Simulation of thunder propagation through a realistic atmosphere model

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We are investigating numerically shock propagation due to thunder. An original method called Flhoward (Flow and Heterogeneous One-Way Approximation for Resolution of Diffraction) is presented. It relies on a scalar nonlinear wave equation, which takes into account propagation with effects of diffraction, flow motion, heterogeneities and nonlinearities, particularly the wind: ambient flow and turbulence are fully taken into account in a new and more precise way. Thus propagation of acoustical waves can be calculated using outputs of well known meteorological models (e.g. MesoNH) describing the atmosphere in a realistic way. Comparison of the dispersion relations associated to that model and to usual parabolic equations shows that the present approach is more precise. This method will be used to interpret the thunder data which will be measured during the HyMeX project (HYdrological cycle in Mediterranean EXperiment).

1. Introduction

Intensively studied during the early Eighties natural shock wave propagation are nowadays of great interest through the design of the International Monitoring System for the respect of the Comprehensive Nuclear-Test-Ban Treaty (CTBTO) [1].

Developed in Pierre et Marie Curie University (UPMC), a new method called Flhoward (Flow and Heterogeneous One-Way Approximation for Resolution of Diffraction) [2] addresses the numerical simulation of nonlinear acoustic shock wave propagation in a weakly heterogeneous medium, it is especially well suited for simulation of propagation through atmospheric boundary layer. This paper has two main goals: firstly the principle of the method will be exposed focusing on physical and numerical properties. Secondly the HyMeX meteorological project (HYdrological cycle in Mediterranean EXperiment) will be described. It will be shown how fine meteorological data obtained during this campaign will be used by Flhoward to model the propagation of thunder in an atmospheric medium closer to the reality.

2. The Flhoward method

2.1. Theoretical construction

Based on new derivation of linearized Euler equations with weak flow motion [3], the 2D Flhoward method models the pressure field in the nonlinear regime. Special attention is paid to the order of approximations. In the case of a weak Mach number (0.1 or below) nonlinear heterogeneous wave equations with flow motion, precise up to order M^2, are obtained.

The numerical resolution process is based on a split-step algorithm. The diffraction effect is solved by an analytical solution in the spectral domain of the full homogeneous wave equation (no parabolic approximation is made), but only one privileged propagation direction is kept (one-way approach). The heterogeneous corrections and flow motion are computed by a finite difference scheme. At last the nonlinearity is calculated using the quasi-analytical Burgers-Hayes method.

2.3. Advantages and Drawbacks

The major advantage of this algorithm is to go beyond limitations of parabolic equations: the method is applicable on weakly focused waves, scattered away from the main propagation direction by inhomogeneities, or by the presence of sheared flows.

On the other hand the drawback of this method comes from the one-way approximation: back-scattered waves (created for example by partial reflexion of the propagating wave on an heterogeneity) are systematically lost during the numerical propagation.

Thanks to the use of split-step algorithm and finite difference scheme the model equation is able to take into account terms representing heterogeneities and flow motion.

It appears eventually that the Flhoward method is well suited to simulate thunder acoustic shock wave propagation through a realistic model atmosphere.

2.3. Validation method and results

Each physical effect: homogeneous diffraction, heterogeneities, flow motion and nonlinearities is validated separately on characteristic examples.

Thus the homogeneous diffraction effect is validated on a piston source radiating a monochromatic sound in a two-dimensional fluid. As the analytical expression of the radiation diagram is known, comparison with the Flhoward results is possible.

Heterogeneities are as well validated through numerical simulation of academic examples for which analytical expressions are well established: for instance the case of forward scattering of a harmonic plane wave incident on a cylindrical heterogeneity.

Nonlinearities are confronted to laboratory experimental results.

Last but not least, the resolution of slowly moving medium is computed for the case of a 2D acoustical wave guide of width L (arbitrary) and infinite length. The ambient flow is sheared. Physical modes are computed analytically (Lilley equation) and then propagated by Flhoward: the validation test is made on dispersion relations comparison (see Fig. 1).

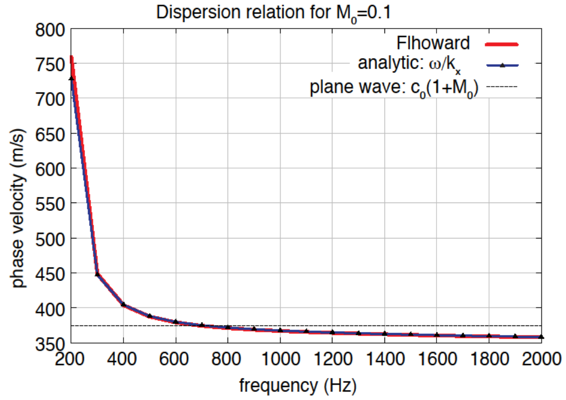

Fig. 1: Numerical dispersion relation compared to the analytical expression in the case of the propagation of an acoustic wave along the wave guide. An ambient Poiseuille flow of maximum mach number M_0=0.1 is present. The graphic shows good agreement of the analytical result compared to Flhoward simulations.

3. The HyMeX project

Directed toward the study of hydrological cycle in the Mediterranean, the HyMeX project [4] aims to understand the processes involved in nowadays climate changes, water shortage and major weather events, occurring in the global European basin. It started in 2011 and will last ten years.

In the frame of this project, special observation campaigns will be organized including lightning measurement [5]. One of these campaigns will be hold next Autumn 2012. CEA will install an acoustic station composed of four microbarographs and four microphones to measure the acoustic pressure due to thunder. A lightning mapping array (LMA) will give the source geometries. The conjunction of these various tools will produce a rich and unique set of new observation data.

4. Conclusion: HyMeX data confronted to Flhoward results

Atmosphere model required by Flhoward can be obtained through the use of well known meteorological model like MesoNH [6].

Flhoward results will then be used to confront the observation data.

3. References

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