RAY TRACING ON A MINI-COMPUTER

by

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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 and 2 μs are the norm for 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 μs 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 for 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 min 10 s 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 min
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, p.739, 1970.

DEMONSTRATION AND DISCUSSION

A short demonstration of the ray tracing facilities on SACLANTCEN's
Hewlett Packard computers followed the presentation. Both the fast
ray tracing program and the modular system were shown. Delegates
had the opportunity to operate the systems themselves and were invited
to suggest any improvements that they thought necessary. One such
suggestion was that the representation of the rays would look more
'natural' if the rays were drawn as continuous curves instead of
straight line segments. In reply it was stated that a routine for
such a plot had been written and tried but the increase in running
time became unacceptably high.

The demonstration clearly showed the usefulness of the mini-computer
as a ray tracing device; remarks such as the favourable speed of
obtaining results, and the advantage of man-machine interfacing
through the conversational mode were typical. It was also considered
by many that laboratories with large computer systems and a large
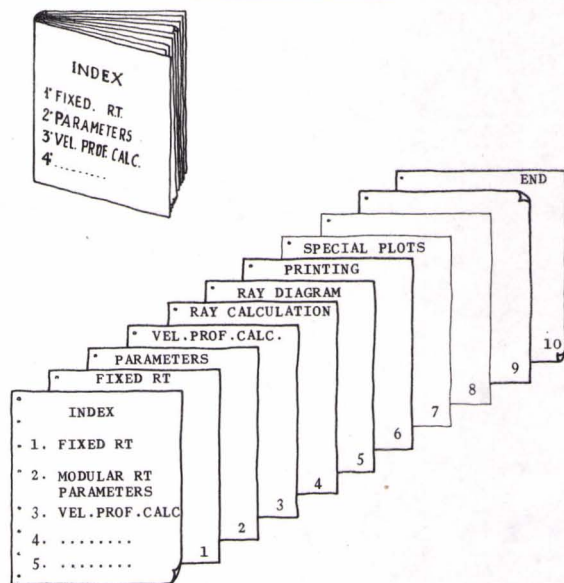workload could use a mini-computer ray tracing capability to great
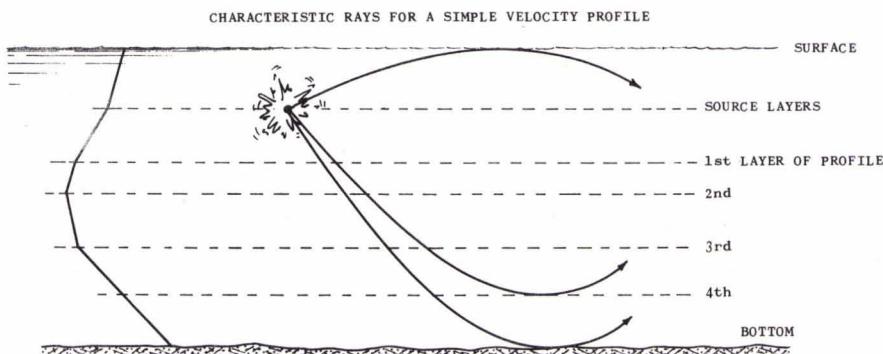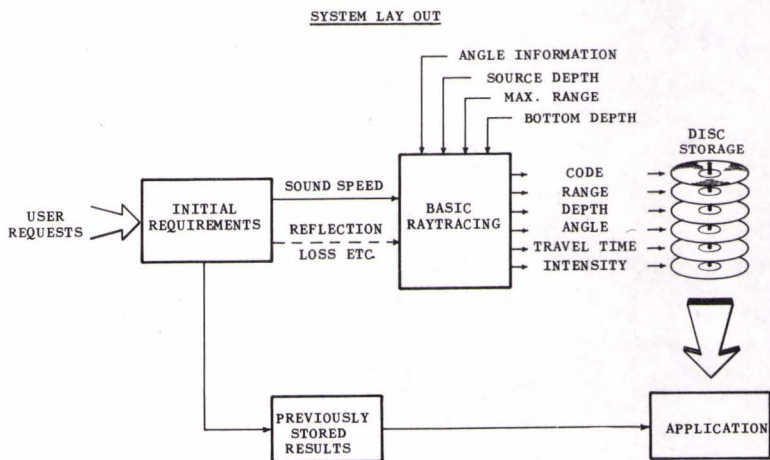advantage.

FIG. 1

CHARACTERISTIC RAYS FOR A SIMPLE VELOCITY PROFILE

SURFACE

SOURCE LAYERS

1st LAYER OF PROFILE

2nd

3rd

4th

BOTTOM

FIG. 2

SYSTEM LAY OUT

ANGLE INFORMATION
SOURCE DEPTH
MAX. RANGE
BOTTOM DEPTH

DISC STORAGE

USER REQUESTS

INITIAL REQUIREMENTS

SOUND SPEED

REFLECTION LOSS ETC.

BASIC RAYTRACING

CODE
RANGE
DEPTH
ANGLE
TRAVEL TIME
INTENSITY

PREVIOUSLY STORED RESULTS

APPLICATION

FIG. 3

RAYTRACING

INITIAL QUESTIONS TO DETERMINE INPUT AND OUTPUT REQUIREMENTS
IN ALL THE FOLLOWING QUESTIONS TYPE $\emptyset$ ‹=NO› OR 1‹=YES› CR.LF
IS A SOUND SPEED PROFILE TO BE INPUT? 1
IS A RAY DIAGRAM TO BE PLOTTED? 1
ARE ANY SPECIAL PLOTS REQUIRED? $\emptyset$
IS PRINT OUT ON LINE PRINTER REQUIRED? 1
ARE RESULTS TO BE STORED ON MAG. TAPE? $\emptyset$

INITIAL PARAMETERS FOR
RAYTRACING CALCULATIONS

FIG. 4

MAKE SURE SOUND SPEED OR TEMPERATURE/SALINITY PROFILE IS IN PHOTOREADER
PROBLEM NUMBER ‹MUST BE ›$\emptyset$› = 1
SOURCE DEPTH IN MTS.= 1$\emptyset$8
DEPTH OF BOTTOM IN MTS.= 15$\emptyset$
MAX. RANGE IN MTS.= 25$\emptyset\emptyset$
INITIAL ANGLE FROM SOURCE IN DEGREES = -11
INCREMENT ANGLE IN DEGREES = 1
MAX. ANGLE FROM SOURCE IN DEGREES = $\emptyset$

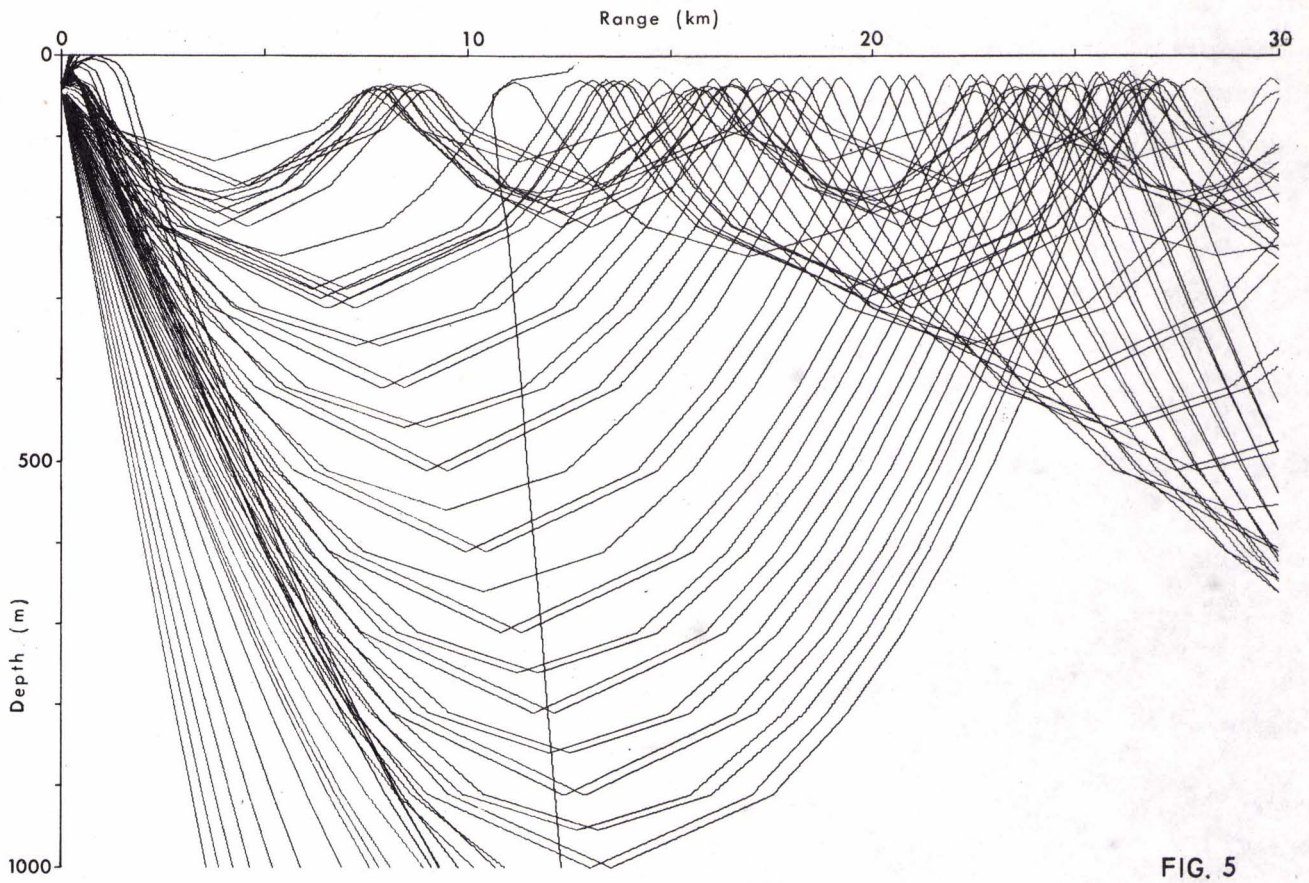## RAY DIAGRAM (SOURCE AT 45 m; SURFACE AND
BOTTOM REFLECTIONS SUPPRESSED)
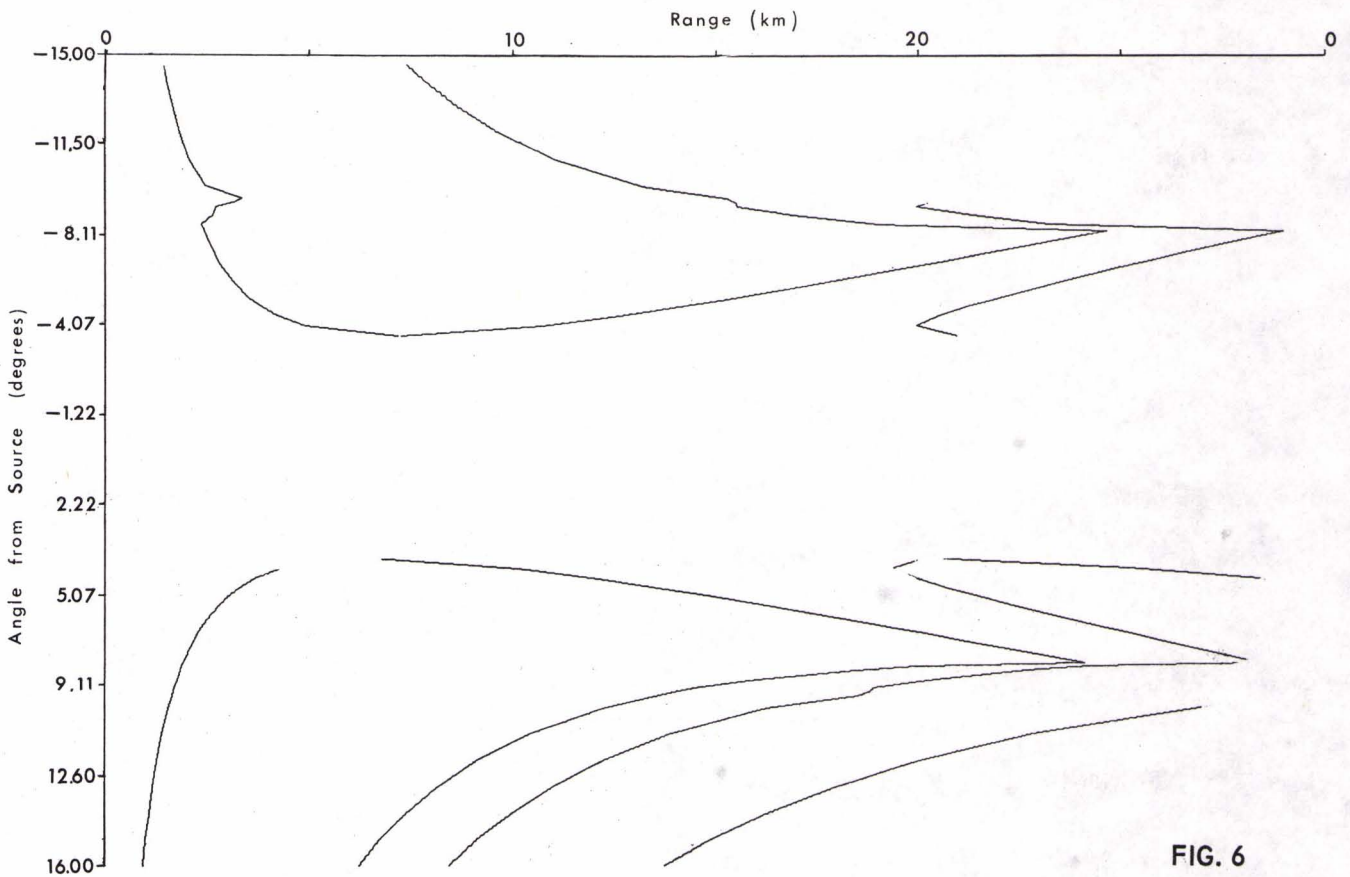

FIG. 5

ANGLE FROM SOURCE vs RANGE
LAYER DEPTH 310 m

FIG. 6

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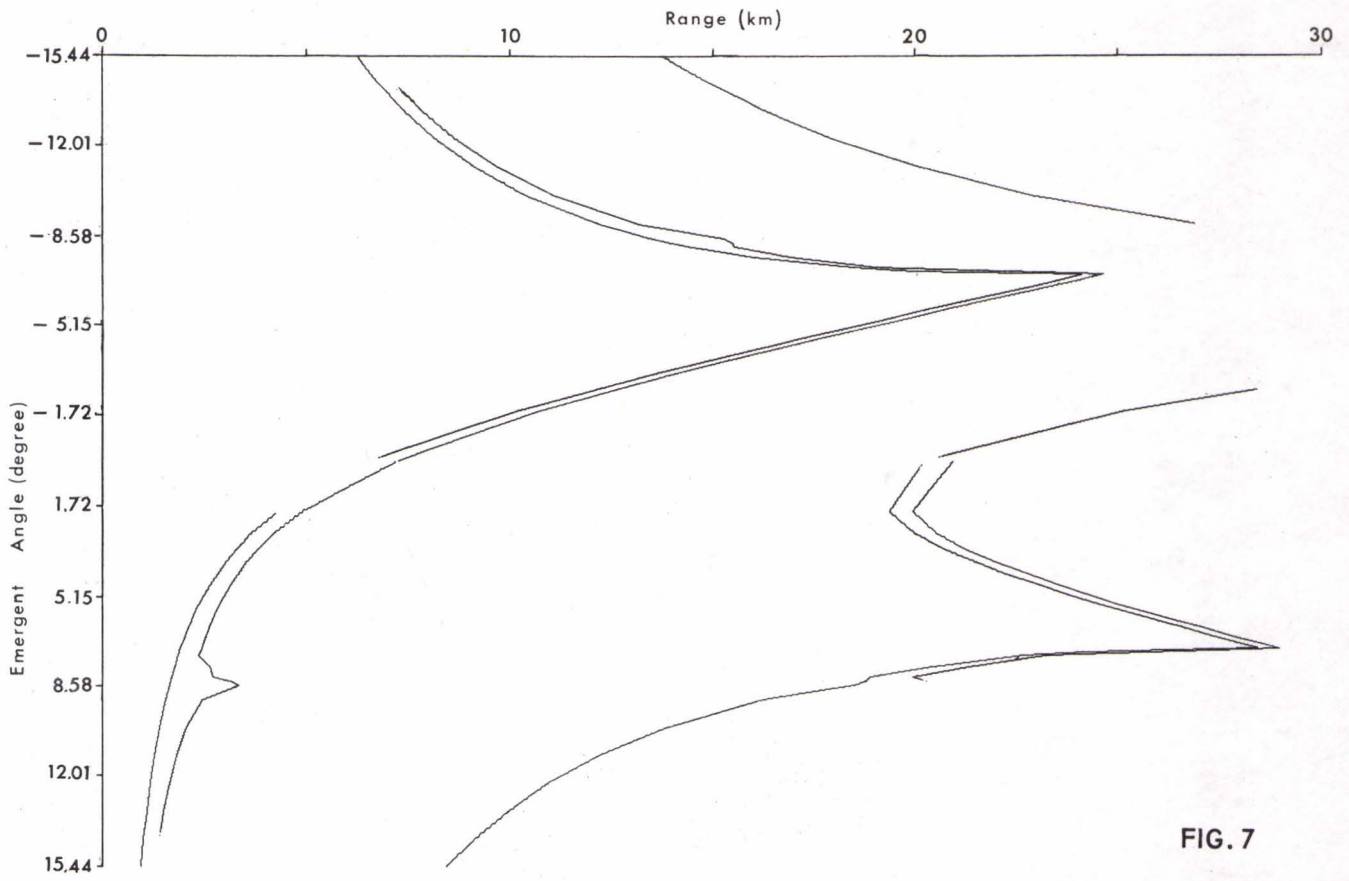## EMERGENT ANGLE FROM LAYER vs RANGE
LAYER DEPTH 310 m

Range (km)

FIG. 7

TRAVEL TIME vs RANGE
LAYER DEPTH 310 m

Range (km)

FIG. 8

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