 5. Signal Processing Hardware.

Analog Input Subsystem. Acoustic data for training scenarios are available from the Naval Sensor Training Aids Department (NAVSTAD). NAVSTAD, a division of the Naval Education and Training Support Center, Pacific, is the agency responsible for production and distribution of training tapes. NAVSTAD has supported research at the Naval Training Systems Center (NTSC) by providing acoustic data written on videocassette tapes by a pulse code modulator (PCM). The PCM method of recording acoustic data provides a frequency response from 5 to 20,000 Hz. with essentially no frequency variation due to modulation or to tape speed variation.

The analog input subsystem shown in Figure 5 consists of the equipment necessary to convert the information recorded on a video cassette by pulse code modulation (PCM) into a voltage signal required by the A/D converter.

- Video Cassette Recorder. The video cassette recorder (VCR) is the instrument used to read information from the cassette tape and provide the PCM signal for demodulation.

- Pulse Code Modulator. The Pulse Code Modulator converts the coded information into an acoustic signal that duplicates the original acoustic data.

- Analog Filter. An analog filter is used to insure that there are no frequencies beyond twice the sampling frequency present in the analog signal to be sampled.

Analog-to-Digital Conversion System. The analog conversion system samples the analog signal at prescribed intervals and stores the result in the digital computer. The conversion equipment is part of the digital computer system used for the signal processing, and the conversion is controlled by the digital computer.

Digital Computer System. The digital computer configuration used to perform the signal processing operations on the digitized converted acoustic data is shown in Figure 6. In addition to the peripherals normally associated with a general-purpose computer complex, the digital computer system includes an array processor used to increase the computation speed in the signal processing operations.

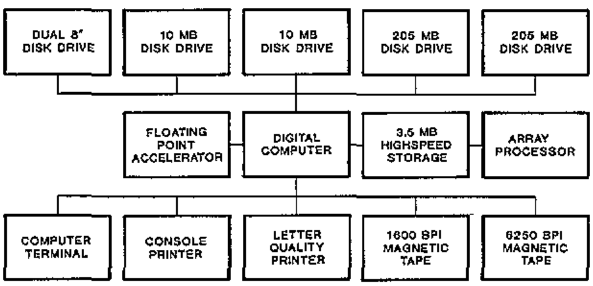


Figure 6. Digital Computer System Components.

DEVELOPMENT OF A PROOF-OF-CONCEPT MODEL

The NTSC was tasked in June, 1984, to implement a proof-of-concept model passive acoustic analysis (PAA) trainer for the AN/BQR-20,22 and 23 and AN/BQQ-3,5 and 6 sonar operators. This trainer is a generic model in that it does not duplicate the operation of a specific sonar set. Instead, it provides a trainer that has the basic features of the class of sonar devices for which AA training is to be provided. The trainer provides a means of training submarine sonar operators to analyze and classify various commercial ships, surface warships and submarines utilizing aural and physical classification techniques. This proof-of-concept trainer, which was designed, developed, assembled and tested at NTSC, was installed at SUBTRAFAC in June, 1986. Photographs of the instructor station and student station for this trainer are shown in Figures 7 and 8.

Figure 7. Photograph of Instructor Station

Figure 8. Photograph of Student Station

Hardware Implementation

The proof-of-concept trainer consists of an instructor station and 10 student stations interconnected by a local area network (LAN). The major components of each student station are a microcomputer system (CPU, memory, I/O interfaces, Winchester disk, and floppy disk), graphics display system (graphics controller and high-resolution monitor), audio record/replay system, audio communication equipment and computer network interface. The instructor station consists of a microcomputer station (like that in the student station, but with the addition of dual 200 MByte disk drives, line printer, and letter quality printer), a graphics monitor, a dual audio record/playback system, an audio switch, audio communication equipment, and a computer network interface. Block diagrams of the student station and the instructor station are shown in Figures 9 and 10.

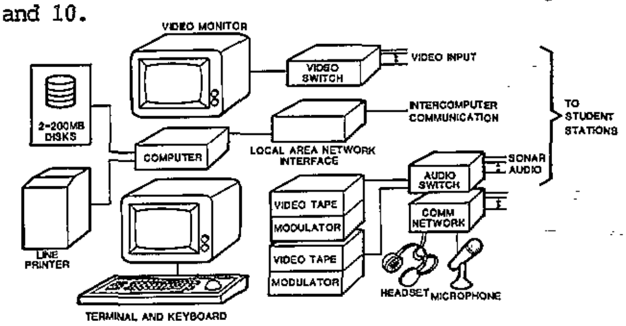


Figure 9. Instructor Station Components.

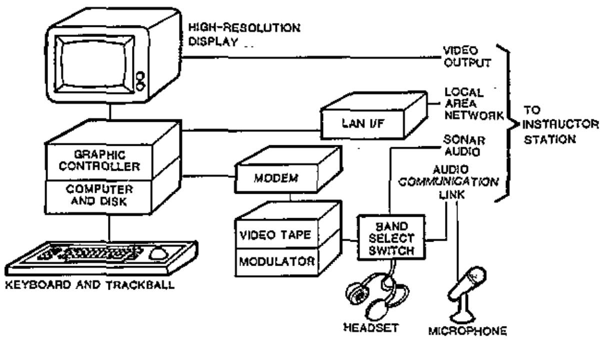


Figure 10. Student Station Components.

Trainer Operation

Prestored data for 200 training scenarios reside on the large removable disks. The normal mode of operation is for the instructor to assign one of two selected scenarios to each student station. The data for the assigned lesson is transferred to each student station via the LAN. The instructor then plays the audio tapes of the two lessons. During the transmission of the acoustic data from the instructor station, the student is able to monitor the audio signal and view the corresponding graphics display in any of the formats available: (1) low, medium and high lofar ranges, (2) two demodulated lofar (DEMON) ranges, and (3) a high-resolution vernier range. Once the initial transmission of acoustic data is complete, the student is be able to rewind the tape copy at the student station to any point and replay the scenario from that point, monitoring the audio and viewing the corresponding display for the mode selected. A video switch allows the instructor to view any student station display on the video monitor at the instructor station. An audio communication channel is provided to allow the instructor to communicate with any selected student station or to all student stations simultaneously.

## THE NEXT GENERATION

The next generation of table-top acoustic trainers will build upon the techniques developed for the proof-of-concept trainer. The next generation of trainers will provide (1) proportional resolution displays typical of sonar signal processors such as the OL-82 and the UYS-1, (2) displays and controls designed for platform-specific training rather than generic training, (3) training in active AA (AAA) in addition to PAA, (4) a richer variety of acoustic contacts tailored to meet curriculum requirements, and (5) a self-contained CAI system. A standard set of hardware will be used for all applications; specific training for the various platforms provided by software changes. Further, the hardware configuration will support part-task training in other areas. For example, a combination part-task trainer for AA and Inverse Synthetic Aperture Radar (ISAR) is being developed for training of aircrews.

Hardware Implemenation

Implementation of the next generation of AA trainers will incorporate improvements in technology to increase trainer capability and to reduce cost and weight, thereby providing a truly portable table-top AA trainer. The major change will be use of laserdisc storage for the data base, a plasma touch panel for the trainee interface, and a digital audio system.

Platform-Specific Training

The proof-of-concept PAA trainer implemented a generic example of a sonar system. The techniques developed for that trainer are being extended to make the displays and the operator interfaces platform specific. This requires modification of the signal processing algorithms, the cursors and trackball operation, and the operator interfaces. These are software modifications that will not affect the hardware configuration.

Signal Processing. The major change in signal processing will be creation of a logarithmic displays like those produced by the signal processing in the the UYS-1 or the OL-82. This will require more extensive processing than was needed for the proof-of-concept trainer. However, the basic processes are essentially the same, so the hardware configuration used for the proof-of-concept trainer will support the expanded processing requirements.

Trainer Software. The need for platform-unique displays requires a different set of software for each trainer application. This requires detailed analysis to determine what features of each sonar set will be provided in the table-top trainer and the development of unique software for each application. Approximately 30 per cent of the software will be platform unique.

Active Sonar

The next generation of AA trainers will include AAA. The research tasks described below will provide the technology to provide displays for AAA training, based upon prestored data, that are as realistic as those now provided for PAA training.

- o Determine what active sonar displays are appropriate for active acoustic analysis. Provide a description of the displays including operator controls and data content.

- o Study methods for using actual acoustic contacts to create prestored data bases to produce realistic active sonar displays for AAA. Determine the advantages and disadvantages of each method considered using appropriate metrics.

- o Develop algorithms to process the acoustic source data to create the ASW displays.

- o Obtain the source data needed to create active sonar displays for 10 ten-minute scenarios. (Currently available data may not permit the full population of all scenarios including all transmit modes).

- o Investigate and evaluate various hardware configurations to be used for an AAA. Implement the hardware configuration selected and the concepts developed to permit an evaluation of their effectiveness.

Synthetic Acoustic Contacts

Since the actual acoustic scenarios available for training are limited, there is a need to supplement these acoustic contacts with data generated by other methods. The method selected for new-term generation of synthetic contacts is the use of a stimulator, a device consisting of an acoustic signal generator controlled by a digital computer. This technique, illustrated in Figure 11, has been used in preparing synthetic acoustic tapes for use in the Aviation Antisubmarine Warfare Basic Operator Trainer (AAWBOT). This generation of synthetic acoustic tapes not only increases the number of contacts available for training, but allows the construction of scenarios to fit the training curriculum. In addition, synthetic acoustic tapes provide a means of providing advanced signature prediction examples based upon intelligence data on new threats.

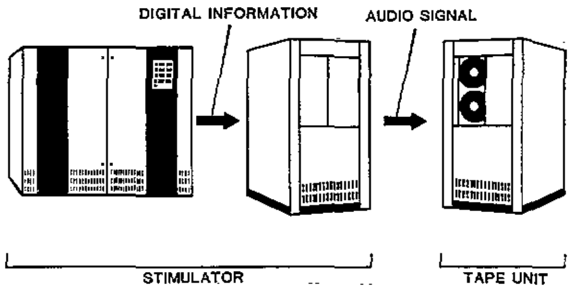


Figure 11. Preparation of Synthetic Acoustic Scenario.

The near-term means of satisfying the need for synthetic acoustic contacts is to use an off-the-shelf stimulator. The stimulator will be used in conjunction with the Common Acoustic Data Base (CADB), which describes those acoustic intelligence (ACINT) parameters considered to be necessary for developing useful ASW simulator/stimulator targets. This data base, being developed jointly by the NTSC, the Naval Underwater Systems Center (NUSC), the Naval Intelligence Support Center (NISC), and the Naval Surface Weapons Center (NSWC), is intended to support Navy needs in acoustic target simulation modeling for training device and operational equipment research, development, test, evaluation, and long term testing/training scenario applications.

The development of synthetic acoustic contacts is supported by an on-going research program to improve the realism that can be provided. In addition to an effort to expand and improve the CADB, the following research tasks are being conducted to improve sonar simulation.

Mathematical Modeling. Any improvement in the realism provided by synthetic generation of acoustic contacts depends on the mathematical modeling of the physics of (1) target noise generation, (2) propagation of sound through the ocean, (3) ocean background noise, and (4) other effects such as Doppler shift and interference patterns. Improved mathematical modeling, in conjunction with the CADB, is the basis for the following three tasks to increase the realism of the aural and visual presentation of acoustic data for training.

Stimulator Improvement. The stimulator used for generation of synthetic acoustic tapes will be improved in its capability to model and synthesize acoustic signals. The results of the research in mathematical modeling will be applied to the modeling portion of the stimulator to provide a more realistic definition of the acoustic output desired. The hardware which converts the computer output to acoustic signals will be improved to enhance the realism of the acoustic signal that can be generated.

Direct Lofargram Generation. In the generation of data for the table-top AA trainer, direct computation of the lofargram from a mathematical model offers a significant saving in processing time and an improvement in the realism of the final product. This method eliminates 90 percent of the signal processing required in generation of a data base from acoustic recordings. It also eliminates the signal degradation inherent in the processes of conversion of mathematical results into an acoustic signal, recording and playback of the acoustic signal, analog filtering, and analog-to-digital conversion.

Aural Signal Generation. The acoustic signal required for aural listening differs from that required for stimulating a sonar set or for input to a computer process to produce a lofargram. The aural signal must include biologic noise, and transient sounds such as hatch opening and bow plane or rudder movement. Research in the generation of sounds for aural listening will provide a method for producing synthetic acoustic recordings that include all of the sounds needed for training.

## Instructional System

The use of the table-top AA trainer for deployed applications requires an instructional system that can function without an instructor. The AA instructional system includes features for presenting training, managing training, and authoring instructional exercises. Features for presenting and managing training are incorporated in the table-top trainer itself. Authoring of training exercises is performed by a separate support system. Development of an instructional system will begin with the implementation of a simplified version for evaluation.

Trainer Functions. The trainer will incorporate the instructional functions necessary to perform the roles of both tutor and administrator in the traditional training process. The instructional system performs the functions required for communication between the trainee and the trainer, evaluating each student response and providing appropriate feedback to enhance learning, and scoring and recording student performance. The recording of student performance is particularly important, because it allows a supervisor to monitor student progress without being present during the training exercise.

Courseware Preparation. AA courseware will be developed in a central support system using hardware and software that is not part of the trainer. Authoring functions will allow the development of instructional exercises by an acoustic analyst rather than a computer operator.

Evaluation System. A simplified version of the instructional system developed for evaluation will allow the student to freeze, replay and otherwise control the acoustic scenario, provide instructions to the student, and evaluate student performance. This instructional system will (1) present a specific scenario for analysis, (2) allow the student to operate cursors and select displays in performing the analysis, (3) display questions about the analysis, (4) accept and evaluate student responses, and (5) provide remediation when the student response is incorrect. An authoring system will be provided to allow creation of a lesson sequence, entry of questions to be presented, and entry of hints or comments to be presented in response to student answers.

## SUMMARY

This paper has presented a description of a new generation of low-cost trainers for AA. These trainers are based upon using prestored data to provide realistic displays comparable to operation of a actual sonar set at sea. The key step is the preparation of a data base in a one-time, off-line process. This eliminates the need for mathematical modeling in the trainer, thereby reducing the trainer computational problem to retrieval and display of prestored data. The availability of compact, low-cost hardware to implement trainers using prestored data will provide table-top trainers that can be made available in the schoolhouse and to fleet and reserve units. The result will be more training opportunities for the new operators and a chance for experienced operators to retain their skills.

The first trainer using prestored data provides ten student stations and an instructor station. It was installed at the Submarine Training Facility, San Diego, in June, 1986. The data base delivered with the trainer consists of 200 acoustic scenarios, and this data base is being expanded as new scenarios become available. Five additional trainer suites, based upon this proof-of-concept model, are being procured for use at other training sites.

The next generation of table-top AA trainers will incorporate improvements in technology to reduce cost and to increase the trainer capability that can be provided. It will provide platform-specific training in a portable unit that can be deployed with fleet units. The use of prestored data will be extended to training in active AA. Methods of generating synthetic acoustic scenarios will be improved to provide the realism necessary for AA training. An instructional system will be added to allow training in a stand-alone mode without an instructor.

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