

## RAY TRACING ON A MINI-COMPUTER

by

M. Thompson and W. Wijmans  
SACLANT ASW Research Centre  
La Spezia, Italy

### INTRODUCTION

It would appear that most people engaged in solving problems in ray-tracing, use programs written for large computers. These machines commonly have large memory sizes, fast cycle times and large word length. This paper describes how SACLANTCEN has provided a ray-tracing capability on a mini-computer.

Let us firstly define what we mean by a mini-computer. It is typically a machine with a memory size of between 1K and 32K words, each word being of between 12 and 18 bits in length. Cycle times of between 1 $\mu$ s and 2 $\mu$ s are the norm of this type of computer. Standard peripherals are a system teletype, photo-reader and paper tape punch. Extra peripherals can be added easily by using plug-in card interfaces; memory expansion is often available so that a user can build up a system to his own requirements.

### Reasons for Using Mini-Computer

Now let us consider why we should wish to use a mini-computer instead of a larger, often faster, system.

Firstly, most large ray-tracing programs are very inflexible. Particularly, if the program is of monolithic structure and if a user requires any additions to the program, then major modifications are normally required.

Secondly, complicated data tapes must be produced by the user, [Ref. 1], and if a mistake is made then the error is not found until the job has been run, which depending on the workload of the particular computer, may take several hours.

We have tried to eliminate both these points, as I will describe later.

The third, and possibly most important reason for using a mini-computer is the need to have a ray-tracing capability on board ship during propagation experiments at sea. With this capability available, a scientist on board will be in a better position to decide whether an experiment should continue as planned or be modified because of the prevailing propagation properties of the medium.

#### Ray Tracing on Board Ship

This latter point was first implemented on an Olivetti 101 desk-top calculator, [Ref. 2], which has a very limited memory size and register length. It was therefore necessary to have the program split into several parts so that memory restrictions were overcome, and to simplify some of the formulae, especially those containing the sines of small angles, to overcome accuracy problems.

Each part of the program was stored on magnetic cards and the output of one program had to be manually input into the next part of the program. Three typical parts of the program could be:

- (1) Conversion of depth, temperature, salinity values to a sound speed profile.
- (2) Calculation of Snell's constant for a given source depth and initial angle.
- (3) Computation of the coordinates of the ray path.

Other cards for the calculation of travel time, path length and intensity made this a comprehensive program but necessitated many hours and much patience to get the desired results.

Last year, however, a number of Hewlett-Packard 2116B mini-computers were purchased by SACLANTCEN. One of these computers is available for shipborne use, and is loaded on board ship as required. This machine has a cycle time of  $1.6\mu\text{s}$  and a memory size of 32 000 16-bit words. Apart from the standard peripherals we also have a fixed-head disc, magnetic tape, Calcomp incremental plotter and a Tektronix 4002 (visual display device), which is used as the machine-operator interface and fast plotting device.

Its physical size is such that it can easily be transported and loaded on board ship. It is  $31\frac{1}{2}$ " high,  $19\frac{3}{8}$ " deep and is mounted in a standard 19" rack. All of its peripherals can also be rack mounted.

We have at present two programs for ray-tracing on this machine. Both are written in Fortran II, which should facilitate easy conversion to most other machines.

The first program is designed to give the scientist on board ship a quick plot of the ray diagram. It has a memory size of 3500 locations and therefore can be run on a basic 4K mini-computer which is fitted with some plot device. It simply calculates the ray paths from a source at a given depth to a given range in constant increment steps of angle, using a sound speed profile divided into layers of constant gradient input on the photo-reader.

The ray diagram is displayed, in our case, on the Tektronix terminal. Using the cursor provided with this terminal, a user can quickly indicate a new source depth on the sound speed profile and obtain a new ray diagram, thus seeing quickly the effect of moving the source on the ray diagram.

The computation time of this program is approximately 60 ms per layer crossing. Using an Epstein profile, as described in Ref. 3, divided into 75 layers, 45 rays from the source and a range of 2500 m, took 4 minutes 10 seconds for computation and plotting.

This program is analogous to some hardware machines which are commercially available solely for ray tracing purposes. The physical dimensions of the equipment necessary, and the time of computation and display, compare favourably with these machines, with the added advantage that the equipment is available for other jobs when ray tracing is not required.

### Modular Ray Tracing

The second program being implemented is a comprehensive ray-tracing program which we feel will be easy to modify in the future and easy to run.

It is partly based on the philosophy of the program for the Olivetti machine in that it is of modular structure, each module being a completely self-contained sub-program. We can make an analogy to a loose-leaf book system as shown in Fig. 1, where each 'page' is a separate 'chapter' of the book and all the relevant 'chapters' can be found in the index. For instance, page 1 of Fig. 1 is called 'Fixed RT' and after choosing this option in the index, the fast program described earlier would be called into the memory of the computer ready for execution.

Pages 2 onward are part of the comprehensive program; a user can start from a depth, temperature, salinity profile and calculate a sound speed profile, or alternatively directly input a sound speed profile into the ray calculation page. These profiles can be produced off-line from previous data or on-line from the sensor instruments which are interfaced to the computer.

Other necessary inputs are source depth, bottom depth (a flat bottom is assumed), maximum range and ray information. Rays can either be specified by the user as a set of constant increment angles from the source, or found automatically as the rays from the source which have a vertex at a layer depth in the velocity profile [Fig. 2]. We have termed these rays the 'characteristic' rays, and the user may specify the number of rays to be interpolated between two 'characteristic' rays.

Page 3, the ray calculation page, computes ray coordinates, travel time, path length and intensity at each layer crossing and stores all the information on the disc storage device,

From here, depending on what the user chose from the index (Page 1), the data can be

- (a) stored permanently on magnetic tape;
- (b) ray diagram plotted;
- (c) printed out on line printer;
- (d) special plots, i.e. plots of travel time, intensity, start angle, emergent angle versus range for a given depth, and constant increment intensity contours.

Figure 3 shows the general layout of the system. With this form of system it is hoped that additions and/or modifications to the program should be a simple matter. For instance, Fig. 1 indicates blank pages which we envisage as being addition of continuous gradient sound speed profiles, range dependent ray tracing etc. The flexibility inherent in this system means a user may make his own modifications or replacements and each user can pick a system best suited to his needs.

To ensure that the program is easy to operate by people without experience of either computers or ray tracing, a conversational mode has been employed [Fig. 4]; all data are entered through simple self-explanatory questions and each step in the running of the program is preceded by a set of clear instructions on how to do it.

Figures 5 to 8 show some examples of the output produced by this program.

Using the same Epstein profile as described previously, and all the other data remaining the same, the modular ray tracing took 13 minutes for calculation and display. The greater time as compared to the previous program is due to the greater amount of information that is computed and the file management on the mass storage device that is required.

The size of this program, if considered as a whole, is of the order of 16 000 memory words. However, as it consists of a number of self-contained sub-programs, it is an easy matter to have the program in, say, two or three small parts, where one part automatically calls the next part into the computer memory when necessary. In this way we never use more than 7000 words of memory. This program can therefore be successfully used on a moderate sized mini-computer.

### CONCLUSION

Ray tracing is easily implemented on a mini-computer, and can be extended to be a comprehensive program.

For laboratories with only limited computing facilities, and for shipborne use where it is only possible to have a computer installed of small physical dimensions, the programs described provide a powerful tool for the investigation of the propagation properties of the ocean which will satisfy the requirements of most users.

Because of the limited word length available on most mini-computers an accuracy of more than 6 decimal places cannot be expected. Also, computation times are by no means fast when compared to that obtainable with large modern computer systems. If, therefore, we require extra speed and accuracy, we envisage that a modular program like the one described here, with its advantages of flexibility and conversational mode, would be an excellent method of applying ray tracing to a large multi-access machine.

### REFERENCES

1. I. Verdoni, "Acoustic Ray Tracing at SACLANTCEN on the Elliott 503 Computer", SACLANTCEN Internal Note No. 260, 1 December 1970.
2. A. Skretting, "Sound Field Computation by Means of Desk Top Computers", SACLANTCEN Technical Report No. 141, 15 March 1969.

3. C.B. Moler and L.P. Solomon, "Use of Splines and Numerical Integration in Geometrical Acoustics", J.Acoust.Soc.Am., Vol.48, 1970, p.739.

RAY DIAGRAM (SOURCE AT 45 m; SURFACE AND  
BOTTOM REFLECTIONS SUPPRESSED)

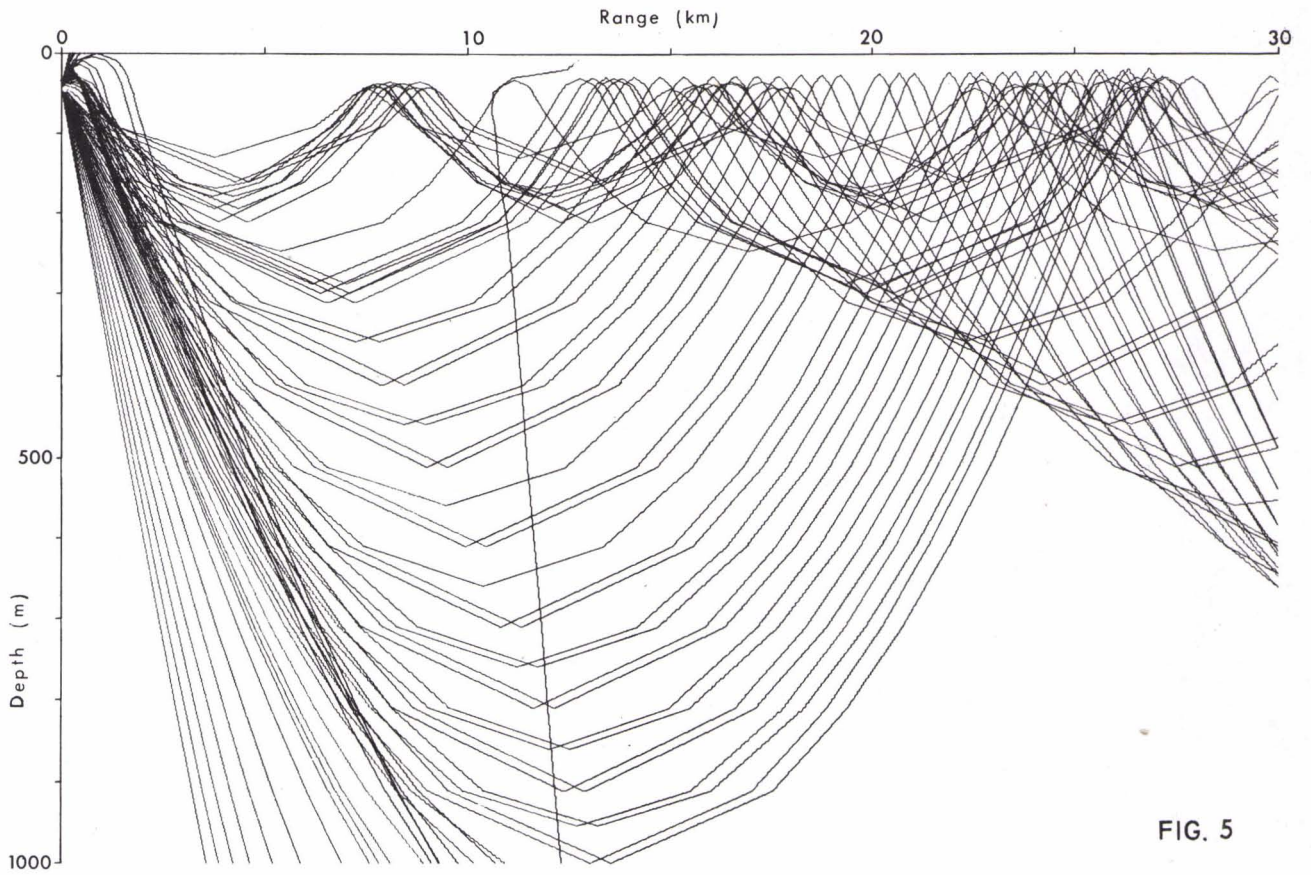


FIG. 5

ANGLE FROM SOURCE vs RANGE  
LAYER DEPTH 310 m

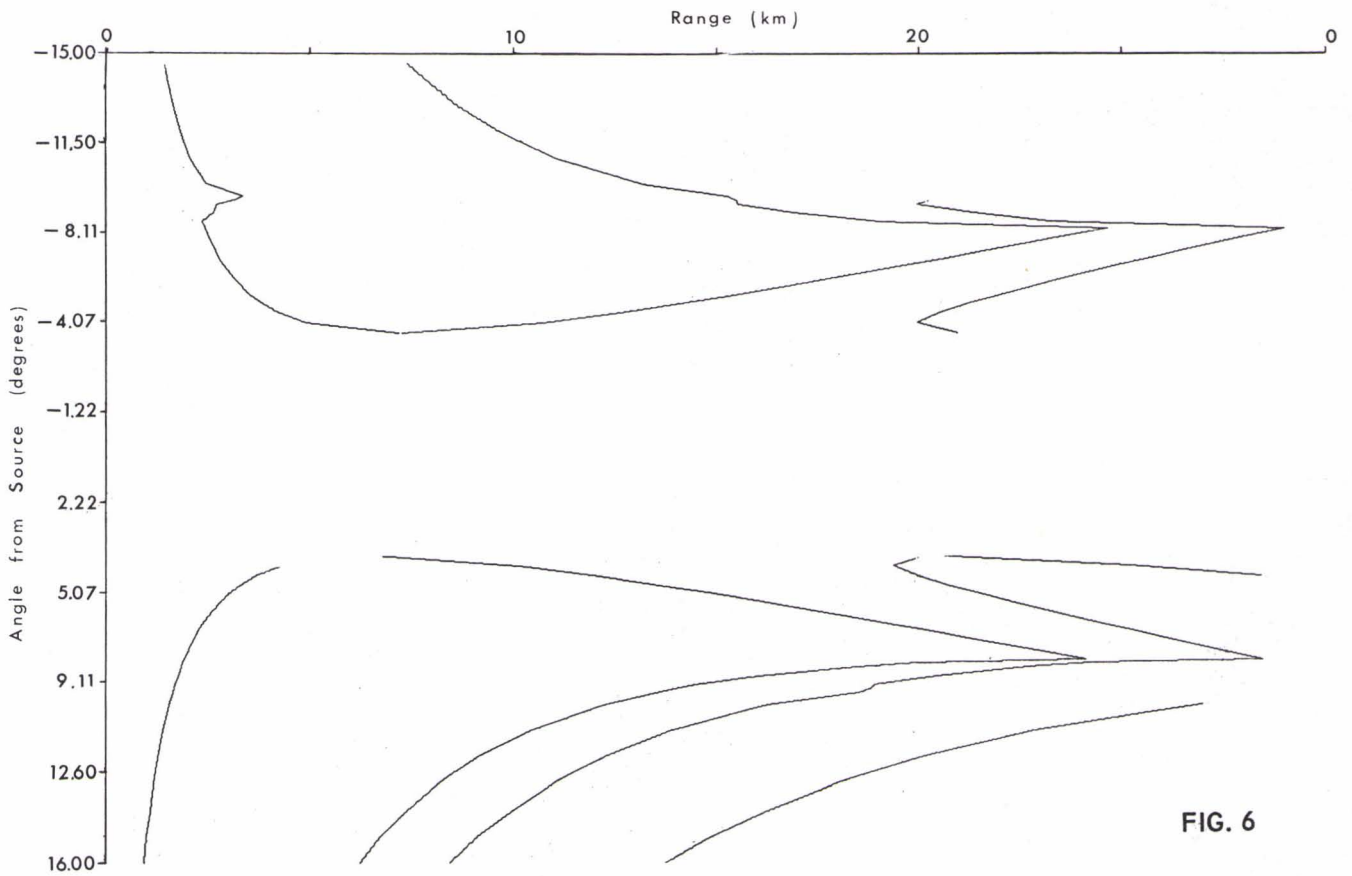


FIG. 6

EMERGENT ANGLE FROM LAYER vs RANGE

LAYER DEPTH 310 m

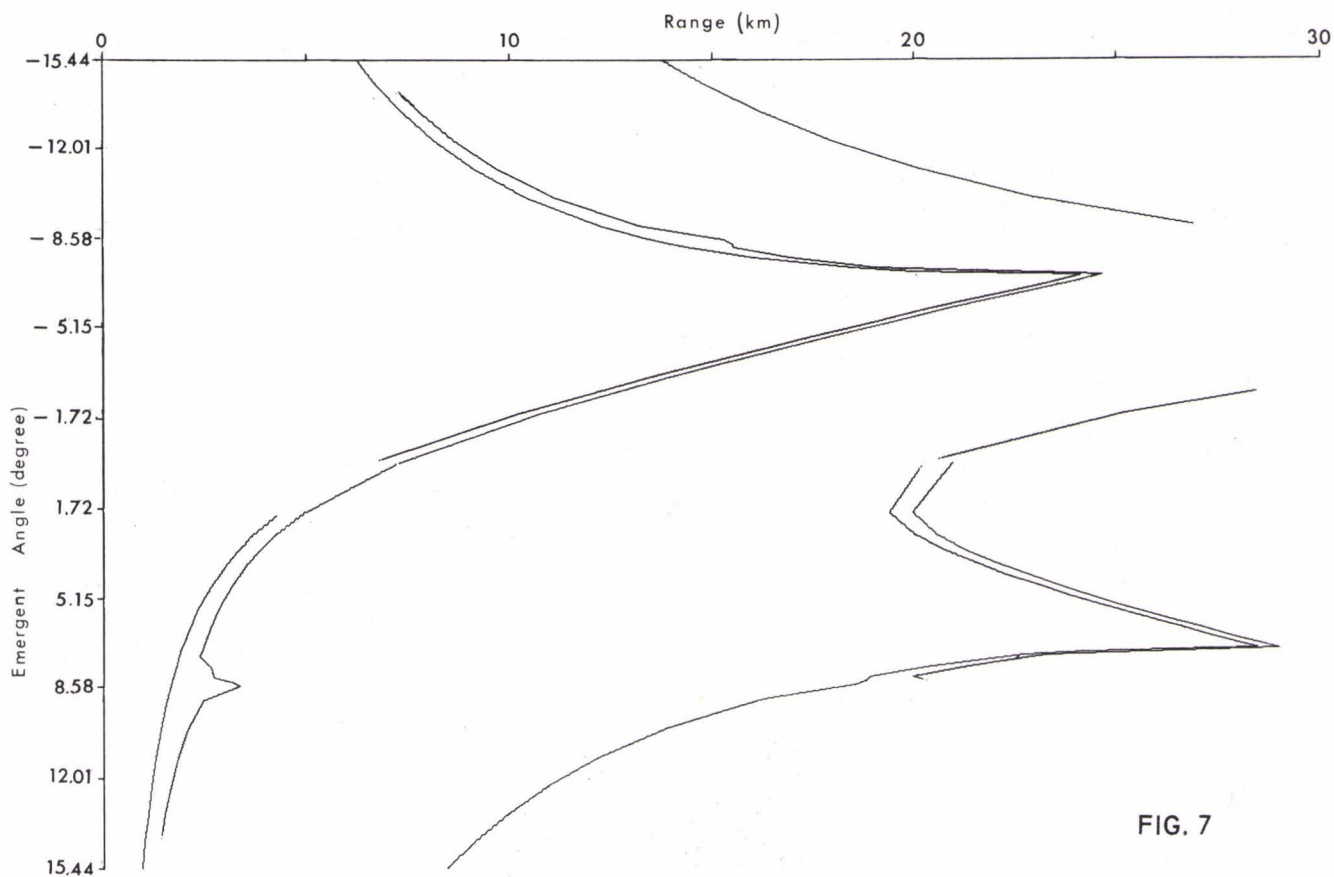


FIG. 7

TRAVEL TIME vs RANGE

LAYER DEPTH 310 m

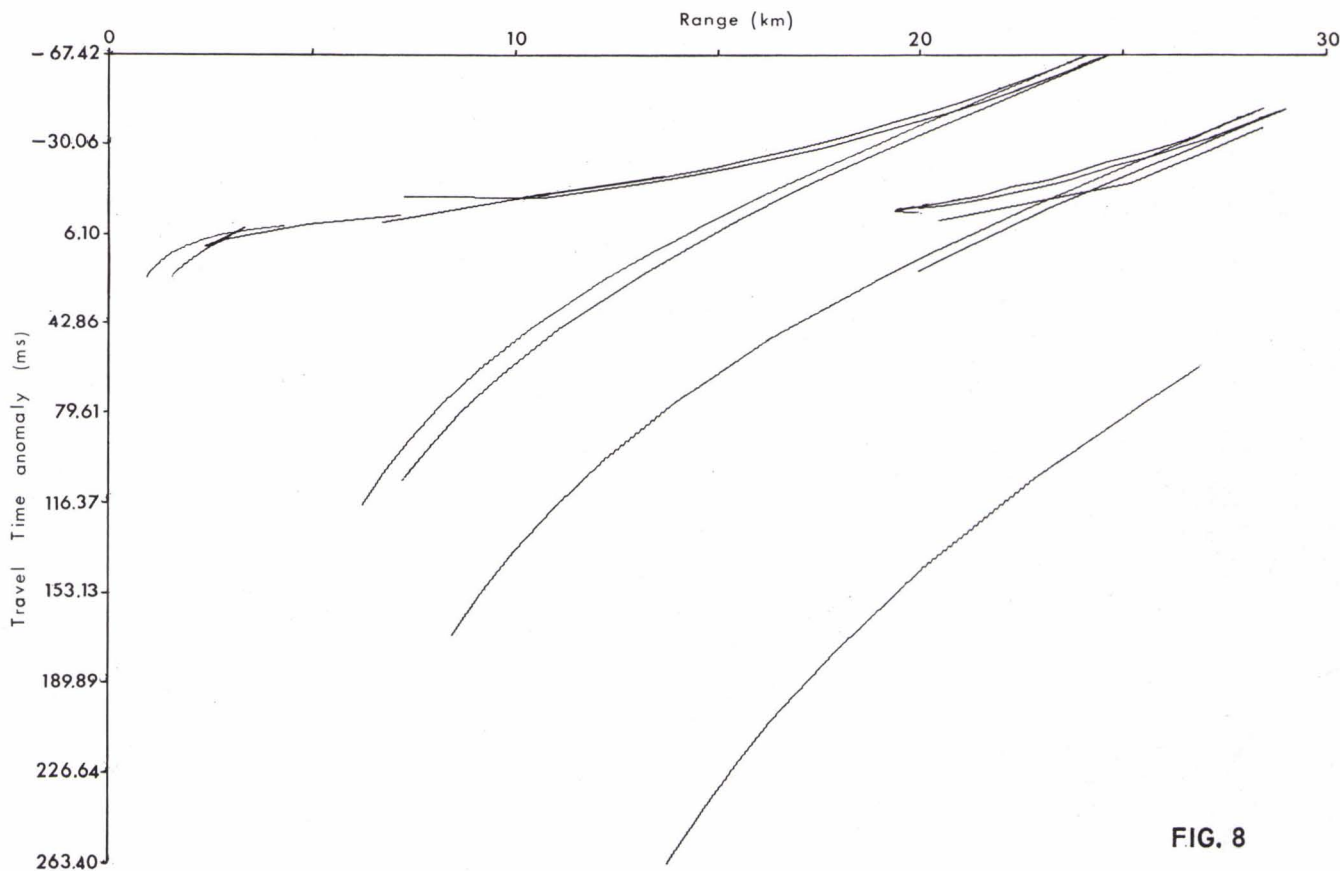


FIG. 8