Closed-Loop Jet Control for Aeronautical Applications

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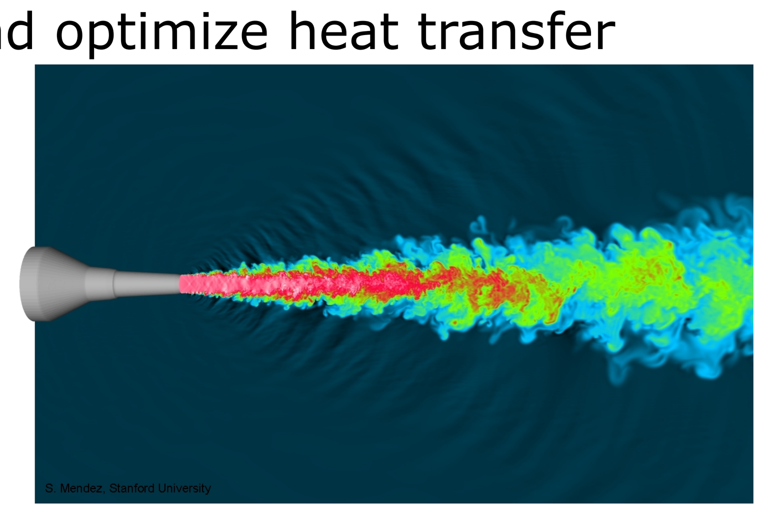
Motivation

Turbulent jets are dominated by advective flow structures which affect noise and heat transfer.

Active control can reduce acoustic emissions and optimize heat transfer in aeronautical and industrial applications.



Applications

- **Reduce noise pollution** around airports
- Turbine blade **cooling in Jet Engines**
- **Enhance performance** of industrial jet systems

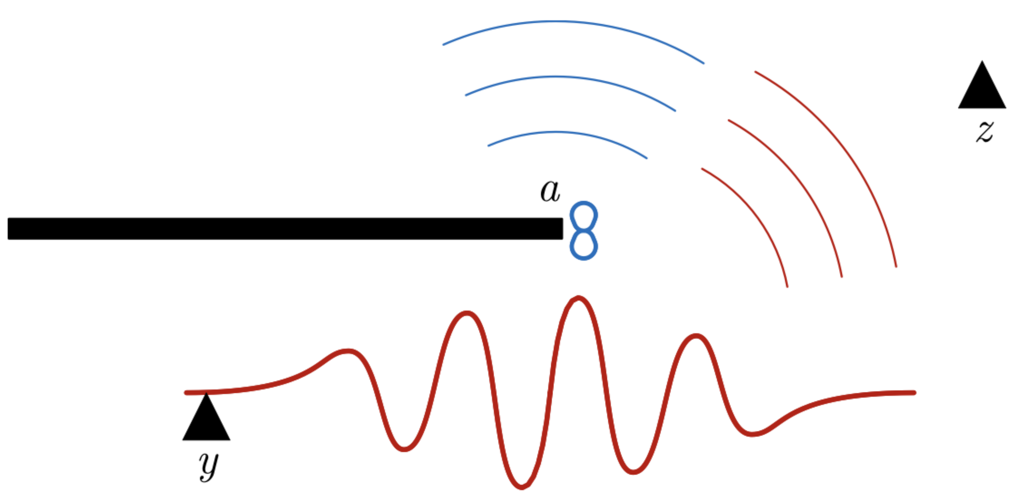
Hypothesis

It is possible to develop robust closed-loop control strategies for turbulent jets, both free and impinging, using reduced-order models and machine learning, despite the inherent nonlinearity, noise, and high dimensionality of turbulent flows.

Tools and Objectives

Convectively Unstable System Control[6]

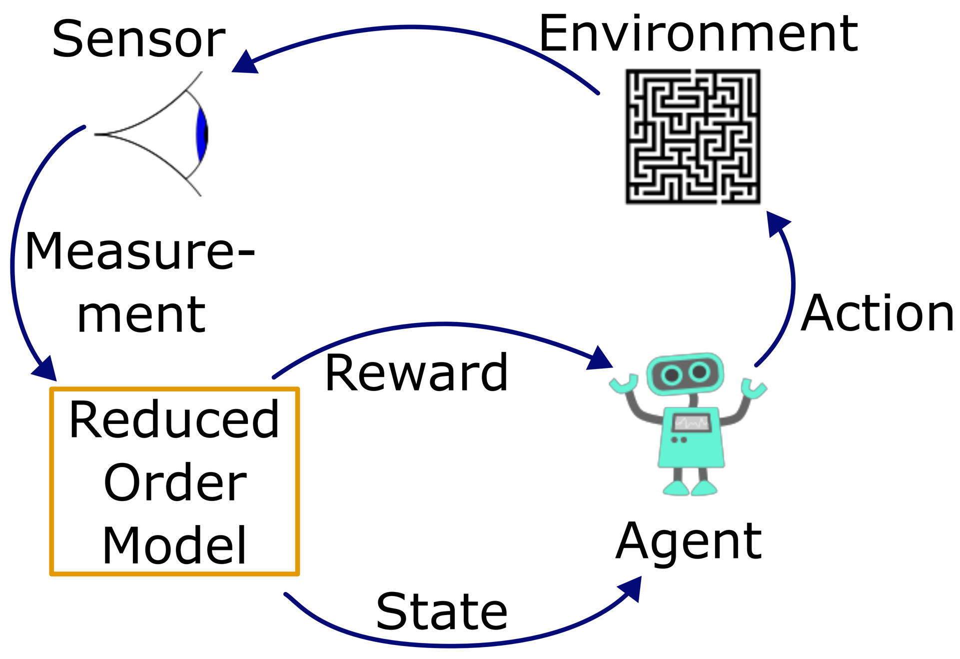
Modelled through Ginzburg-Landau equation



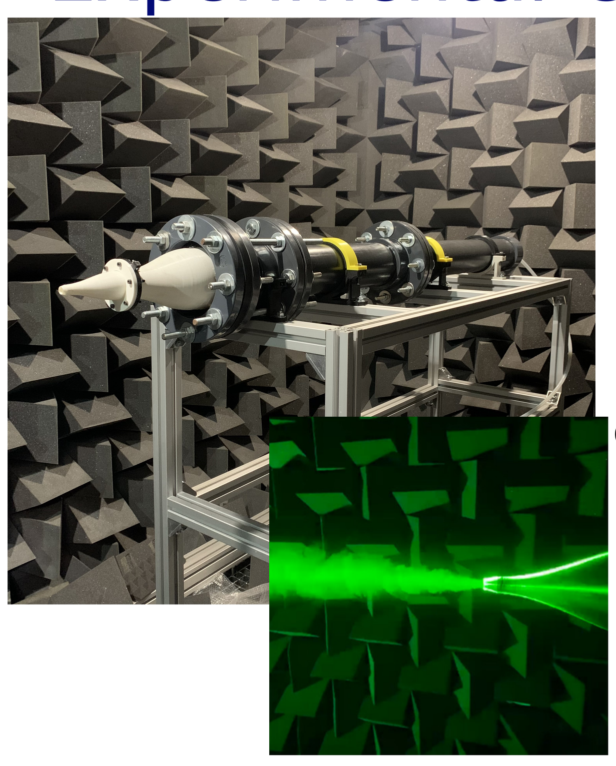
y: Noise source   z: Reward point

Data-augmented Reinforcement Learning Agent

Uses data-driven models to **enhance the data provided by the sensors**



Experimental Control



Jet Testing Facility

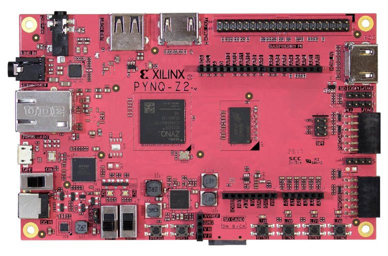
Anechoic chamber to isolate jet noise effects

Equipped for PIV to enable correlated flow-acoustic diagnosis

FPGA

Control "brain"

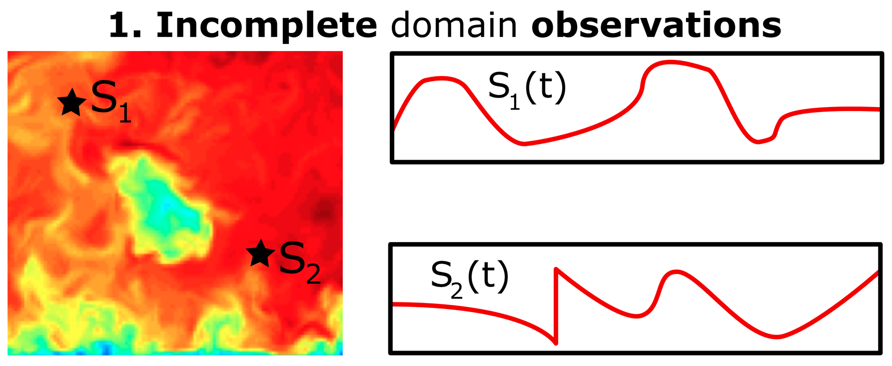
Fast I/O management



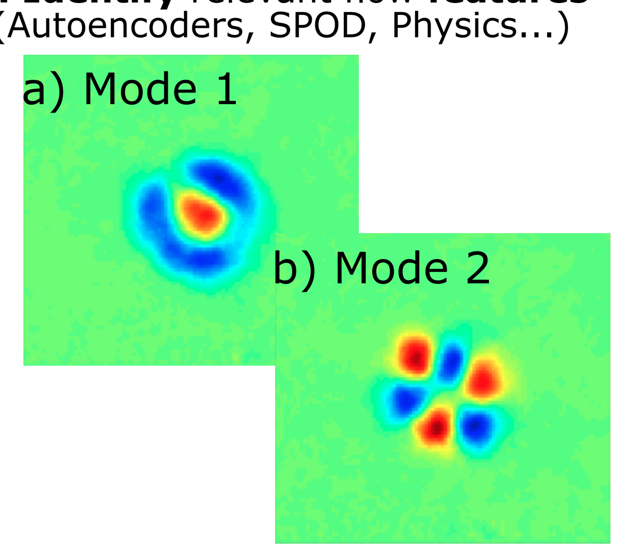
Reduced Order Modelling

Enhance sensor data from patterns

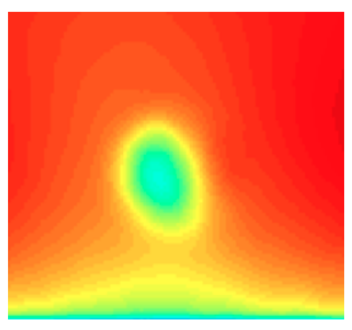
1. Incomplete domain **observations**



2. Identify relevant flow **features** (Autoencoders, SPOD, Physics...)



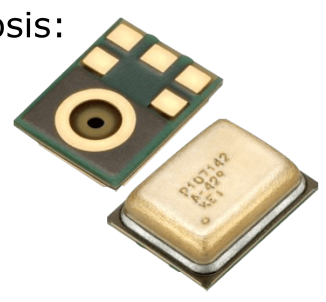
3. Combine data and patterns **to infer the** complete **state**



Work In Progress

Develop effective sensing and acting devices

High frequency sensing for flow diagnosis:
- MEMS microphones
- Pressure gauges



Actuation with high control authority
- Synthetic jets
- Microblowers

Context

Development of jet noise theory and observations[1]		**1950s**
Late 1990s - Early 2000s		**Early active flow control in simulations and experiments**[2]
Popularization of reduced order models. Applied for jet noise and fluid structure identification[3]		**Mid-Late 2000s**
2010s		**Use of reduced order models for feedback control in simulations**[4]
Real-time feedback using Data-Driven approaches and Machine Learning tools in simplified problems[5]		**Late 2010s - Early 2020s**

Thesis Plan

1st year - 2025		**Control simulated environment.** Simplified case Test theoretical behaviour
2nd year - 2026		**Construction of experimental setup.** Test real controller and acquisition system
3rd year - 2027		**Training and validation of the controller.** Research stay Thesis writing

References

[1] M. J. Lighthill (1952). On sound generated aerodynamically I. General theory. In: Proc. R. Soc. Lond. A211564–587

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[3] A. Dowling *et al.* (2008). Reduced-order models for jet noise. In: J. Acoust. Soc. Am. 123, 3021.

[4] L. Alvergue *et al.* (2015). Feedback Stabilization of a Reduced-Order Model of a Jet in Crossflow. In: AIAA J. 53, 2472–81.

[5] B.R. Noack *et al.* (2020). Artificial intelligence control of a turbulent jet. In: J. Flu. Mech. 897, A27.

[6] U. Karban *et al.* (2024). Modeling closed-loop control of installed jet noise using ginzburg-landau equation. In: Flow Turbul. Combust. 113, 721–746.

Acknowledgements

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