FULLY FUNDED PHD POSITION (36 months) • 2027–2030

Instrumental gesture and rate-induced tipping points in self-oscillating musical instruments: combined effects of multiple time-varying control parameters and of noise

This PhD is **funded by the French National Research Agency** (ANR) through the **BEBOP** project (Beyond Classical Bifurcation Analysis: New Perspectives for Mechanical Engineering).

Background

Many n**onlinear dynamical systems** encountered in physics, biology, climate science, and engineering exhibit multiple stable states for the same set of parameter values—a phenomenon known as **multistability**. **Understanding** and **predicting** the resulting complex dynamics remains a major scientific challenge today.

Over the past few decades, classical bifurcation analysis has become a widely used tool, well beyond research laboratories. While it reveals the possible steady-state regimes (stable and unstable) for a given set of constant parameter values, it does not predict the effect of the time evolution of these parameters. Yet this effect is crucial: in multistable systems with time-varying parameters, the resulting oscillatory regime depends not only on the values reached by the parameters, but also on the **rate at which they change**. In dynamical systems theory, this phenomenon is referred to as **rate-induced tipping** (R-tipping) [1, 2], a concept that has emerged relatively recently, primarily in the context of climate science and ecology.

Self-oscillating musical instruments, such as the saxophone or the violin, provide an ideal framework for studying this phenomenon in mechanical engineering. Indeed, (i) they are multistable: the desired note is generally not the only possible stable regime for a given fingering or string length; (ii) during the attack of a note or the transition from one note to another, the musician continuously varies several control parameters (the mouth pressure and the force applied by the lip on the reed for a reed instrument; the bow velocity and the bow force on the string for a bowed-string instrument); and (iii) well-established models are available, some of which are both simple and representative of complex behaviors, and they lend themselves easily to experimentation.

Recent work, carried out in particular at LaMé, has shown that R-tipping sheds light on regime selection under bistability in simplified models of the saxophone [3, 4] and the violin [5]. These results pave the way for a better understanding of the link between instrumental gesture and the sound produced, and highlight the relevance of this phenomenon in mechanical engineering.

Scientific challenges and objectives

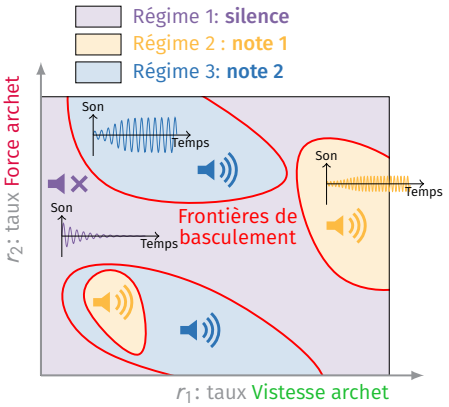
R-tipping theory focused on deterministic systems with **a single time-varying parameter**, and has mainly been developed for conceptual climate models. Yet, in mechanical engineering as in musical acoustics, real systems are driven by several **simultaneously time-varying parameters** and are **subject to random perturbations**. This is typically the case for instrumental gesture, which involves the variation of at least two control parameters in an intrinsically noisy system (flow turbulence, control fluctuations). Predicting tipping in such systems remains, to date, a **largely open research question**.

When a single parameter varies and then settles at a target value, there may exist **a critical rate** beyond which the system tips from one stable state to another. This threshold constitutes a tipping point. A recent tool [3, 4, 5], the **tipping separatrix** (or **R-separatrix**), has made it possible to characterize the tipping point of simple models with a single time-varying parameter in a deterministic framework. In the bistable regime, the R-separatrix is a trajectory (or a family of trajectories) in the state space augmented by the parameter, which divides this space into two parts: depending on which side the initial condition lies, the system converges to one regime or the other. Since the R-separatrix depends on the rate of change, R-tipping occurs when, for a given initial condition, a change in rate causes the separatrix to move across it. The critical rate is the one for which the initial condition lies exactly on the separatrix.

The **main objective** of this PhD is to extend the framework established in [3, 4, 6] to more realistic situations, combining the simultaneous time variation of several parameters, multistability involving more than two regimes, and the presence of noise, and then to validate these results experimentally.

It is broken down into four sub-objectives:

O1 — Characterizing tipping boundaries. When several parameters vary simultaneously, the tipping point is no longer a single number: it becomes a **tipping boundary** in the space of rates of change. The adjacent figure shows an example of the expected mapping in the case of the violin..



O2 — Quantifying the combined effect of noise and rates of change. The presence of noise, even at very low intensity, can significantly alter the tipping predicted in a deterministic framework. The aim is therefore to compare the deterministic maps established above with their noisy counterparts, expressed in terms of **R-tipping probability**.

O3 — Testing the predictions against experiments. The R-tipping maps, both deterministic and noisy, will be compared with laboratory measurements obtained using controlled playing devices (artificial mouth, motorized bow) that allow reproducible variations of several parameters to be imposed.

O4 (More prospectively and exploratory) — Linking these results to realistic instrumental gestures and, through them, to the **playing strategies of expert musicians**.

Methodology

In pursuing these objectives, the future PhD student will be able to develop, through concrete examples, **general skills in nonlinear dynamics** — applicable in many fields, from mechanical engineering to climate science — while **addressing current research questions**. The proposed research framework is as follows:

1. **Modeling:** selection and, where necessary, reduction of existing models of self-oscillating instruments (reeds [6] and bowed strings [5]) in order to obtain minimal yet representative, multistable and multiparameter models.
2. **Deterministic framework:** development of theoretical and numerical methods to define and compute R-separatrices under multiparameter variations and multistability of order higher than two, in order to determine the tipping boundaries.
3. **Probabilistic framework:** following a review of existing theoretical and numerical approaches, implementation of a framework for computing tipping probabilities. Monte Carlo simulations will initially provide reference results.
4. **Experimental validation:** measurement campaigns on the test benches of the BEBOP project partners, for bowed strings (LAUM, Le Mans) and/or reeds (LMA, Marseille).
5. **Comparison with realistic profiles:** use of existing experimental data to identify R-tipping situations on real instruments and to extract the time profiles of the associated control parameters.

In keeping with the **ambitions of the BEBOP** project, this work will situate its results in a broader context, beyond musical instruments, connecting them to mechanical engineering and to current challenges in nonlinear dynamics.

Profile of the candidate

Holder (or prospective holder) of a Master's degree (M2) or an engineering degree in mechanics, acoustics, physics or applied mathematics.

A background in nonlinear dynamical systems and/or nonlinear vibrations, experience in scientific programming, and an interest in mathematical modeling and analysis as well as in numerical simulation and experimental work will be appreciated.

An interest in music or playing an instrument would be a plus, but is not required.

Research environment and supervision

The PhD will be carried out in the Dynamics and Vibrations of Structures (DVS) team of the **Laboratoire de Mécanique Gabriel Lamé** (LaMé, UR 7494), on the Blois campus of INSA Centre Val de Loire, in close collaboration with the partners of the BEBOP project: the *Laboratoire d'Acoustique de l'Université du Mans* (LAUM, UMR CNRS 6613) and the *Laboratoire de Mécanique et d'Acoustique* (LMA, UMR CNRS 7031) in Marseille. Within this framework, research stays in Le Mans and/or Marseille may be arranged.

Supervision will be provided by:

- Baptiste BERGEOT, Associate Professor (HDR), LaMé, thesis director
- Soizic TERRIEN, CNRS Research Scientist, LAUM, co-supervisor
- Christophe VERGEZ, CNRS Research Director, LMA, co-supervisor

Salary: €2,300 gross per month (approximately €1,850 net), with the possibility of additional paid teaching duties.

How to apply

Applications, including a CV, a cover letter, first- and second-year Master's (or equivalent) transcripts, the title of the final-year research internship and, optionally, contact details of one or two referees, should be sent to:

Baptiste Bergeot (baptiste.bergeot@insa-cvl.fr)

PhD start date: 1 October 2027

Références bibliographiques

1. Ashwin, P., S. Wieczorek, R. Vitolo, & P. Cox. *Tipping Points in Open Systems: Bifurcation, Noise-Induced and Rate-Dependent Examples in the Climate System*. Philos. Trans. R. Soc. A 370.
2. Wieczorek, S., C. Xie, & P. Ashwin (2023). *Rate-Induced Tipping: Thresholds, Edge States and Connecting Orbits*. Nonlinearity 36, 3238–93.
3. Terrien, S., B. Bergeot, C. Vergez, & S. Missoum (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*. J. Sound Vib. 618: 119241.
4. Bergeot, B., S. Terrien, & C. Vergez (2024). Predicting Transient Dynamics in a Model of Reed Musical Instrument with Slowly Time-Varying Control Parameter. Chaos: 34(7): 073146.
5. Bergeot, B., S. Terrien, & C. Vergez. *Rate-induced tipping in a dry-friction oscillator under parameter drift*. Paper presented at EURODINAME III - International Symposium on Dynamic Problems of Mechanics, 8–11 June 2026, Giens (FR).
6. Gilbert, J., S. Maugeais, & C. Vergez (2020). *Minimal Blowing Pressure Allowing Periodic Oscillations in a Simplified Reed Musical Instrument Model: Bouasse-Benade Prescription Assessed through Numerical Continuation*. Acta Acust. 4(12).