OFFRE DE CONTRAT DOCTORAL (36 mois) • 2027–2030

Investigating the playability of self-sustained musical instruments with a dynamical systems point of view: basins of attraction and transient dynamics of control parameters

Context

Nonlinear dynamical systems such as pulsing lasers, musical instruments or climate models, are known to exhibit **complex behaviours**. This includes the coexistence of multiple stable regimes for identical parameters (a situation referred to as multistability), a possible sensitivity to initial conditions or sudden transitions between regimes under the small change of a parameter. **Understanding and predicting** the dynamics of such nonlinear systems remains a major scientific challenge.

Numerical bifurcation analysis has attracted considerable attention over the last decades, and lead to substantial progresses by giving access to **bifurcation diagrams** which represent ideally all the possible stable and unstable solutions of a system, with respect to a parameter of interest. Nevertheless, bifurcation analysis also has important limitations. In particular, it unveils the **multistability regions** of the system (the range of parameters for which several stable solutions coexist) but says nothing on which regime (solution) is reached in practice.

Self-sustained musical instruments, such as wind instruments and bowed string instruments, are an excellent testbed to explore general phenomena in nonlinear dynamics. Indeed, sound production in these instruments relies on a wide diversity of nonlinear mechanisms in connexion with various scientific fields (contact mechanics, aeroacoustics, biomechanics…). Such instruments have also been shown to produce a wealth of sound regimes whose properties and existence depend - often sensitively - on **design and playing parameters.**

From a musical point of view, **multistability regions** are particularly interesting as they allow the musician to access a wide range of sound regimes, while also posing challenges in controlling them. **In practice, how to access a particular sound regime amongst the different possible ones?** From a dynamical systems perspective, this raises the question of **basins of attraction**, that is to say the question of initial conditions that make the system converge towards a particular solution.

Recent work at LAUM and LMA [1,2] focused on developing numerical tools to compute **borders between basins of attraction**, with application to physical models of musical instruments. In parallel, preliminary work [3,4] have demonstrated that the **temporal evolution (dynamics) of control parameters** can play a crucial role in determining which regime is observed, and even trigger unexpected transitions between regimes. Such rapid variations of parameters are observed for example during the so-called **attack transients,** when a musician starts to play a note and varies rapidly the contact force between the bow and the string and/or the bow speed. These observations relate to the phenomenon of **rate-induced tipping,** which has attracted considerable attention recently, particularly in the context of climate modelling [5].

This PhD thesis is part of the project BEBOP, funded by the French National Research Agency (ANR). This project aims at exploring the dynamics of nonlinear systems beyond the classical bifurcation analysis, in order to better understand and predict the complex dynamics of nonlinear systems in general, with a focus on self-sustained musical instruments.

Objectives

This PhD thesis aims at **characterising the basins of attraction** in self-sustained musical instruments, both numerically and experimentally, in relation with the practical control of the instrument in a musical context. From a more general point of view, we expect this work to contribute to a better understanding of complex phenomena in nonlinear dynamics, such as rate-induced tipping.

Methodology

The work will combine **physical modelling, numerical simulations and experiments.**

A **first work axis** will make use of numerical methods developed recently in LAUM to characterise the **influence of design and control parameters on the geometry of basins of attraction in a model of a reed musical instrument** (saxophone).

A **second axis** will explore the **links between basins of attraction and control strategies as used by musicians.** In particular, the following questions will be investigated:

- What is the influence of small perturbations on control parameters (e.g. bow speed of pressure in the musician's mouth) on the system state variables and therefore on the regime reached in practice ?
- Can attack transients, during which the control parameters change rapidly, be a mean for musicians to navigate between basins of attraction and therefore to control in practice which regime is played in case of multistability ? Said differently, do performers use **rate-induced tipping** in a musical context ?

These axis will include **numerical and experimental aspects,** and will take advantage of existing numerical methods and experimental testbenches, although they may require further adaptation. Finally, particular attention will be devoted to discussing the results in the broader context of current research questions in nonlinear dynamics, extending beyond their specific applications to musical instruments.

Profile of the candidate

Students who hold a master's degree in mechanical engineering, acoustics, nonlinear physics or a related scientific field are welcome to apply. A background in nonlinear dynamics, in scientific programming, and/or in experiments in mechanics/acoustics will be appreciated. An interest for music will be a plus.

Environnement and supervision

The PhD thesis will take place at the **Laboratoire d'Acoustique de l'Université du Mans (LAUM)**, a research lab of CNRS and Le Mans Université. It will be supervised by Soizic Terrien, research scientist at CNRS, and Frédéric Ablitzer, lecturer at Le Mans Université and lecturer at INSA Centre Val de Loire/Lamé (Blois, France).

This PhD thesis is part of the collaborative project BEBOP funded by the French National Research Agency (ANR), involving three research lab (LAUM in Le Mans, Lamé in Blois and LMA in Marseille). As such, occasional travels to Marseille and Blois should be expected. Presentations in national and international conferences will also be scheduled during the PhD.

The salary will be in accordance with CNRS pay scales.

How to apply

CV, cover letter, academic transcript and contact of academic referees should be sent to Soizic Terrien (soizic.terrien@univ-lemans.fr) no later than 31st of May 2027. Informal enquiries are welcome.
Starting date: 1st of October 2027, for three years.

References

[1] Passa, T., Terrien, S., Maugeais, S., & Gazengel, B. (2025). Basins of attraction of periodic solutions in a multistable model of self-oscillating musical instrument. *Journal of Sound and Vibration*, 119467.

[2] Pégeot, M., Colinot, T., Doc, J. B., Fréour, V., & Vergez, C. (2024). Playability of self-sustained musical instrument models: statistical approaches. *Acta Acustica*, *8*, 74.

[3] Bergeot, B., Terrien, S., & Vergez, C. (2024). Predicting transient dynamics in a model of reed musical instrument with slowly time-varying control parameter. *Chaos*, *34*(7).

[4] Terrien, S., Bergeot, B., Vergez, C., & Missoum, S. (2025). Basins of attraction in a dynamical system with a time-varying control parameter: The case of attack transients in a simple model of reed musical instrument. *Journal of Sound and Vibration*, *618*, 119241.

[5] Ritchie, P. D., Alkhayuon, H., Cox, P. M., & Wieczorek, S. (2023). Rate-induced tipping in natural and human systems. *Earth System Dynamics*, *14*(3), 669-683.