Ph.D. Positions at the Fluid Mechanics and Acoustics Laboratory (Lyon, France)

The **Center for Acoustic Research** is currently seeking Ph.D. candidates to conduct research on the following topics:

1. propagation of infrasonic waves in a turbulent atmosphere;
2. acoustic radiation from volcanic jets emitted by Plinian eruptions;
3. acoustic radiation from impulsive volcanic eruptions.

Detailed descriptions of these projects are provided in the attached documents.

The employment period for successful candidates will be three years, with a minimum monthly net salary of approximately 1800 euros.

Required qualifications

Prospective candidates should possess:

- a master's degree in aerospace or mechanical engineering, physics, mathematics, or a related field;
- a strong background in fluid mechanics, acoustics, and computational fluid mechanics;
- hands-on experience with computing in C/C++, Fortran, Python, or similar programming languages;
- excellent written and verbal communication skills in English.

Experience with MPI and CUDA would be an asset. Proficiency in French would be preferred.

Duties

Successful candidates will be responsible for conducting original research, including a critical literature review, and generating, collecting, and analyzing data. They will be expected to publish their findings in top-tier journals and present at international conferences. Candidates will also engage in professional development activities, including seminars, lectures, and workshops.

Application procedure

To apply, please email Roberto Sabatini (roberto.sabatini@ec-lyon.fr) and include the following documents:

- an up-to-date Curriculum Vitae (CV);
- academic transcripts of all university degrees (e.g. bachelor's and master's degrees);
- a cover letter;
- names and email addresses of at least two references.

About the Center for Acoustic Research

The Center for Acoustic Research is one of the five research teams of the **Fluid Mechanics and Acoustics Laboratory** (LMFA, UMR5509). Today, the center's research activities revolve around three main subjects, namely: the propagation of acoustic waves in non-homogeneous media, the dynamics of compressible shear flows, and the aeroacoustics of rotating surfaces. For more information, please visit the center's website at `https://acoustique.ec-lyon.fr`.

Propagation of infrasonic waves in a turbulent atmosphere

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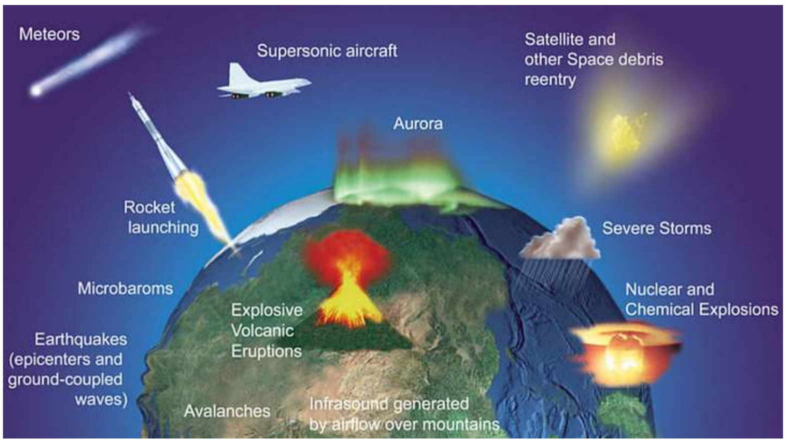
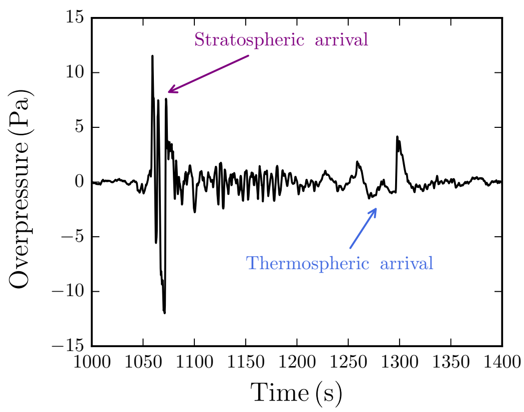
Context and motivation

Infrasonic waves are acoustic waves with frequencies lower than the human hearing threshold, around 20 Hz, and wavelengths between 20 m and 8 km. They can be generated by natural hazards, like earthquakes and volcanic eruptions, and human-made sources, such as chemical and nuclear explosions or the sonic booms produced by supersonic aircraft (see Figure 1a). Infrasound can travel through the atmosphere over horizontal distances ranging from a few hundred to several thousand kilometers and vertically up to the thermosphere above a hundred kilometers altitude. At great distances from their source, infrasonic pressure signals generally exhibit distinct wave packets known as arrivals (as seen in Figure 1b). These arrivals provide important information about the excitation mechanisms and the interaction between the infrasonic waves and the propagation medium.

The atmosphere is a complex, unsteady, and intrinsically turbulent flow. In addition to large-scale variations in temperature and winds, primarily controlled by solar activity and planetary waves, turbulent fluctuations with spatio-temporal scales close to acoustic wavelengths and frequencies are continuously observed. These fluctuations are notably generated by the breaking of gravity waves (mechanical waves due to the buoyancy of the air and with frequencies lower than a few millihertz) and can considerably affect the infrasonic arrivals. Although several studies have been carried out on acoustic propagation in turbulent flows, the interaction between infrasound and atmospheric turbulence remains a topic of ongoing research. Understanding this interaction is essential to improve our ability to interpret infrasonic recordings.



(a)



(b)

Figure 1: (a) Infrasound sources. (b) Pressure signal recorded at 300 km distance from an explosion.

Description of the research project

The atmospheric propagation of infrasonic waves has conventionally been modeled using approximate methods, such as ray tracing or normal modes, which keep computational costs low. However, the efficiency of these techniques comes at the expense of a detailed description of the physics of infrasound propagation. Thus, recent

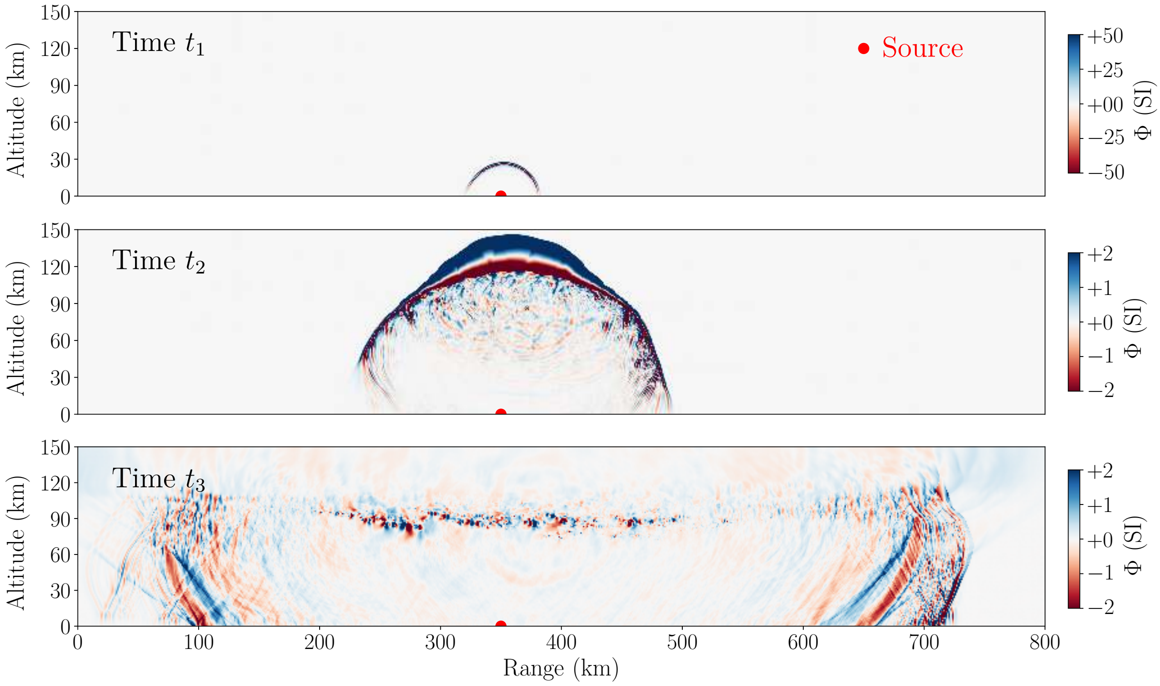


Figure 2: Pressure perturbations at different times due to an infrasonic wave that is generated by an impulsive source on the ground and travels through the turbulent field induced by the breaking of a gravity wave.

research conducted at the Center for Acoustic Research has investigated infrasonic waves by direct numerical simulations of the Navier-Stokes equations [1–6]. These equations describe acoustic propagation without approximations, providing unparalleled insight into the physical phenomena affecting infrasound, such as refraction caused by large-scale temperature and wind variations, non-linear effects, absorption due to viscous and thermal effects, caustics, and diffraction.

The proposed doctoral research aims to build on the aforementioned investigations and study the propagation of infrasonic waves generated by an impulsive source in a turbulent atmosphere induced by the breaking of gravity waves. To this end, three-dimensional numerical simulations of the Navier-Stokes equations will be carried out using an algorithm based on high-order finite difference schemes [7]. This approach will enable the simultaneous description of the spatio-temporal evolution of the turbulent atmosphere (including the generation of gravity waves, their breaking, and the turbulent cascade) and the acoustic propagation through the turbulent atmospheric field. The computations will be executed on clusters of GPUs (Graphics Processing Units) using a code written in C/C++/CUDA. A preliminary two-dimensional investigation was conducted in 2019 [5] (see Figure 2).

As part of the doctoral research, a method for exciting a realistic spectrum of gravity waves will first be developed. The interaction between the turbulent inhomogeneities generated by the breaking of these waves and the pressure signals recorded a few hundred kilometers from the acoustic source will then be analyzed. Finally, the effects of turbulence on arrival waveforms and frequency content will be examined for various source characteristics (energy, spectrum).

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Acoustic radiation from volcanic jets emitted by Plinian eruptions

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Context and motivation

Plinian eruptions are explosive volcanic eruptions characterized by the continuous ejection at high speed ($150-600\,\mathrm{m.s^{-1}}$) and high temperature ($\sim 1000°\mathrm{C}$) of solid rock fragments, known as pyroclasts, as well as gases such as water vapor, carbon dioxide, and sulfur dioxide [1]. The lowermost section of the eruptive column resembles the jet of an aircraft engine (cf. Figure 1) and generates aerodynamically-induced noise [2–5]. Due to their large diameter ($\sim 100\,\mathrm{m}$), these volcanic jets emit acoustic waves with frequencies typically below the human hearing range ($< 20\,\mathrm{Hz}$). These waves, called infrasound, can travel hundreds of kilometers through the atmosphere and carry significant information about their source [6–10]. As a result, one of the main objectives of research in volcano acoustics is to establish a correlation between specific characteristics of volcanic eruptions, such as ejection velocity or mass flux, and the spectrum of pressure signals recorded at long range [2–5]. Understanding the mechanisms of acoustic radiation of volcanic jets is essential for improving our ability to interpret these infrasonic recordings [5].

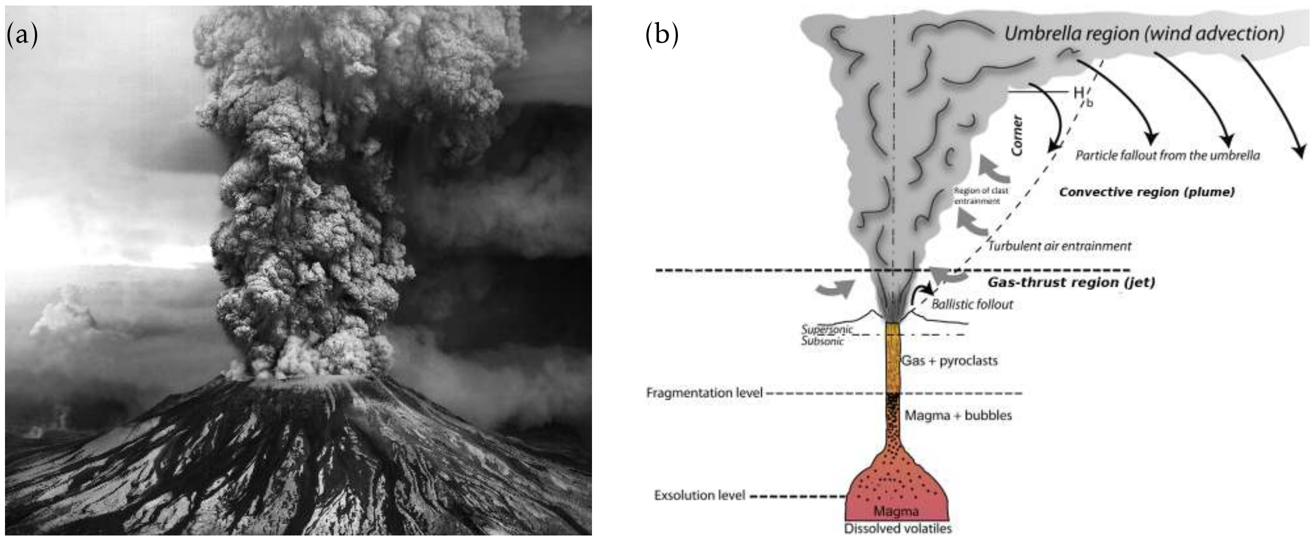

Figure 1: (a) Eruption of Mount Saint Helens (USA) in 1980. (b) Schematic illustration of a Plinian eruption.

Description of the research project

A volcanic jet is a multiphase flow, typically composed of a gas phase (comprising water vapor, carbon dioxide, and sulfur dioxide) and a solid phase (pyroclasts). These two phases may not necessarily be in mechanical and thermal equilibrium with each other [11]. However, in numerous studies concerning volcanic jets, it is assumed that the gases and pyroclasts share the same velocity and temperature [12-14]. This assumption finds justification in typical Plinian eruptions. In these cases, the volcanic jet can be regarded as a "pseudo-gas" (with thermodynamic properties intermediate between the two phases) that is ejected into the air [12-14]. The dynamics of the jet and the noise production can then be described by the Navier-Stokes equations for a mixture of two gases, namely the aforementioned pseudo-gas and the atmosphere.

The present doctoral project aims to investigate the acoustic radiation from jets resulting from Plinian volcanic eruptions. To this end, three-dimensional large-eddy simulations will be conducted by solving the Navier-Stokes equations via high-order finite difference schemes [15]. These simulations will be performed on mesh grids containing several hundred million points, enabling the simultaneous study of the jet dynamics and its acoustic radiation. This direct approach to calculating aerodynamically-induced noise has been developed at the Center for Acoustic Research since the end of the nineties and has already been successfully applied to subsonic and supersonic air jets [16-20]. An illustration of the obtained results is presented in Figure 2, and additional examples are available on the following website: `https://acoustique.ec-lyon.fr/caaweb.php`. Furthermore, the large-eddy simulations will be run on CPU and GPU (Graphics Processing Units) clusters using a code written in C/C++/CUDA.

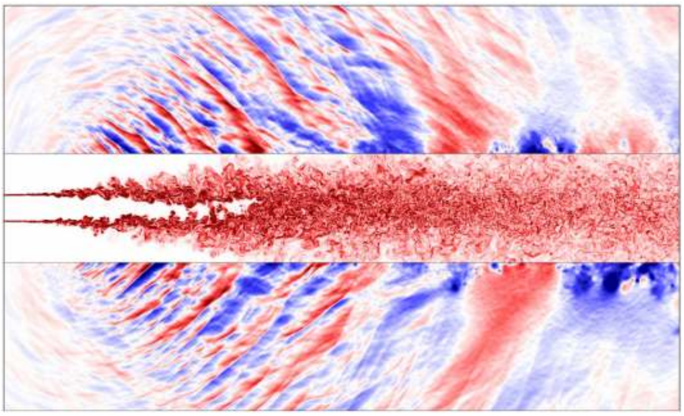

Figure 2: Simulation of a Mach 2 air jet: vorticity field inside the jet and pressure fluctuations outside (P. Pineau's Ph.D. thesis, LMFA, 2018).

In the scope of the proposed thesis, the first step will be to validate the numerical approach using one-dimensional and two-dimensional test cases [21]. Subsequently, the acoustic radiation from volcanic jets will be investigated for various ejection conditions in terms of velocity, pressure, and temperature. Finally, comparisons will be made between numerical results and data recorded during recent explosive eruptions [2,4].

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Acoustic radiation from impulsive volcanic eruptions

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Context and motivation

Vulcanian eruptions are short-lived explosive volcanic events (cf. Figure 1(a)) lasting from seconds to minutes [1,2]. They initiate when a plug or dome, initially sealing a volcanic conduit, is abruptly disrupted (cf. Figure 1(b)) due to the buildup of sufficiently high pressure in the underlying magma ($1-10\,$MPa). Upon plug disruption, a decompression wave, followed by a fragmentation front, travels down the conduit while a compression shock propagates into the atmosphere. At the fragmentation front, magma transitions into a mixture of solid fragments, known as pyroclasts, and hot gases, including water vapor, carbon dioxide, and sulfur dioxide. This mixture is propelled upward and ejected into the atmosphere as a high-temperature starting jet ($\sim 1000°$C) with velocities ranging from sonic to supersonic, sometimes exceeding $400\,\mathrm{m.s^{-1}}$. This ejection is characteristically impulsive and unsteady.

The displacement of atmospheric air due to explosive vulcanian events induces acoustic waves [3–10], primarily within the infrasound range (frequencies below 20 Hz), which can propagate hundreds of kilometers through the atmosphere and convey valuable information about the eruptions [11–15]. As a result, infrasonic signals recorded at ground level are increasingly employed for detecting and monitoring volcanic activities as well as to constrain eruption parameters such as the eruptive volume and mass, the plume height, and the crater dimensions [3–10]. Within this context, understanding the relationship between eruption properties and acoustic radiation becomes crucial for effectively utilizing infrasound observations to advance our comprehension of explosive eruptions.

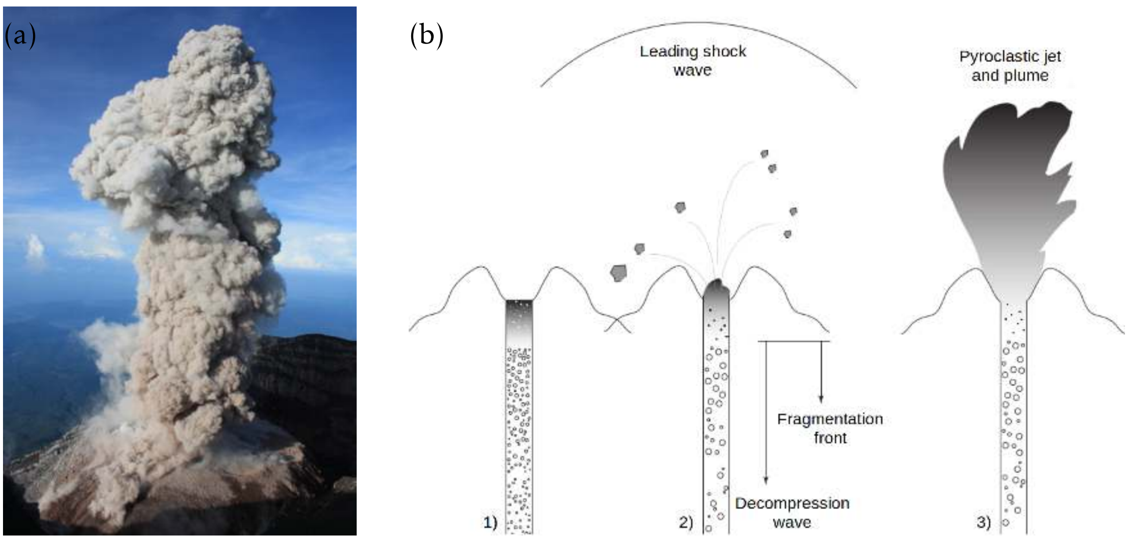

Figure 1: (a) Eruption of Semeru volcano (Indonesia). (b) Schematic illustration of a Vulcanian eruption.

Description of the research project

Most investigations on infrasound generated by unsteady explosive volcanic activities often rely on simplified assumptions [3]: volcanic explosions are typically represented as impulsive monopole point sources radiating acoustic waves isotropically, while the dynamics of the starting jets near the volcanic vent is neglected; additionally, infrasound propagation is commonly assumed to be linear. While these simplifications have been valuable in interpreting volcano infrasound signals and linking observations to eruption characteristics, they may not always be applicable and can lead to inaccurate estimates of eruption parameters. To advance our understanding of eruption dynamics and improve the accuracy of infrasound-derived constraints on eruption properties, it's imperative to revisit these assumptions and adopt more realistic source models.

The objective of the present doctoral project is to study the acoustic radiation from unsteady explosive eruptions. More specifically, the propagation of the leading shock wave and the dynamics of the subsequent unsteady hot jet will be investigated numerically by solving the Navier-Stokes equations via a high-order finite difference method [16]. Three-dimensional large-eddy simulations will be performed. The calculations will be run on CPU and GPU (Graphics Processing Units) clusters using a code written in C/C++/CUDA. Mesh grids containing several hundred million points will be employed, which will enable the simultaneous study of the flow dynamics and its acoustic radiation. This direct approach to calculating aerodynamically induced noise was developed at the Center for Acoustic Research over two decades ago and has already been successfully applied to subsonic and supersonic air jets [17-21]. Illustrations can be found on the following website: `https://acoustique.ec-lyon.fr/caaweb.php`.

As part of the proposed thesis, the initial step will involve validating the numerical approach against previous investigations [3,22]. Subsequently, the acoustic radiation from explosive volcanic eruptions will be studied for various volcanic ejection conditions in terms of velocity (sonic and supersonic), pressure, temperature, and gas composition.

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