Technical Memorandum

1923
Kang
AECU-3213Photostat Price \$ 3.30Microfilm Price \$ 2.40

Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

46-55-54

RAYPAC

A SPECIAL-PURPOSE ANALOG COMPUTER

H. B. Durham

ABSTRACT

As an aid in forecasting possible blast damage in areas distant from a bomb burst point, a special-purpose electronic analog computer has been developed. Sound ray paths (orthogonal trajectories to sound wave front) are computed as a function of meteorological conditions.

2981

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

Case No. 416.31

1955

1955

March 24, 1955

L-1235

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Copy to:

Dr. J. B. Hersey, Woods Hole Oceanographic Institution, Woods Hole, Mass.
Mr. James W. Smith, Department of the Navy, Office of Naval Research, Washington 25, D. C.
Dr. Wilbert Annis, Department of the Navy, Office of Naval Research, Washington 25, D.C.
Dr. Norman A. Haskell, Geophysics Research Division, AF, Cambridge Research Center, Boston, Mass.
Mr. A. P. Crary, Geophysics Research Div., AF Cambridge Research Center, Boston, Mass.
Dr. A. B. Focke, Marine Physical Lab., Scripps Institute of Oceanography, San Diego 52, Calif.
Dr. C. T. Johnson, U.S. Naval Electronics Laboratory, San Diego 52, California
Mr. Gordon J. Watt, Sperry Gyroscope Co., Great Neck, New York
Dr. C. W. Lampson, Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland
Dr. Gregory K. Hartmann, U.S. Naval Ordnance Laboratory, White Oak, Silver Spring, Maryland
Mr. George B. Olmsted, Headquarters, USAF, Office of Atomic Energy, DCS/O, Washington 25, D.C.
Dr. J. M. Richardson, 1709 Mariposa Avenue, Boulder, Colorado
S. C. Hight, 5100
R. A. Bice, 5200
G. A. Fowler, 5400
E. F. Cox, 5110
H. E. Lenander, 5220
T. S. Church, 5410
T. F. Marker, 5420
H. H. Patterson, 5440
D. MacKenzie, 6010
B. J. Bittner, 5412
J. P. Shoup, 5413
H. J. Plagge, 5241-4
R. K. Smetlzer, 1922-2
M. K. Linn, 1923 (6)

DO NOT
PHOTOSTAT

RAYPAC
A SPECIAL-PURPOSE ANALOG COMPUTER

INTRODUCTION

Prior to each atomic test at the Nevada Test Site, it is necessary to determine if blast damage is probable in any of the towns within a 150-mile radius.

In the past, it has been necessary to calculate a few approximate ray paths in each direction of interest with the aid of a calculating machine. A well-trained man, with considerable experience and intuition, requires approximately one and one-half hours to complete these calculations. Since weather conditions are all-important in determining blast damage, and it is quite possible for weather conditions to change from favorable to dangerous within an hour, there is a need for a faster means of computing the ray paths. This is the function of the ray path computer.

RAY PATH EQUATIONS

As an aid to solving the ray path problem, several assumptions are made.¹ These assumptions are:

1. Vertical wind components are negligible compared to the speed of sound.
2. Atmospheric conditions (winds and temperature) are constant over the entire region of interest (at any particular altitude).
3. Horizontal wind components are small compared to the speed of sound.

With these assumptions we can derive the equation for the approximate ray path. Snell's law states that

$$\frac{c}{\cos \theta} + V_w = K \quad (1)$$

where

c = speed of sound

θ = angle of inclination from the horizontal of a particular ray path

V_w = wind velocity in direction of interest

K = constant for any particular ray

(This relationship applies only for horizontal winds, but it is assumed that vertical wind components are negligible.)

1

Everett F. Cox, H. J. Plagge, and J. W. Reed, "Meteorology Directs Where Blast Will Strike," Bulletin of the American Meteorology Society. Vol. 35, pp. 95-103, (1954).

From equation (1)

$$\frac{c + V_w \cos \theta}{\cos \theta} = K \quad (2)$$

If we assume that

$$c + V_w \cos \theta = V$$

where V is now the velocity of sound, it is possible to make the following statement:

$$\frac{V}{\cos \theta} = \frac{V_o}{\cos \theta_o} = K \quad (3)$$

for any particular ray path, where V_o is the speed of sound at the origin of the ray path, and θ_o is the initial angle of inclination of the ray path.

One other relationship in conjunction with equation (3) is necessary to solve the ray path problem. With reference to Figure 1, we can state $\cot \theta = \frac{dr}{dh}$ where dr is

Figure 1

an increment in range (r) of the ray path corresponding to a given increment in height (dh).

Therefore,

$$r_H = \int_0^H \cot \theta \, dh \quad (4)$$

From equation (3)

$$\theta = \cos^{-1} (V/V_o \cos \theta_o) \quad (5)$$

Combining equations (4) and (5)

$$r_H = \int_0^H \text{Cot} \left[\text{Cos}^{-1} (V/V_0 \text{ Cos} \theta_0) \right] dh \quad (6)$$

As an aid to the computer in solving the ray path equation, we may arbitrarily state $h = + Kt$ since the desired output of the computer is the relationship $r = f(h)$ and not necessarily a real time presentation of "h" and "r". Substituting $h = + Kt$ in equation (6) results in the equation used to solve the ray path,

$$r(t) = K \int_0^T \text{Cot} \left[\text{Cos}^{-1} (V/V_0 \text{ Cos} \theta_0) \right] dt \quad (7)$$

INPUT DATA

From equation (7), it can be seen that two pieces of input data are necessary to solve the integral. These inputs are V/V_0 and $\text{Cos} \theta_0$; V/V_0 is simply the speed of sound (in a particular angle of azimuth) as a function of height, normalized to the speed of sound at the point of origin. A typical V/V_0 curve is shown in Figure 2.

Figure 2

Points for this curve are computed from meteorological data obtained at the test site.

$$V_h = C_h + V_{wh} \quad (8)$$

where:

- V_h = velocity of sound at a particular h
- C_h = speed of sound corrected for temperature at h
- V_{wh} = component of wind velocity in particular angle of azimuth.

The other input, $\cos\theta_0$, is a constant for any particular ray path, but it is the variable parameter necessary to produce a family of ray paths in one angle of azimuth. Changes in azimuth angle require a new V/V_0 curve, since a change in azimuth changes the last term in equation (8).

COMPUTER DESCRIPTION

With reference to the computer block diagram, Figure 3, a brief description of the computer will be given.

A diode line segment function generator in conjunction with amplifier A_1 and A_2 are used to generate the V/V_0 curve. Figure 4 is a simplified diagram showing the manner in which the V/V_0 curve is generated. Since V/V_0 is a function of "h", the "h" voltage is the input to the function generator. As the "h" voltage increases in the positive direction (corresponding to an increase in "h"), successive diodes become conducting. A potentiometer, associated with each diode, sets the slope of the line segment at that particular break point. In this manner the V/V_0 curve is approximated by a series of straight line segments. The function generator uses 19 line segments at predetermined break points to generate the V/V_0 curve.

Following the V/V_0 function generator is the $\cos\theta_0$ attenuator. This attenuator consists of a group of precision resistors in a voltage divider arrangement. A stepping relay selects a new point on the divider, corresponding to a new $\cos\theta_0$, at the end of each ray path solution. The operator has a choice of 1° , 2° or 4° increments in θ_0 . Due to the limited resolution of analog devices, it is impossible to resolve the small changes in $\cos\theta_0$ (for a given increment in θ_0) near $\theta_0 = 0^\circ$; therefore, the minimum value of θ_0 is 5° . In general, values of θ_0 greater than 30° are not of interest since ray paths departing at angles greater than 30° are not refracted.

The term $[V/V_0] \cos\theta_0$, in the region of interest, varies from about 1.0 to 0.7. With the scale factors chosen for the computer, this represents 50 to 35 volts at the input to A_3 . It is the function of A_3 to remove the 35-volt bias and multiply by $6-2/3$. This provides a 0- to 100-volt output to drive the cotangent function generator.

The cotangent function generator is similar to the V/V_0 function generator in that it sums a series of line segments to approximate the function. The six line segments used to approximate

7

Figure 3

2986

7

the function are summed by A_4 . The integrated output of the function generator is proportional to the range of the ray path.

As mentioned earlier, the assumption that $h = +Kt$ is made to simplify the computation process. A_5 is a feedback integrator with a fixed magnitude input, but the polarity of the input is changed, depending upon the portion of the ray path being computed ($dh = +K$). The output of A_5 is added with an initial value of h (h_0) by means of A_6 . The output of A_6 is fed to the Y or height axis of the X-Y recorder.

Before discussing the function of A_8 and A_9 , it might be advisable to look at the plot of a typical ray path (Figure 5). From the origin to the apex of the ray path (point A), dh/dt is positive; therefore, the input to the "h" integrator is positive. At the apex, it is necessary to reverse the sign of dh . As a means of detecting the apex, it will be noticed that $dr/dh \rightarrow \infty$ at the apex. Due to the method of computation used, this means $dr/dt \rightarrow \infty$ at the apex of the ray path. Obviously, it is impossible to go to ∞ with the analog of dr . As a practical limit, the ray path is assumed to be horizontal ($\frac{dr}{dh} = \infty$) when the ray path comes within 2° of being horizontal. At this point the sign of dh is reversed. Amplifier A_8 is used to detect the apex of the ray path.

Point B on the ray path ($h = 0$) also requires the sign of dh to be reversed. Amplifier detects $h = 0$ and reverses the sign of dh . Amplifiers A_8 and A_9 operate a bistable multivibrator. A relay controlled by this bistable multivibrator selects the proper dh voltage. Conventional computing amplifiers are used to detect $dr \rightarrow \infty$ and $h = 0$ because of the precision required in detecting these points.

Two additional detectors are used in the computer. They are $r = r_{\max}$ and $h = h_{\max}$. When $r = r_{\max}$ the computing process is stopped, integrators are zeroed, the $\text{Cos}\theta_0$ stepping relay moves to the next value of $\text{Cos}\theta_0$, and the computation of a new ray path is started. This process continues until the entire family of ray paths is computed or until $h = h_{\max}$. When $h = h_{\max}$, the computation is stopped and no further ray paths are computed. This is desirable since the ray path that exceeded $h_{\max}$ and all further ray paths in that family will not be refracted; therefore, they are not of interest. These two detectors are simple regenerative feedback amplifiers; therefore, they are not as precise as the detectors used for $dr \rightarrow \infty$ and $h = 0$. Since they do not enter in the computing process, but merely set limits, their precision is of no importance.

Two range scales are available. They are 0-20 miles and 0-100 miles. The height scale, regardless of the range scale, is 0-100,000 feet. It is difficult to speak of the time necessary to compute one ray path since the computing time depends upon the particular ray path. Computation is made at a constant dh/dt which is 5,000 ft/sec. on the 100-mile range and 2,000 ft/sec. on the 20-mile range.

9

Figure 4

2988

HEIGHT

10

A

B

RANGE

Figure 5

0

2989

10

The dc amplifiers used in the computer are Electronic Associates, Inc., type 16-6H dual-channel, chopper-stabilized amplifiers. Power is furnished by two power supplies (+300v and -300v). The load is approximately 150 ma on each power supply. There is a small 100-v unregulated power supply to operate the relay circuitry.

The output device is a Librascope X-Y recorder, which uses paper with a 10" x 15" writing area, allowing plotting of the V/V_0 curve and the family of ray paths associated with this curve.

Experience with the computer indicates the maximum range error of any ray path is less than 2% of full scale. However, if this error is referred to $\cos\theta_0$, it represents an error of less than 1% in $\cos\theta_0$.

H. B. DURHAM - 5413

Case No. 416.31

March 24, 1955

298 10

12

Figure 6

298 11

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK