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Final Report

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by

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ABSTRACT

This is the Final Report for N.A.S.A. Grant Number NAG-1-929. It summarizes research results and lists publications and reports, presentations, software distribution, and students who performed N.A.S.A. research.

INTRODUCTION

This Final Report summarizes progress under National Aeronautics and Space Administration Grant Number NAG-1-929, which provided support for the period from 15 November 1988 to 14 November 1991.

Section I summarizes our research on methods for analysis of sound propagation through the atmosphere and on results obtained from application of our methods. Section II lists ten written documents of N.A.S.A. research, and these include publications, manuscripts accepted, submitted, or in preparation for publication, and reports. Section III indicates twelve presentations of results, either at scientific conferences or at research or technical organizations, since the start of the Grant period. Section IV provides names of organizations to which software produced under the Grant has been distributed, and also describes the current arrangement whereby the software is being distributed to the scientific community. Finally, Section V gives the names of seven graduate students who worked on N.A.S.A. research and received Rensselaer degrees during the Grant period, along with their current employers.

I. RESEARCH SUMMARY

There is a significant level of interest in the analytical and numerical modeling of lower frequency atmospheric acoustic propagation. The parabolic approximation method, often more accurate than ray models for frequencies of interest, can be applied to acoustic propagation in the atmosphere. In Reference 1 we discuss appropriate physical and asymptotic conditions under which this model is valid. Modifications of an existing implicit finite difference implementation for computing solutions to the parabolic approximation are discussed. In addition, we present calculations of acoustic intensity levels in a windy atmosphere and contrast the results with those of ray theory.

The effects of a ridge on a low frequency acoustic propagation in quiescent and windy atmospheres are investigated using a parabolic approximation.[2] A logarithmic wind speed profile, commonly employed to model atmospheric wind currents, is modified and used to model two-dimensional atmospheric flow over a triangularly shaped hill. The parabolic equation is solved using an implicit finite difference algorithm. Several examples are examined to determine the combined effects of source-ridge distance, ridge dimensions, wind speed profile, and cw source frequency on the received acoustic field.

Many mechanisms can be responsible for fluctuations of sound intensity and phase through the atmosphere over the Earth's surface. The effect of wind gusts on received intensity at short range is examined.[3] Using a parabolic approximation, relative intensity for a continuous wave omnidirectional source is calculated using the effective sound speed profiles obtained from meteorological data. Two characteristic scale thicknesses are used to model the wind gust profiles. The thinner layer thickness can result in temporal intensity fluctuations as high as 10 dB at a range of 100 m. It is emphasized that these fluctuations are refractive and deterministic. In an actual experiment, these fluctuations would be detected along with additional variations caused by wind noise turbulent scattering.

There is substantial interest in the analytical and numerical modeling of low frequency, long range atmospheric acoustic propagation. Ray based models, because of their frequency limitations, do not always give an adequate prediction of quantities such as sound pressure or intensity levels. However, the parabolic approximation method, widely used in ocean acoustics and often more accurate than ray models for frequencies of interest, can be applied to this type of acoustic propagation in the atmosphere. Modifications of an existing implicit finite difference implementation for computing solutions to the parabolic approximation are discussed.[4] A locally reacting ground surface is used with a one parameter impedance model, while a non-reflecting boundary condition is used to handle the upper boundary. Relative sound pressure level calculations are performed for a number of flow resistivity values in both homogeneous and nonhomogeneous atmospheres. Comparisons to experimental data are made which suggest this modeling approach can be useful in the study of these types of propagation problems.

Long range, low frequency sound propagation over varying terrain conditions is an important problem with many applications. The modeling of cw acoustic signals are considered[5] as they propagate over variable impedance topography. We use the NASA Implicit Finite Difference (NIFD) implementation of the parabolic approximation sound propagation model that incorporates variable impedance ground surfaces. The accuracy of this numerical model is demonstrated with a pair of benchmark problems. An application of the results is used to predict excess attenuation of pure tone signals whose propagation path includes portions of a flat lake surface. Both quiescent and windy atmospheres are treated. For long ranges, multiple impedance boundaries have a significant effect on sound attenuation at higher frequencies in both the no wind and receiver downward cases.

A parabolic equation (PE) method for predicting coherent, low frequency acoustic propagation through small-scale atmospheric turbulence is presented.[6] Frequency constraints on the applicability of stochastic parabolic approximations are avoided by first averaging the stochastic Helmholtz equation and then applying a parabolic approximation to the resulting deterministic equation. Turbulence effects are incorporated by means of spatially varying effective wave numbers. Comparison of exact solutions in the case of infinite space propagation demonstrates the advantages and limitations of this approach. A uniform asymptotic expression for the effective wave number profile in the case of isotropic turbulence is used to develop a half space PE formulation that is valid in the limit of low frequency, small-scale inhomogeneity. For anisotropic turbulence that is correlated more strongly in range than height, a modified mean value theorem for the two-dimensional Helmholtz operator is used to find the effective wave number. Numerical examples demonstrate that excess attenuation due to the imaginary component of the effective wave number is the primary effect of weak turbulence on coherent, low frequency propagation.

The effects of a large ridge on low frequency acoustic propagation through an ideally moving atmosphere are investigated[7] using a narrow-angle, two-dimensional parabolic approximation. The winds in this investigation are associated with an ideal two-dimensional fluid flow. The ridge is taken to be triangularly shaped with a horizontal earth-air interface on both sides. Consequently, a Schwarz-Christoffel transformation is used to translate the flow into one over a horizontal boundary. For the acoustics problem, the parabolic equation with a rigid earth-air boundary is solved using an implicit finite difference algorithm. Several examples are examined to determine what effects this method of modeling the wind has on sound pressure levels.

Low frequency, long range sound propagation from sources at low to medium altitude inevitably involves interaction with the topography and the acoustical characteristics of the ground surface. Improvement of propagation predictions from parabolic approximation methods therefore requires accurate treatment of acoustic interactions with the ground. In order to handle impedance boundary conditions in connection with finite difference implementations of parabolic approximations, new procedures which are more accurate than existing ones are developed.[8] The case of horizontal boundaries is treated first, and then extensions are provided for bottom topography which is modeled by piecewise linear slopes. The methods are employed in the NASA Implicit Finite Difference (NIFD) implementation. Benchmark tests are included to document the accuracy of the boundary condition treatments. Numerical illustrations over model bottom topography are also provided, with comparisons to results from earlier algorithms.

Using the parabolic approximation, effects of multiples ridges on low frequency long range propagation in an atmosphere with winds are investigated.[9] The ridges are perfectly reflecting perturbations along the ground boundary, and they are examined with different heights, sizes, and locations. The windy atmosphere is comprised of a typical logarithmic velocity profile and is bounded above by an artificial absorbing layer beneath a pressure release surface. Excess attenuation levels within the atmospheric waveguide are determined by solving an appropriate parabolic equation using the NASA Implicit Finite Difference (NIFD) algorithm. Numerical results are compared to determine the effects of variations in the number of ridges, ridge separation, and ridge dimensions. Also discussed are the effects of wind profile and frequency variations.

Acoustic propagation calculations performed to full wave methods typically produce a large amount of numerical data. This data represents the relative intensity or excess attenuation of the acoustic field at each range and height/depth location of interest. Efficient display of this information is essential for developing useful interpretations of results and for determination of the mechanisms that influence the propagation. The DISSPLA library of Fortran subroutines is used to develop a collection of subprograms for presenting acoustic propagation results.[10] Two-dimensional graphs of intensity versus range or height, three-dimensional plots of intensity versus both range and height, contour plots of intensity in a range-height plane, and contour shade plots are among the main types of displays for which subprograms are provided. The subprograms are designed for portability to systems for which the DISSPLA library is available. Local system run commands are provided.

II. PUBLICATIONS AND REPORTS

1. J. S. Robertson, M. J. Jacobson, and W. L. Siegmann, "Mathematical Modeling of Sound Propagation in the Atmosphere using the Parabolic Approximation," Trans. Sixth Army Conference on Applied Math. and Computing, Army Res. Office (Res. Triangle Park, NC), Report 89-1, 125-131 (1989).

2. J. S. Robertson, M. J. Jacobson, W. L. Siegmann, and D. P. Santandrea, "Acoustical Effects of a Large Ridge on Low-Frequency Sound Propagation in Stationary and Moving Atmospheres," Applied Acoustics **31**, 265-280 (1990).

3. J. S. Robertson, "Numerical Simulation of Intensity Fluctuations Caused by Wind Gusts," J. Acoust. Soc. Am. **87**, 1353-1355 (1990).

4. J. S. Robertson, W. L. Siegmann, and M. J. Jacobson, "Low-Frequency Sound Propagation Modeling over a Locally Reacting Boundary with the Parabolic Approximation," manuscript accepted for publication, J. Acoust. Soc. Am.

5. P. J. Schlatter, J. S. Robertson, W. L. Siegmann, and M. J. Jacobson, "Low-Frequency Long-Range Sound Propagation over Impedance Discontinuities with the Parabolic Approximation," manuscript accepted for publication, J. Acoust. Soc. Am.

6. I. W. Schurman, W. L. Siegmann, M. J. Jacobson, and J. S. Robertson, "Parabolic Approximations for Coherent Low Frequency Acoustic Propagation through Atmospheric Turbulence," manuscript submitted for publication, J. Acoust. Soc. Am.

7. M. J. Jaye, M. J. Jacobson, J. S. Robertson, and W. L. Siegmann, "Influence of an Ideal Wind Profile of Sound Propagation over a Ridge," draft manuscript completed, in preparation for submission.

8. T. M. Kastner, J. S. Robertson, W. L. Siegmann, and M. J. Jacobson, "An Improved Implicit Finite Difference, Locally Reacting Ground Surface Model for the Parabolic Approximation," draft manuscript completed, in preparation for submission.

9. D. P. Santandrea, M. J. Jacobson, J. S. Robertson, and W. L. Siegmann, "Acoustical Effects of Multiple Ridges on Low-Frequency Propagation in a Moving Atmosphere," draft manuscript completed.

10. M. L. Linnington, W. L. Siegmann, J. S. Robertson, and M. J. Jacobson, Graphical Display of Underwater and Atmospheric Acoustic Propagation Results, "RPI Mathematical Sciences Report 185, June 1990.

III. PRESENTATIONS

1. J. S. Robertson, "Analytical and Numerical Modeling of Atmospheric Propagation using the Parabolic Approximation," NASA Langley Research Center, June 1989.

2. J. S. Robertson, "The Parabolic Approximation in Atmospheric Acoustics: Target Acquisition Ramifications," Northrup Corporation, Anaherm, CA, July 1989.

3. J. S. Robertson, "The Parabolic Approximation in Atmospheric Acoustics," JASON Summer Study Institute, LaJolla, CA, July 1989.

4. J. S. Robertson, M. J. Jacobson, and W. L. Siegmann, "Low-Frequency Long-Range Sound Propagation Modeling over a Locally-Reacting Boundary with the Parabolic Approximation," 118th Meeting of the Acoustical Society of America, St. Louis, MO, December 1989.

5. J. S. Robertson and W. L. Siegmann, "Long-Range Sound Propagation over Variable Impedance Boundaries," NASA Langley Research Center, Hampton, VA, January 1990.

6. J. S. Robertson, M. J. Jacobson, and W. L. Siegmann, "Mathematical Modeling of Long-Range Sound Propagation in the Atmosphere using the Parabolic Approximation," U. S. Army CECOM Test Integration Working Group, Fort Monmouth, NJ, March 1990.

7. J. S. Robertson, "Applications of Computational Acoustics to Problems Arising from Passive Detection of Rotary Wing Aircraft," Naval Postgraduate School, Monterey, CA, April 1990.

8. J. S. Robertson, P. J. Schlatter, W. L. Siegmann, and M. J. Jacobson," Numerical Modeling of Long-Range Sound Propagation over Variable Impedance Boundaries," Fourth International Long-Range Sound Propagation Symposium, NASA Langley Research Center, Hampton, VA, May 1990.

9. J. S. Robertson, "Application of Computational Acoustics to Problems Arising from Passive Detection of Rotary Wing Aircraft," The Open University, Milton Keynes, England, September 1990.

10. M. J. Jaye, M. J. Jacobson, J. S. Robertson, and W. L. Siegmann, "The Influence of an Ideal Wind Profile on Sound Propagation over a Ridge," 121st Meeting of the Acoustical Society of America, Baltimore, MD, May 1991.

11. P. J. Schlatter, J. S. Robertson, and W. L. Siegmann, "Low-Frequency Long-Range Sound Propagation over Impedance Discontinuities with the Parabolic Approximation," 121st Meeting of the Acoustical Society of America, Baltimore, MD, May 1991.

12. I. W. Schurman, W. L. Siegmann, M. J. Jacobson and J. S. Robertson, "Parabolic Approximations for Coherent Low-Frequency Acoustic Propagation through Atmospheric Turbulence," 123rd Meeting of the Acoustical Society of America, Salt Lake City, UT, May 1992.

IV. SOFTWARE DISTRIBUTION

1. NASA Langley Research Center, Hampton, VA.
2. U. S. Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM.
3. Georgia Institute of Technology Research Institute, Atlanta, GA.
4. Illinois Institute of Technology Research Institute, Chicago, IL.
5. U. S. Army Laboratory Command, Adelphi, MD.
6. U. S. Army Construction Engineering Research Laboratory, Champaign, IL.
7. Sanders Associates, Nashua, NH.
8. U. S. Army Communications-Electronics Command, Ft. Monmouth, NJ.
9. COLSA Incorporated, Huntsville, AL.

Electronic Distribution

A file transfer protocol (ftp) server has been established for distributing computer codes and related matter to acousticians with access to Internet. The server, which is accessible from sites all over North America as well as Europe and Austrialia, has files containing the source code to the NASA Implicit Finite Difference (nifd) model. These are available via anonymous ftp from euler.math.usma.edu. The Internet Protocol (IP) address is 129.29.79.198 and the files are located in the */ftp/acoustics* directory. These files will be updated periodically as refinements are made.

In addition, acousticians wishing to share their codes with the acoustics community may submit them directly to euler.math.usma.edu. They may be placed in the */ftp/incoming* directory. Questions regarding submission procedures should be directed to robertson@euler.math.usma.edu.

Recent retrievals of NIFD

Date				Originating machine	Who
May	2	93	22:56	ckwang.gatech.edu	leem@ckwang.gatecvh.edu
May	4	93	23:24	almaak.usc.edu	asdf@
May	5	93	13:08	nimue.hood.edu	mayfield@nimue.hood.edu
Apr	18	93	19.33	mesu7.ust.hk	ckleung@hkumea.hku.hk
Apr.	21	93	08:25	mines.u-nancy.fr	smerzouk@mines.u-nancy.fr
Mar	30	93	05:35	137.195.28.5	andrerw@uk.ac.hw.phy
Apr	2	93	15:57	skule.ecf.toronto.edu	lindsas@ecf.utoronto.ca
Mar	18	93	11:56	titan.yorku.ca	fs300021

V. GRADUATE STUDENTS PERFORMING NASA RESEARCH

1. Daniel P. Santandrea, Master of Science in Applied Mathematics, May 1989 [Currently at General Electric Corporation, Syracuse, NY].
2. Philip J. Schlatter, Master of Science in Applied Mathematics, May 1990 [Currently at United States Military Academy, West Point, NY].
3. Michael J. Jaye, Master of Science in Applied Mathematics, May 1990 [Currently at United States Military Academy, West Point, NY].
4. Michael L. Linnington, Master of Science in Applied Mathematics, May 1990 [Currently at United States Military Academy, West Point, NY].
5. Thomas M. Kastner, Master of Science in Applied Mathematics, May 1991 [Currently at United States Military Academy, West Point, NY].
6. Curtis W. Clark, Master of Science in Applied Mathematics, May 1991 [Currently at Loral Corporation, Lexington, MA].
7. Iman W. Schurman, Doctor of Philosophy in Applied Mathematics, July 1991 [Currently at The Johns Hopkins University Applied Physics Laboratory, Laurel, MD].