NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

DESIGN APPROACH FOR A COMPUTER GRAPHICS SYSTEM APPLICABLE TO TORPEDO TRACKING AND EVALUATION

by

Lee Neal Schofield

June 1975

THESIS ADVISOR: V. MICHAEL POWERS

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Design Approach for a Computer Graphics System Applicable to Torpedo Tracking and Evaluation		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis June 1975
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Lee Neal Schofield		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE June 1975
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Postgraduate School Monterey, California 93940		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This paper presents a design approach and specific considerations for a dedicated, real time, interactive, computer graphics system to be used in the tracking and evaluation of torpedoes utilizing an input from a three-dimensional tracking range. The basic parameters for making output, software and hardware decisions are presented with alternative examples given in each area of the design process.

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(Page 1) S/N 0102-014-6601 |

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Design Approach for a Computer Graphics System Applicable to Torpedo Tracking and Evaluation

by

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requirements for the degree of

MASTER OF SCIENCE IN COMPUTER SCIENCE

from the

NAVAL POSTGRADUATE SCHOOL
June 1975

ABSTRACT

This paper presents a design approach and specific considerations for a dedicated, real time, interactive, computer graphics system to be used in the tracking and evaluation of torpedoes utilizing an input from a three-dimensional tracking range. The basic parameters for making output, software and hardware decisions are presented with alternative examples given in each area of the design process.

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I. INTRODUCTION

The area of interactive computer graphics is one of the newer developments in the computer field, starting in the early 1960's with Dr. Ivan Sutherland at M.I.T. Lincoln Laboratory. The rapid development through various laboratories since then has lead to a rapid proliferation of both hardware and applications within the last five years. Uses have been found in electronic circuit design, highway construction design, flight simulators and numerous other examples that require decisions based on the relative positions of lines and points.

The system design approach presented here is general and could be applied to many types of computer graphics applications to tracking problems. The specific design alternatives have been structured toward a feasible system design for use at the U.S. Naval Torpedo Station, Keyport, Washington.

This application to torpedo tracking and evaluation concerns the display of a three-dimensional torpedo testing range, showing the vessels on that range and providing the range operator with the required information so that he can conduct a safe and productive torpedo evaluation.

II. PROBLEM DISCUSSION

A. NATURE OF THE PROBLEM

The general requirement of the tracking system is to provide information about several vehicles on the range. The Range Operator will use this information to assure the safety of the boats on the range, the target vehicles and the torpedoes. A second requirement is conducting the torpedo run within the confinements of the run plan and collecting useful data for post-run analysis.

The display should provide additional evaluation aids if required by the operator or on-site technicians to determine the effectiveness of the run and recommend the run be continued, altered or aborted. The display does not need to be complicated but should provide an experienced operator with real time, technical, meaningful information without sacrificing usefulness to the untrained observer.

Operator fatigue must be considered in the system design since the operator could be on the job up to eight hours at a time. Body movement and eye movement should be kept to a minimum with all controls within easy reach and the information compact.

In summary, the Range Operator needs a display system that quickly provides the necessary information and:

- is easy to read,
- requires minimal eye and head movement,

- has positive control within easy reach,
- requires minimal interaction of the operator,
- provides fast reaction capability for additional information.

B. PROPOSED SOLUTION

The use of a real-time, interactive, graphics system will satisfy the previous requirements. It provides a compact, versatile display which allows the operator a three-dimensional representation on a two-dimensional CRT screen with multiple independent views of the range and the interactive capability to:

- select range viewing angle (including top and side views)
- select a portion of the range to be viewed,
- determine speed and rate of climb or dive of the vehicle,
- determine such critical facts as closest point of approach (CPA) to other vessels and relative positions in the range area,
- alert the Range Operator to potentially dangerous situations.

Computer graphics is the current state-of-the-art in display technology and offers a wide range of hardware and software. The growth potential and versatility of computer graphics will insure an extended useful life of the system.

III. SYSTEM DESIGN

Systems design is an iterative process of working toward an optimal design which will meet all the user requirements and remain within the design constraints.

The method which was taken in the following system design, as shown in Figure 1, is to identify the output requirements then consider the software and hardware components with the interfaces between each component. The interface between the user and the software consists of the requests and replies displayed on the CRT, hardcopy plotter, line printer or magnetic tape. The interface between the hardware and software consists of the instruction set of the selected computer plus any restrictions associated with the peripheral devices.

Feasibility studies using an analytic model or system simulation would determine if the system as designed will produce the desired results or if changes can be made to improve the system. Queue lengths, bottlenecks and run times can be estimated and from these it can be determined if an acceptable reaction time is possible.

Some factors governing the design of this system are that it will be a real time, dedicated system with one primary user program. The system should have some time-sharing capability since multiple, independent terminals will be used with the Range Operator having priority.

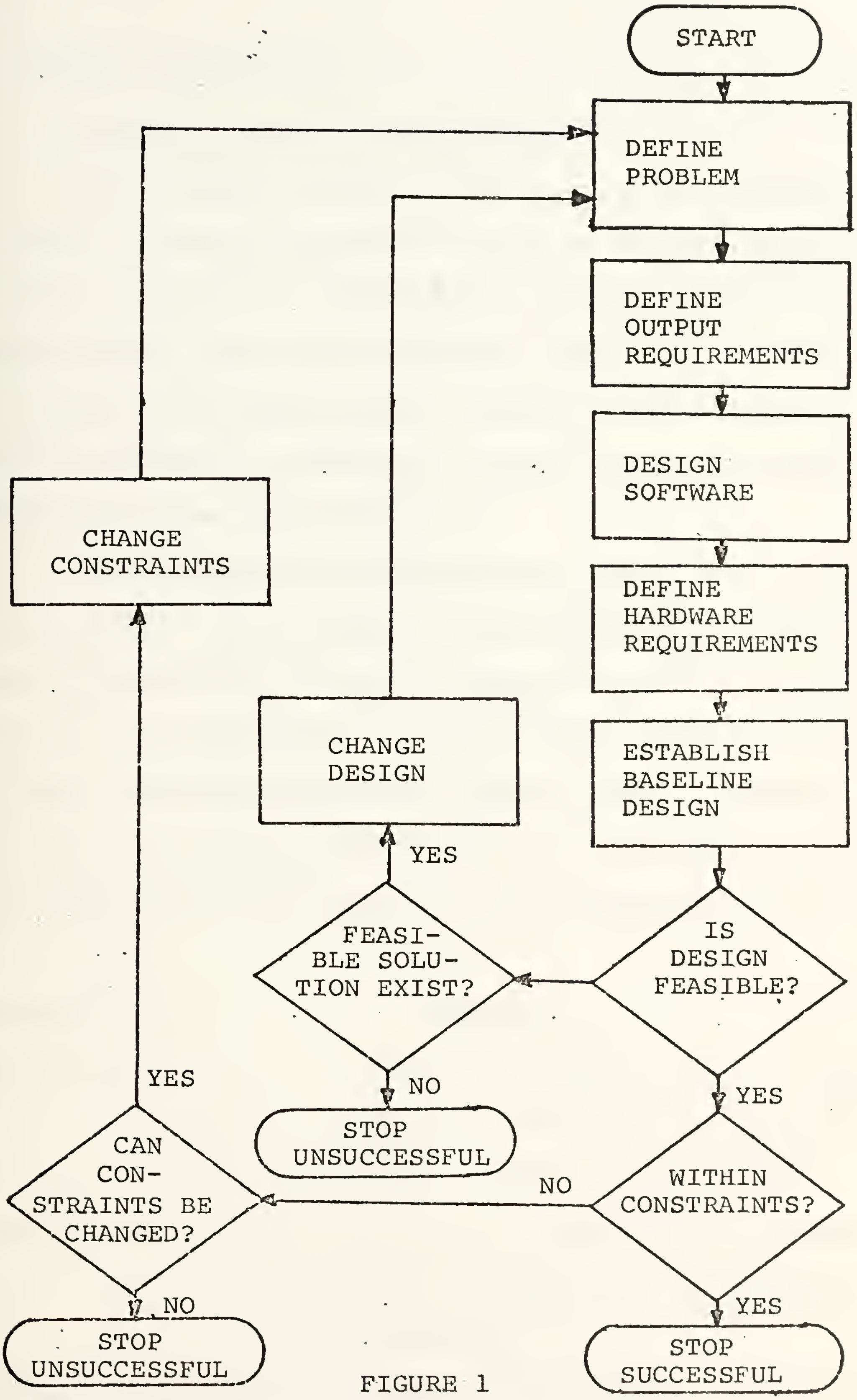


FIGURE 1
SYSTEM DESIGN ALGORITHM

A. OUTPUT REQUIREMENTS

1. Display Design Considerations

The graphics output display should be designed around the user's need for information with consideration given to the past solution to these needs to establish the information requirements. Once the information requirements have been determined, the technological ability of the proposed system must be explored to determine the most efficient method of satisfying these requirements.

Established design parameters should be followed whenever possible. The following list of design parameters are based on Reference 1, and its numerous charts and tables. Some of these parameters are obvious and some are designed into most available hardware. These display parameters can be used in the display design and as a basis for desired characteristics in the selection of a graphics display terminal.

Parameter	Comment
Display size	- limited to state-of-the-art design. At this time most displays are between 144-400 square inches.
Character size	- set by the manufacturer depending on the screen size and character font available.
Brightness/Contrast	- ratio of 2:1, display: ambient for brightness and up to 10:1 for contrast.

Resolution - a measure of the number of separately addressable positions on the coordinate grid. If a ten inch display has 1024 addressable points along each axis, then the resolution of the deflection system is 1024/10 or 102.4 points per inch.

Viewing Distance - 18-30 inches.

Viewing Angle - not smaller than 45°, optimal 60° - 90°.

Type of Coding (i.e., color, alphanumerics, symbols)

(1) Coding should be used:

- when a variety of information must be presented in a single display.
- when the observer's task may be difficult.
- when the observer must respond quickly (in less than ten seconds) coding is required.

(2) Recommended practice

- use alphanumerics when identification is most important.
- use color when searching or locating is most important.
- use symbols/shapes when qualitative objects are represented.

(3) Alphanumerics vs. color coding

Alphanumeric coding is particularly useful when the observer's task is largely identification of a character set. Outside of the particular advantage color codes have for locating the desired character set (shorter search time) alphanumerics are about as effective as color codes. In addition, they are much less expensive and less technically difficult to display than color codes.

(4) Other types of codes

- size coding - identify characters by size or line thickness. Effective for only three different sizes.
- brightness coding - most effective when limited to two steps, dim and bright.
- warning lights - used to warn of actual or potential danger. Should be limited to only one. If several warning lights are required, use a master warning or caution light and a word panel to indicate specific danger conditions. Flashing lights should be reserved only for extreme emergencies.

Character/Background relationships

- Light symbols on a dark background are recognized more accurately under low ambient lighting. Dark symbols on a light background are recognized

more readily under medium and high ambient illumination. For intermediate values of symbols and background brightness, the direction of contrast is not significant in legibility.

Frame rate - set by equipment at about 30-40 frames per second.

2. Display Format Design

In the design of the display format several types of trial displays were programmed on an ADAGE AGT - 10. Some of the more immediate problems encountered were:

- How should the range itself be displayed?
- What type of track display for the vehicles being tracked gives the required information?
- What type of coding should be used to distinguish between torpedoes or between torpedoes and targets?
- How much information is necessary for the operator to perform his job?
- How much interaction can the range operator use effectively and how can this be achieved with the minimum interference?
- How is input data identified?

A discussion of these problems appears in the following sections, and some alternative approaches are presented.

a. Range Design

In an underwater tracking situation which involves working inside the defined space rather than outside the space as in the tracking of airborne vehicles, the displayed range boundaries must accurately define the range limits and also leave the area as open as possible so that the relative positions of the vehicles' tracks and range limits are unobscured.

Realizing there are many ways to represent a closed area, the problem is in deciding which representation will be the least complicated to understand and at the same time adequately define the range. Several approaches were taken, from a complete bottom contour of the range to the simple box design that defines the safe region in which the vehicle can maneuver freely.

The safe region is to be defined to allow for the reaction time of the operator and the vehicle to recover or abort the run before the vehicle actually hits the bottom or an obstacle in the range.

The 3-D "wire frame" display as shown in Figure 2, is an uncomplicated way of showing the safe region of the range and can be proportioned to fit any range situation while still making maximum use of the display area. The sea mound and shallow area define unsafe regions and also help to orient the range.

Any one or group of the defining lines can be displayed as solid, dashed, points or a combination of these depending upon the type of display terminal. The intensity

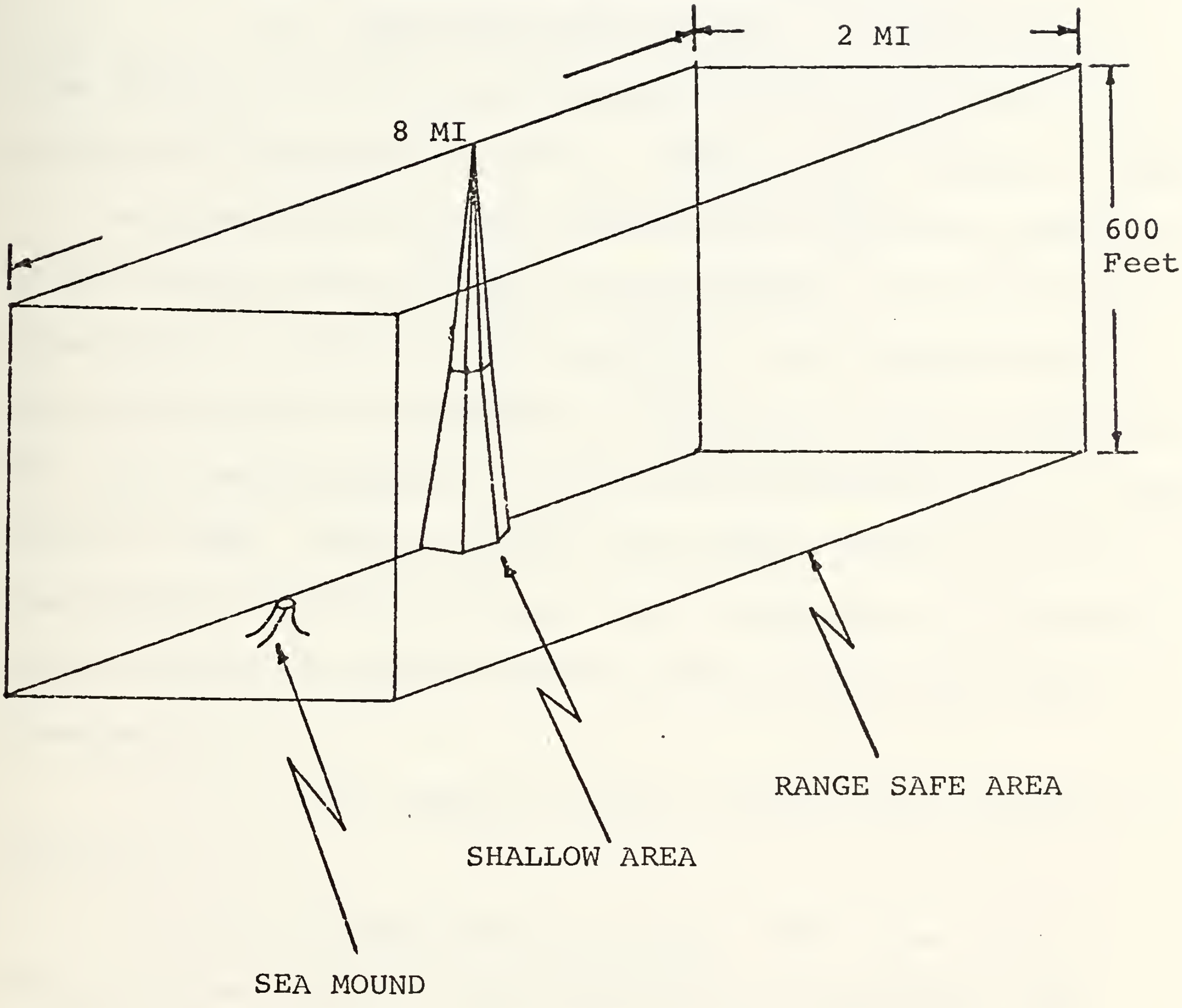


FIGURE 2
3-D WIRE FRAME RANGE DISPLAY

can also be varied. The desired combination of line type and intensity can be very effective in enhancing the 3-D aspect of the display and still allow the operator good judgment of the relative positions of the vehicles.

b. Types of Vehicle Track Displays

(1) Continuous Line Display. The continuous line display connects the data points with a line and gives a continuous line from the time of launch until recovery. This is a very definitive type of display and allows the operator a view of the past maneuvers of the vehicle. The major disadvantages of this type of display are the storage required for the many points generated in a long run and the confusion the track would generate if the vehicle doubled back on itself several times. This confusion and storage problem would be compounded if several vehicles (i.e., torpedoes, two targets, launch vessel and recovery boat) were being tracked simultaneously.

An example of this type of track is shown in Figure 3.

(2) Comet Effect Display. The "comet effect" display shows only the last few minutes of generated data points. The number of points displayed is arbitrary or could be variable depending on the vehicle being tracked but two minutes of data would probably be sufficient. This would give the operator enough points to indicate whether the vehicle is in a turn, diving, climbing or continuing on a

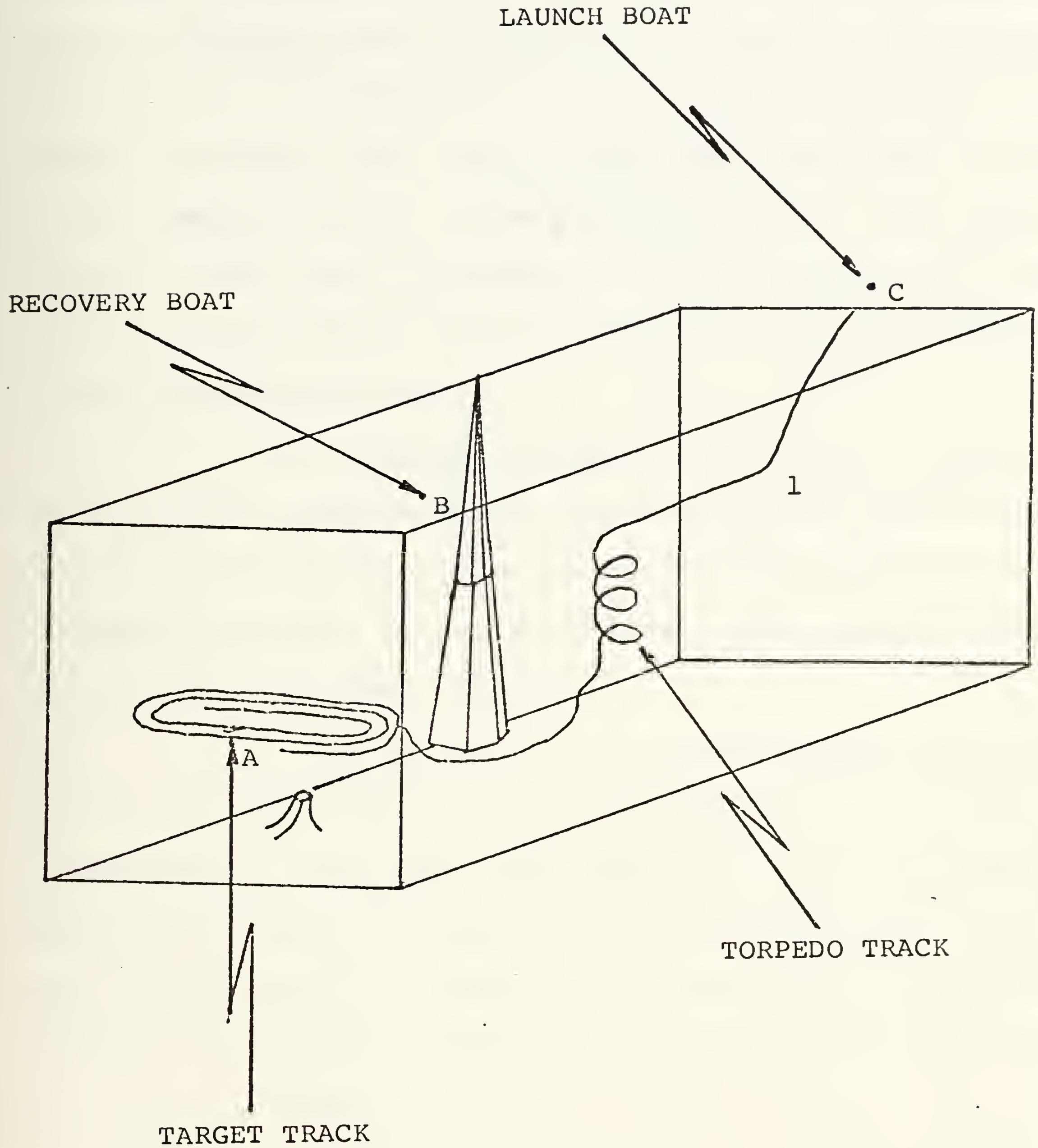


FIGURE 3
CONTINUOUS LINE TRACK DISPLAY

straight and steady course. This type of display would require the least amount of storage, as described in Section III B.3.b, and facilitates manipulation of data points because the points that are no longer displayed could be written onto a magnetic tape or other storage devices. As shown in Figure 4, when only 100 points or so are displayed for each vehicle, the display picture remains uncluttered and each vehicle remains distinct.

(3) Animated Display. The animated display simulates the appearance and movement of the range vehicles giving an indication of the vehicle's future position by showing it turning in that direction. This display could also incorporate the comet effect.

In Figure 5, it can be seen that this would give an accurate display of several vehicles on the range simultaneously and would not clutter the screen with past positions. However, accurately indicating pitch, roll and yaw by this manner of presentation would require more complex sensing and transmitting equipment than is presently planned.

c. Coding

Possible coding methods were listed in Section III A.1. Some choices must be made from that list to construct an example display.

- Since the Range Operator is concerned with identification and not searching, an alphanumeric type of coding can be used.

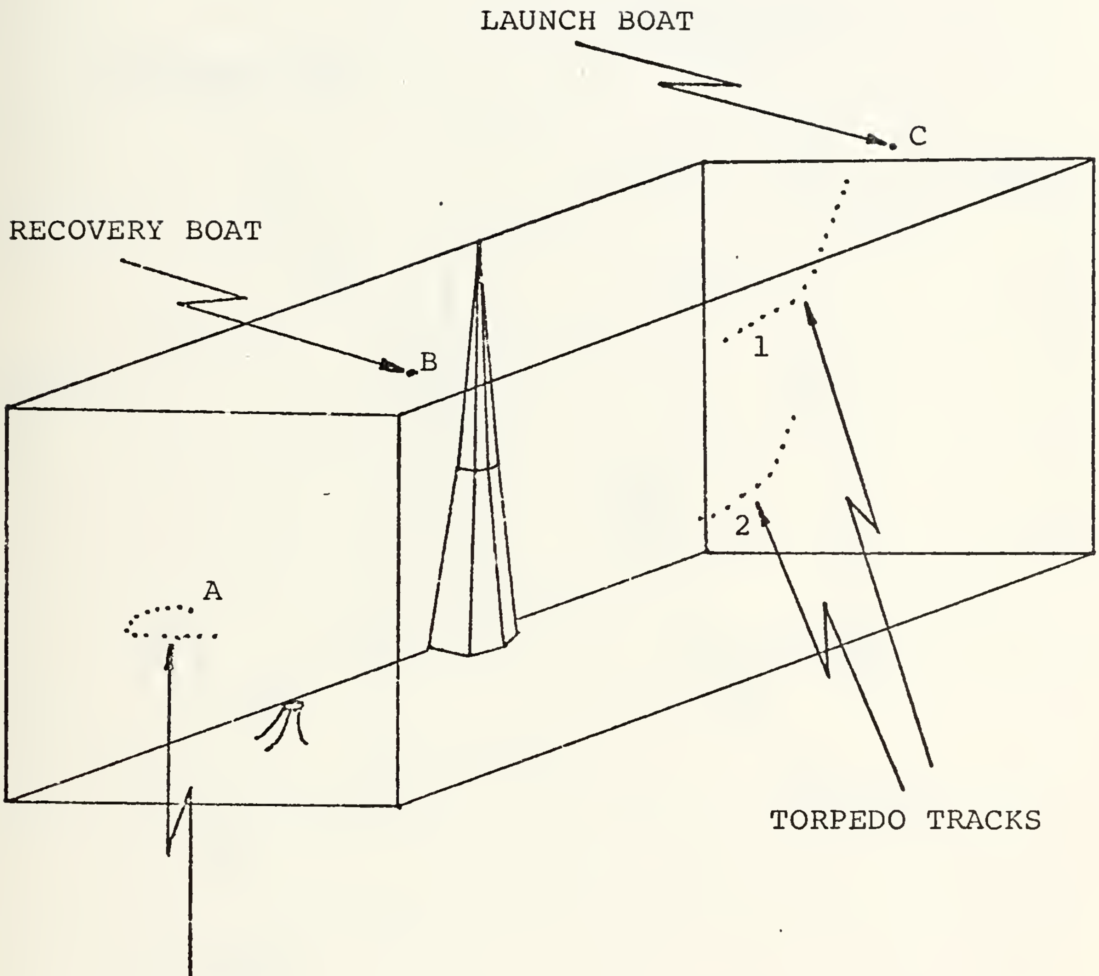


FIGURE 4
COMET EFFECT TRACKING DISPLAY

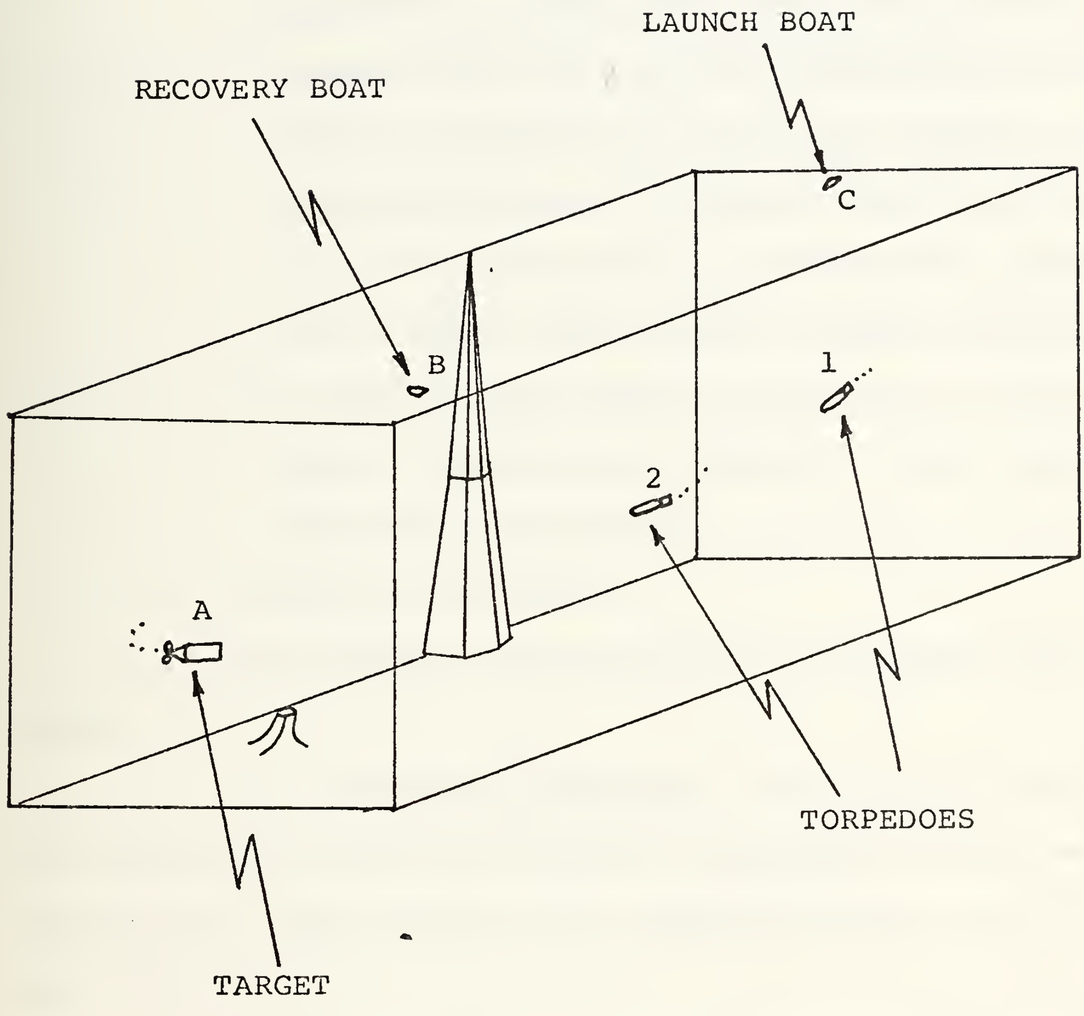


FIGURE 5
ANIMATED TRACKING DISPLAY

- Color coding will not be used because it does not increase efficiency but does increase the cost of the system.
- In order to offer some distinction between the weapons and the auxiliary vehicles, the weapons will be numbered and the other vehicles lettered. These vessels will be designated by pointing out the vehicle with a lightpen and inputting the correct code with the terminal keyboard.
- A warning light will be used only if the torpedo or target goes outside the safe region defined on the display.

d. Display Information

The display information can be divided into three areas:

(1) Dynamic Information. This is the part of the display that will be rotated, transformed or windowed and contains the range outline, the vehicles on the range and their labels.

(2) Static Information. This part of the display remains in a fixed viewing position throughout the run and includes run number, run time, distance and depth scales.

(3) Callable Information. This is information that is needed for a short duration of time, such as CPA of torpedo 1 to target B, dive/climb angle to torpedo 1 or overlay of SPVT (salinity, pressure, velocity, temperature) data.

This information could be requested by the operator and removed shortly afterward or replaced by the answer to the next request.

These three categories of information form a basic structure. If the system is designed and programmed to handle this type of format, the particular needs of the Range Operator can be added to or deleted from this structure.

e. Operator Interaction

The Range Operator's primary task is observing; he should have a minimum of distraction from this task. There could be situations when additional information would aid his judgment and possibly prevent a run from being prematurely aborted.

There are numerous graphics interrupt devices on the market to provide interaction for the input of requests for this information and the hardware selected will most likely have this equipment optionally available. The interrupts desired for this system would include function switches, light pen and a set of variable control dials.

Function switches usually come in a set of 12-20 individual switches which could be programmed to call for different views of the range; such as top, side or a prepositioned view, or to call for additional information such as CPA, climb or dive angle.

The light pen is a pointing device which could be used to label the tracks or identify two objects between which a CPA is desired.

Variable control dials would be used to rotate the display for viewing angles not pre-programmed.

Although the amount of interaction is of concern because it distracts from the observation of the entire range situation, the important point is to have the information available with an effective means of calling it for use even if it is not frequently used. An interactive graphics display system is capable of providing many types and quantities of information, virtually instantaneously. The choice is what information to have available.

f. Inversion

An inherent problem with wire frame three-dimensional displays is inversion of the display. This is an optical illusion which makes the back lines of a three-dimensional drawing on a two-dimensional surface appear to be the front lines and the front lines appear to be the back lines. It appears to be more of a problem with regularly shaped, symmetric figures than with irregular forms.

This problem is minimized by using identifying objects in the display, such as sea mounds and shallow areas, and by experience in operating with the display. With experience the operator anticipates what he is going to view and does not look for an inversion. Some techniques that will reduce the inversion problem are combinations of dotted and dashed lines, hidden line elimination and bottom shading. The use of hidden line elimination or various degrees of

bottom shading would also tend to eliminate or obscure the safety boundaries which the Range Operator needs to determine the relative positions of the vehicles.

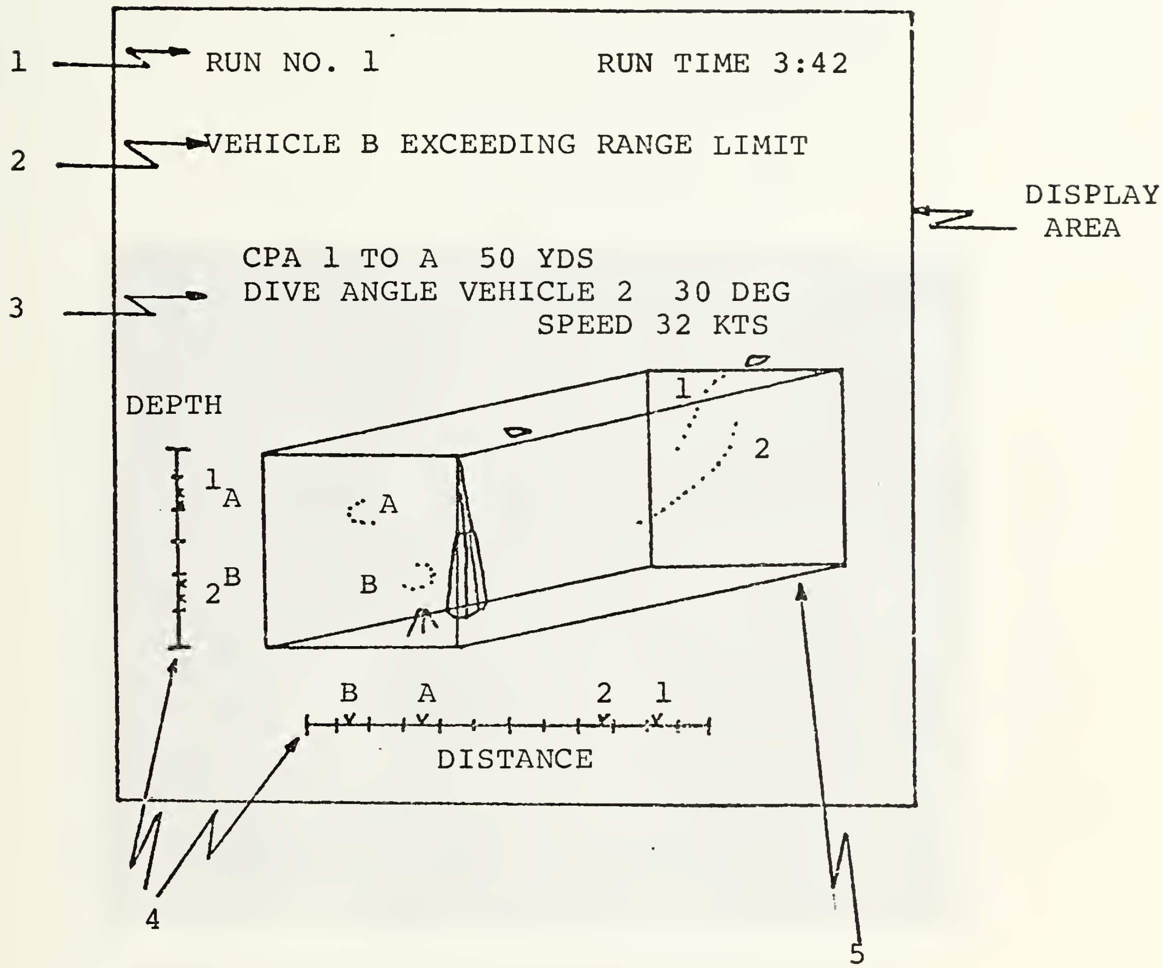
3. Display Summary

A workable display format, Figure 6, has been constructed using the parameters and consideration of the previous two sections. Although the output display for an actual tracking system would most likely be entirely different, the important point is that by using some engineering parameters combined with the technical possibilities of current machines a useful and informative display can be designed.

A simulated trial display was programmed to show the feasibility of the display format. Figures 7 through 10 show photographs of a simulated torpedo run on a CRT with four different viewing angles. The display format of Figure 6 was used with the exception of the depth and distance indicators which were not included in the program. The viewing angle of the photographic equipment was not large enough to include the static information (run number and run time) at the top of the screen. The tracks appear as lines instead of individual dot positions because the line intensity is set to maximum for photographic purposes.

Figure 7 shows the start of the run with two torpedoes entering the range at the right and two targets on the left at depths of 150 and 300 feet. Figure 8 is a top view of a crossing situation. The depth scale on the left would, in a fully developed implementation, indicate that the torpedoes

DISPLAY FORMAT



1 - STATIC DISPLAY RUN NUMBER PUT IN BEFORE EACH RUN BEGINS.

2 - WARNING MESSAGE (FLASHING)

3 - CALLABLE INFORMATION AREA (WHEN NEEDED)

4 - STATIC DISPLAY DEPTH AND DISTANCE INDICATORS WITH MOVABLE ALPHANUMERICS INDICATING VEHICLE DEPTH AND DISTANCE.

5 - DYNAMIC DISPLAY
1) COMET EFFECT TRACK
2) ALPHANUMERIC CODE
3) 3-D WIRE FRAME RANGE

FIGURE 6
FEASIBLE DISPLAY FORMAT

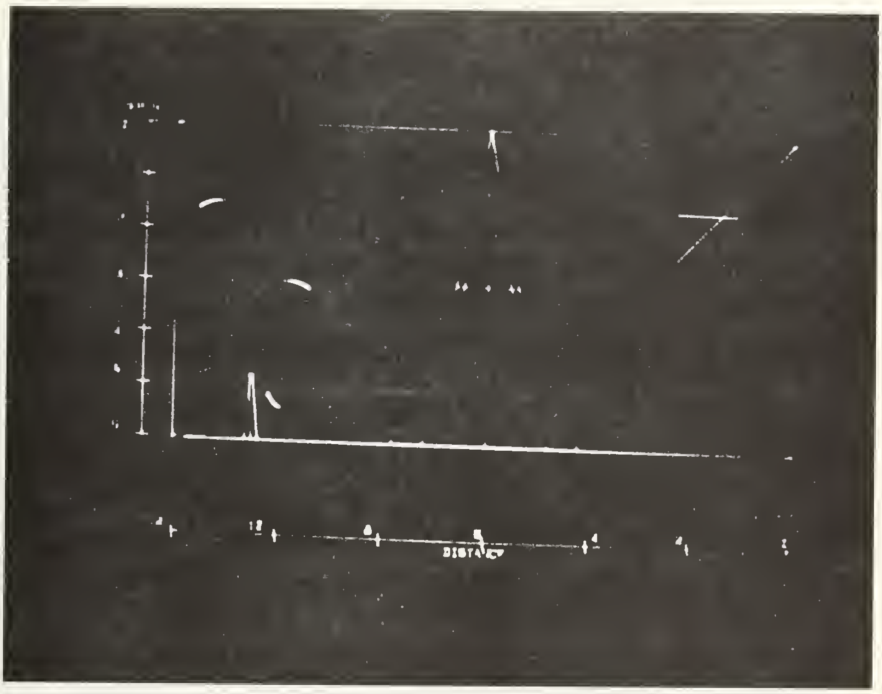


FIGURE 7
SIDE VIEW OF RANGE

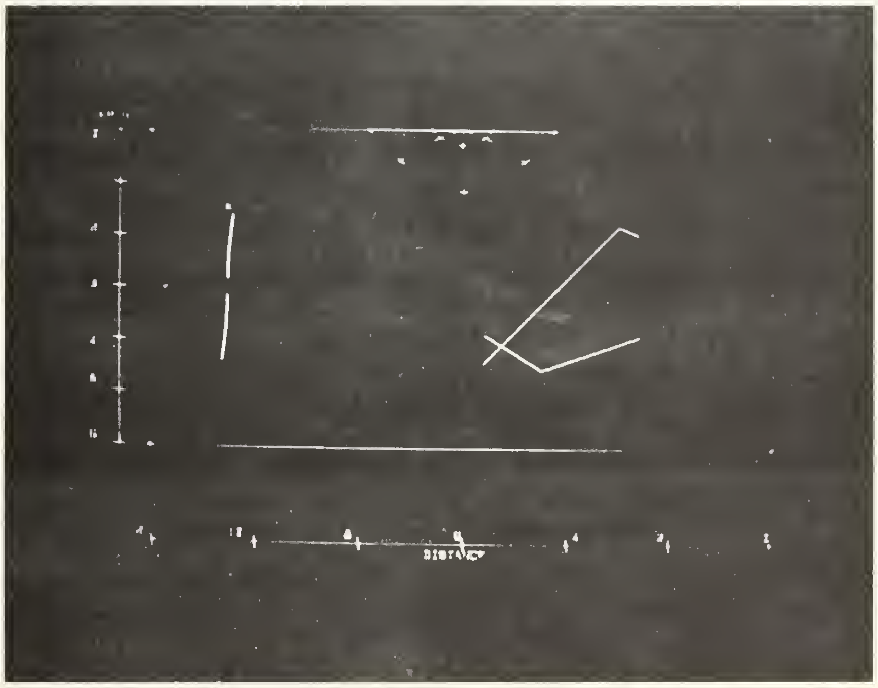


FIGURE 8
TOP VIEW OF RANGE

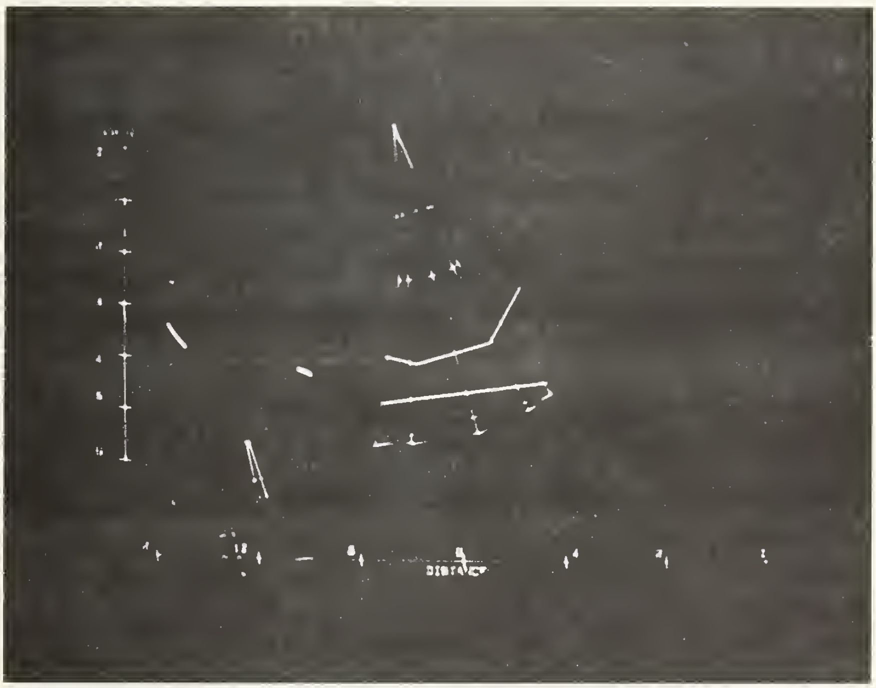


FIGURE 9
VIEW FROM NORTH END OF RANGE

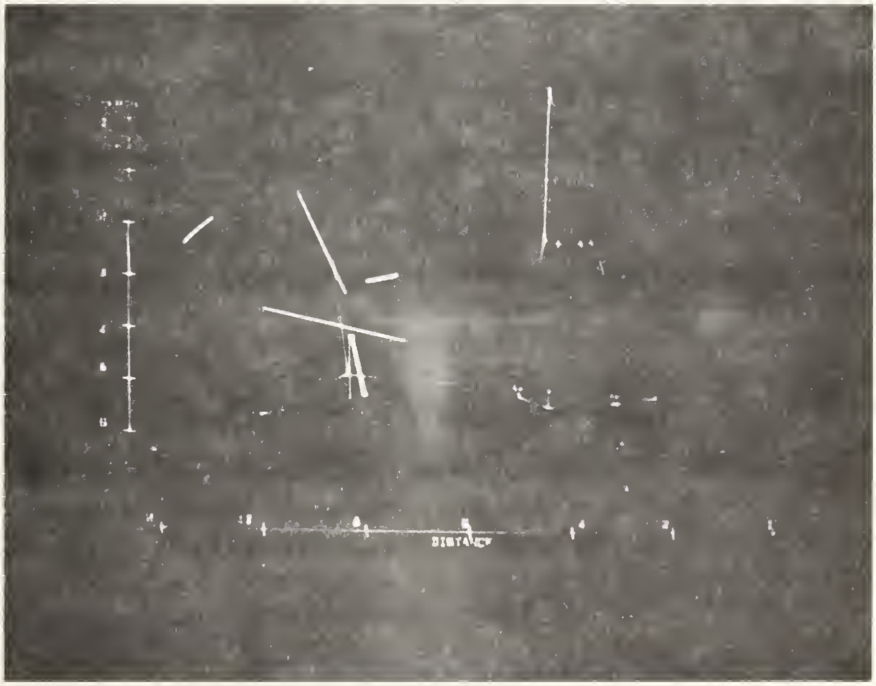


FIGURE 10
VIEW FROM SOUTH END OF RANGE

are separated by 150 feet. Figure 9 shifts the viewer to the north (left) end of the range showing the torpedo tracks against the background of the shallow area on the east side of the range. Figure 10 is the end of the run as seen from the south (right) end of the range.

4. Additional Uses of Data

The data processed by the tracking system will have other uses and provide the input for further analysis. The output must be compatible in both format and content with the processing performed for these uses.

The primary uses will be for post analysis and could include the areas of: research and development, proofing and oceanographic/acoustic analysis. The medium for these uses will be magnetic tape, the hardcopy plot of the run and range information such as SPVT data. Some secondary demands on the system could be for conversion to T.V. monitor display which would be used for ships force closed-circuit T.V. or for conversion to large screen display either in real time or for post analysis.

Future uses of the range data should be anticipated. Examples of these uses could be to provide input to a torpedo range simulation device or the transmission of real time range data to remote displays both on-site and off-site for non-operating personnel.

Although some of these uses could be made to conform to the system rather than the system designed to interface

with them, if these interfaces were known in the design stage, it should make their implementation cheaper and easier.

B. SOFTWARE

1. General Considerations

The most complicated and, very likely, the most expensive part of the system is the package of programs that direct the computer activities. These can be broken down into two areas: the operating system and the application program. In a real time system there is overlap in these two areas and the distinction is sometimes hard to make.

The basic function of the operating system is to supervise and coordinate all activities taking place in the real time system. The applications program performs the logical processing required by the users at their terminals.

A couple of decisions must be made before software can be considered. First, are software packages going to be purchased or will software be specifically designed for this application? Second, is security going to be a factor now or in the future?

a. Program Packages vs. Program Design

Operating system packages are available for real time systems which, with some modification, could be used on this system.

One of the disadvantages of these packages is that they were written to be of a general purpose nature designed to apply to many different applications and may not be as

efficient as an operating system written for a specific installation. Since the software vendor usually maintains the package, any changes must be made or approved by them at an additional expense. The applications program must then conform to the constraints of the operating system.

Some advantages of software packages are that they have been produced and are ready to use, therefore saving time to make the system operational and they have been debugged and proven on previous systems (which is no small task on any system).

Unless the present programming staff is capable of handling the programming design and maintenance or plans are made to expand the existing staff, the cost of the software packages may be offset by the time saved in making the system operational and the avoidance of the continuing cost of an increased staff size.

b. System Security

System security must be considered before the software decision is made and designed into the system from the beginning because it is virtually impossible to patch security into an unsecure system. If remote terminals are to be used now or in the future, then some type of security measures are necessary. If provisions are made in the original system, it will preclude redoing the system at a later time.

Since security is not a general requirement of most systems and because there are few secure systems utilizing remote facilities, the operating system may have to be specifically designed for the system and will probably not be available in package form.

c. Programming Language

Programming languages should be discussed before returning to the functions of the operating system and applications programs. A language should be chosen that will handle arithmetic expressions efficiently and provide the data structure and file handling capability necessary for a real time system. It should be at a high enough level to make changes easy. It should be a language that is in general use so that compatible extensions and library packages can be purchased if desired.

Some of the desired packages would be applications packages, debugging routines and performance evaluation packages. Attention should be given to the type and extent of diagnostics produced. Another consideration would be, are these packages structured so that additions or changes can be made?

An example of a programming language that is in general use which could satisfy these requirements is FORTRAN IV. It is also compatible with many hardware components and there are editing, testing and library routines available in this language.

2. Operating System Program

Since each real time system usually has a different hardware configuration, the operating systems appear to differ widely from one system to another. However, most operating systems will perform the following functions which are reworded here from Reference 2:

- The operating system performs the input and output functions on the various peripheral devices in the system at the explicit request of a user program. Most of the error checking and error recovery is also performed by the operating system.
- If the user programs and data are maintained on secondary storage such as a disc or drum, it is often the job of the operating system to organize and maintain those files. Thus, the operating system normally contains a data management system.
- It protects the programs and data of all users while in main memory or on secondary storage from programming errors and electrical failures. This is accomplished partially by hardware and partially by programming.
- The operating system schedules the use of the computer's resources. In a time-sharing system this primarily means scheduling the use of the CPU.
- The operating system attempts to minimize the ill effects of a system failure. This may be done

with a duplexed or some other "fall back" system.

The operating system is probably the most difficult part in the software design of any real time system. How it handles data and the priority system assigned to each function will require the major portion of the design decisions. The size and complexity of this program makes it difficult for one person to maintain the overall picture because any change could have degrading effects in another portion of the program.

The primary objective is an efficient operating system because there is little that can be done with hardware configurations or applications programs that can counter an inefficient or poorly designed operating system.

3. Applications Program

a. General Comments and Assumptions

The applications program is the one area of the system that identifies the system for the specific use of torpedo tracking and evaluation. The basic objective of this program is to receive the point from the analog/digital converter, identify it and display it. The method for accomplishing this depends upon the language, the hardware, the operating system, the applications program and the programmer. Since none of these have been identified, some general approaches will be discussed.

Assumptions to allow estimates of program characteristics include the following:

- The comet effect will be used with the last 100 points of the track being displayed.
- A maximum number of ten objects will be tracked.
- A position in X, Y, Z coordinates will be received in digital form from the receivers.
- FORTRAN IV language will be used.

b. Data Base

The data base will be the first consideration because it is basic to the applications program. Each object tracked will be an array with 300 elements, 100 elements each for X, Y and Z; therefore, the data base will have a maximum of ten arrays which comprise 3000 elements. Additional information such as time position was taken and identification may be included if desired. The data base can be maintained either in memory or on the drum. As new points are received at a rate of one point every 1.3 seconds from each object being tracked, the previous 101st point is buffered or transferred to magnetic tape, maintaining 100 points on each object.

All the subroutines will work with these 100 points and the previous track history will not be needed by the Range Operator for his information aids. This saves memory or storage since a tremendous number of points will be generated by some of the vehicles being tracked, such as the target vessel which could be in the water for six to eight hours. The history tape file will be used in post analysis.

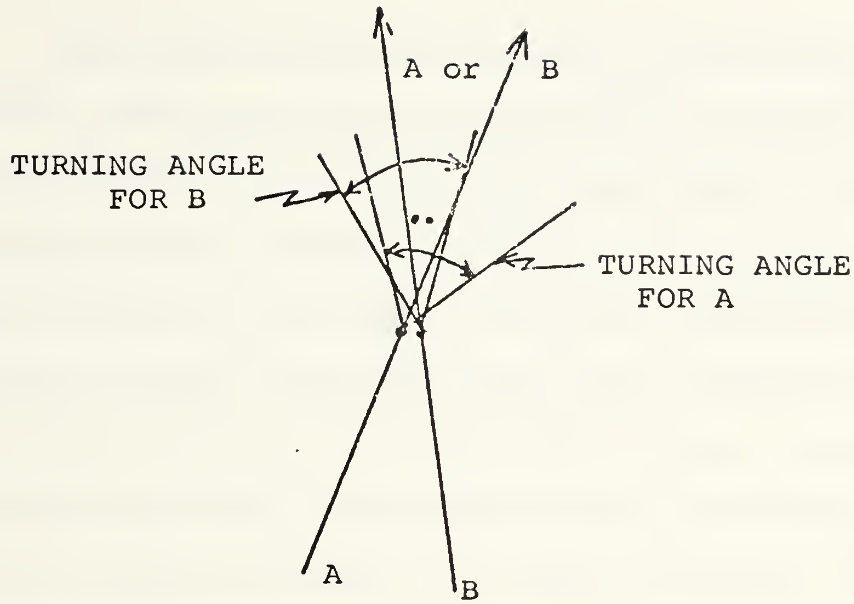
c. Identification Algorithm

Now that the data base has been established, the points must be identified and assigned to the array for the vehicle that produced them.

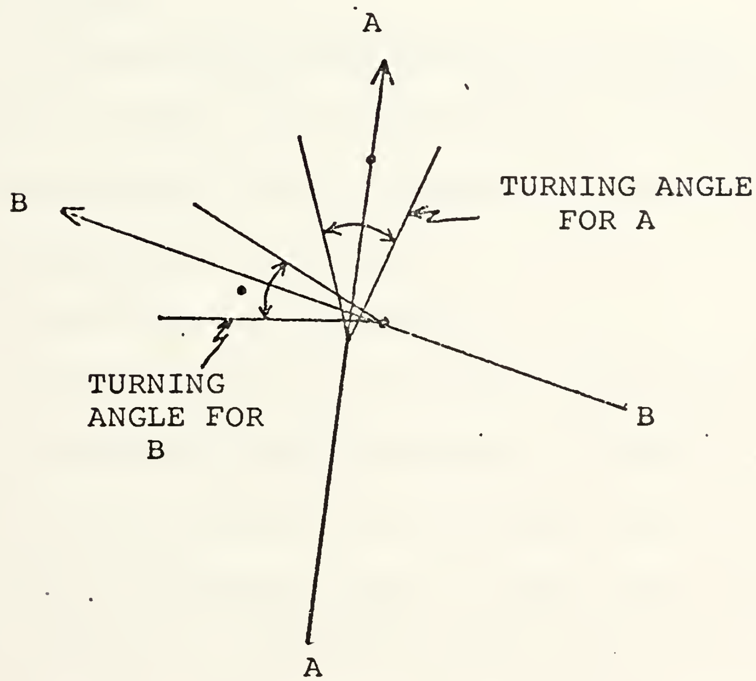
An algorithm can be produced which will identify the points based on their proximity to the previously identified points. The first few points of the run will have to be identified by the Range Operator via the light pen and keyboard control. After the first set of points have been identified, the remaining points will be assigned to the correct list based on its proximity to where the next point should be.

There are several anomalies which will arise and must be sorted out by the Range Operator based on his evaluation of the situation, such as crossing situations and points generated by extraneous noise.

Some of these situations can be eliminated by a more complicated algorithm. For example, the algorithm could identify the vehicles in most crossing situations based on the angles of approach and speed of the vehicles and comparison with the maximum turning radius or dive/climb angle characteristics of the two vehicles. The point would then be assigned to the list of points that did not exceed that turning radius. At very shallow angles of approach this would not be possible because the vehicle could possibly be in either list as shown in Figure 11. If the algorithm labelled the point incorrectly, the label could be corrected by the Range Operator.



SHALLOW ANGLE OF APPROACH



WIDE ANGLE OF APPROACH

FIGURE 11

This algorithm must be used on every point received in the system. Not every point can be given a correct positive identification in all situations, regardless of how extensive the algorithm is. Given the rarity of occurrence of complicated crossing situations, a realistic approach would be to use a fairly simple algorithm which will identify a majority of the points and put the unidentified points, including points produced by noise, in a miscellaneous list which can be sorted out in post analysis. The time involved in processing an extensive identification algorithm would most likely produce a backlog of input points which would rapidly degrade the picture from a real time system to a "what the picture used to be" system.

If the range configuration is changed so that an identification is given with the position, a modified identification algorithm may still be useful to keep a check on the range identification of positions.

d. Filtering and Smoothing

The miscellaneous list and noise-generated points present the problem of track filtering. Filtering can take place before points are put into the data base or before the data is recorded on magnetic tape, or the tape can be edited during post analysis. Questions arise, such as how much filtering of noise and extraneous points is desired, when should the input data be filtered and is filtered or raw data desired for post analysis?

Because the post analysis data tape will be used by several different groups for different types of analysis, it would probably be more beneficial to all groups if raw data were used and each group filtered its own data. For example, noise may be significant in determining range detection performance but not wanted in the post analysis of torpedo performance.

Smoothing and curve fitting can be accomplished if points are lost upon input or put into the miscellaneous list. The time required to perform curve fitting would be an important consideration in the necessity of smoothing and the accuracy desired.

e. Subroutines

Several different subroutines must be provided to rotate, window, obtain a CPA, project a track, etc. These subroutines provide the basic display output and suplementary information required by the Range Operator. The subroutines for rotation and windowing can use the hardware features as specified in Section III C. A priority system must be assigned to the callable subroutines based on the importance of the information they provide.

An additional subroutine should be included that will provide for a preprogrammed, simulated run of a torpedo so that a simulated run can be viewed before the real run is made. This will give the Range Operator an indication of how

the actual run should look and enable him to readily spot an abnormal situation when or if it arises.

Special monitoring routines should be included to be used in collecting statistical data for performance measurement.

4. Program Optimization

If program design is chosen instead of program packages, steps should be taken to optimize the program in regard to execution time. Software improvements can be achieved by several methods which use existing facilities to obtain and analyze statistics on the program then use the results to make improvements on the language.

Assume that monitoring routines show that 10 percent of the code uses 95 percent of the CPU time. A lot of time can be saved in program improvement if that 10 percent of the code can be identified and improved. A method for this approach is as follows:

- Write and debug the program in the higher level language, such as FORTRAN IV.
- Run the program to obtain statistics.
- Analyze statistics to determine the sections in the program where most of the execution time is spent.

Improvements in these sections can be achieved by modifying the high level language code or by writing a special purpose operator, perhaps in assembly language, and calling this operator with the high level language.

If FORTRAN IV is used for the programming language, there are extensions available that will optimize the generated code with respect to program execution speed and core allocation.

Performance optimization in a dedicated system designed for long term usage will have to be a continuing consideration until the system is stabilized and payoffs in optimization are insignificant.

Reference 3 is a bibliography of performance measurement articles which could be of assistance in deciding which technique would be the most useful in optimizing a system.

C. HARDWARE COMPONENTS

The previous two sections have set some output and software requirements which will be used as constraints in the selection of the hardware components to form a baseline system design. The basic hardware components of the system are the display terminal, the central processing unit, multiplexor, memory, high speed storage unit and various peripheral devices. Cost, reliability and compatibility considerations should be applied to each hardware component selected.

1. Display Terminal

The display terminals are the primary output devices. The success of the system will depend, to a large extent, upon choosing a graphics display terminal that will most efficiently produce the designed display.

Information was solicited from 22 manufacturers of graphics terminals [Ref. 4]. Sixteen replies were received and about six of them had the features that would be desirable for this system. Some of the desirable features found in these graphics display terminals are:

- size of display area	based on output information needs and graphics displays available should be no smaller than 12 x 12 inches
- refresh graphics	allows for rotation, transformation without momentary loss of picture
- three-dimensional scaling, rotation and transformation as hardware features	reduces memory requirement
- vector generator	reduces the number of points needed to generate a line and also allows for a variety of line combinations (i.e., dot, dash-dot, point or solid lines)
- direct memory access	less than 1 us
- word size	at least 16 bits
- sharable memory with the remote processor	reduces access time

- intensity cue	diminishes line intensity with depth in a 3-D plot
- interrupt devices	keyboard, function switches, light pen, variable control dials
- character generator	faster printing, less memory used to generate characters

The need for well-defined, sharp lines and a flicker-free picture are basic to any display and are best determined with a demonstration by the vendor of his product.

Due to the rapid advances in the technology of interactive graphics display hardware, it is recommended that a further market survey be made so that the products can be compared and demonstrated, if possible, prior to their inclusion into the design.

2. Central Processing Unit

The central processing unit (CPU) is usually the most important piece of hardware in a real time system because the choice of the CPU will determine the amount of growth and flexibility the system has and will govern the overall performance of the entire system.

A CPU suitable for use in a real time system will have the following characteristics:

- an instruction set to perform arithmetic; input/output and data movement operations,

- a master mode and a slave mode to permit some programs in the programming system to assume responsibility for all activities in the system,
- a real time clock to facilitate time sharing. The clock must be capable of interrupting the processor at a fixed interval or at some desired interval,
- the ability to address a sufficient number of input/-output devices,
- the ability to be interrupted by the completion of an input/output request on any of the peripheral devices,
- memory should be basic 32K expandable in increments to 128K with a memory cycle time of less than 1 us. This is an estimate based on a simulated tracking program.

Some qualitative/quantitative differences in CPU's to check for are:

- ease of programming
- popularity - software and peripherals available
- modem - speed and capacity
- data transfer rate - memory cycles required

3. <u>Peripheral Devices</u>

The peripheral devices required for the system provide an area for flexibility and compromise, with speeds and capacities being the major considerations.

The system must have some means of storing input data until it can be processed and a permanent record capability for future analysis. Some of the many devices available for this are disc, drum, magnetic tape, paper tape, and cards. A feasible solution would be to use drum storage as an input device for speed and reliability and magnetic tapes for the permanent record because it is durable, compact and easily transported.

The other peripheral devices needed are: a line printer for program modification and output listings, a hardcopy plotter to record plots from the CRT and a card reader for program modification.

4. Reliability

The degree of reliability required of the system is another consideration both in cost and complexity of the system design. The system must be able to function continually for eight to ten hours a day, and a system malfunction resulting in a loss of the display at the wrong time could have disastrous results. Based on the previous experience of the user, it might be decided that a torpedo run could be aborted, if a system failure occurred, with minimum danger to the other vessels on the range. In this case, reliability would not have to be a factor in the system design. However, since the unit cost of the range vehicles sometimes exceeds a million dollars, the added expense of reliability would be a good investment.

Software reliability would be established by program testing that would insure that all the code has been exercised and performs as designed. This would have to be accomplished prior to approval of the programs for actual implementation. The following hardware configurations deal with providing a reliable system in terms of the degree of hardware failures that can be tolerated by the user.

The system specifications therefore may call for "failsafe" operation, where no system interruption is allowed or for "fail soft" operation, where some degradation of system performance is allowed but total shutdowns are not allowed. The goal of a reliable system is achieved in various ways such as:

- Parallel operations are defined so that either one of two computers operating in parallel can fail without losing application time.
- Duplex computers systems have spare and active computers sharing I/O devices and key data in storage, so that the spare computers can take over the job on demand.
- Multiprocessing can use several computers sharing the load in such a way that a single failure degrades but does not interrupt the system performance.

Multiprocessing would probably hold the advantage over the other configurations for the system under consideration here because a degrading of performance could be tolerated and

it is cheaper since the computing power of both CPU's can be used. This type of system will be discussed in the next section.

5. Baseline Design

Now that initial specifications for the hardware have been made a baseline design can be constructed. For the system under consideration here, Figure 12 shows a system without hardware redundancy and an optional preprocessor. The time required to process the identification algorithm could prove to be a bottleneck in the system. A preprocessor could be used to identify the input points which would allow the main processor more time to process the applications program.

Five CRT display terminals are used in the system. This will allow the Range Operator three independent terminals for: overall range display, viewing specific areas of the range and additional information needs. The other two CRT's are for the target controller and an on-site viewer.

The recommended system, as shown in Figure 13, is a multiprocessing system with two CPU's which are processing the same program and input but divide the terminals' interactive requests. In the case of one system failure the system would operate as shown in Figure 12. The added interactive requests would reduce capability but it would not be lost. If CPU 1 were crossed to Multiplexor 2 and CPU 2 crossed to Multiplexor 1 as shown by the dashed lines in Figure 13, this would add to the reliability in case of multiplexor failure.

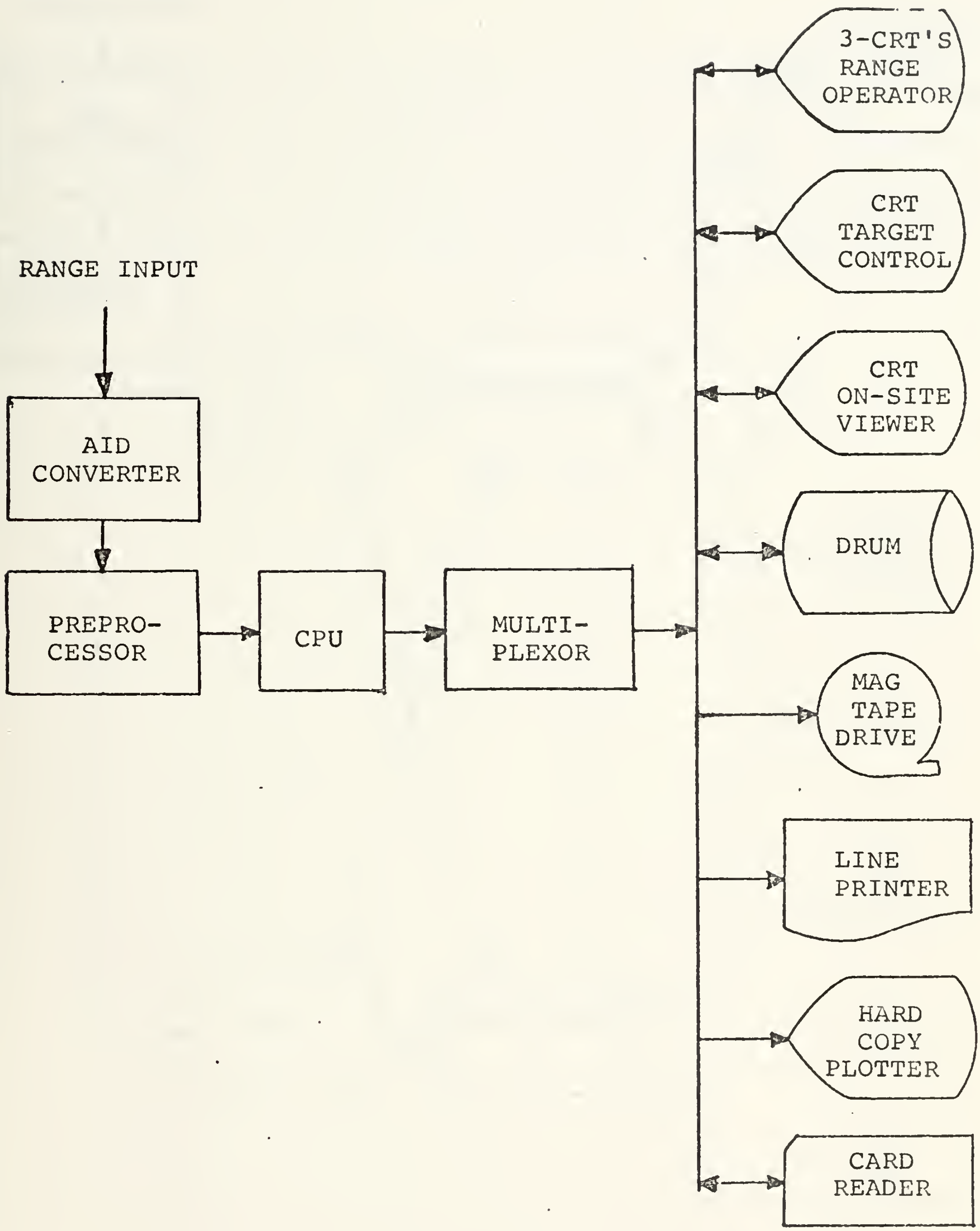


FIGURE 12
BASELINE SYSTEM WITHOUT RELIABILITY
AND OPTIONAL PREPROCESSOR

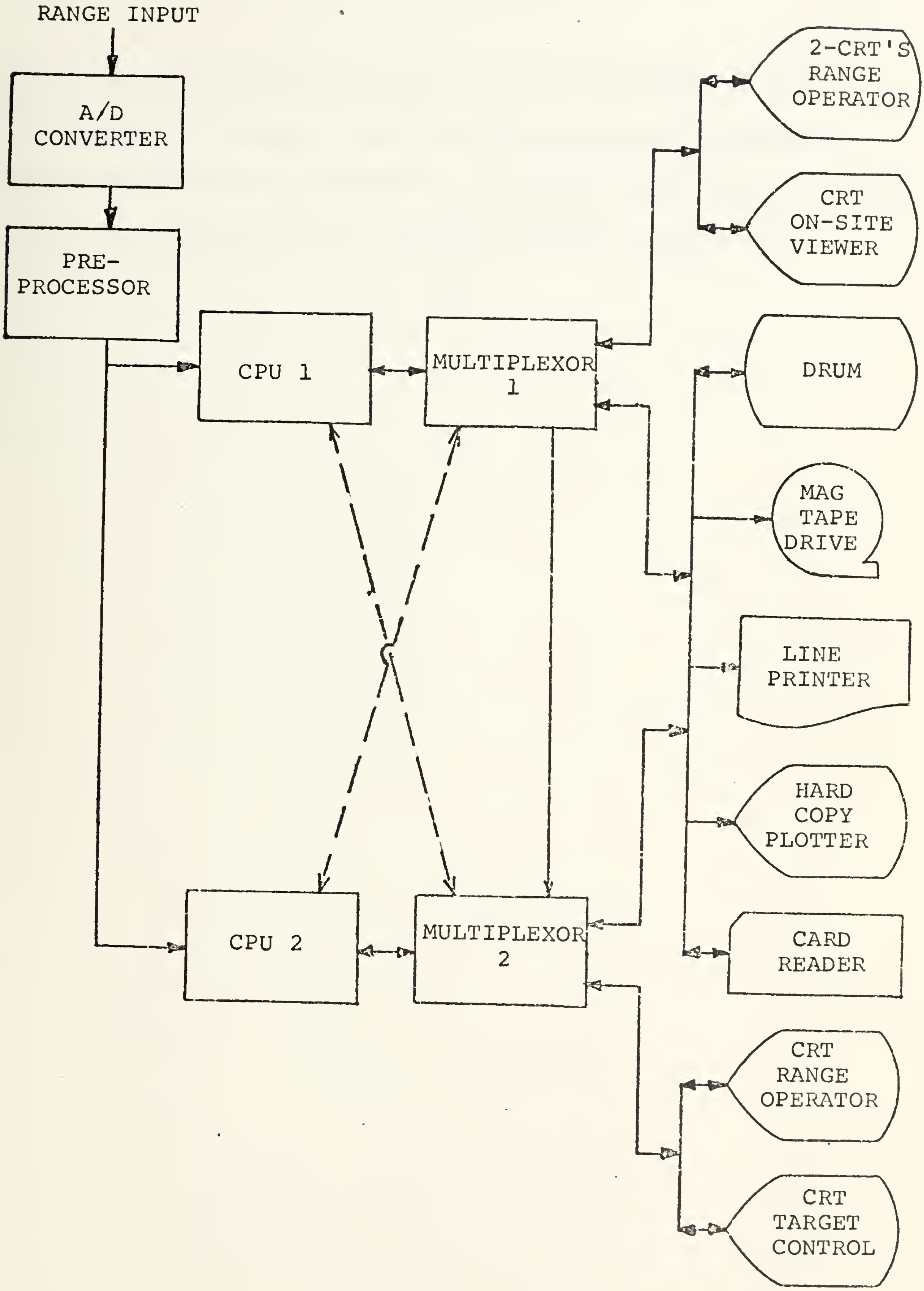


FIGURE 13
BASELINE SYSTEM WITH RELIABILITY

One or two preprocessors could be used depending on the degree of redundancy desired. The other peripherals could be shared because they are not required to complete the torpedo run safely but the display of the range situation is required.

IV. CONCLUSIONS

In reference to Figure 1, it can be seen that the initial steps have been taken in the design process. When the design decisions have been made with regard to the output requirements, software designed, hardware selected and the baseline configuration established, then an analysis of the system can be made to decide, before contract commitments are made, if the system will actually perform as expected.

The evaluation of analytical models and systems simulations based on user requirements and cost constraints will determine if an optimal system solution has been achieved or if design changes are necessary to achieve an optimal solution. The questions of feasibility and constraints being met are not as distinct as indicated in Figure 1, because the feasibility study may indicate alternative design changes which would bring the design within the constraints specified.

A real time, interactive, computer graphics system provides not only the visual display required in a tracking problem but also the computing power to provide additional information and resolve conflicts that are normally considered in post analysis.

The rapid development in interactive graphics is approaching theoretical limits in hardware design with speeds compatible with the other components of the system. Future advancements in the field will most likely be in the area of software

development. The need for a graphics language and program packages is now apparent and design efforts in this direction will enhance computer graphics applications. In general, therefore, the system will continue to be the best that is technologically available for several years. The main problem will be in the proper evaluation of the requirements and planning the implementation.

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Design approach for a computer graphics system applicable to torpedo tracking and evaluation.