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# AIRBORNE ACOUSTICS OF EXPLOSIVE VOLCANIC ERUPTIONS*

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A recently developed theoretical model of the airborne acoustic field from an explosive volcanic eruption of the Strombolian type is described in this article. The magma column is assumed to be a circular cylinder, which is open to the atmosphere at the top, and which opens into a large magma chamber below. The magma itself is treated as a fluid, and the surrounding bedrock is taken to be rigid. An explosive source near the base of the magma column excites the natural resonances of the conduit. These resonances result in displacement of the magma surface, which acts as a piston radiating sound into the atmosphere. The source is modeled in much the same way as an underwater explosion from a high-explosive chemical such as TNT, although in the case of the volcano the detonation mechanism is the ex-solution of magmatic gases under extremely high hydrostatic pressure. The new theory shows compelling agreement with airborne acoustic signatures that were recorded in July 1994 at a distance of 150 m from the western vent of Stromboli volcano, Italy. The theoretical and observed power spectra both display the following features: (1) four energetic peaks below 20 Hz, identified as the first four longitudinal resonances of the magma column; (2) a broad minimum around 30 Hz, interpreted as a source-depth effect, occurring because the source lay close to nulls in the fifth and sixth longitudinal resonances and thus failed to excite these modes; and (3) radial resonance peaks between 35 and 65 Hz. On the basis of the theory, an inversion of the acoustic data from Stromboli yields estimates of the depth ($\approx$ 100 m) and radius ($\approx$ 16 m) of the magma column as well as the depth ($\approx$ 83 m), spectral shape and peak shock-wave pressure ($\approx$ 1 GPa) of the explosive source. Most of the parameters estimated from the acoustic inversion compare favorably with the known geometry and source characteristics of Stromboli.

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# SOUND GENERATION OF INTERACTING PERTURBED VORTEX RINGS*

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A numerical study of interaction of the vortex rings is carried out. The vortex ring is modelled by using a slender vortex filament in unbounded space. The motion of the vortices is simulated by the Biot–Savart Law. The present investigation studies the sound generation of vortices with phase differences of $\Delta\gamma = 0$ and $3\pi/4$. Results show that the phase differences influence the shapes of the vortices and their associated instability, thereby affecting the generation of sound.

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# A WIDE-ANGLE PARABOLIC EQUATION FOR ACOUSTIC WAVES IN INHOMOGENEOUS MOVING MEDIA: APPLICATIONS TO ATMOSPHERIC SOUND PROPAGATION*

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Two new derivations of "vector" parabolic equations (PE) for use in acoustic propagation have recently been published. In these cases, PEs have been derived from first principles and incorporate velocity fluctuations of the medium as two additional vector terms. In the simpler case, large spatial-scale velocity fluctuations can be accommodated. In the more general case, multi-scale velocity fluctuations can be accommodated.

In this paper we report on a series of two-dimensional numerical experiments which compares sound propagation predicted from traditional PEs with sound propagation predicted from these two "vector" PEs. Two types of velocity fields are simulated. One, suitable for approximating an atmospheric boundary layer, is a field in which velocity has only a horizontal component, but whose magnitude can depend on height, i.e., $\boldsymbol{v} = v_x(z)$. The other is a field having random spatial fluctuations over a range of length scales and could be suggestive of atmospheric turbulence. In both cases celerity inhomogeneities are also included.

Results suggest that at least, in two dimension, the standard PE using an effective index of refraction is not accurate to describe the effects of the mean and turbulent velocity on sound propagation near the ground. We suspect that in three-dimensional problems, the added terms in the "vector" PEs will significantly increase in importance.

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# ACOUSTICS OF KINEMATICALLY COMPLEX SHEAR FLOWS*

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A new nonasymptotic method is presented that reveals an unexpected richness in the spectrum of acoustic fluctuations in a shear flow with nontrivial (kinematically complex) mean kinematics. The usefulness of the method is illustrated by analysing three different specific cases of compressible hydrodynamic shear flows. The temporal evolution of perturbations spans a wide range of nonexponential behavior from shear-modified oscillations, transitions between oscillatory and nonperiodic (vortical) modes of motion to monotonic growth. The principal characteristic of the revealed acoustic phenomena is their *asymptotic persistence.* Exotic regimes like "Echoing" as well as unstable (including parametrically driven) solutions are identified. Further areas of application, for both the method and the new physics, are outlined.

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# ULTRASOUND PROPAGATION THROUGH A ROTATIONAL FLOW: NUMERICAL METHODS COMPARED TO EXPERIMENTS*

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Sound propagation through a vortex is studied numerically using two different techniques: ray-tracing and finite-differences. Geometrical acoustics and ray-tracing are shown to yield a good picture of the interaction between a sound wave and a vortex when the ratio of the vortex radius to the acoustic wavelength is larger than one. In particular, this technique allows to take into account finite-size effects such as edge waves and the results are compared to experimental data. The interest of the finite-difference approach is demonstrated for cases where sound scattering occurs. We show the ability of such a simulation to account for both sound scattering and finite-size effects. Those two numerical techniques are compared and their validity is investigated.

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# WAVE PROPAGATION ON AN ELASTIC BEAM TRAVELING IN A TUBE: LINEAR THEORY OF AERODYNAMIC LOADING*

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Linear theory is developed of flexural wave motions of an elastic beam of circular cross-section traveling along its axial direction at a constant speed in an air-filled, circular tube placed coaxially. The beam is constrained to deflect in a plane and is subjected to a restoring force in proportion to the magnitude of deflection. Both beam and tube are assumed to be long enough for end effects to be ignored. Taking account of aerodynamic loading on the lateral surface of the beam, wave propagation is examined under a long-wave approximation that a characteristic wavelength of flexural waves is much longer than the tube's radius. Using the lossless, acoustic wave equation for the velocity potential of the air, and the classical, flexural wave equation for the deflection of the beam, an asymptotic-expansion method is applied based on the long-wave approximation. A linear wave equation for the deflection is derived and its dispersion relation is examined by comparing with the exact one derived previously without any long-wave approximation. Higher-order effects of the axial curvature of the beam and the compressibility of air on the aerodynamic loading are also discussed.

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# ON THE VIBRATION OF MEMBRANE PARTIALLY PROTRUDING ABOVE THE SURFACE OF LIQUID*

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The problem of free oscillations of membrane partially submerged into the layer of liquid is considered in the rigorous mathematical statement. The exact analytical solution of the problem is constructed. The eigen frequencies and the eigen functions of vibrating membrane basing on analyses of exact solution are calculated. The influence of liquid's level on eigen frequencies and on eigen functions is analysed.

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# VIBRATIONAL ANALYSIS OF SHIPS WITH COUPLED FINITE AND BOUNDARY ELEMENTS*

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The vibrational analysis of ships involves the solution of a coupled fluid-structure interaction problem in order to simulate the inertia response of the water to the structural vibrations. The paper describes a coupled FE-BE procedure for the computational solution of this problem. Regarding the structural equations, special emphasis is put on the modeling of damping. Various models of damping, in particular local damping, are discussed and implemented into the FE-model of the ship structure. The computational results are compared to data from large-scale measurements.

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# TRANSVERSE RESONANT OSCILLATIONS IN ACOUSTIC DUCTS*

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A theoretical study is made of the flow induced by a piston, performing rotational sinusoidal vibrations in a uniform two-dimensional planar duct. A frequency of the forced vibrations is close to a cut-off frequency. It is shown that exactly at a cut-off frequency the steady-state response represents a transverse periodic shock wave, propagating between duct walls and decaying algebraically in the far field.

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# NOISE SHIELDING BY SIMPLE BARRIERS: COMPARISON BETWEEN THE PERFORMANCE OF SPHERICAL AND LINE SOUND SOURCES*

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This study is concerned with the theoretical solution to the problem of sound screening by simple hard barriers on the ground with special emphasis given to the type of wave incidence, namely a comparison between the use of either a spherical or a cylindrical sound source. For a receiver at the shadow of the noise source, the field may be assumed to be due to the edge wave and for this, exact solutions are used. Regarding the wave reflection on an impedance ground, exact formulations are also used, and finally, some calculations are made on the performance of a hard noise barrier on a two-impedance ground. As a conclusion, it is found that although the sound level at the receiver may show some small differences depending on the frequency and on the geometry of the problem, the overall insertion loss of the thin hard barrier is almost the same for the spherical and the line source, and the differences are found to amount to less than 1 dB for geometries of practical occurrence.

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# WAVE PROPAGATION THROUGH HOLLOW BODIES AND NOISE REDUCTION*

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Low frequency noise (2–200 Hz) reduction in the passenger compartment has emerged in the past few years as a crucial subject of research in the car industry. This kind of noise is mainly due to the panels' vibrations, therefore our aim is to decrease the part of structural energy that reach them, i.e., we want to increase the part of energy that dissipates while propagating in the car body frame. This approach requires the understanding of structural wave propagation through the beam like structure (pillar, cross members...) as well as reflection and transmission at the structural joints. This is the physical problem that we want to address in this paper.

Since car body frames are much too complex for physical understanding, we focused on simpler representative academic structures. We developed a numerical tool for the prediction and visualization of wave propagation, based on finite element models (FEM). Our FEM are first validated by comparison with experimental modal analysis, and then used for transient analysis. In both cases, the good agreement between calculations and experiments shows the reliability of our model and allows us to use it for wave propagation visualization. We illustrate our results by making a movie that helps to understand how waves propagate through a two hollow bodies junction.

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# GENERATION OF GROUND ELASTIC WAVES BY ROAD VEHICLES*

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Ground elastic waves, or ground-borne vibrations, represent one of the major adverse environmental impacts of road vehicles, especially of heavy lorries. In the present paper, ground elastic waves generated by road vehicles are investigated theoretically. Two main generation mechanisms are considered. The first one is associated with vehicles traveling on rough or bumpy road surfaces, in particular over road humps and speed cushions installed by local authorities at some sensitive road locations as a simple method of traffic calming. The second mechanism of generation is associated with acceleration and braking of road vehicles. General analytical results are illustrated by numerical examples and are compared with the existing experiments.

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