Register jumps on the clarinet: numerical and in-vitro investigation into basins of attraction and phase-tipping

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Laboratoire de Mécanique et d'Acoustique

Outline

1. Introduction
    - The register hole of the clarinet
    - The clarinet as a nonlinear dynamical system
    - Problem statement
2. Experiment
    - Experimental setup
    - Blowing pressure ramps
    - Hole openings
3. Simulations
    - Model
    - Reproduction of the experiment
    - Focus on the transition regions
        - Evidence of phase-induced tipping
        - Exploring extremely long transients
4. Conclusion

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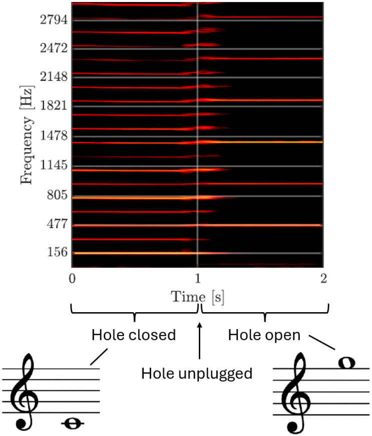
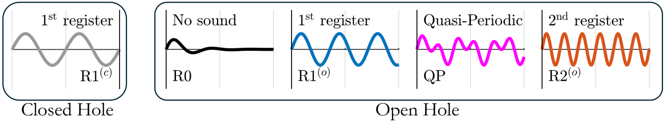
The register hole of the clarinet

- Most upstream hole of the instrument
- Smallest diameter (≈ 3 mm)
- Longest chimney length (> 10 mm)
- Enables to play at a frequency close to the 2nd mode of the resonator: second register ($\mathrm{R2}^{(o)}$)



The clarinet as a nonlinear dynamical system

Observed regimes

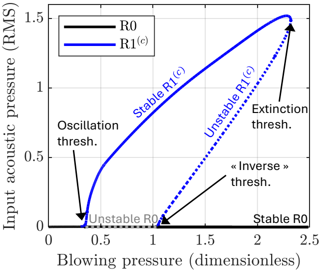


Main control parameters

Blowing pressure P_{blow}; Embouchure (remains fixed throughout the experiment)

Multistability

Different stable regimes can be played for the same control parameters.

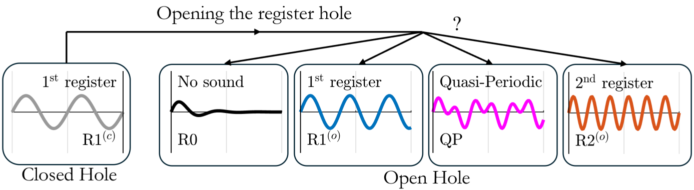


Problem statement

- The hole is closed.
- The blowing pressure is constant.
- The first register is played ($R1^{(c)}$).

We open the register hole.

Can we guess which regime is going to be produced?



It depends on which regimes are stable for the open hole configuration.

- Only 1 stable regime (e.g., R0): 1 possible solution.
- 2 or more stable regimes: depends on the initial conditions at which the hole is opened → **basins of attraction**

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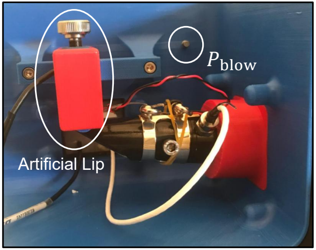
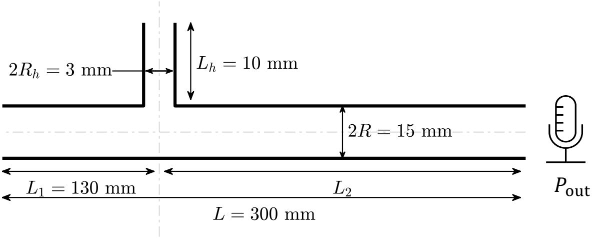
Experimental setup

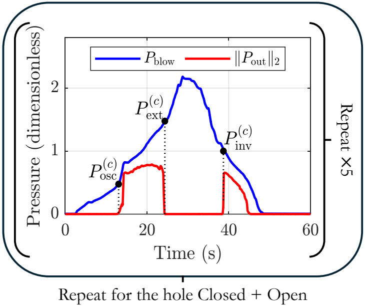
- Resonator: cylindrical tube + 1 register hole
- Artificial mouth:
  - Position of the lip is fixed
  - Modify P_{blow} only
  - Measure P_{blow} and P_{out}





Blowing pressure ramps

- *Crescendo* of P_{blow} followed by *diminuendo*
- Repeat 5 times, for the closed$^{(c)}$ and open$^{(o)}$ hole cases.
- Find the stability regions of R1$^{(c)}$, R0$^{(o)}$, R1$^{(o)}$, R2$^{(o)}$



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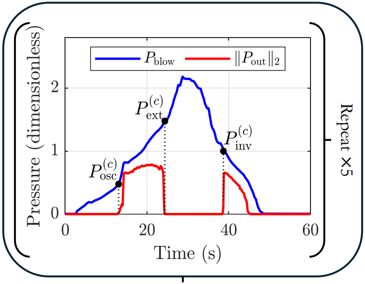
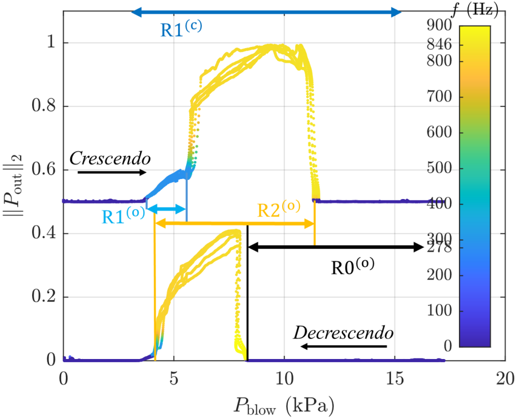


Repeat for the hole Closed + Open

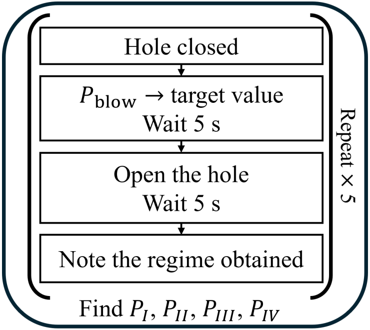


Open hole regimes Multistability
R2$^{(o)}$ and R0$^{(o)}$
R2$^{(o)}$ and R1$^{(o)}$

Hole openings

- Find the stability region of $\mathrm{R2}^{(o)}$ when opening the hole from $\mathrm{R1}^{(c)}$
- Identify four thresholds:
  - P_{II}: minimum blowing pressure that always leads to $\mathrm{R2}^{(o)}$
  - P_{III}: maximum blowing pressure that always leads to $\mathrm{R2}^{(o)}$
  - P_{I}: maximum blowing pressure lower than P_{II} that never leads to $\mathrm{R2}^{(o)}$
  - P_{IV}: minimum blowing pressure greater than P_{III} that never leads to $\mathrm{R2}^{(o)}$

$$P_{\mathrm{I}} < P_{\mathrm{II}} < P_{\mathrm{III}} < P_{\mathrm{IV}}$$



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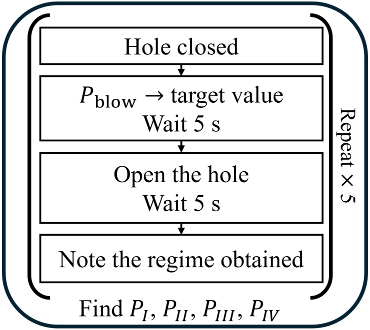

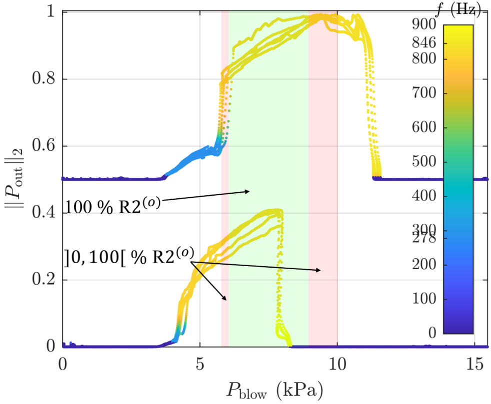

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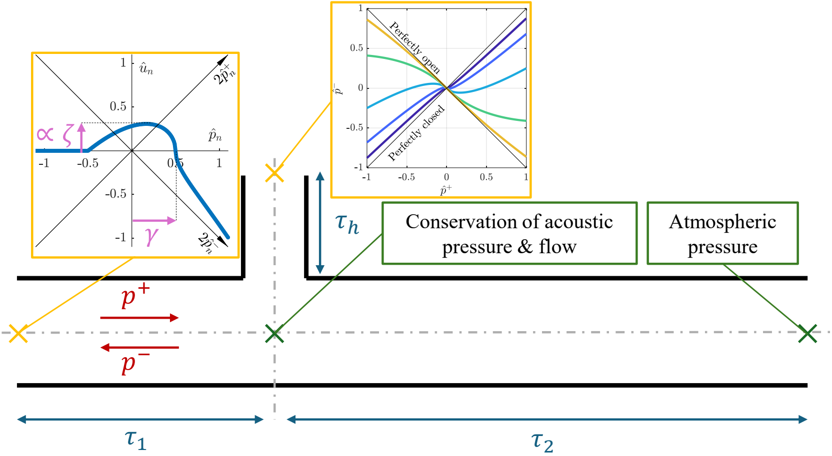
Numerical model

Formalism	Delay lines: $p = p^+ + p^-$
Nonlinearities	Flow crossing the reed channel at the input
	Nonlinear losses in the register hole
Control parameters	Blowing pressure γ, Embouchure ζ



Reproduction of the experiment

- Blowing pressure ramps:
  Steady embouchure ($\zeta = \text{Cst}$), linear increase of the blowing pressure γ
- Hole openings at constant control parameters:
  $N_o = 200$ openings at different times spread over a period of $\text{R1}^{(c)}$. Register is determined after each opening.

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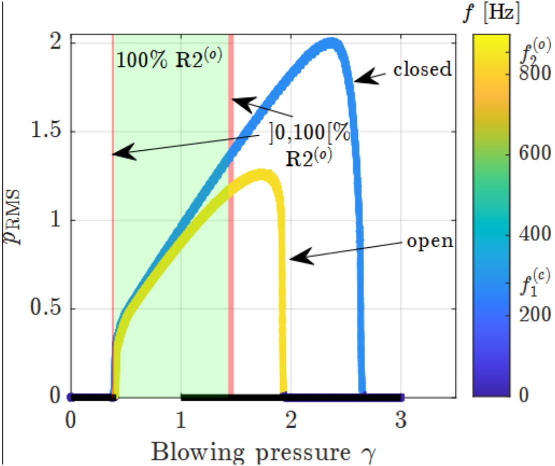
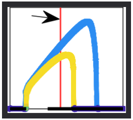
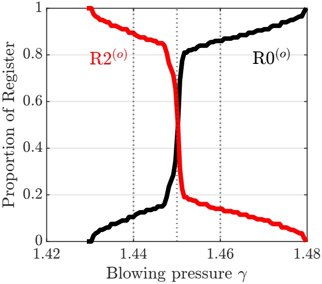


Focus on the transition region (high blowing pressure)



- Abrupt decrease of the proportion of R2$^{(o)}$



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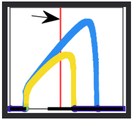
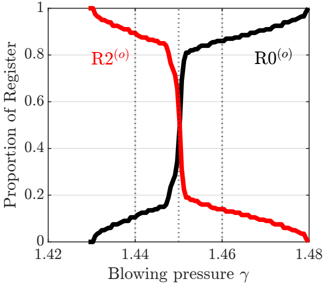
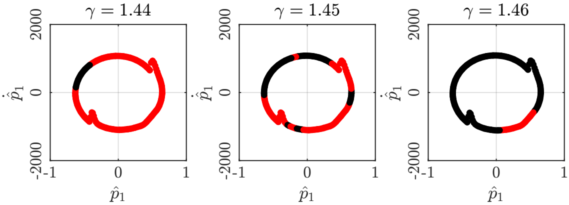


- Abrupt decrease of the proportion of $R2^{(o)}$

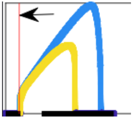


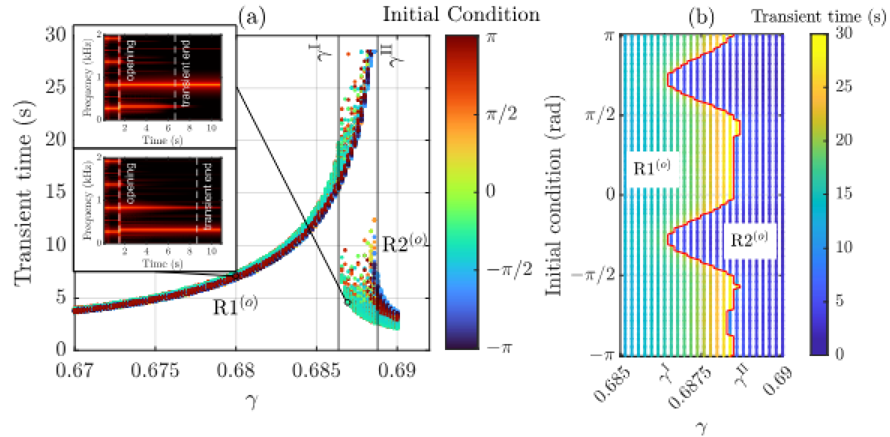


From the phase space $(p_1, \dot{p}_1)$:

- Limit cycle of the **closed hole**, just before the opening
- Convergence to a given regime depends on the **phase** at which the hole is opened ($R0^{(o)}$/$R2^{(o)}$)

Long-lasting transient quasiperiodics at low blowing pressure





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Is phase-tipping responsible for the probabilistic regions observed in the experiment?

- Opening a hole is not instantaneous: lasts for more than 5 periods of R1$^{(c)}$ (+rate-induced tipping)
- Amplitude of noise on P_{blow} is as large as 10% of the transition region

→ Nearly impossible to isolate phase-tipping experimentally...

→ ... but the transition region highlights the competition between basins of attraction

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$\rightarrow$ Nearly impossible to isolate phase-tipping experimentally...

$\rightarrow$ ... but the transition region highlights the competition between basins of attraction

Recommendations for musical instruments modelers:

- Stability is not enough to quantify the playability of an instrument
- Do not modify the system always at the same time: other solutions might be missed

Thank you!

Looking for a postdoc!

I'm currently looking for a postdoc, starting in 2026. Feel free to contact me if you think my work aligns with your research!

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Rate-induced tipping during a smooth hole opening