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SOUND PROPAGATION OVER UNEVEN GROUND
AND IRREGULAR TOPOGRAPHY

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by

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TABLE OF CONTENTS

	Page
INTRODUCTION	8
PERSONNEL	5
EXPERIMENTAL PROGRESS	6
PAPERS AND PUBLICATIONS	22
REFERENCES	48

List of Figures

Fig.	Page
1. Frequency spectrum of typical nearfield acoustic pressure pulse. The pressure signal was measured at the reference microphone; the quantity plotted is the absolute magnitude of the Fourier transform of the pulse.	8
2. Design drawing of microphone positioning apparatus. Drawing shows the three dimensional mobility of the apparatus as well as the relative size and shape of structural parts.	11
3. General diagram of experimental software configuration for studying sound propagation over model topographical ridge. The boxes represent different environments in which the various automated tasks are carried out.	14
4. Graphs of typical reference and farfield pressure pulses versus time. The farfield microphone was positioned 41 cm (16 inches) directly above the far side lower edge of the ridge, where it meets the table top.	16
5. Graphs of absolute magnitudes of Fourier transforms of reference and farfield pressure pulses versus frequency. The farfield microphone was positioned 41 cm (16 inches) directly above the far side lower edge of the ridge, where it meets the table top.	17
6. Graphs of typical reference and farfield pressure pulses versus time. The farfield microphone was positioned 23 cm (9 inches) directly above the far side lower edge of the ridge, where it meets the table top.	18
7. Graphs of absolute magnitudes of Fourier transforms of reference and farfield pressure pulses versus frequency. The farfield microphone was positioned 23 cm (9 inches) directly above the far side lower edge of the ridge, where it meets the table top.	19
8. Graphs of typical reference and farfield pressure pulses versus time. The farfield microphone was positioned 5 cm (2 inches) directly above the far side lower edge of the ridge, where it meets the table top.	20

9. Graphs of absolute magnitudes of Fourier transforms of reference and farfield pressure pulses versus frequency. The farfield microphone was positioned 5 cm (2 inches) directly above the far side lower edge of the ridge, where it meets the table top.

INTRODUCTION

The goal of this research is to develop theoretical, computational, and experimental techniques for predicting the effects of irregular topography on long range sound propagation in the atmosphere. Irregular topography here is understood to imply a ground surface that (1) is not idealizable as being perfectly flat or (2) that is not idealizable as having a constant specific acoustic impedance. The interest of this study focuses on circumstances where the propagation is similar to what might be expected for noise from low-altitude air vehicles flying over suburban or rural terrain, such that rays from the source arrive at angles close to grazing incidence.

The objectives of the project, the experimental facility, and the early progress up through February 1986 have been described in the two previous semiannual reports [1,2]. The present report discusses those activities and developments that have resulted during the period, February 1986 through August 1986.

PERSONNEL

In addition to the principal investigators, A. D. Pierce and G. L. Main, a graduate student, James Kearns, and a senior undergraduate student in mechanical engineering, Jeff Riley, are presently working on the project. Two other undergraduates, Dan Benator and James Parish, worked on the project up until the beginning of April. Riley was hired to replace Benator and Parish, both of whom were graduating seniors, and worked on a part time basis up until the end of the academic year. He has resumed work on a part time basis with the beginning of the Fall quarter at Georgia Tech. The division of tasks during the past reporting period has been such that the students have been engaged primarily in the construction of a microphone positioning apparatus, calibration of the laboratory equipment, and design and implementation of an automated experimental procedure. Dr. Main has been supervising the experimental phase of the project and Allan Pierce has been working

primarily on the theoretical aspects.

Exploratory experiments have been recently run, with both students participating. The experiments, which up until now have been mostly of a diagnostic and field characterization nature, are described further below in the present report.

As described in the previous semiannual report, all of the personnel concerned with the project except Riley visited NASA Langley Research Center in November 1985 and discussed complementary NASA and Georgia Tech research activities with the NASA technical officer, Dr. John Preisser, and his colleagues.

EXPERIMENTAL PROGRESS

The past six months have been spent completing the construction of the experimental facility and running diagnostic experiments. This includes designing and constructing a microphone positioner, gathering data for characterizing the surface impedance and for establishing acoustic regions of interest, and automating the experimental procedure. Recently, the progress was interrupted because of the breakdown of the power supply used in the spark source apparatus and of the local unavailability of repair people or of a suitable replacement. Just very recently, an alternate power supply was loaned to the project by another laboratory at Georgia Tech; the original power supply (of unknown vintage) is being sent to the manufacturer with hopes of it being eventually repaired. With the borrowed power supply, the experimental configuration is now complete, calibrated, and ready for collection of the desired field data. The mobility of the microphone positioner along with the automated experimental procedure should allow for rapid data collection. It is anticipated, however, that ongoing adjustments to the experimental procedure and set-up will be necessary as the experiments progress further.

Spark Generator

Some thought has been given to possible schemes to better tune the spark source to the desired frequency band of the experiment. The currently used spark source was designed somewhat hurriedly using components already existing here at Georgia Tech and is not

wholly satisfactory, so some efforts may be required to improve it; a possibility under consideration is to purchase a commercially available spark source designed for acoustic modelling work.

A typical frequency spectrum (or, strictly speaking, the absolute magnitude of the Fourier transform of the pressure) of the nearfield acoustic pressure pulse produced by the originally designed spark generator (described in the previous semiannual report of February 1986) is shown in Figure 1. The spectrum is spread over a wide range with the presence of dominant peaks located at 4, 7 and 33 kHz, respectively. The magnitudes of these peaks are approximately 1.5 times larger than any others. Clearly, a significant portion of the incoming acoustic energy is outside of these three peaks. An ideal signal would have a large percentage of its energy located in a frequency band around 10 kHz. To approximate the ideal more closely, two ideas for tuning the frequency output of the spark source have been studied. Initially, experiments were run using an inductive loop within the current path of the spark generator. Trials with several different loop inductors showed little variation in the frequency output of the spark generator. To modify the spectrum, a resonant chamber design has been proposed and is being constructed for testing. The spark will drive the tuned structural vibrations of the chamber which encloses it. The power output of this method is only limited by the current which can be driven across the spark gap. Complementing this approach, a high voltage triggering electrode is being installed to enable dictation of the discharge voltage level and, thus, enhance the current driven across the gap.

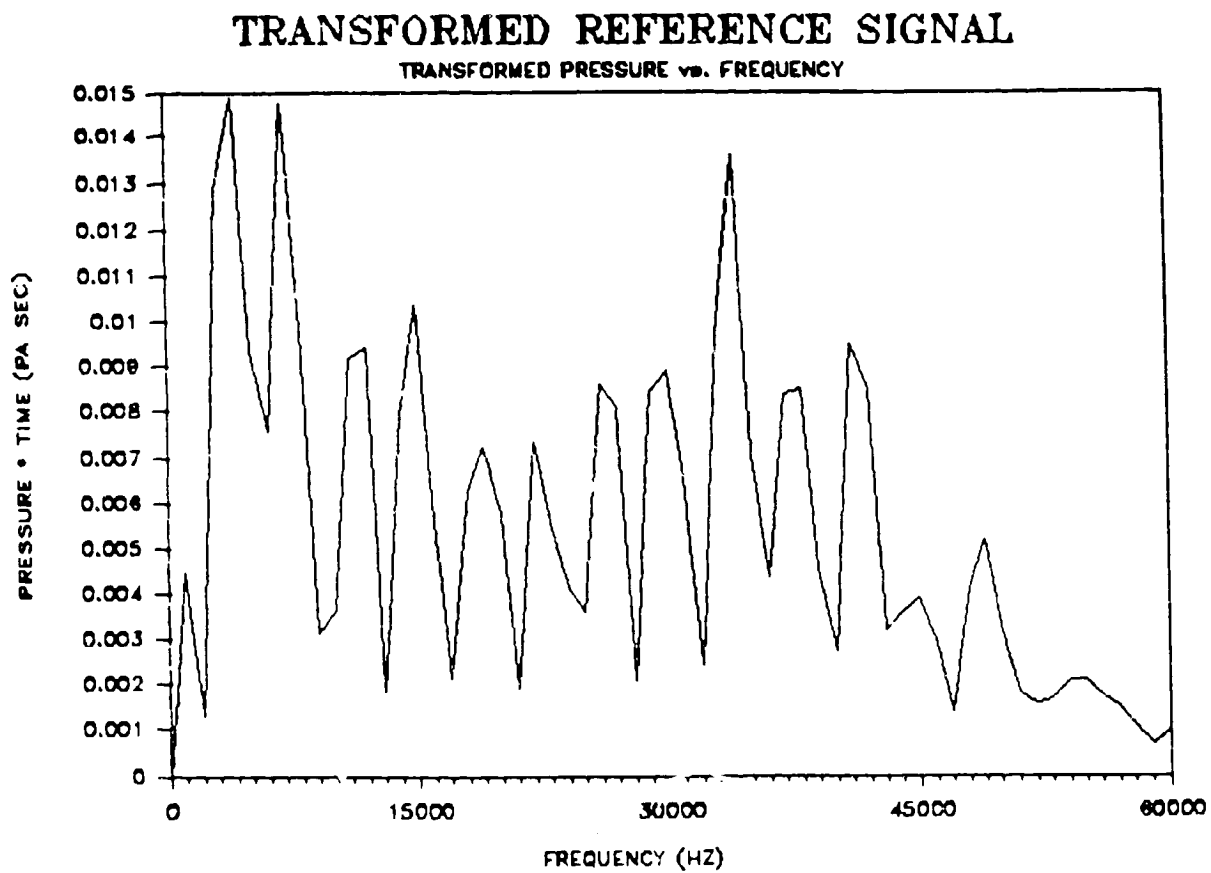


Figure 1. Frequency spectrum of typical nearfield acoustic pressure pulse. The pressure signal was measured at the reference microphone; the quantity plotted is the absolute magnitude of the Fourier transform of the pulse.

Microphone Positioner

A microphone positioner (Fig. 2) was designed and constructed to quickly and precisely position the far field microphone. The positioner consists of three perpendicular trolley rails. This triad accounts for three translational and mutually orthogonal degrees of freedom. Each rail has a trolley block mounted about it. A block consists of two aluminum plates fastened together with screws. Parallel, semi-circular grooves cut in each plate form cylindrical guide holes when the plates are clamped about the rails. Two of the rails are made of galvanized steel pipe while the third is a thin, 2 cm diameter aluminum tube.

The lateral position of the microphone is set by a block mounted on the horizontal rail. This rail is clamped to both ends of the table's back face. The rail and block are completely submerged below the plane of the table top. Attached directly to the horizontal block is a vertically oriented block of nearly identical construction. This block clamps the vertical rail pair to the horizontal block. Thus, the horizontal block supports the remaining positioner assembly through the vertical rail. Vertical positioning is achieved by moving a smaller third block along the vertical rail pair. This smaller block holds an aluminum tube horizontal and parallel to the table top centerline. The tube is free to slide in and out of its block. Thus, the moving parts of the positioner assembly are the horizontal block, the small block, and the aluminum tube. This permits changes in the microphone's centerline position through movement of the small block and aluminum tube alone. Both of these are light parts.

In addition to mobility, the positioner has no large reflecting structures in the vicinity of the microphone. Nearly all of the entire assembly is located at the far end of the table. The narrow aluminum tube is the only part which is suspended over the table top. The microphone cord runs inside the length of the tube with the microphone projecting out of the far end. The tube diameter is roughly three times that of the cartridge head with a tapered section joining the two. This design minimizes field disturbances due to reflection in the vicinity of the microphone.

The gross microphone position is marked by precision lathed etchings along the vertical rail and the aluminum tube. The aluminum tube houses a slightly smaller but concentric tube which telescopes into the sound field. The smaller and larger tubes have etchings every 2 cm and 5 mm, respectively. A variable length rigging system permits fine adjustments to the gross microphone position. Braided picture wire runs through 1 cm pulleys attached

to the top of the vertical rail. The wire is tied to the table edges through a screw & bolt assembly which is used to tighten or loosen the rigging. An advantage of this arrangement is that the microphone's gross position can be changed without disassembling the rigging. Bubble-type levels are mounted on the table top, the small block, and part way along the single rail. Fine adjustment of the microphone position is guided by visual inspection of the relative bubble levels. For a pressure wave of 10 kHz this positioner provides accurate placement to within approximately one-half of a wavelength.

The near field microphone is suspended several centimeters in front of the ridge by two braided wire cables. The microphone sits on the cables so as to point directly at the spark source. This microphone measures the incoming sound field for use as a reference across many experimental trials.

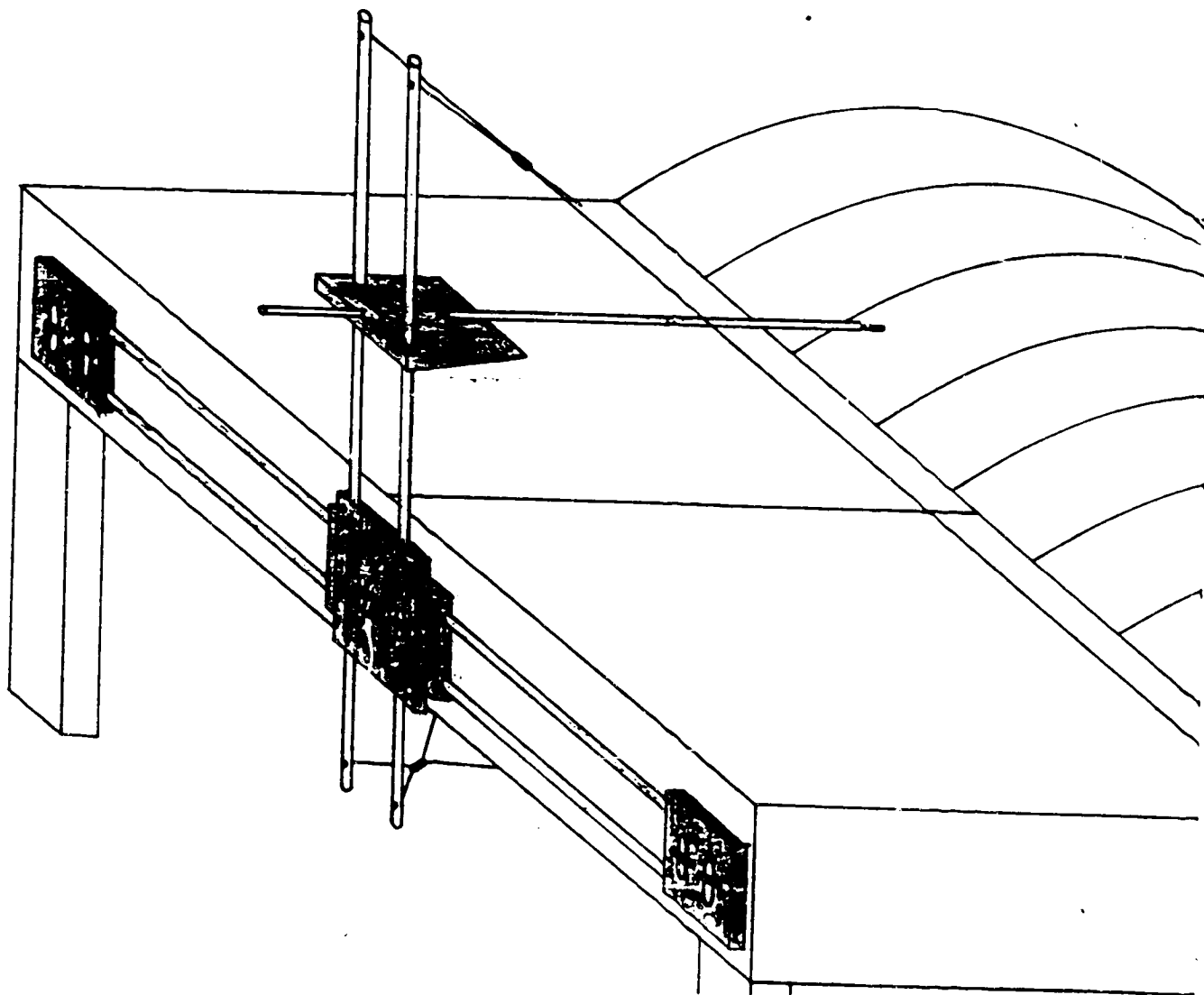


Figure 2. Design drawing of microphone positioning apparatus. Drawing shows the three dimensional mobility of the apparatus as well as the relative size and shape of structural parts.

Experimental Procedure

A group of three batch programs have been written to enhance data collection, processing, and storage. The programs automatically guide the user through the various steps involved in a single experiment. The first program prompts the user for an experiment number which is then used to label all stored data produced by that experiment. All data storage procedures are also controlled by the programs which produce data directories that are uniform in style across all experiments. The user is also prompted for Yes/No answers to data conditioning and frequency analysis questions. In addition, the programs alert the user to run-time errors or inconsistencies and provide access to the editor in these instances.

Referring to Figure 3, a typical experiment begins when the batch program COLLECT is called and the spark generator is ready to fire. After giving COLLECT an experiment number, the program enables the RC Electronics ISC-16 hardware & software (see semiannual report of 2/86), and prompts the user for important set-up information concerning microphone placement and the spark generator. The program then waits for the spark generator to fire before triggering data collection.

Data is collected by the ISC-16 analog-to-digital conversion instrumentation. The collected data is viewed immediately and the user may decide to save or discard the data. When a suitable data sample is saved the program copies the data to the DATA directory and executes the RC Electronics Process7 data conditioning program. Process7 allows the user to choose a data window of interest while deleting the remaining data. The data is subsequently zeroed about the time axis and inverted. This new set of data is also sent to the DATA directory. COLLECT terminates by clearing the RC ELEC directory of any remaining data files, and by creating a DATA subdirectory called SPARK.*label* specifically for the files previously stored in DATA. Successive experiments may be run by recalling COLLECT, choosing a new label, and resetting the spark generator.

Frequency analysis is carried out within the ANALYSIS directory by the batch program FORTRAN. This program prompts the user for a saved data label and automatically retrieves the data associated with the label. FORTRAN prepares the data for input to the the fast Fourier transform program called FOURT and then executes FOURT. FOURT is a version

of the Tukey-Cooley fast Fourier transform. The input and output files of FOURT are then prepared by FORTRAN for graphics and copied to the DATA subdirectory named *label*. FORTRAN terminates by clearing the ANALYSIS directory of all data files.

Hard copy printing and plotting is handled by the PLOT batch program within the GRAPHICS directory. Again, the program prompts the user for a saved data label and then imports the labeled data to the GRAPHICS directory. The data is then either printed using LOTUS 1-2-3 graphics or plotted on the Hewlett Packard 7470A plotter. A generic plotting program based on HP-GL is used to read the data and write it to the plotter. All graphics files produced by LOTUS are stored permanently in a labeled subdirectory within the GRAPHICS directory. A Toshiba P321 printer is presently on order to provide quality printing and graphics capability.

AUTOMATED LABORATORY SCHEMATIC

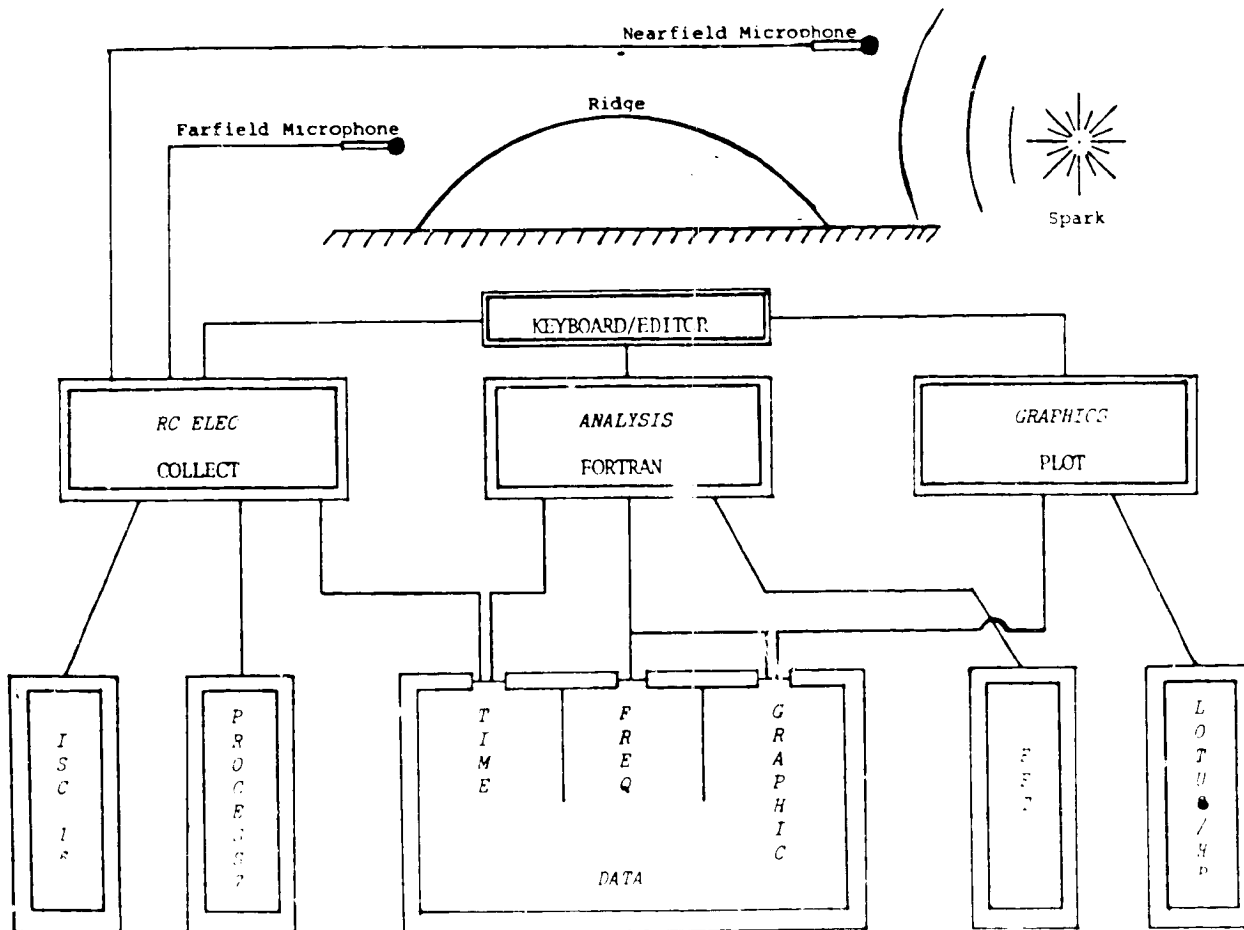


Figure 3. General diagram of experimental software configuration for studying sound propagation over model topographical ridge. The boxes represent different environments in which the various automated tasks are carried out.

Data Summary

Typical data samples are displayed in Figures 4-9. Each sample contains plots of the reference data as well as the farfield data. The data is represented in both time and frequency domains.

Figures 4, 6, and 8 are plots of the pressure versus time data as output by the Process7 software package. This implies that the original data received by the ISC-16 analog-to-digital converter has been centered about zero, inverted, and multiplied by the appropriate calibration factor. Complementing these plots, Figures 5, 7, and 9 are plots of the absolute magnitude of the Fourier transform of the same data.

The reference data represents the near field signal (i.e. the signal prior to its encounter with the ridge). The farfield is defined as the entire field which is significantly affected by the presence of the ridge. For the samples shown, the farfield microphone was positioned directly above the line where the far end of the ridge meets the flat table top. The samples are only different in the height of the microphone above this line. The three farfield samples were taken at heights of 5 cm, 23 cm, and 41 cm above the table.

Examination of Figures 4-9 clearly shows the presence of a relative shadow zone at the far field base of the ridge. Notice the large attenuation of the farfield signal relative to the reference signal in Figure 8 as opposed to that in Figures 4 and 6. As expected, the peak farfield amplitude decreases as the microphone is more and more obstructed by the ridge. Likewise, the figures also indicate the presence of a geometrical acoustic region above the ridge by the distinct separation of the direct and reflected waves. Each signal exhibits peaks in the frequency domain around 6 and 33 kHz, respectively. The 6 kHz region is always the most dominant.

Data samples have been taken at centerline points along the surface of the ridge and at varying heights above the far field base of the ridge. A complete data base will include samples over a rectangular matrix of points spanning a vertical plane through the table centerline. Off centerline measurements will be made to deduce the degree of edge effects on the centerline data.

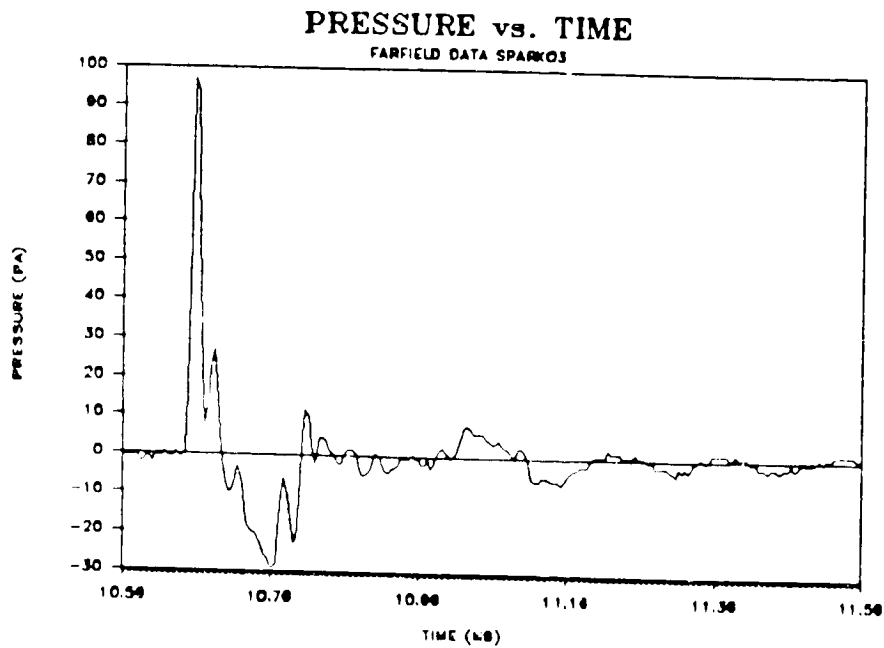
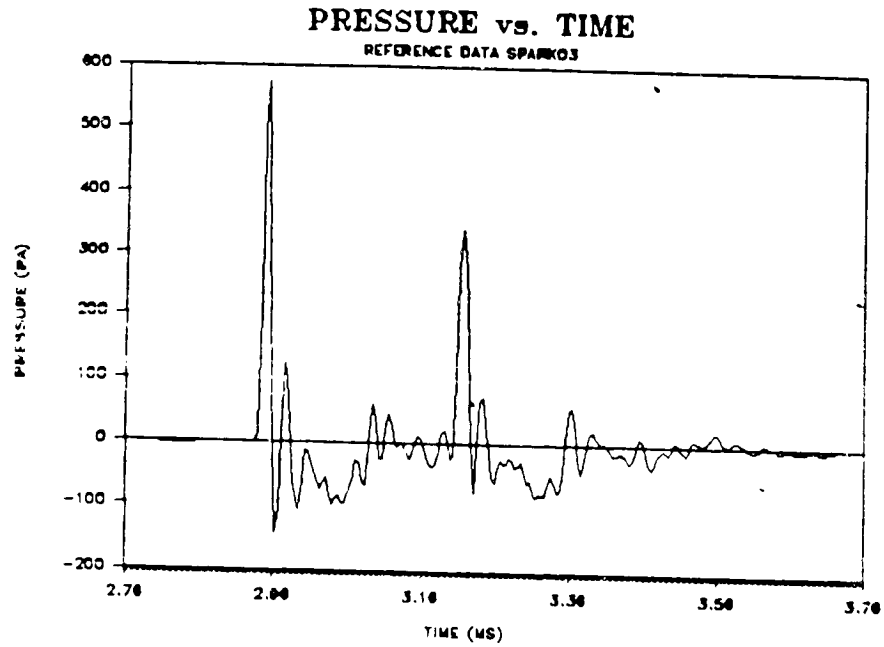


Figure 4. Graphs of typical reference and farfield pressure pulses versus time. The farfield microphone was positioned 41 cm (16 inches) directly above the far side lower edge of the ridge, where it meets the table top.

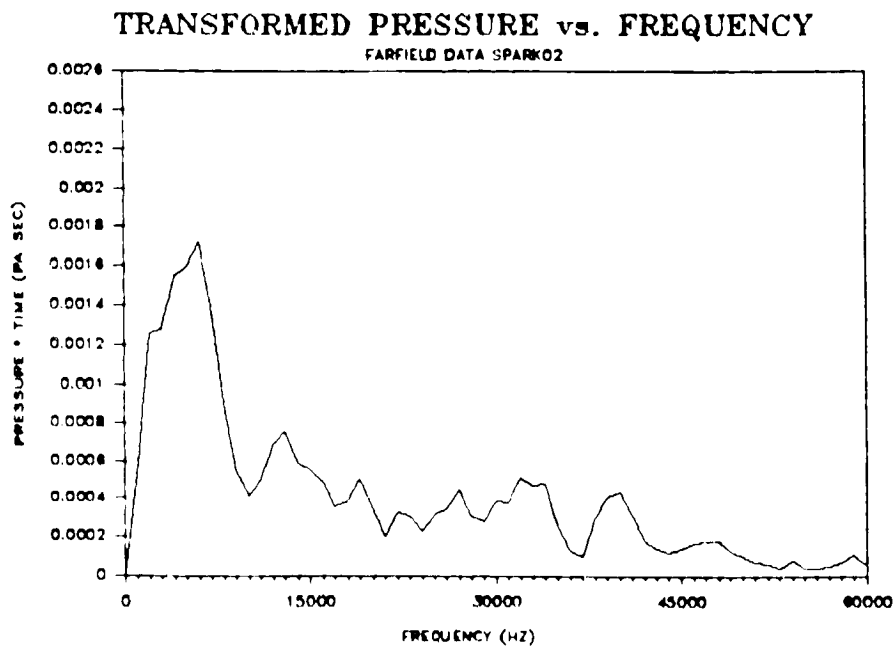
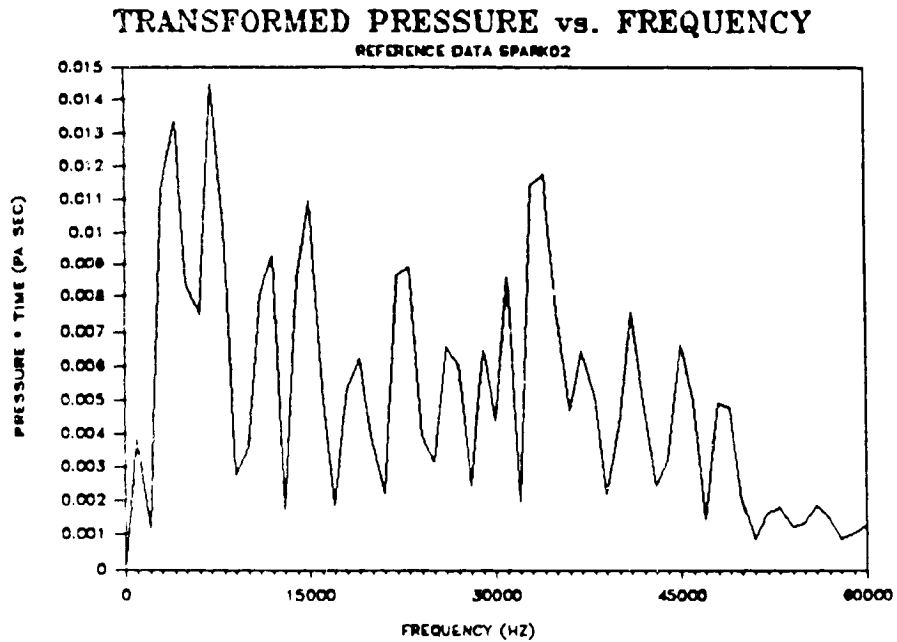


Figure 5. Graphs of absolute magnitudes of Fourier transforms of reference and farfield pressure pulses versus frequency. The farfield microphone was positioned 41 cm (16 inches) directly above the far side lower edge of the ridge, where it meets the table top.

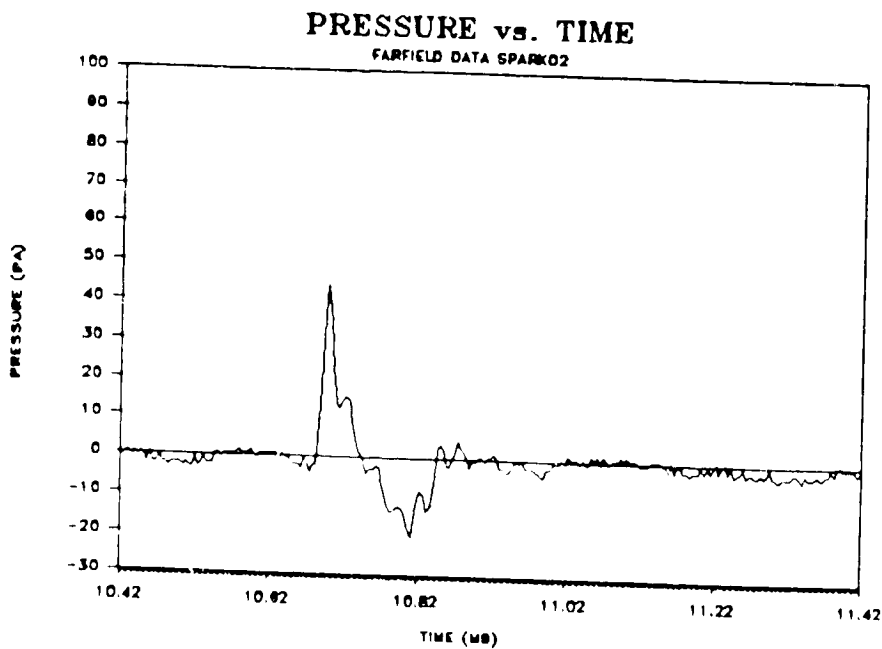
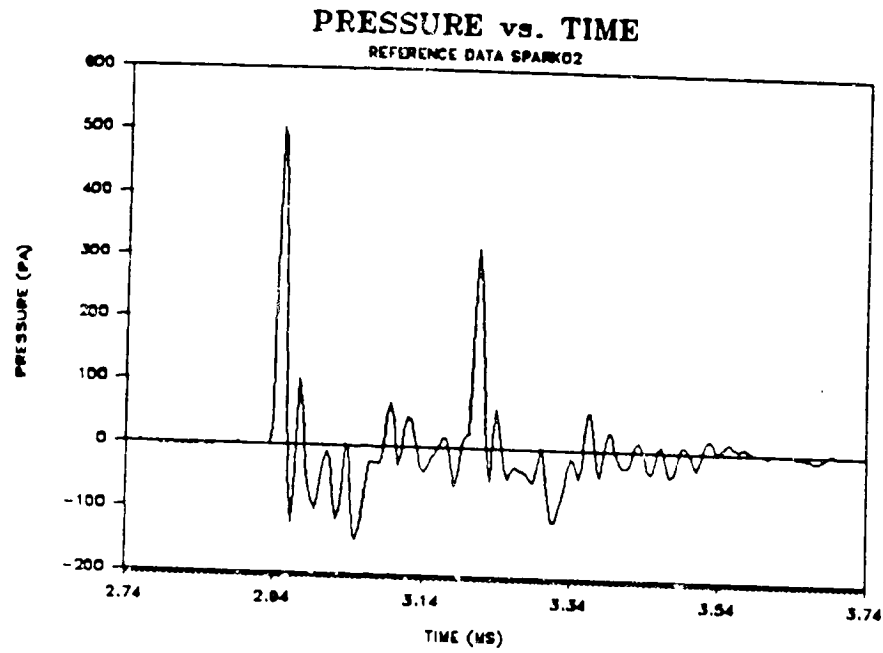


Figure 6. Graphs of typical reference and farfield pressure pulses versus time. The farfield microphone was positioned 23 cm (9 inches) directly above the far side lower edge of the ridge, where it meets the table top.

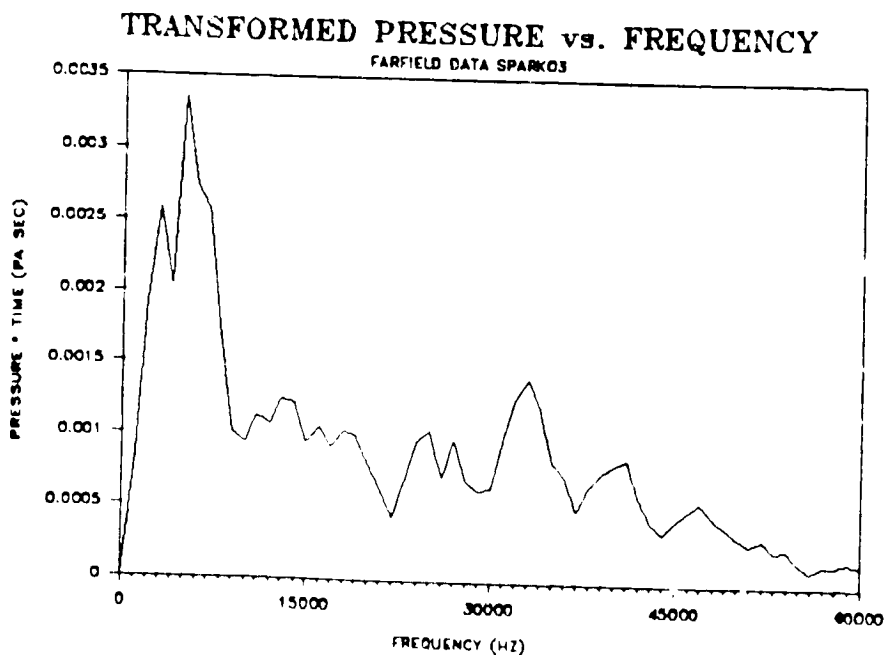
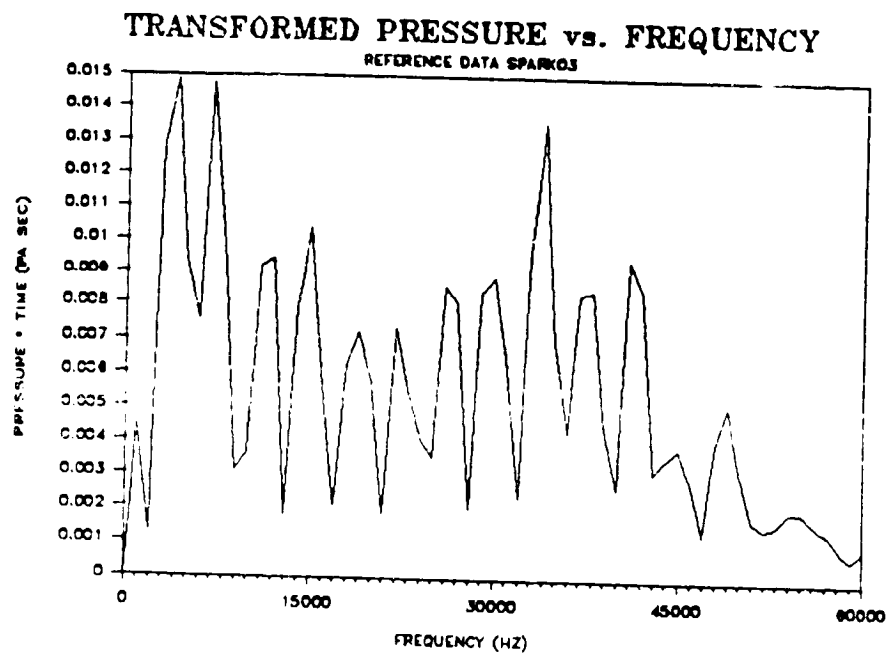


Figure 7. Graphs of absolute magnitudes of Fourier transforms of reference and farfield pressure pulses versus frequency. The farfield microphone was positioned 23 cm (9 inches) directly above the far side lower edge of the ridge, where it meets the table top.

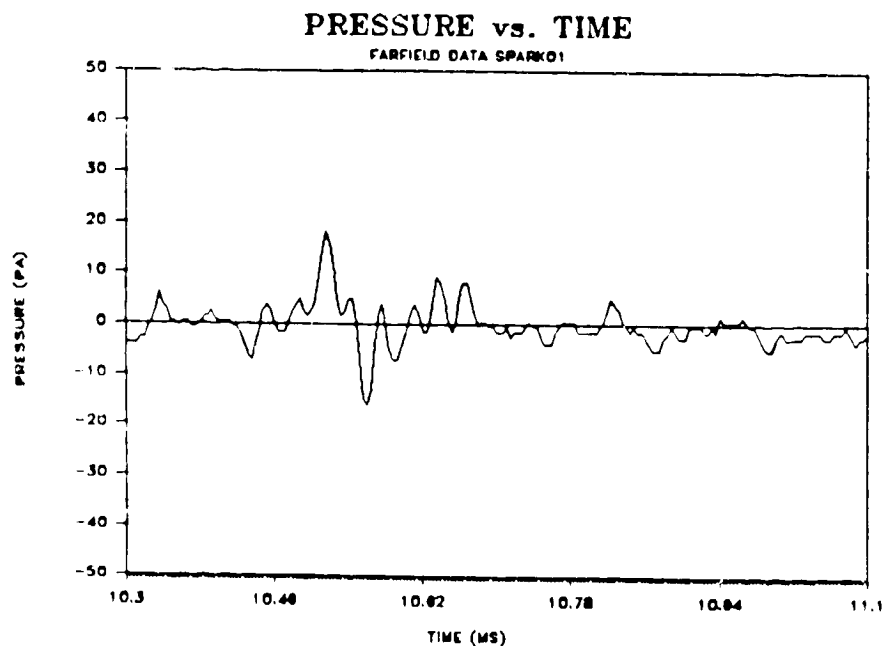
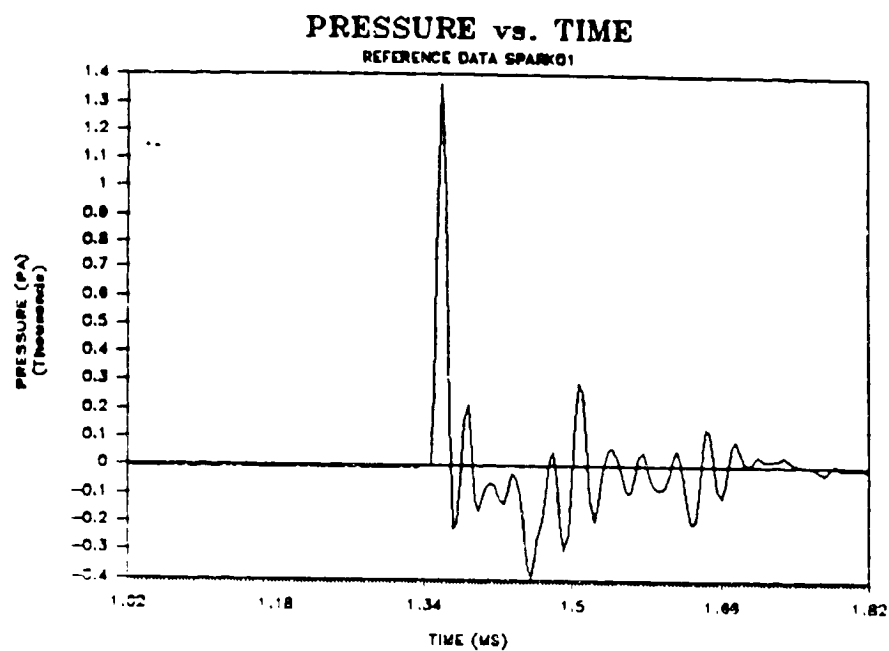


Figure 8. Graphs of typical reference and farfield pressure pulses versus time. The farfield microphone was positioned 5 cm (2 inches) directly above the far side lower edge of the ridge, where it meets the table top.

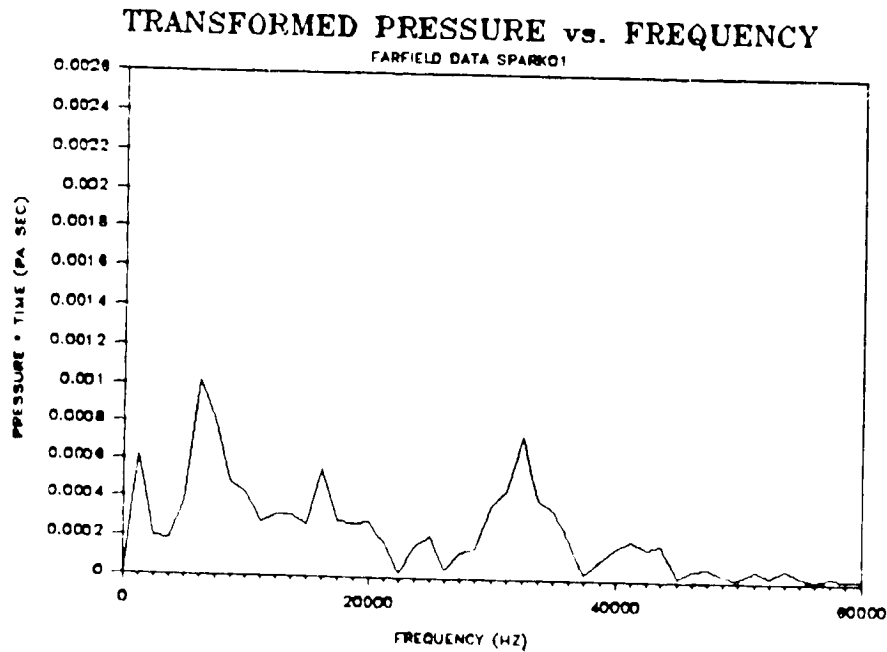
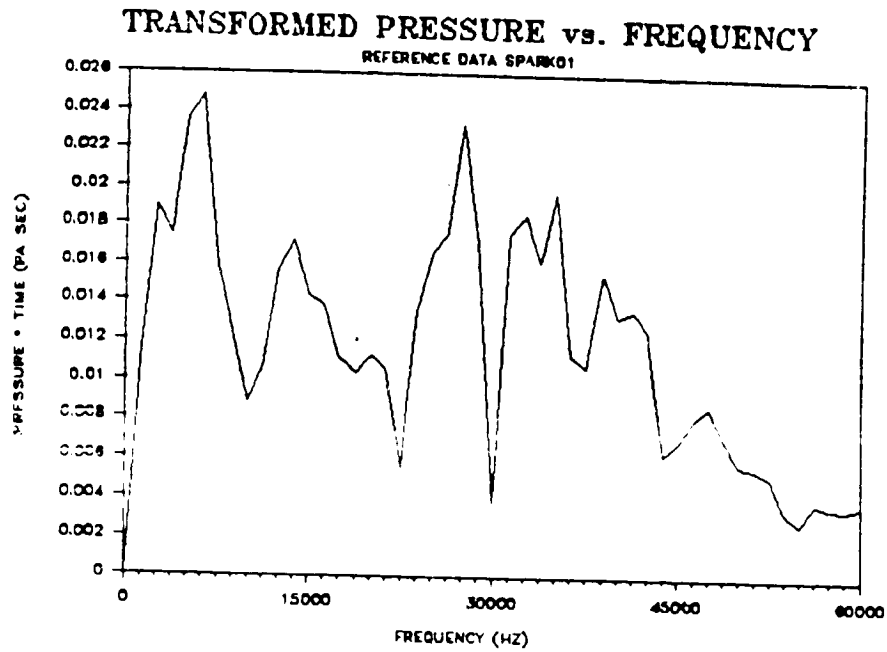


Figure 9. Graphs of absolute magnitudes of Fourier transforms of reference and farfield pressure pulses versus frequency. The farfield microphone was positioned 5 cm (2 inches) directly above the far side lower edge of the ridge, where it meets the table top.

PAPERS AND PUBLICATIONS

During the subject reporting period, three papers on the project's results were given at international and national meetings. Two of these were accompanied by written papers in the meetings' proceedings. Because of the lead time required for the submission of manuscripts in advance of the meetings and the desire to give the most up-to-date results in the talks, the papers do not fully describe what was reported at the meetings. They are nevertheless reprinted here as they give a relatively polished discussion of progress made on the project. A less polished but more up-to-date overview of the analytical work is contained in the slides used in the presentation at the recent Acoustical Society of America meeting.

Sound Propagation over Large Smooth Ridges in Ground Topography

This paper was published in the proceedings of the 12-th International Conference on Acoustics which took place in Toronto on July , 1986. It had a prominent place on the program and was the first paper in a session (which Allan Pierce was asked to chair) on outdoor sound propagation. A complete citation for this paper is as follows:

Allan D. Pierce, Geoffrey L. Main, James A. Kearns, Daniel R. Benator, and James R. Parish, Jr., "Sound propagation over large smooth ridges in ground topography," in *Proceedings of the 12th International Congress on Acoustics*, Vol. 3, edited by T. F. W. Embleton, G. A. Daigle, M. R. Stinson, and A. C. C. Warnock, Beauregard Press Limited, Toronto, 1986, paper J2-1.

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