AD-A-267386

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
June 1993

3. REPORT TYPE AND DATES COVERED
Professional Paper

4. TITLE AND SUBTITLE
TACTICAL NAVAL APPLICATIONS OF ADVANCED 3-D DISPLAY TECHNOLOGIES

5. FUNDING NUMBERS
PR: CE31
PE: 0603707N
WU: DN308298

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Command, Control and Ocean Surveillance Center (NCCOSC)
RDT&E Division
San Diego, CA 92152-5001

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Chief of Naval Operations
Department of the Navy
Washington, DC 20350

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

A group of rapidly maturing technologies are coming together to permmit a new way of displaying and controlling information. The increasing speed and decreasing cost of high-resolution graphics computers is making it practical to generate complex imagery with acceptable realism in real time. Small high-resolution monochrome cathode ray tubes (CRTs) have long been used for military helmet-mounted displays (HMDs). Liquid crystal displays (LCDs) with acceptable resolution are just now becoming available. Both are finding their way into commercial stereoscopic display systems. Commerical versions of position sensors developed for military head-trackers are becoming increasingly affordable, and their use has been expanded to create three-dimensional (3-D) controllers. Finally, the newest technology on the scene is digitally modified sound that presents the operator with realistic 3-D binaural hearing. These 3-D and other diplay technologies are being studied for their application to tactical Naval operations at the Naval Ocean Systems Center which has recently been integrated into the new Naval Command, Control and Ocean Surveillance Center (NCCOSC) as the Research, Development, Test and Evaluation Division. Among the potential beneficiaries of this technology are airborne early warning and forward air control, platform and force level battle management, air traffic control, compact flight trainers and mission planners, and many aspects of anti-submarine warfare (ASW). This mission area is currently being investigated for the improvement of shipboard ASW sensor information displays.

Published in *Proceedings for the NAVAIR Third Annual Airborne Weapons Training Exposition and Technology Review*, January 1992, pp. 337–352.

14. SUBJECT TERMS
man–machine interface
decision support
virtual reality
decision aids/decision making
ASW
operability, operator functions

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAME AS REPORT

21a. NAME OF RESPONSIBLE INDIVIDUAL	21b. TELEPHONE (Include Area Code)	21c. OFFICE SYMBOL
D. Rousseau	(619) 553-9221	Code 442

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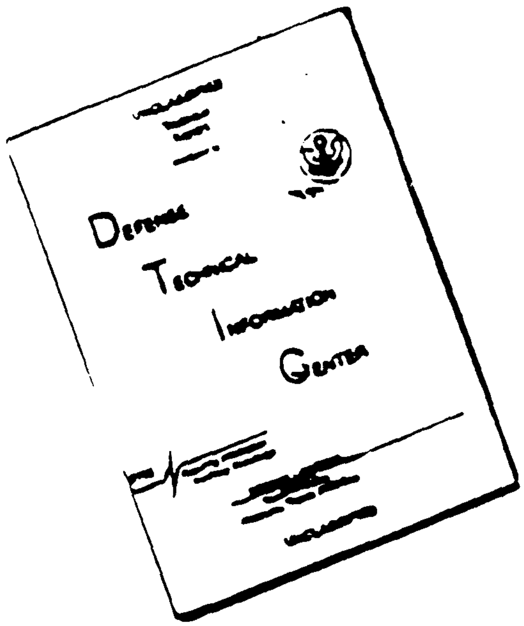

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Tactical Naval Applications of Advanced 3-D Display Technologies

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Introduction

A group of rapidly maturing technologies are coming together to permit a new way of displaying and controlling information. The increasing speed and decreasing cost of high-resolution graphics computers is making it practical to generate complex imagery with acceptable realism in real time. Small high-resolution monochrome cathode ray tubes (CRTs) have long been used for military helmet-mounted displays. Liquid crystal displays (LCDs) with acceptable resolution are just now becoming available. Both are finding their way into commercial stereoscopic display systems. Commercial versions of position sensors developed for military head-trackers are becoming increasingly affordable, and their use has been expanded to create three-dimensional (3-D) controllers. Finally, the newest technology on the scene is digitally modified sound that presents the operator with realistic 3-D binaural hearing. These 3-D and other display technologies are being studied for their application to tactical Naval operations at the Naval Ocean Systems Center (NOSC). Among the potential beneficiaries of this technology are airborne early warning and forward air control, platform and force level battle management, air traffic control, compact flight trainers and mission planners, and many aspects of anti-submarine warfare (ASW). The mission area currently being investigated at NOSC is in the improvement of shipboard ASW sensor information displays.

Discussion

It is known that performance with displays improves when operator workload is reduced[1, 2, 3] and that this effect is amplified by prolonged operations.[4] This is because reduction in operator workload frees up cognitive resources which can then be applied to other tasks such as improved decision making.[1, 2] Therefore, displays which minimize this work load should result in improved operator performance and improved decision making. The need, therefore, is for displays which present information in ways which take advantage of natural human perceptual and cognitive skills. Few display systems in use today are more abstract than those used to support the ASW mission area.

Sonar displays have not changed significantly for roughly ten years. Existing ASW displays present information that is frequently truncated, altered, or otherwise simplified due to limitations in data processing, or the physical limitations of the display devices themselves. Currently, diverse sources of information must be correlated by the sonar operator who creates a mental model of the multi-dimensional ASW environment. The majority of this mental image must be derived from multi-dimensional acoustic, physical, and temporal information that has been presented in a very abstract visual two-dimensional (2-D) format from a number of sources (Figure 1). This method of presenting complex, cross-sensory, multi-dimensional information on abstract 2-D displays may soon become obsolete. The application of new 3-D visual and audio display technologies to this problem could yield significant improvements in operator performance and operational effectiveness. These 3-D systems could present the critical tactical information in a far more intuitive and integrated way, thereby reducing the cognitive interpretation burden and learning time, while improving the tactical success rate over current systems. Figure 2 depicts the nature of the relationship between cognition, response time, and error rate. When the task of interpreting information is complicated, the response or reaction of the individual will be slower and the error rate will increase.

An advanced technology ASW display system could consist of, 1) the application of 3-D, stereoscopic, high-resolution, helmet-mounted or boom-mounted displays, 2) a 3-D position tracker (for the HMD) and 3-D manipulators for computer function control, 3) the incorporation of 3-D audio for presentation of multiple beams from the sonar for intuitive cuing and for correlation of acoustic transients and active returns to the ocean environment, and 4) the intuitive depiction of high-resolution computer-generated imagery of the ASW environment based on integrated display of active, passive, and environmental sensor information. The exact nature of the displays that may prove most effective are yet to be determined, but speculation unfettered by display constraints leads to some intriguing possibilities.

For example, in the active sonar mode the 3-D ASW display could provide the operator with a 360° field-of-regard image of the ocean bottom topography and water properties integrated with wave fronts representing the propagation of the sonar pulses (Figure 3). The operator would see these wave fronts being reflected off of the local topography and all known obstacles in that data base, and refracted by the model of the local water properties. The operator would therefore be able to see which returns are from known obstructions and compare that with the actual returns received by the sonar. Integrating this 3-D visual representation with acoustic analysis and cuing from the 3-D audio system would give the operator an intuitive picture of the ASW situation. Similarly, in the passive sonar mode the operator would be able to look around at real-time noise sources with cuing from the 3-D audio system (Figure 4). He could also view the sonar history over a desired time span for all bearings and elevations in a single 3-D volume (Figure 5). In each case any sonar beam could then be designated for spectral analysis.

Similar display approaches could be used for fixed site ASW facilities. Application of such a display system to airborne ASW is more challenging due to the strict size and weight limits of ASW aircraft, but computer size and weight are constantly decreasing. Many of the displays developed for surface ASW would be directly applicable to both airborne and ashore ASW. A few specialized displays may be added for such things as sonobuoy coverage however (Figure 6).

Significant enhancements to total system effectiveness could result, without redesign of other system components (e.g., sensors and sources of self noise). Recent experiments measured significant changes in sonar operator performance due to relatively minor modification of a standard sonar display.[5] These experiments were conducted under ideal signal-to-noise conditions and measured a multiple db loss due to a proposed fusion of data on a conventional ASW display.

As this research continues, new methods for presenting ASW information could arise that would make data relationships more apparent, increase situational awareness and enhance the quality of operator problem solving. This, in turn, may enable development of more sophisticated and effective tactics. Certainly, current tasks of target detection, localization, and classification would improve. Reductions in operator training and increases in retention could also be significant, and the effectiveness of each sonar operator could be multiplied as well.

This technology could also be applied effectively to ASW tactical support by providing the shipboard ASW officer (or submarine approach officer, Figure 7) with a 3-D image of the ocean environment, his weapons engagement envelops, sensor coverage volumes, and the hostile submarines that have been identified.

3-D display technology could also provide E-2C controllers with 3-D aircraft engagement information including launch envelopes, detection system coverage, etc. (Figure 8).

It could be applied to the display of battle management information (Figure 9) where location and status of assets determines weapons and sensor coverage.

A simpler application would be for air traffic control afloat or ashore (Figure 10) where only limited organic sensor information must be presented. Such a system might also benefit from the incorporation of real-time voice control of the communications system.

The Technologies

Four technologies are maturing sufficiently to permit a serious investigation of their operational use in an integrated information display system. They are high-speed graphics computers, miniature high-resolution displays, 3-D position sensors, and digital 3-D audio.

COMPUTERS

High-speed graphics computers are capable of generating acceptably realistic imagery that is updated fast enough to present an operator with useful information in real time. In the past, such capabilities were limited to massive and costly supercomputers. Fortunately the highly competitive nature of this industry continues to push cost down and performance up. Present high-speed graphics computers surpass the performance of these older machines at a fraction of the cost and size. A few years ago a small computer that could run at 5 million floating point operations per second (MFLOP) and generate about 6,000 polygons per second was the hottest thing on the market. Today that would be a "low-end" machine. The "high-end" graphics computers today run about 30 times faster (180,000 polygons per second) at a comparable price. All of these machines are using multiple processors to achieve these speed and cost improvements with large supercomputers now operating with thousands of processors. The next ten years will see a continued increase in performance with a corresponding decrease in cost and size. Today's high-speed graphics computers will seem slow by the time a 3-D display system is ready to enter the Fleet.

DISPLAYS

Miniature high-resolution displays evolved from weapons control and sensor display requirements for military aircraft. Much of this work was pioneered at the Naval Weapons Center at China Lake under the AGILE Missile program and by the Air Force at Wright-Patterson AFB. Although the Navy fielded the first operational helmet-mounted display (HMD), the most widely used of these systems can be found aboard combat helicopters. These systems now use cathode ray tubes (CRTs) as small as 0.5 inches in diameter with 1,000 line resolution. Approximately 875 to 1000 line resolution is required for "seamless" imagery in an HMD with an average field of view. By way of comparison, a photograph is approximately 4,000 pixels high. All of these small CRTs are either monochrome or black and white. There appears to be a technology barrier against making full-color CRTs of this size, although there has not been a strong military or commercial requirement to push small color-CRT technology.

Small monochrome CRTs from portable TVs are in use in boom-mounted stereoscopic displays. Unfortunately, the process of magnifying the imagery from these CRTs for a stereoscopic display with an average field of view causes resolution problems. The use of standard TV technology (550 line NTSC video) results in very noticeable black stripes across the image due to the return stroke blanking used in conventional raster scan video. The use of high definition TV would reduce or eliminate this problem, but the day that such displays are available in the small-portable market is a long way off.

Color active-matrix Liquid Crystal Displays (LCDs) for the miniature TV market are now being used for displays in the majority of the commercial stereoscopic systems. These displays have recently doubled in linear resolution to the point of being comparable with standard television resolution (LCD image height of 480 pixels vs. 500 lines of raster-scan video for conventional TV). Although this is a great improvement over the previous generation of 240 pixel-high LCDs, this resolution is still low enough that the image appears very grainy when magnified as part of a stereoscopic display system. Unfortunately, higher resolution LCDs are not likely to emerge from the commercial market unless the demand increases by several orders of magnitude. The technology for creating a 1.0 inch diagonal 1,024 x 1,024 pixel active-matrix color LCD is available, but the fabrication costs are estimated to be about $1 million dollars for the process development and production set up.

3-D POSITION SENSORS

The most prevalent 3-D position sensor system in use today is the Polhemus tracker. This device uses a magnetic field generator affixed to the local environment and a field sensor attached to the device to be monitored. A computer system monitors the field sensor and calculates the position and attitude of the sensor based on the nature of the portion of the magnetic field in which it is immersed. These units are small and rugged, but they are sensitive to the presence of ferrous metals which can distort the magnetic field geometry. Work is being done to reduce this problem and to speed up the operation of the system. Other position trackers are now reaching the commercial market however. One unit uses multiple ultrasonic sensors and sources to monitor position and attitude. An analogous multi-element infrared system is also available. These systems are not sensitive to electromagnetic interference, but they do have their own limitations. The Polhemus system is the only one that is currently incorporated into 3-D control devices.

3-D AUDIO

Of all the technologies that are supporting the ability to effectively display information in 3-D, this is perhaps the newest. It is an outgrowth of research into human auditory perception.[6, 7, 8] Initial research demonstrated the importance of the shape of the outer ear to the localization of sounds. Subsequently, the ability to modify sounds using experimentally derived transform functions was achieved. The transform functions were derived by measuring the distortion of known broad-band sounds due to outer ear shape. An undistorted sound, after processing by a transform function incorporated into circuitry, would seem to have emanated from any desired location. This made it possible to alter a sound so that it would seem to have come from any chosen location in space external to the listener. Recent work at NASA, Ames resulted in these transforms being incorporated into digital circuitry and married to computers that could simultaneously monitor the orientation of the operator's head (using a Polhemus tracker) and transform a sound so that it would seem to be stationary while the operator moved. NOSC has the first advanced digital system of this type and is conducting research into its application to various operational tasks.

Conclusions

These technologies are already being applied to numerous civilian tasks including architecture, mechanical design in the automotive and aerospace industries, pharmaceuticals research, medical imagery for 3-D display of CAT scan, NMR, and ultrasonic medical data, education, and functional aids for the handicapped.

If these new technologies are applied to the tactical Naval environment their impact on operational effectiveness could be dramatic and their impact on training methods and systems may be equally dramatic.

History has taught us that the requirement to operate a global Navy will not diminish at a rate commensurate with the decrease in our assets. Budgets and manpower levels will probably continue to decrease over the next decade or two. Therefore the workload for each person will increase, and the tactical cost of loosing one platform out of a reduced inventory will be magnified. Systems that can improve operational performance while requiring lower manning will be critical and those systems that can achieve the greatest performance improvements at the lowest cost will be essential.

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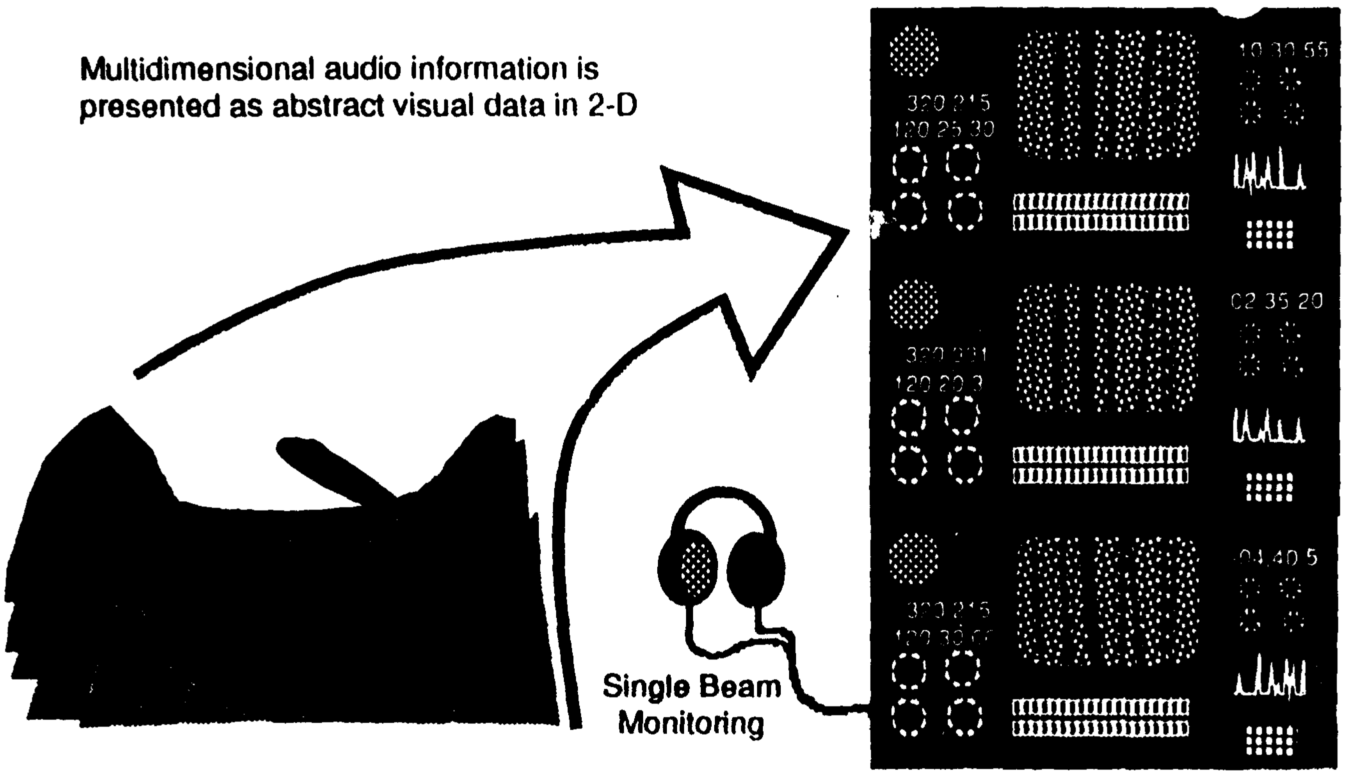

Figure 1. Existing ASW Display System.

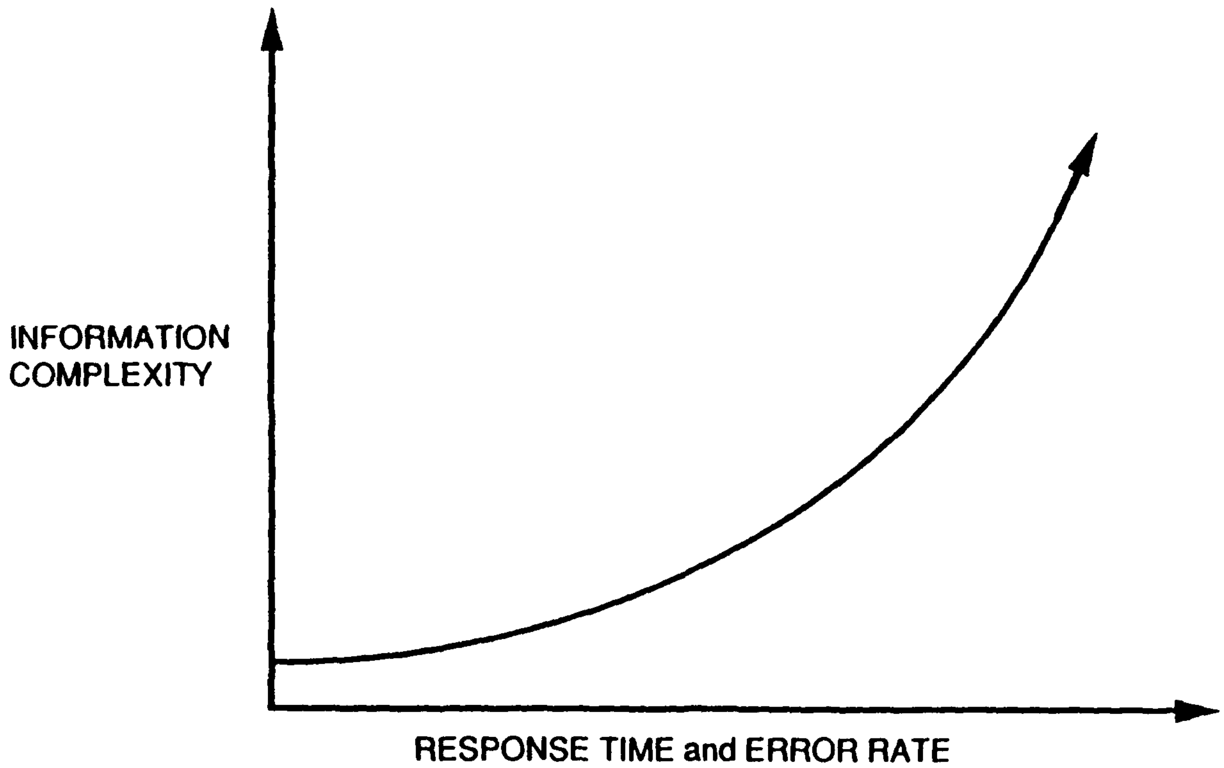

Figure 2. Relationship between information complexity and human performance

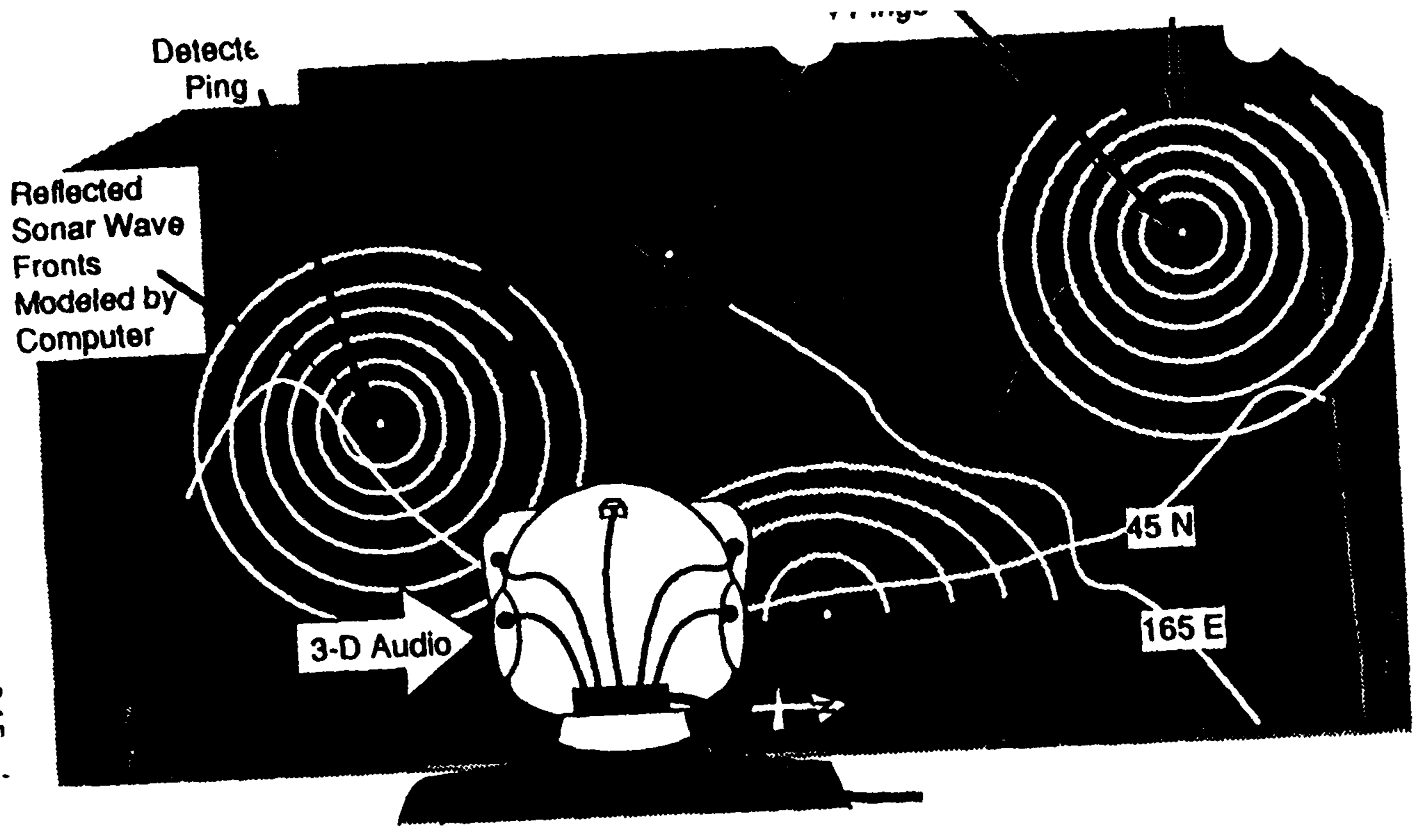

Figure 3. Possible 3-D Active Sonar Dislpay

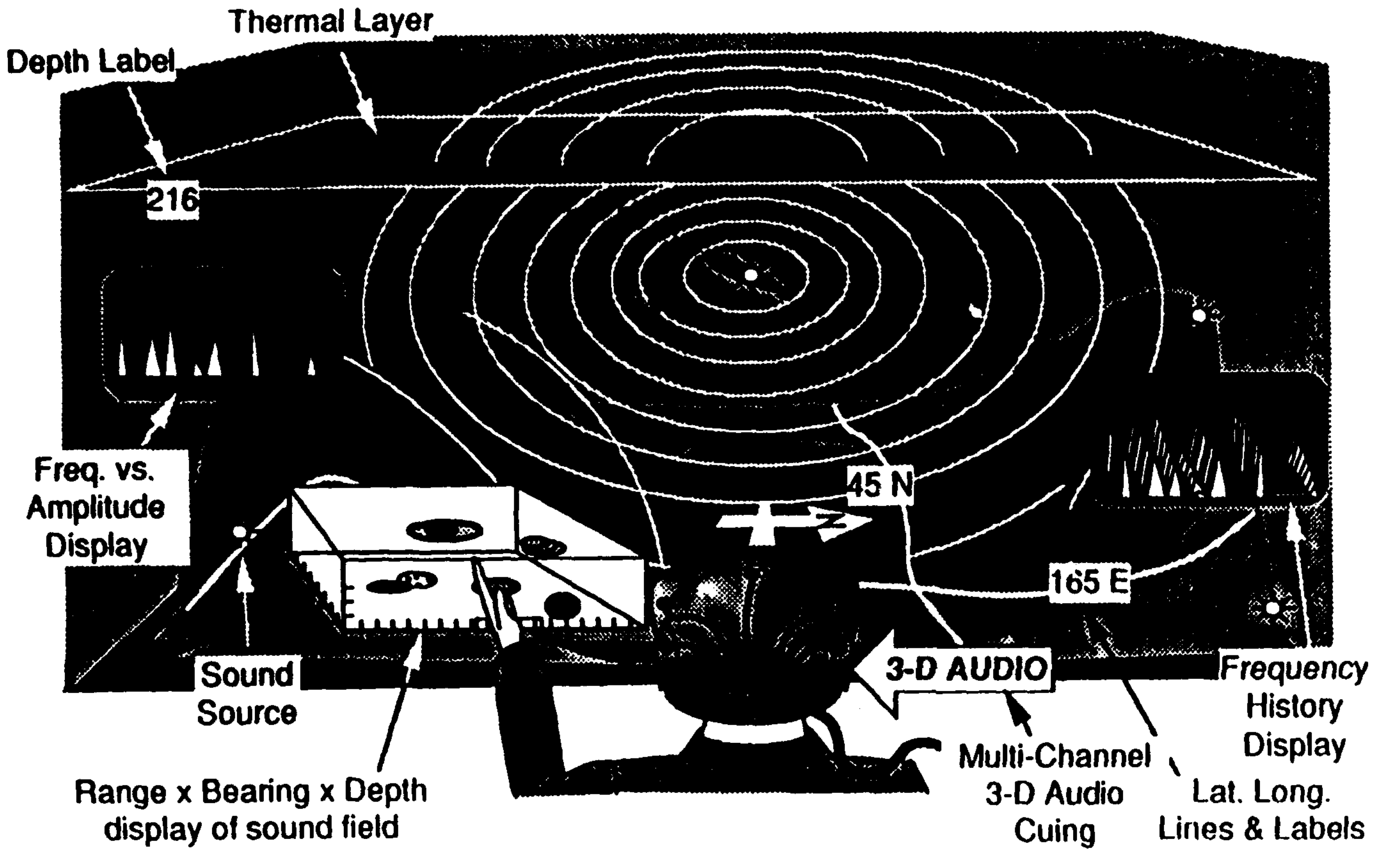

Figure 4. Example passive real-time ASW display.

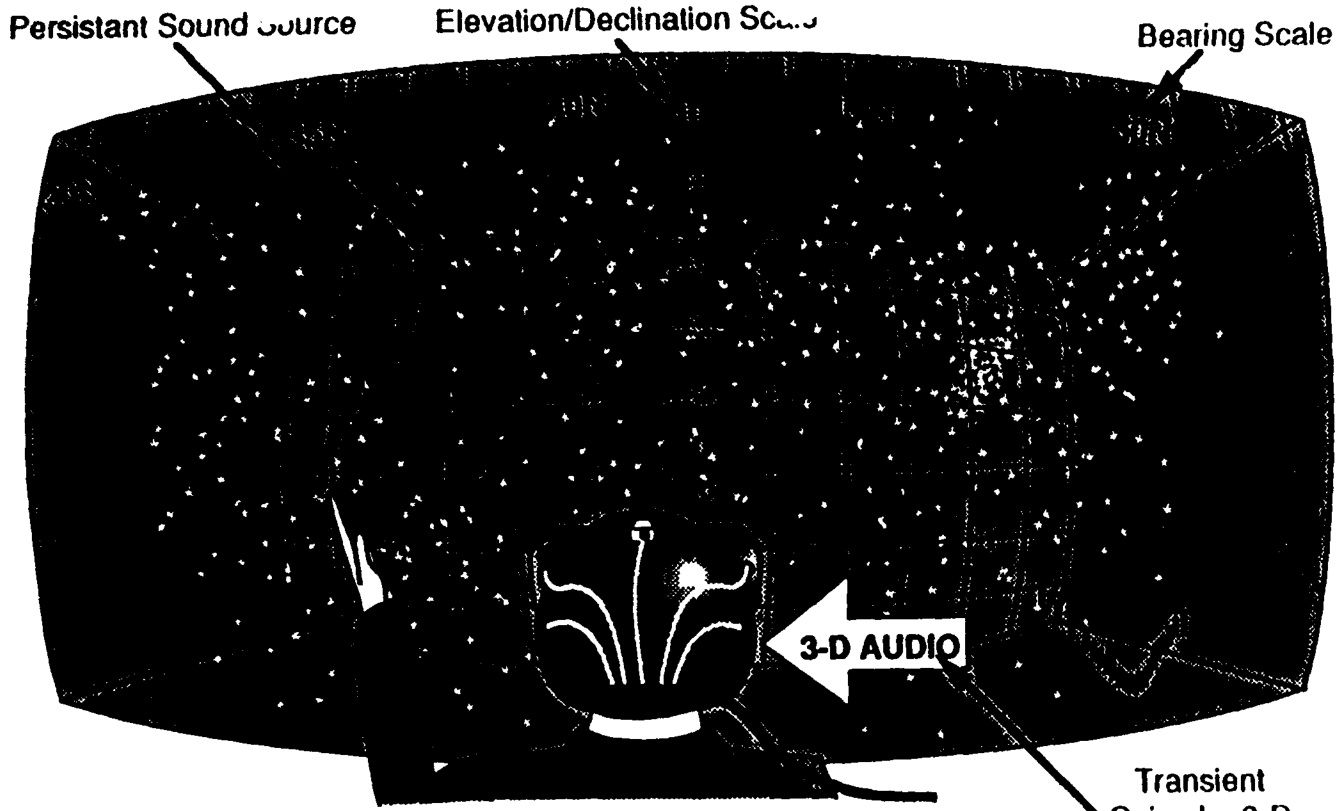

Figure 5. Passive Acoustic History Display
(older data is farther away & current data is in front at the grid).

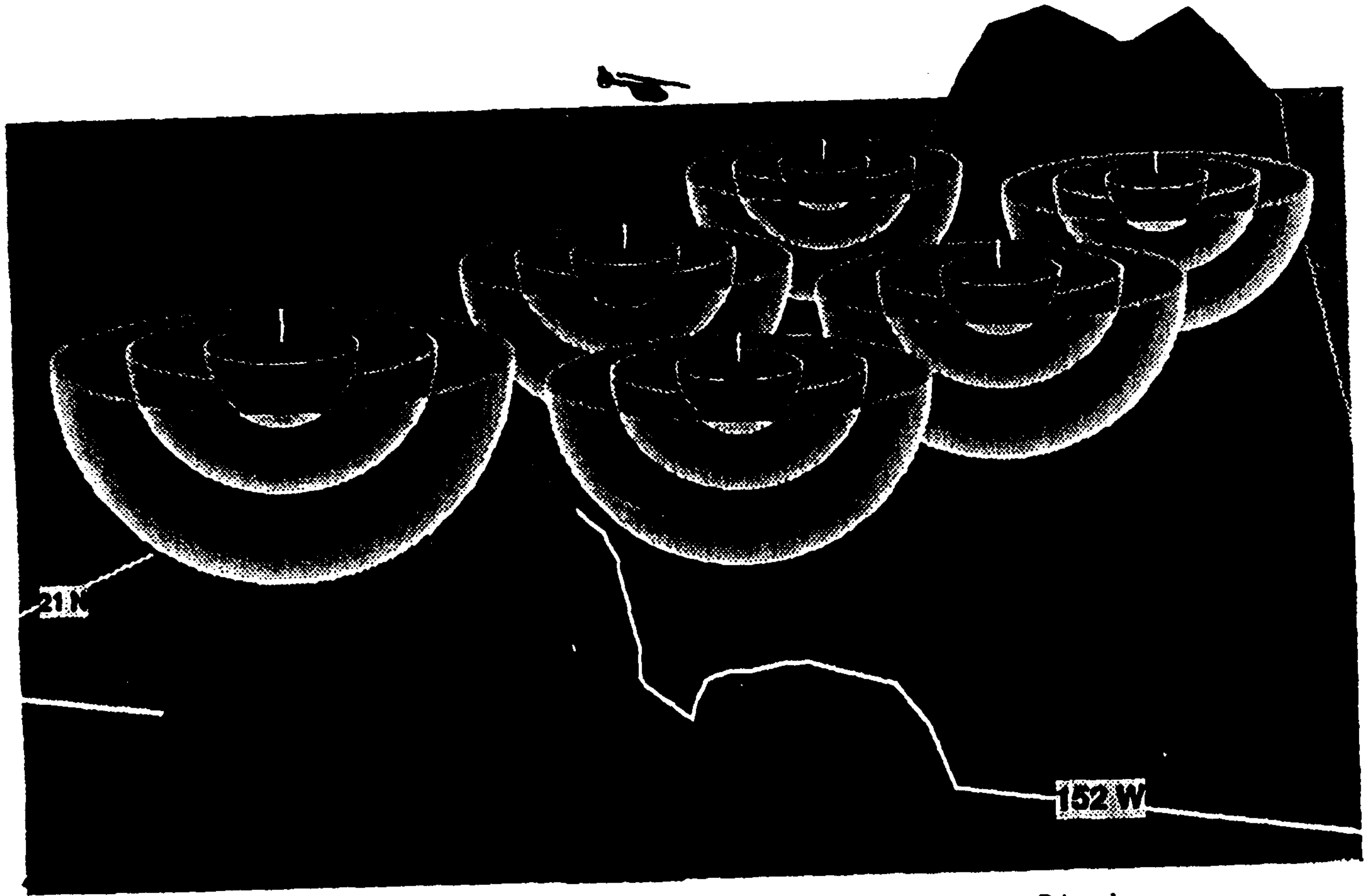

Figure 6. Example of a Sonobuoy Field Coverage Display

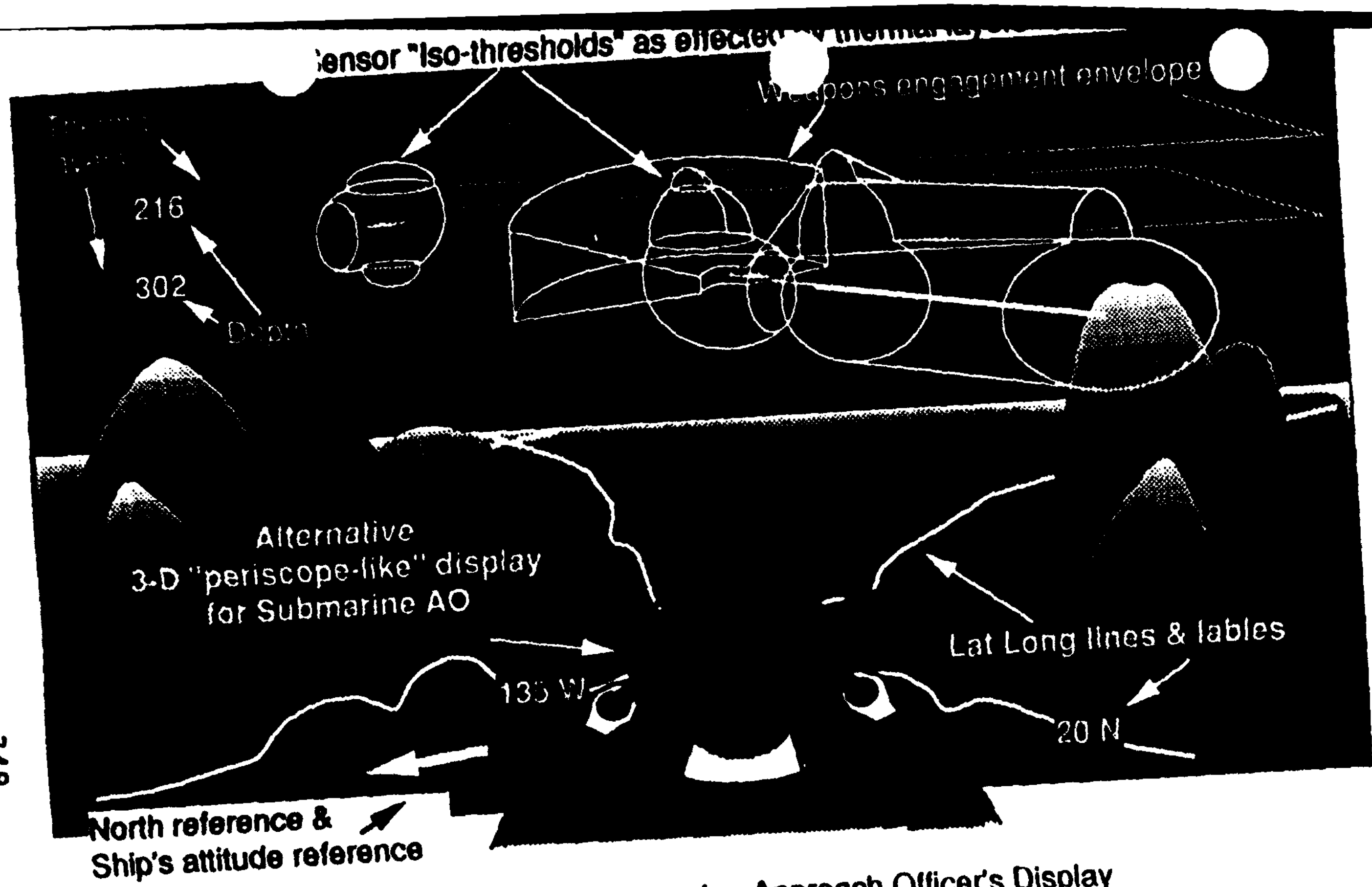

Figure 7. Example Submarine Approach Officer's Display

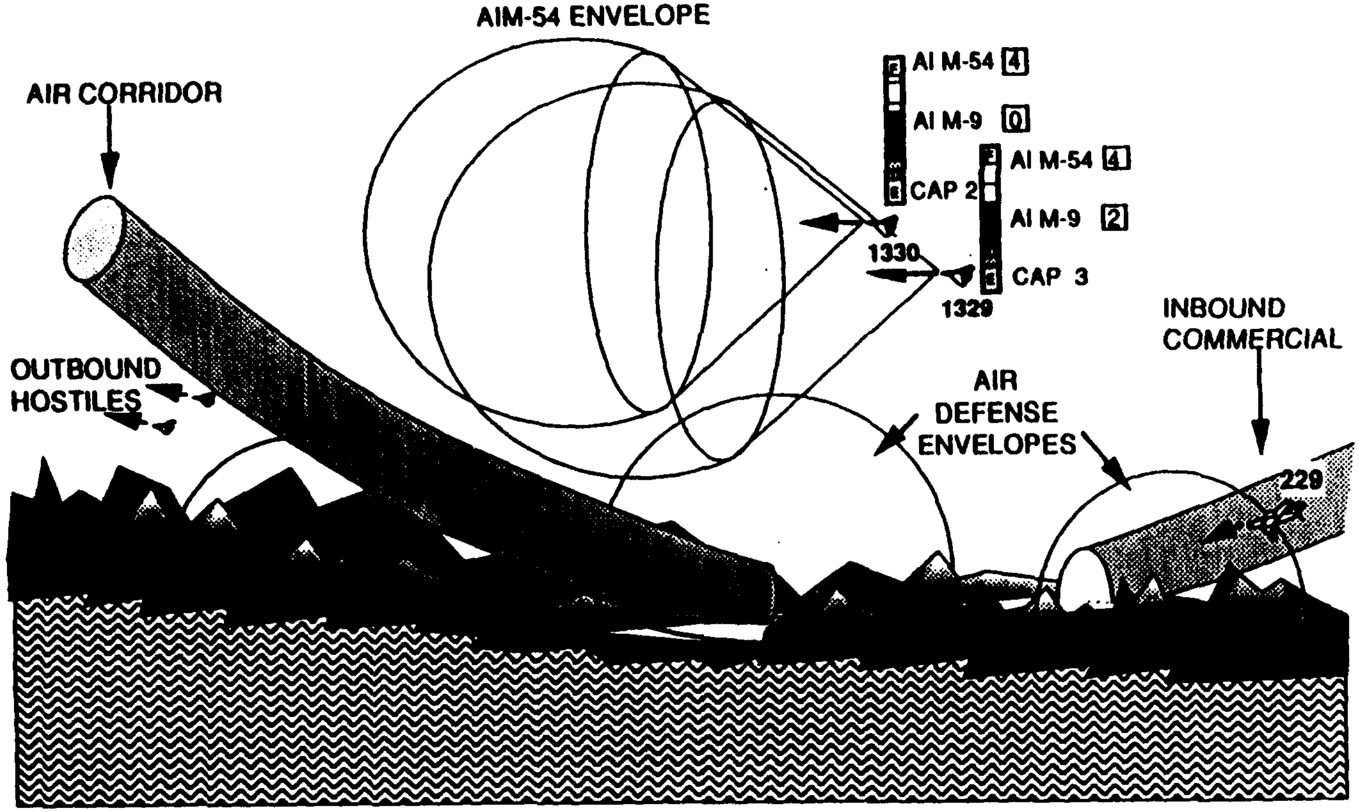

Figure 8. Sample AAW imagery aboard E-2C.

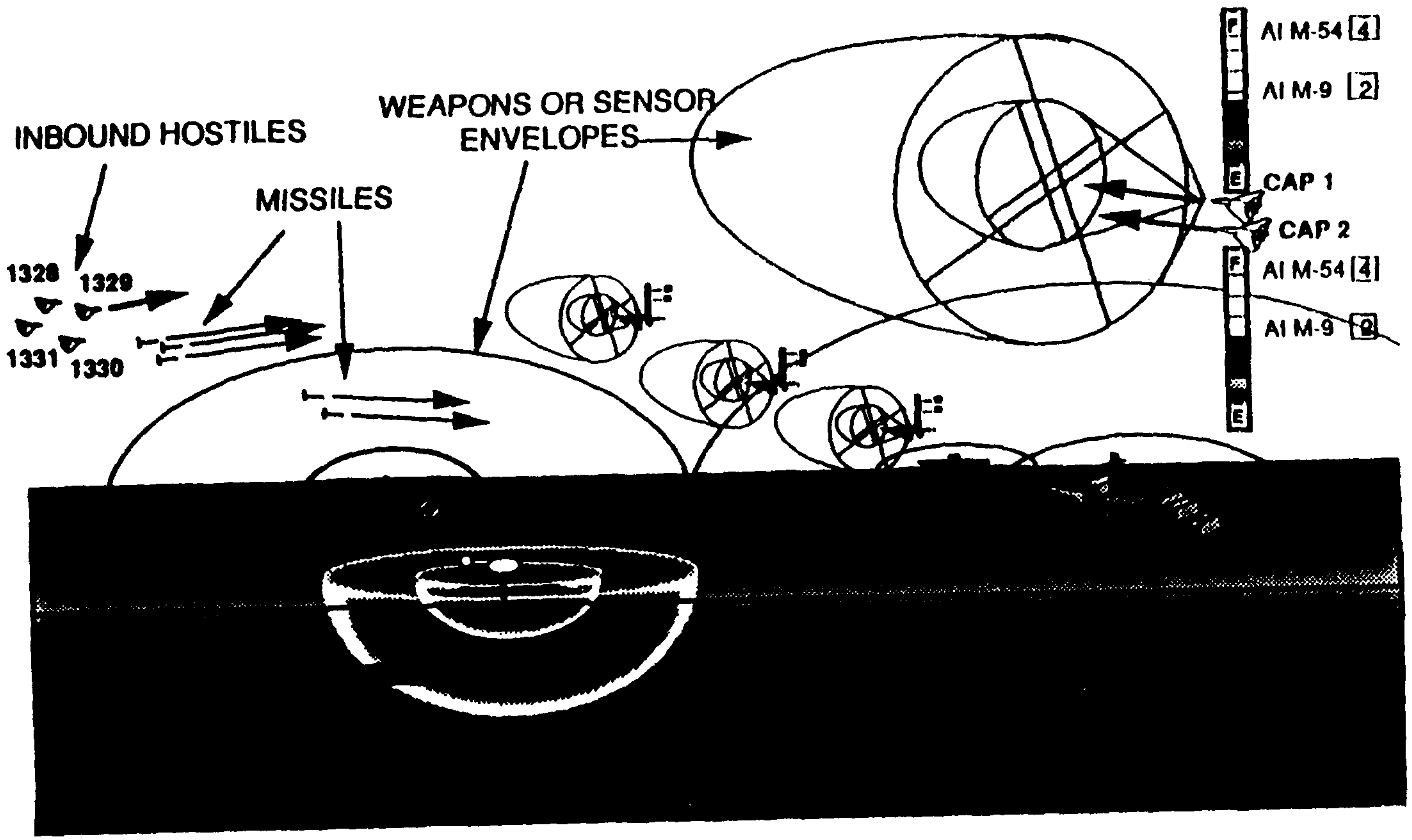

Figure 9. CVBG Tactical Situation Display.

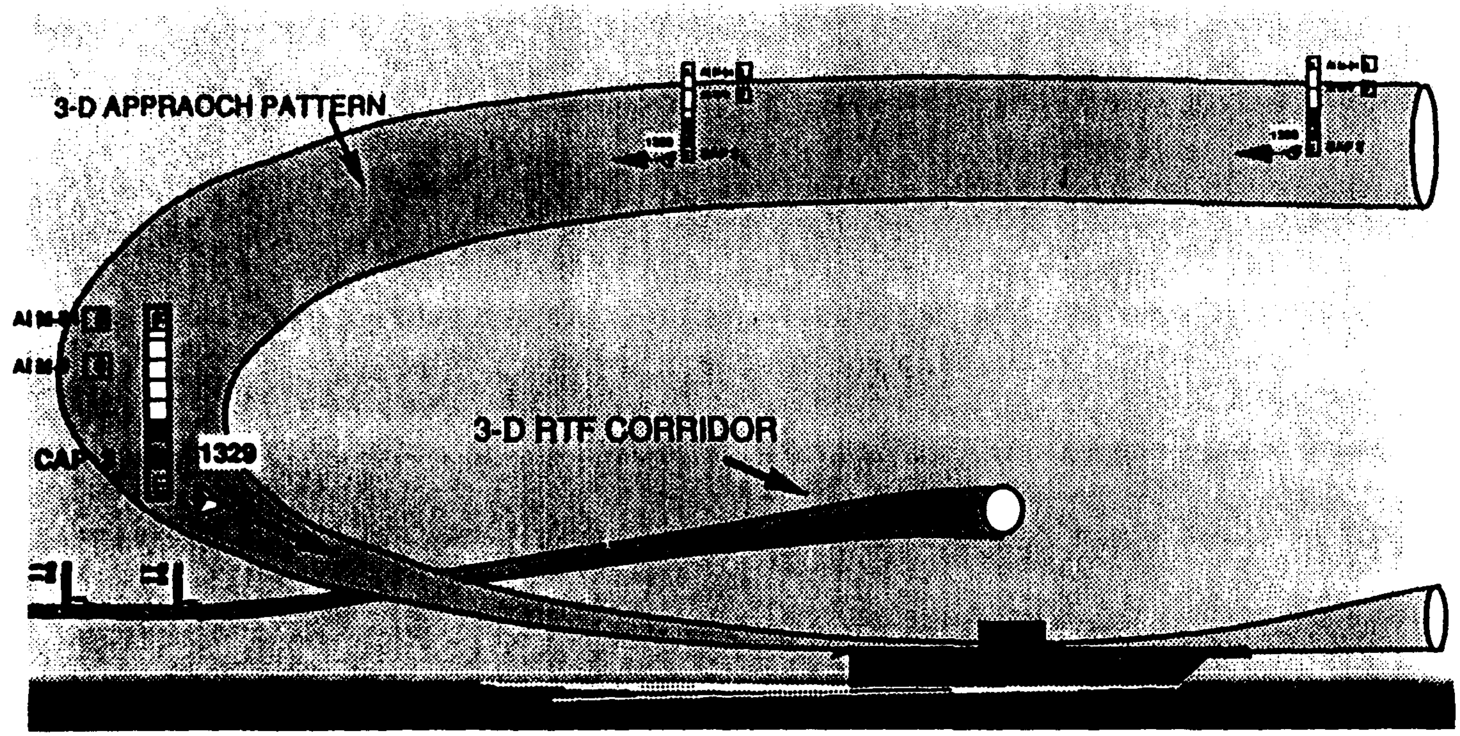

Figure 10. Sample Approach Control Display.