



**HAL**  
open science

# Artificial intelligence control applied to drag reduction of the fluidic pinball

Guy y Cornejo Maceda, Bernd R Noack, François Lusseyran, Nan Deng, Luc Pastur, Marek Morzynski

## ► To cite this version:

Guy y Cornejo Maceda, Bernd R Noack, François Lusseyran, Nan Deng, Luc Pastur, et al.. Artificial intelligence control applied to drag reduction of the fluidic pinball. PAMM, 2019, 90th Annual Meeting of the International Association of Applied Mathematics and Mechanics (GAMM), 19 (1), pp.e201900268. <10.1002/pamm.201900268>. <hal-02398649>

**HAL Id: hal-02398649**

**<https://hal.science/hal-02398649v1>**

Submitted on 7 Dec 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

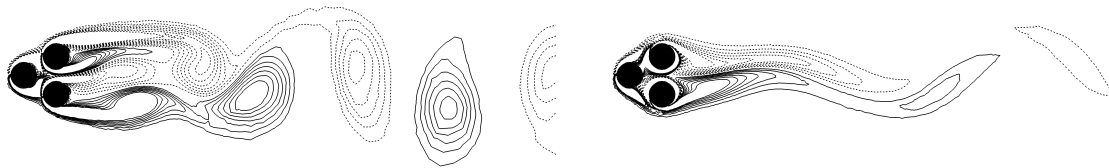


The control law to be derived is thereby a function living in an infinite dimension space. Solving equation (1) implies the resolution of a non-convex optimization problem with presumably multiple local minimas and discontinuities in the search space. To overcome such a problem, a powerful artificial intelligence technique is deployed : genetic programming (GP). It serves to find near optimum solution by identifying both the parameters and the structure of the control law, allowing not only all the previously mentioned mechanisms and methods but also linear and nonlinear combination of them. The control paradigm is illustrated in figure 2 and is further described in Duriez et al. 2016 [3].

Our contribution has been to optimize the metaparameters of the algorithm to improve the speed of the convergence and the quality of the solution. Also, better performance has been achieved thanks to control law complexity penalization.

### 3 The fluidic pinball tamed by AIC

The optimized genetic programming code has been applied to a 2D fluidic pinball. The simulation has been carried out thanks to the UNS3 solver, a highly optimized code that balances speed and accuracy [4]. Increasingly rich control law spaces have been explored to derive the control law. They include multi-frequency forcing; direct sensor feedback thanks to velocity probes (see figure 1); and sensor history. The most performing control law ( $b_{front} = -s(t)$ ,  $b_{bottom} = 1.76 - s(t)s(t-1)$ ,  $b_{top} = -1.80$ ) is found to be a combination of boat-tailing on the back cylinders and phasor control for the front cylinder. It's worth mentioning that GP acts like a sensor optimizer, selecting only one of the fifteen sensors. This control law achieves a 46.0% net drag power reduction outperforming previous optimized open-loop control strategies such as boat-tailing (42.7% net drag power reduction) and leads to a smoother wake, see figure 3.



**Fig. 3:** Contour levels of vorticity for the unforced flow (left) and controlled flow (right) by the control law in section 3. Solid lines and dashed lines represent respectively positive and negative vorticity.

### 4 Conclusion and perspectives

The model-free formulation of the control problem as a non-convex optimization problem enables the exploration of complex, nonlinear dynamics. Such a problem is solved thanks to an iterative stochastic method, genetic programming. An optimization of the metaparameters of the algorithm and complexity penalization of the control law achieved a 46.0% net drag power reduction on the fluidic pinball combining two strategies from literature: boat-tailing and phasor control. The introduction of sensor history in the search space basis has been the key element to deal with a convective flow as the fluidic pinball. Moreover a large variety of dynamics can be explored depending on the cost function formulation: total fluctuation energy reduction, increase of recirculation bubble length, difference to steady solution are as many different objective to be tested; possibly for one of them leading to a full stabilization of the wake. As for the fluidic pinball, the artificial intelligence control approach has the potential to reveal hidden control mechanisms in real-world experiments, unreachable with model-based approaches, and exploiting nonlinearities and frequency crosstalks.

**Acknowledgements** Our research is supported by the ASTRID-ANR-17- FLOWCON project, *Contrôle d'écoulements turbulents en boucle fermée par apprentissage automatique*.

### References

- [1] D. Dracopoulos, Evolutionary Learning Algorithms for Neural Adaptive Control, Springer 1997
- [2] S. Brunton, B. R. Noack, Closed-Loop Turbulence Control: Progress and Challenges, 2015 Appl. Mech. Rev. 67, 050801
- [3] T. Duriez, S. Brunton, B. R. Noack, Machine Learning Control : Taming Nonlinear Dynamics and Turbulence, Springer 2016
- [4] B. R. Noack, M. Morzyński, The Fluidic Pinball: A Toolkit for Multiple-Input Multiple-Output Flow Control. Tech. Rep. 02/2017