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**NSWCDD/TR-00/18**

**USER'S GUIDE FOR THE SOUND INTENSITY  
PREDICTION SYSTEM (SIPS) AS INSTALLED AT THE  
NAVAL EXPLOSIVE ORDNANCE DISPOSAL  
TECHNOLOGY DIVISION (NAVEODTECHDIV)**

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**FEBRUARY 2000**

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## FOREWORD

The Sound Intensity Prediction System (SIPS) is a tool employed to reduce the number of complaints about noise from explosive operations. This report is presented as a user's guide for the SIPS model, Version 1.1, which has been installed at the Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) located in Stump Neck, Maryland. The guide is intended as an aid to the personnel who must execute SIPS and interpret its output.

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This report has been reviewed and approved for release by Thomas Del Guidice, Head, Weapons Integration and Technology Branch, and Robert Stiegler, Head, Combat Systems Safety and Engineering Division.

Approved by:



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## 1.0 INTRODUCTION

This User's Guide for the Sound Intensity Prediction System (SIPS) implementation at the Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) proceeds from the general to the specific. Some definitions and background are presented, but the main intent of this guide is to assist the user with the SIPS program operation, interpret the program output, and deal with judgement issues based upon that output. In addition, since no computer tool should circumvent the use of common sense and experience, some discussion is presented on the following problematic areas:

1. Input conditions that cause predictions that can be safely ignored.
2. Obtaining proper weather information.
3. Noise complaints versus safety.
4. Topography data.
5. Rapidly changing weather conditions.

SIPS is a noise-complaint management tool for range commanders to help control the impact of noise from explosive operations on surrounding communities. Upper-level meteorological data gathered near the origin of the explosive site, or ground-zero location, is input to a computer program that predicts where and how the atmosphere will refract the resulting sound. If there is a prediction of greatly reduced sound or refraction to an area where no one will complain, a decision to continue the operation is in order. Predictions of sound intensification near populated areas may indicate a postponement of activities until the weather changes.

The SIPS computer model is written and compiled in FORTRAN to execute in a Windows® environment; the dialog window presented to the user upon start-up is coded in FORTRAN 90, as provided by Digital Equipment Corporation. SIPS is designed to run on at least a 486 Personal Computer and the NAVTECHDIV version requires roughly 30 megabytes of hard disk space because the SIPS graphic output uses a proprietary program, AXUM® Version 6.0.

The main work of SIPS is ray tracing. An examination of the physics and origin of SIPS is provided in Reference 1. Tracing acoustic rays through a horizontally layered atmosphere economically simulates sound propagation from a single noise event. These rays obey Snell's law for refraction. A maximum of 36,000 pairs of rays may be traced from their origins at ground zero to a terminus on land, water, or out of the area of interest, if traced along every azimuth. SIPS checks for concentrations of ray endpoints on land indicating areas of intensification, and reports areas of quiet where the rays never touch down; in the latter case rays are not traced except for optional graphical presentation.

If the total sound energy from an explosion can be thought of as an expanding hemispherical bubble with an origin at ground zero, the acoustic rays project outward from and normal to the surface of that hemisphere. The expanding hemisphere is quickly

distorted by atmospheric refraction since not all parts of the surface are moving outward at the same speed. Higher sound speeds near the ground cause more expansion upwards away from the ground so that perceived sound levels on the ground are less than average. A ray-trace of this situation shows lines reaching up to the stratosphere with none returning to earth. An upper-air inversion will cause those parts of the expanding surface that arrive there first to overtake the lower parts and form into a pocket that returns to earth to create a great intensification of sound energy. A ray-trace of this condition shows a group of lines converging to some spot on the ground. Note that Snell's law was not derived for a moving medium so the addition of winds is handled by an approximation that causes small, but insignificant, errors.

The most difficult part of using SIPS is acquiring the input weather data: air temperature, wind speed and direction versus altitude at one to two hundred-foot intervals up to 5000 ft in an area with flat terrain. Sound speed depends only on these quantities in the SIPS model. Such information requires an expensive meteorological data collection system and a dedicated person to operate it. The method selected for obtaining weather data at NAVEODTECHDIV is to use timely weather data gathered at the Naval Surface Warfare Center Dahlgren Division (NSWCDD). The files are automatically e-mailed to NAVEODTECHDIV as they are produced. The validity of using nearby weather data has been shown in simultaneous meteorological soundings between NSWCDD and Patuxent River Naval Air Station with a 40-mi separation. Additional launches were made at over 80 mi separation across the Great Salt Lake in Utah. If the weather conditions are widespread and stable, good correlation is much more probable.

SIPS is able to account for the effects of topography on the ray paths. A ray descending on water is completely reflected without loss of energy until it hits land. Acoustic rays are completely absorbed by land and can be blocked by mountains. Topography information was once gleaned from geodesic maps produced by the U.S. Geodetic Survey (USGC), but the 'ruler-eye' method was tedious and errors were possible. The present descriptions come from Digital Terrain Elevation Data (DTED) provided by the National Imagery and Mapping Agency (NIMA). Proprietary software produces a grid of elevations that is converted to radial lines-of-sight by NSWCDD programs once a ground-zero location is chosen. Each line-of-sight (LOS) is along an azimuth measured clockwise from true North and a terrain description in that direction is given as a collection of consecutive line segments out to some distance. There may be as few as one LOS or as many as desired; 360 lines-of-sight are employed at even angular intervals around the NAVEODTECHDIV ground zero to fully cover the surrounding area. A SIPS traces 100 pair of rays along each LOS and stores the locations of sound concentrations or quiet areas. After all 360 azimuths are swept through, a map of the area is produced with the information of sound concentrations and reductions overlaid. More information about the form of the topography data is described in the INPUT section.

Finally, there must be a standard against which the sound is compared to determine reduction or intensification. The 'average expected overpressure' is the name for the standard ambient level used as a background. The average expected overpressure is determined from sound measurements in the field as a function of distance from ground zero and TNT equivalent charge weight. The measurements are taken under all conditions during a calendar year. The data can be plotted as logarithm (log) of a scaled

distance (feet/cube root of weight in pounds) versus the decibel level to determine the coefficients of the well-known scaling laws for sound overpressures. In the perfect world of an isotropic atmosphere, the sound overpressure would decay according to the inverse-square rule; doubling the distance results in a six-decibel (dB) overpressure reduction. In an average atmosphere the decay is larger because much of the sound is refracted upwards, never to return in the immediate vicinity. The data supporting the SIPS average expected overpressure estimate came from Aberdeen Proving Ground Ballistic Research Laboratory (BRL). The 'BRL' curve, Reference 2, is considered conservative in that the overpressure decays more quickly with distance compared with the majority of models, Reference 3.

## 2.0 PROGRAM INPUT

The NAVEODTECHDIV SIPS model can be executed by either opening the NAVEOD folder in the Window's Explorer® and double-clicking on the SIPS executable file, or double-clicking the 'Desktop' shortcut icon. A dialog window is presented which collects the user's options and local ground-level weather input as shown in Figure 1. The <Tab> key moves sequentially between options and the <Space Bar> selects the option. In addition, each selection can be made using the point-and-click method with the mouse. The following sections give an explanation of each option. Note that actual selection objects from the dialog window are highlighted in [REDACTED].

Sound Intensity Prediction System for NAVEODTECHDIV Version 1.1

Weather Data Source and Input File Location

What is Producing the Weather Data?

NSWCDD Sodar Unit  NSWCDD Balloon

Enter SODAR Identifier (Omit Trailing .sod)

Enter Weather Balloon Identifier (Omit Leading S)

Locate the Weather Data File

E:\ (Zip Drive)  \WEATHER\  Other

Local Weather Parameters

Operation Date

Operation Time

Local Temperature (Deg F)

Local Wind Speed (Miles/Hour)

Local Wind Direction (Deg)

Please Select the Ordinance

1 Pound of C4

2 Pounds of C4

3 Pounds of C4

4 Pounds of C4

5 Pounds of C4

7 Pounds of C4

10 Pounds of C4

15 Pounds of C4

20 Pounds of C4

If None of the above, Input equivalent weight of TNT for the charge

Sound Propagation Program

SIPS Calculation  Yes  No

Run Program(s) About Cancel

FIGURE 1. NAVEODTECHDIV SIPS INPUT DIALOG

## 2.1 WEATHER DATA SOURCE AND FILE LOCATION

Two sources of weather data were to be available from NSWCDD:

- (1) NSWCDD SODAR,
- (2) NSWCDD Balloon

**NSWCDD SODAR** is not currently available because of extensive maintenance requirements. The only valid choice for weather input is **NSWCDD Balloon**. Weather balloons carrying a RADIOSONDE with either LORAN-C or Global Positioning System (GPS) navigation systems are launched prior to every explosive operation at NSWCDD. The number of balloon launches can vary from one to four per day during range operations. If an operation is planned, a weather balloon is launched and a SIPS noise prediction for the community surrounding NSWCDD is produced. A negative decision will cause additional balloons to be launched at approximately one-hour intervals until the operation is completed or postponed. Of the two meteorological data collection methods, SODAR is viewed as more desirable because it would sample the atmosphere automatically every 15 minutes. In addition, data would be collected even on days of no operations at NSWCDD so that NAVEODTECHDIV would not be dependent on the agenda of the former. In the event NSWCDD does not have operations planned on a given day and weather data is required, NAVEODTECHDIV should contact NSWCDD to request a balloon flight. The payment for the balloon flight would come from the maintenance agreement. Until there is a change in the SODAR status, the current balloon weather data will be e-mailed as file attachments from NSWCDD to NAVEODTECHDIV as it is produced. A web site that can be accessed for the weather data is being investigated as a possibility.

The weather balloon identification number must be entered next. The balloon weather files from NSWCDD are named with following convention: YYTTTT.JJJ, where YY is the year, TTTT is the 24-hour time, and JJJ is the Julian date. S991200.309 indicates a weather file from 5 November 1999 launched at time 1200; this particular weather data file and the SIPS predictions based on it will be used as examples throughout the remainder of this guide. Remember that the leading 'S' of the file name is to be omitted when entering the balloon identifier. NSWCDD weather data is sampled at very frequent intervals since it is required in the performance evaluations of gun projectiles fired over the Potomac River; data intervals are occasionally less than 20-ft apart. Atmospheric layers should be on the order of four times the blast wavelength when used in SIPS. Blast data collected at NAVEODTECHDIV in June 1999 indicates that atmospheric layer thickness should be approximately 150 ft. Thinner layers do not degrade the predictions of SIPS, but are unnecessary since the detail they provide is more transient. A later SIPS version will produce weather files with this larger data spacing.

The next dialog option is the location of the weather data file as it is stored in the user's system:

- (1) the **E:** (zip drive),
- (2) the **Weather** directory,
- (3) some other path of the user's choosing.



The \Weather\ directory is the usual choice as the e-mailed weather balloon files from NSWCDD should be stored there. Note that the \Weather\ folder also has a subfolder \Archive\ that retains the selected options and inputs for each SIPS run. SIPS writes these records for later referral as diagnostic aids if a problem arises. Note that each additional program execution using the same weather file as input overwrites the previous run. \Weather\Archive\ is constructed when the SIPS model is loaded into the user's computer from the installation CD.

## 2.2 LOCAL WEATHER PARAMETERS

The operation date and time inputs are superfluous given the structure of the input weather file name, but may be convenient for record keeping purposes. They may be left blank without consequence.

Local ground-level weather conditions for **air temperature**, **wind speed**, and **direction** are next. Since the weather data is generated from conditions over NSWCDD, the three boxes tie the upper-level data to local ground conditions. Comparisons between weather balloons launched from different locations show that on stable days the upper level conditions remain constant but local ground-level values may differ. User values for temperature, wind speed, and direction at NAVEODTECHDIV are expected in units of degrees Fahrenheit (°F), miles per hour (mph), and degrees clockwise from true north that the wind is blowing from. The user must include a decimal point when entering the temperature and wind speed or the program will misread the entry. The wind direction entry does not require a decimal point.

## 2.3 ORDNANCE SELECTION

The right side of the dialog window contains nine charge weight options given in pounds of composition-C4 explosive that may be used at NAVEODTECHDIV. These options are provided as a convenience to the user as the charge weight equivalency with TNT is accounted for. These standard selections can be changed by NSWCDD if desired. If the user requires some other type or weight of explosive, the expected input value is the TNT equivalent weight in pounds entered in the final dialog box. There is no need for great accuracy in the estimation of input charge weights; an approximation is sufficient since sound overpressure level is a weak function of charge weight. Doubling the charge weight adds no more than three dB to the peak sound level—a barely perceptible increase to the human ear if the events are not strictly consecutive.

## 2.4 SOUND PROPAGATION PROGRAM

The final option selects whether the SIPS program is to be executed or not. This option is a holdover from other installations where more than one process could be executed. Without this option the input window does not operate. If **Yes** is selected the **Display SIPS Output Maps** option becomes active. If **No** is selected, the program ends

when the [REDACTED] button is clicked; the program also ends when the [REDACTED] button at the top is clicked. Again, if [REDACTED] is selected, but the [REDACTED] is not, SIPS will execute and end without showing results. Figure 2 shows a completed input dialog window for balloon S991200.309, where the intended explosive is 5 lb of composition C4. The final input requirement is to click the [REDACTED] button. What follows is covered in the OUTPUT section. The SIPS program execution and the displayed output maps are controlled by AXUM® script files once the user is finished with the dialog window.

FIGURE 2. COMPLETED NAVEODTECHDIV SIPS INPUT DIALOG

### 3.0 PROGRAM OUTPUT

The first display the user sees is an output window named 'Graphics 1' with a set of numbers streaming by vertically. These numbers are the azimuths, 0 through 359 deg, measured clockwise around ground zero as SIPS calculates the ray paths. If there is a problem during the execution of SIPS, the 'Graphics 1' window has proven useful in pinpointing the topography azimuth where the trouble occurred. This window remains in the background during map output and will reappear after program execution. At the completion of the azimuth list, AXUM® Version 6.0 is started automatically and the four output plots of Figure 3 appear. The following sections discuss each plot and its interpretation.

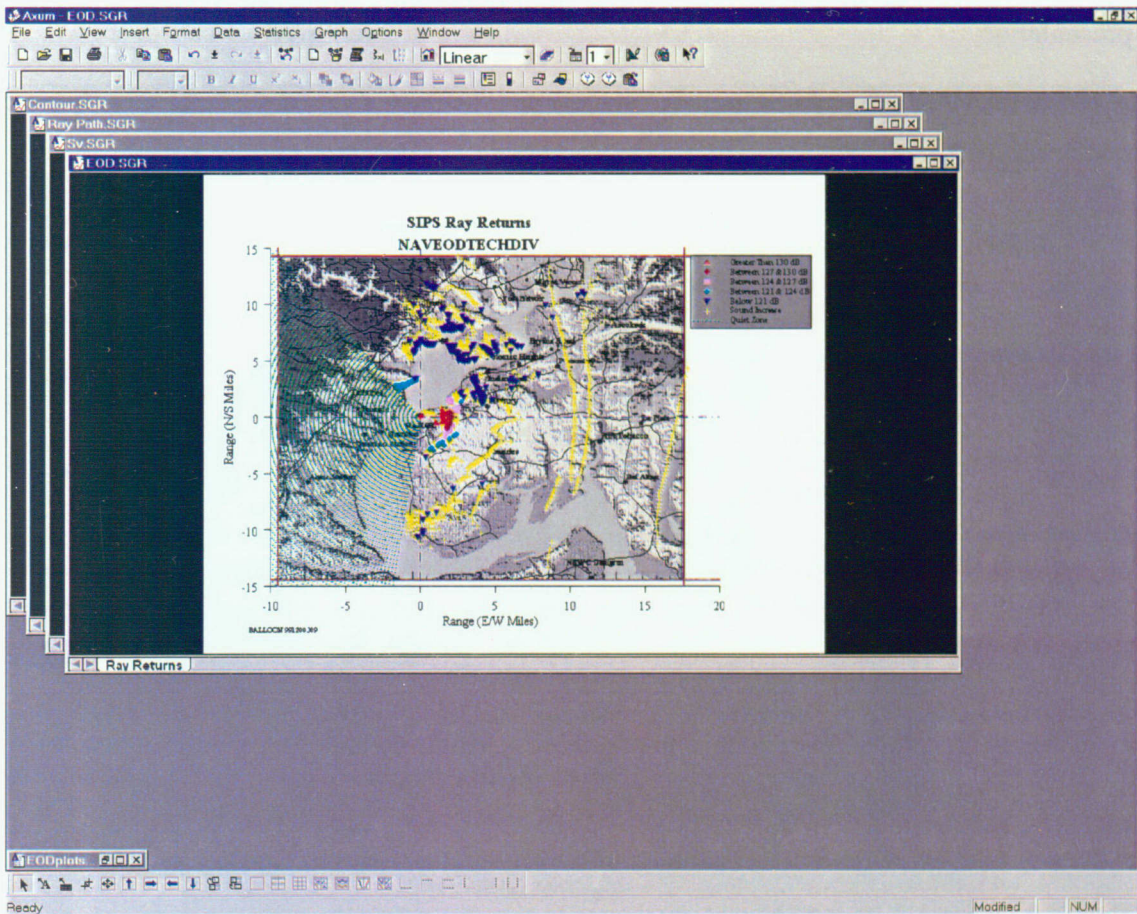


FIGURE 3. SIPS OUTPUT MAPS CASCADED ON SCREEN

### 3.1 CONTOUR PLOT

The first plot drawn by AXUM® is the Contour Plot of constant dB levels around ground zero shown in Figure 4. The Contour Plot is included as a quick check of the relationship between the weather data and the expected noise distribution; this check helps the user decide if the final output of SIPS is plausible. Once a product of the Blast Overpressure Operational Model (BOOM), Reference 4, this contour feature has been incorporated into the SIPS model. BOOM is a simplified empirical noise prediction model for a flat earth originally designed for a hand-held calculator, Reference 5, when other models required expensive computer time. Attempts to improve the accuracy of BOOM employing data recorded at the Utah Test and Training Range have proven fruitless. Nevertheless, the calculated noise estimates provide a quick graphical reference as to which directions the sound energy is concentrated. The contours indicate the direction of sound propagation by distorting outwardly what would be concentric circles of constant dB levels centered about ground zero. Concentric circles would be the result of sound propagation in a single-temperature atmosphere with no winds. Note that the

vertical axis in Figure 4 is the North-South direction and the horizontal is East-West with the units of both being miles; the scale is slightly compressed in the vertical for better presentation.

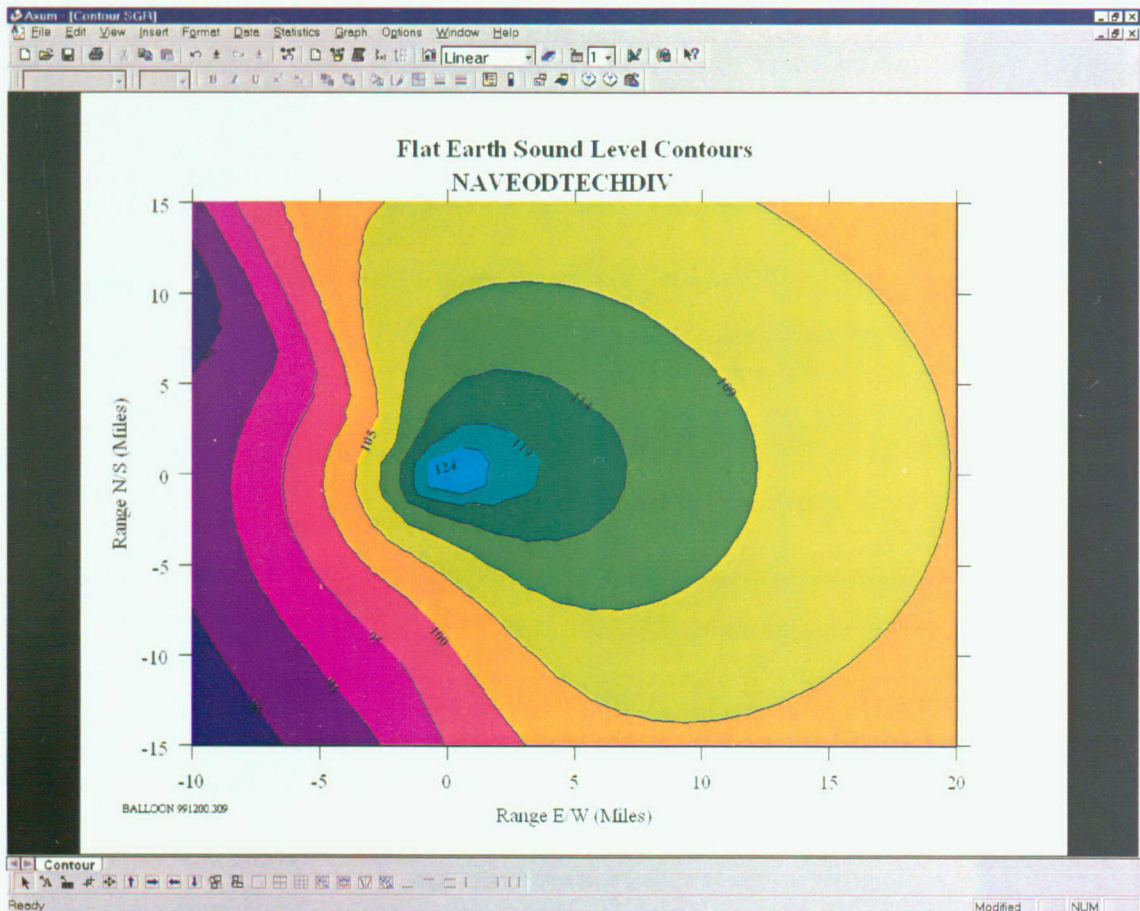


FIGURE 4. CONTOUR PLOT FROM SIPS PROGRAM

### 3.2 SOUND VELOCITY PROFILE

The second plot to be examined is the Sound Velocity Profile Plot for selected azimuth angles around ground zero. There are eight sound velocity versus altitude curves on one page. Because of winds the sound speed varies not only with altitude but also with azimuth. For NAVEODTECHDIV the selected directions are 45 deg apart starting at true north; these angles were chosen arbitrarily and can be changed at the user's request once sensitive areas around ground zero are identified. This plot produces a great deal of significant information. Some of the things that can be learned from the particular example in Figure 5:

- (1) If the sound velocity is a maximum at ground level, all of the sound energy will refract towards the stratosphere as shown by the Azimuth 270° curve.
- (2) Locating sound velocities that are greater above than at ground level can identify inversion layers that cause sound to refract back to earth.
  - (a) The 90° azimuth shows inversions at 500-, 1500-, and 4500-ft altitudes.
- (3) The altitude of the inversion indicates the amount of sound energy refracted back to earth and its return distance from ground zero.
  - (a) The higher in altitude the inversion is located the greater the amount of sound energy refracted back to earth.
  - (b) The higher in altitude the inversion is located the farther away from ground zero the ray will return to earth.

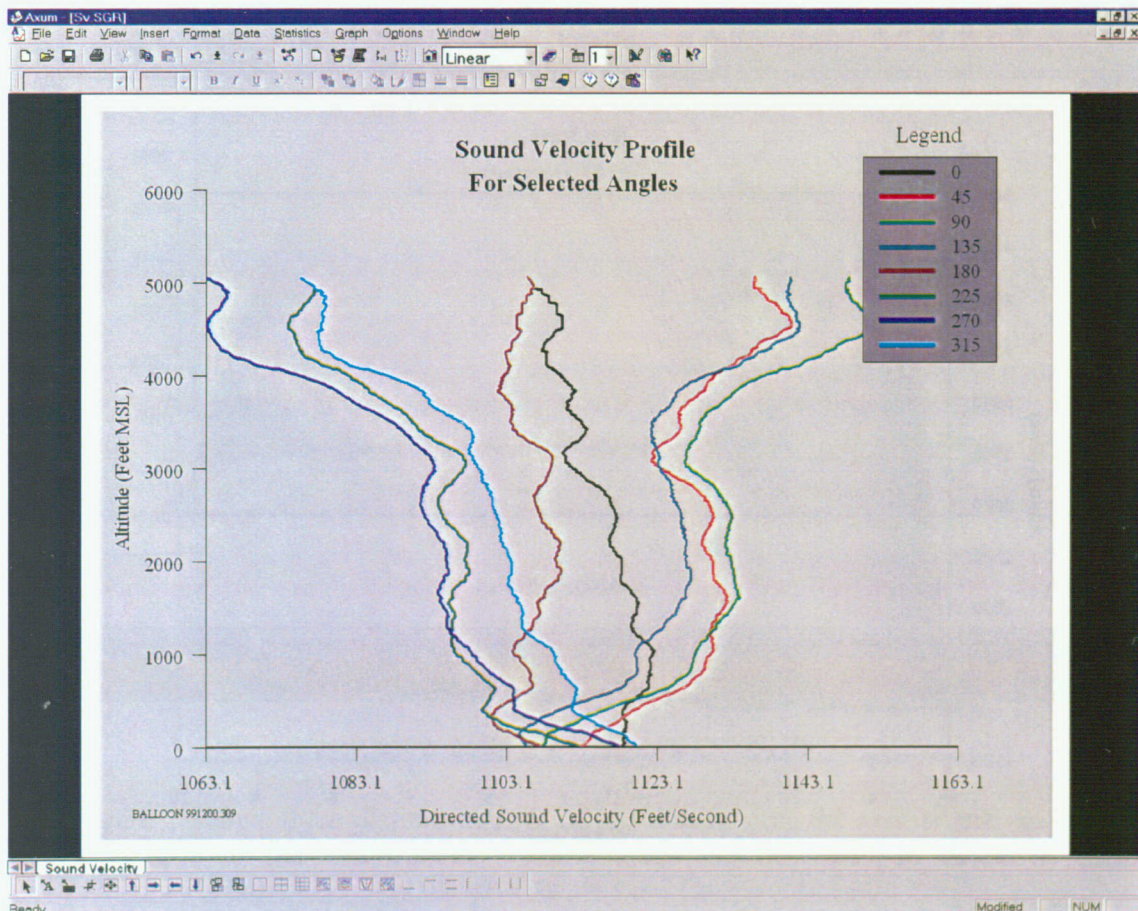


FIGURE 5. SOUND VELOCITY PROFILE FOR SELECTED AZIMUTHS

### 3.3 RAY TRACE PLOTS

The Ray Trace Plots show detailed ray paths as calculated by SIPS from ground zero along the eight azimuths indicated in the Sound Velocity Plot; there is one ray trace plot for each direction. SIPS traces 100 pairs of rays per azimuth when warranted, but only one ray from every other pair is displayed in the plots to control clutter. The information portrayed in a particular sound velocity profile directly affects the way the ray paths in that direction look. Individual cases are examined below to illustrate different principles. The ray trace plots were originally prepared to help in the development of SIPS, but they proved to be so informative that they were kept for the user. Access to an individual plot is accomplished by clicking on the appropriate azimuth tab located across the bottom of the plot. The user should be careful not to close out all the ray trace plots by closing the top plot to see the one underneath – use the tabs.

During the discussion of the sound velocity profiles, the 270° azimuth was singled out as a condition where the maximum sound velocity occurred at ground level. Hence, all of the sound energy for this situation would be refracted upward to the stratosphere. Figure 6 shows the ray trace for that 270° azimuth.

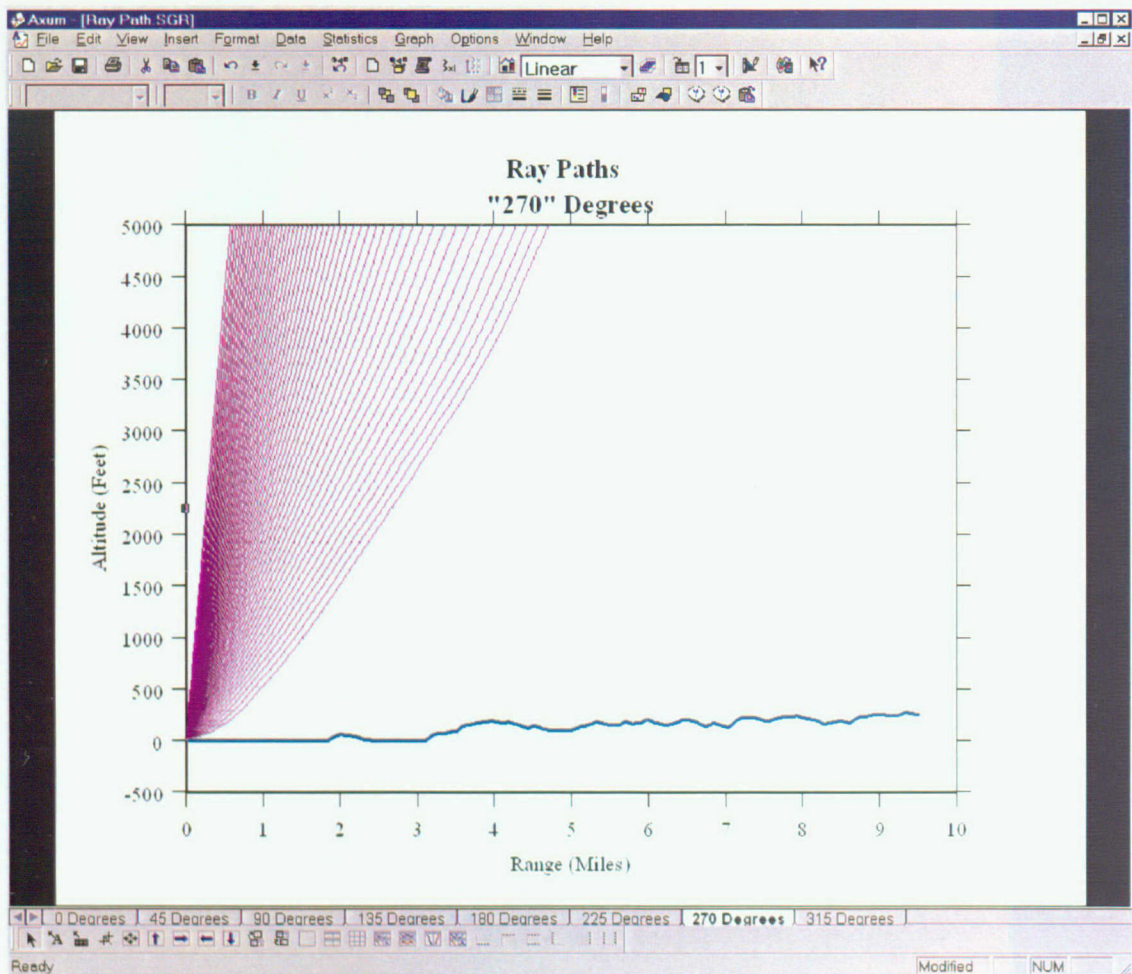


FIGURE 6. 270 DEG AZIMUTH RAY TRACE

The situation depicted in Figure 6 is the most favorable for an operation to occur. When sound energy is refracted to the stratosphere receptors along the ground will not be disturbed by noise. In fact, they may not even know that an operation has occurred as the sound level can be reduced by as much as 30 dB from the expected level. The governing factor for the reduction in sound energy is the slope of sound velocity profile. The shallower the slope, farther to the left it leans, the quicker the sound energy will escape and the greater the reduction from the expected level.

The second situation discussed in Section 3.2 dealt with sound energy being refracted back to earth. Figure 7 shows the ray path plot for the 90° azimuth.

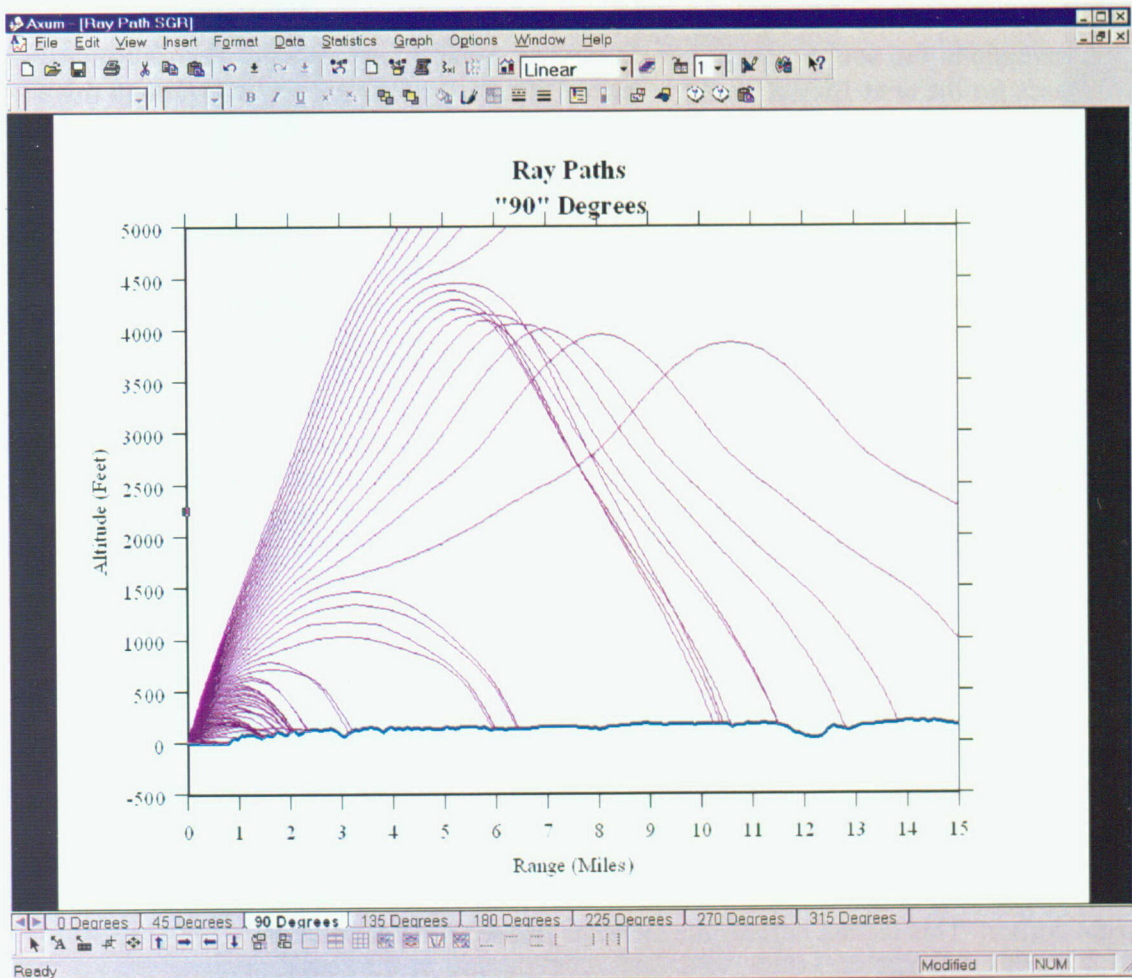


FIGURE 7. 90 DEG AZIMUTH RAY TRACE

Figure 7 shows three distinct regions of ray returns plus the area where the sound energy escapes to the stratosphere. These areas are described in detail in their relationship with the sound velocity profile for the azimuth. The sound velocity profile for the 90° azimuth is shown as the light green line of Figure 5 with a general slope to the

right as the altitude increases. This situation means that sound energy will be refracted back to earth at some point.

During the discussion of the sound velocity profile it was stated that there were three distinct inversion layers present in the 90° azimuth. These occurred at 500-, 1500-, and 4500- ft altitudes. The sound velocity profile shows a fairly constant shallow slope from ground level to the first inversion at 500 ft. The ray paths of Figure 7 show the results of this slope with a large number of rays going up and turning over between zero and 500 ft elevation. The slope between 500 ft and the next inversion at 1500 ft is much steeper on the sound velocity profile; the result is a decrease in the density of the returning rays as they continue to return to earth.

The final inversion of the 90° azimuth occurred at 4500-ft elevation. Between the two inversions the sound velocity decreases for approximately 1500 ft in altitude then increases for the next 1500 ft until the inversion layer begins. The paths through this area show the rays beginning to escape to the stratosphere, then being refracted downward when they encounter the increasing sound velocity.

The downward refractions shown on the 90° azimuth plot suggest that most sound energy returns to earth. Drawing this conclusion would be an error because in reality only a small percentage is refracted back to earth while most of the energy is refracted to the stratosphere. Figure 7 shows, for illustration purposes, six rays located to the left of those refracted at 4500 ft that do not return to earth. The remainder of the upwardly refracted rays is not shown to ease interpretation. All of the returning rays of Figure 7 would probably have an initial angle of departure from ground zero of no more than 10 deg above horizontal; maximum angles of departure are usually much less. When a hemispherical shell is viewed as an energy quantity, the first 10 deg above the horizontal is a small percentage.

### 3.4 RAY RETURN PLOT

The final plot generated from SIPS calculations is the Ray Return Plot, a map locating all of the areas of both sound increases and decreases. The interpretation of this plot may be the most important output of the SIPS program, but it may also be the most confusing for the user. This section will discuss how to interpret the Ray Return Plot.

The first item of note on the plot, shown in Figure 8, is the legend in the upper right corner. This legend defines the symbols needed for a prediction.



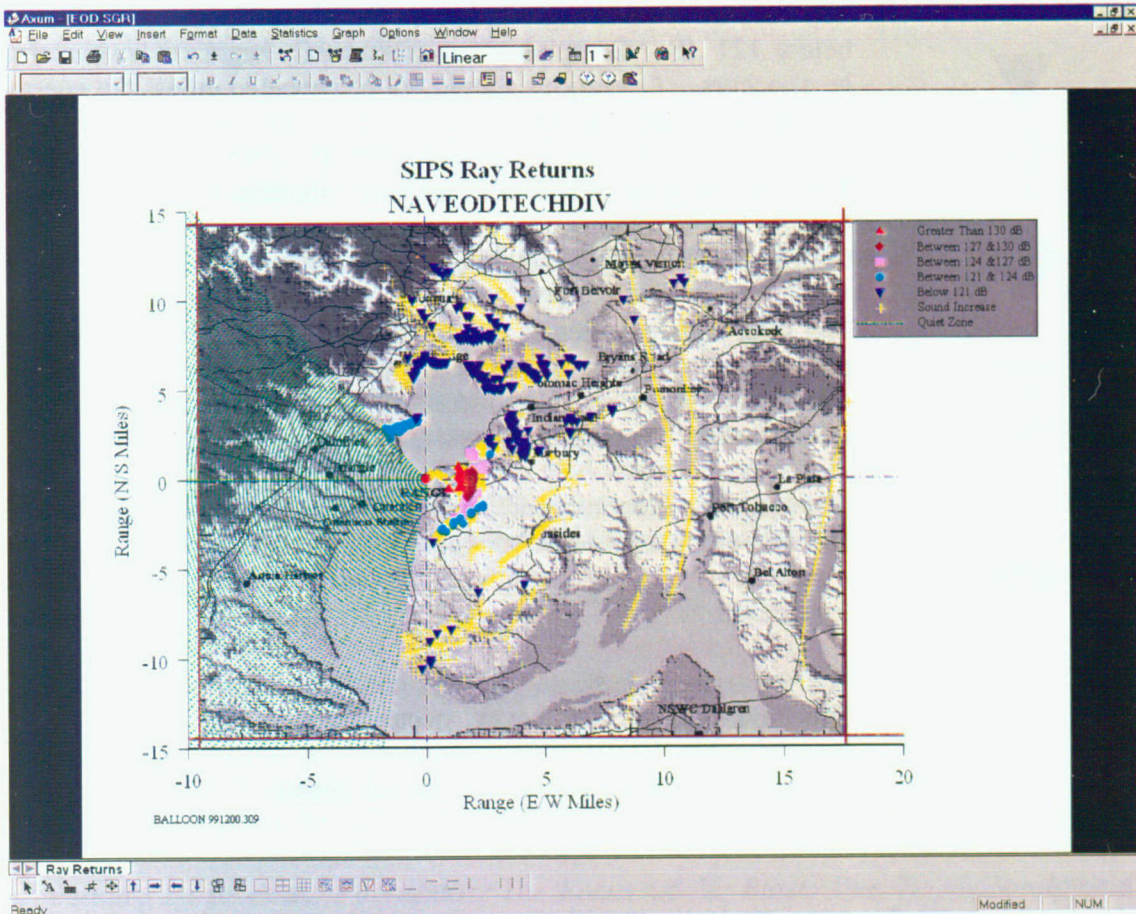




FIGURE 8. SIPS RAY RETURN PLOT

The following list defines each symbol in the legend and describes its impact on the decision to conduct an explosive operation.


 The green dotted line indicates quiet or greatly reduced noise along the direction. The sound energy is being refracted to the stratosphere. This condition indicates the best time for an operation.


 The yellow plus symbol indicates sound energy has returned to earth but does not satisfy focus criteria. The sound level at the receptor would be louder than expected from the decay equation. Operations should not be canceled unless the energy return is in a very sensitive area.



The blue inverted triangle indicates the lowest focusing condition, below 121 dB. Complaints are not usually registered when this level occurs. Operations should not be canceled unless the energy return is in a very sensitive area.



The light cyan circle indicates a focus condition between 121 and 124 dB. Complaints may begin to be registered at this level. Operations may be conducted until sensitive areas are defined.



The pink square indicates focus conditions between 124 and 127 dB. If this symbol is located at a populated area complaints will be registered. Only important operations should be considered, but it would be best to postpone if possible.



The magenta diamond indicates focus conditions between 127 and 130 dB. Complaints will be registered and damage claims become a possibility. Only extremely important operations should be considered.



The red triangle indicates a focus condition in excess of 130 dB. This symbol should never occur outside the boundary of NAVEODTECHDIV. If the symbol lands outside the boundary, postpone the operation to eliminate complaints.

#### 4.0 CONCLUSIONS AND RECOMMENDATIONS

Not all reports of sound focusing on the Ray Return Plot should be accepted without some examination of the Ray Trace plots. There are some low-altitude weather conditions that are either real or only artifacts of the local ground data. In SIPS these conditions are treated as wind shears or temperature inversions and the appropriate predictions are returned. The results can feature very local focal points, or some on the far banks of a nearby body of water. If the local focusing is on the NAVEODTECHDIV property, naturally it can be ignored. If water is nearby, what would be only local focal points may be spread by ray reflection until encountering land and be reported as more distant focusing. The duration of the perceived sound has been increased because of the multiple ray paths.

Experience has shown that complaints are usually registered when the sound at the receptor is a sharp crack, like a shotgun blast. If the duration of the sound is extended to resemble a rolling thunder, the number of complaints is decreased. Therefore, when symbols are located along the shoreline the ray path plot for the azimuth, or the closest one drawn, should be examined. If a low-level inversion caused the rays to bounce on the water, when they reach shore the sound duration will have been extended due to that

bouncing. In this manner, much focusing associated with bouncing on water results from a mathematical solution that does not reflect times of arrival and should not generate complaints. Focusing due to atmospheric conditions above 200 ft should be taken seriously, including that due to bouncing on water.

SIPS predictions are based on the idea that the atmosphere is horizontally consistent. If a weather front is moving into the area, the predictions will not reflect the conditions in the area of interest. The last statement is even more important if the weather data may be coming from NSWCDD – 30 miles away. A condition of stable weather is a requirement for the proper use of SIPS. If the weather is changing, scheduling an operation and avoiding noise complaints may be mutually exclusive wishes.

The noise produced at NAVEODTECHDIV is defined by Reference 6 as 'nuisance noise', to be precise, below 150.8 dB. This criterion distinguishes it from that which can injure people and cause more than cosmetic property damage. In the event that ordnance has been placed and SIPS repeatedly predicts noise in a sensitive area, it will be necessary to weigh the consequences of a complaint with the safety of personnel.

## 5.0 REFERENCES

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