Active control of jet flows using advanced flow diagnostics

Supervisors:

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Doctoral Meetings
03/06/2025

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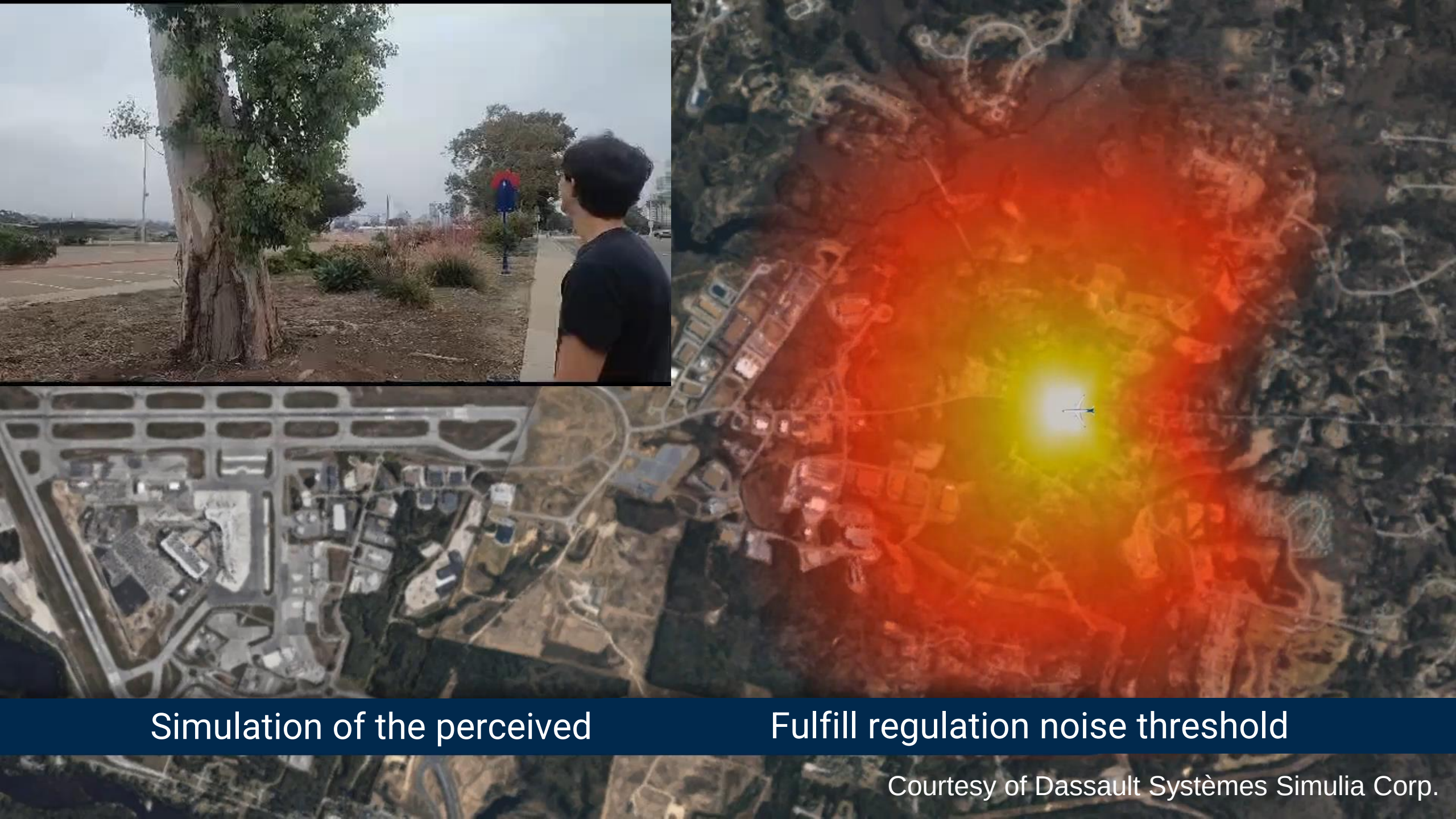
Why not an airport in Madrid-Atocha?

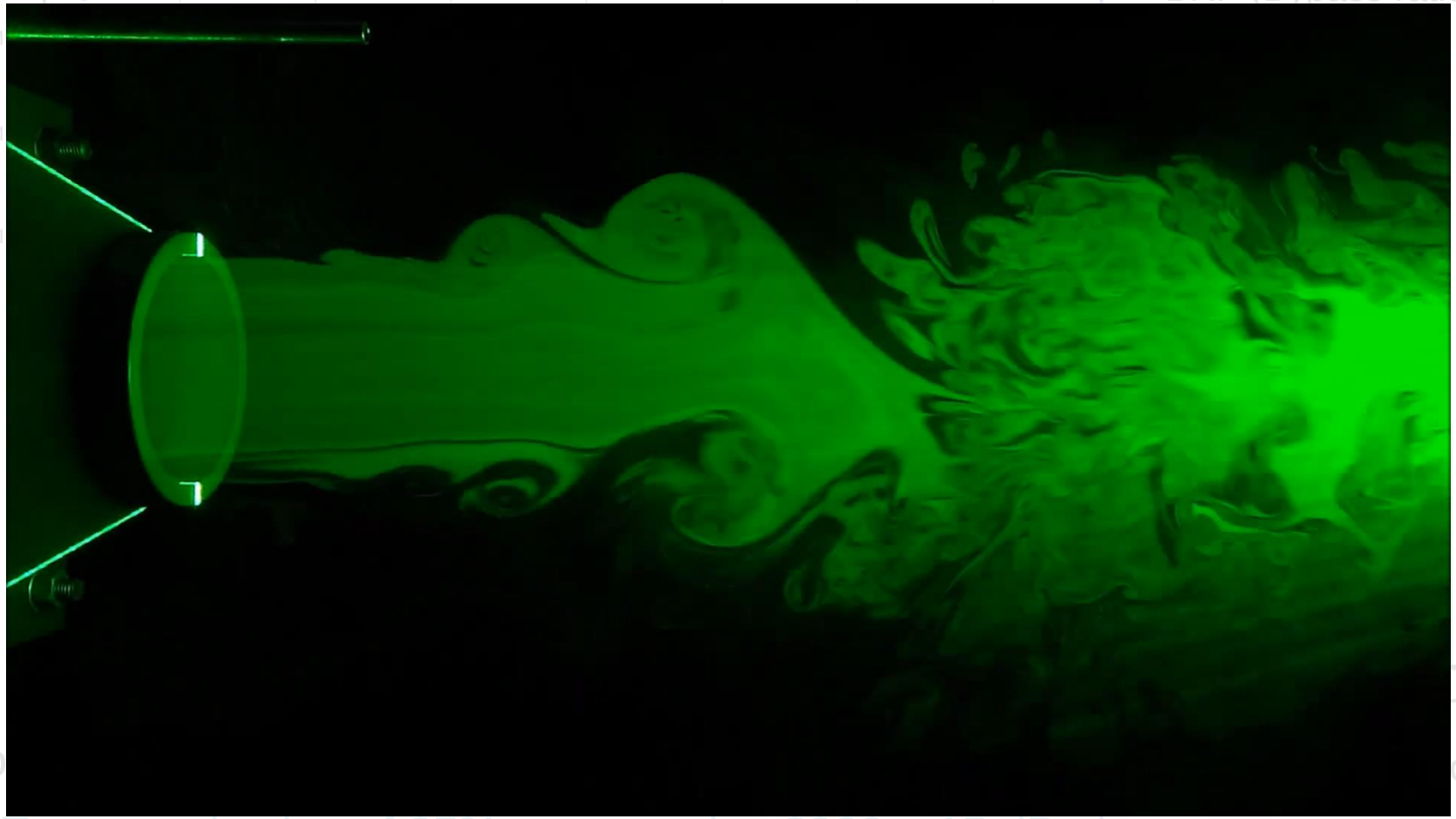


Simulation of the perceived

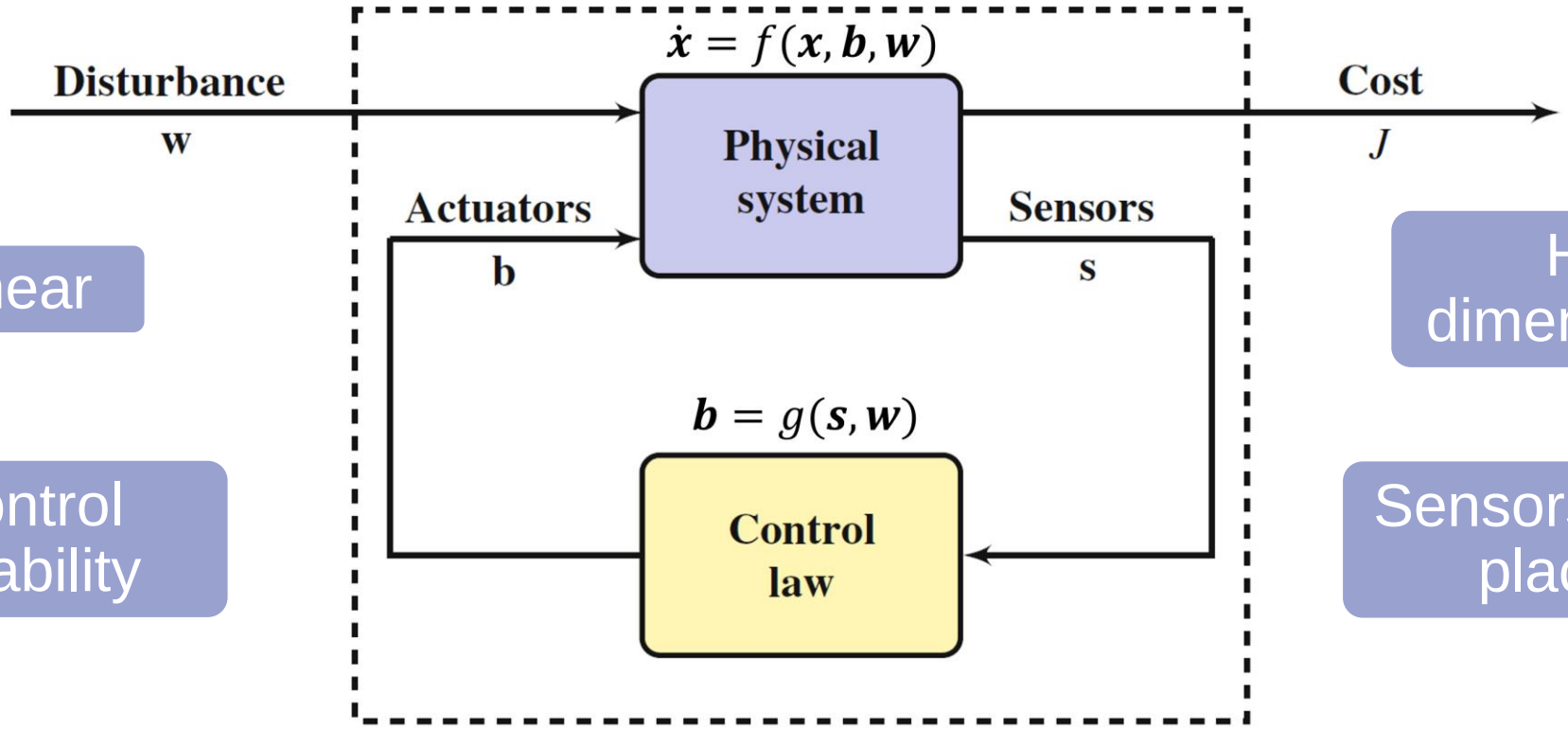
Fulfill regulation noise threshold

Courtesy of Dassault Systèmes Simulia Corp.

The need for aircraft noise reduction ⟹ The need for *jet-flow noise* reduction



Thesis topic: active flow control of jets



Non-linear

High-dimensionality

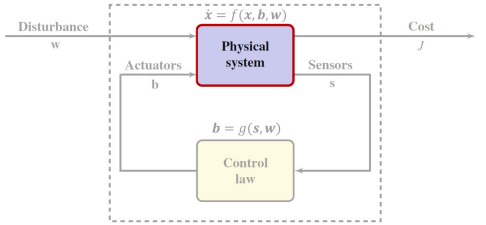
(ML)-Control interpretability

Sensors/actuators placement

- Design and implement an experimental framework for active jet-flow control
- Extract interpretable control solutions

"Machine learning control-taming nonlinear dynamics and turbulence", Duriez T et al. (2017)

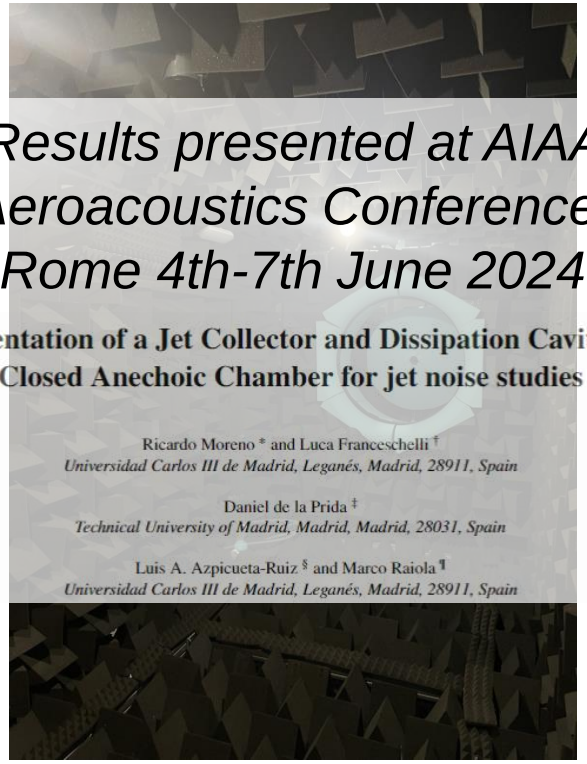
Physical System: jet-flow facility and anechoic chamber



Reproduce free-field environment in the lab

Acoustic

No reverbaration ✓



Results presented at AIAA Aeroacoustics Conference, Rome 4th-7th June 2024

Implementation of a Jet Collector and Dissipation Cavity into a Closed Anechoic Chamber for jet noise studies

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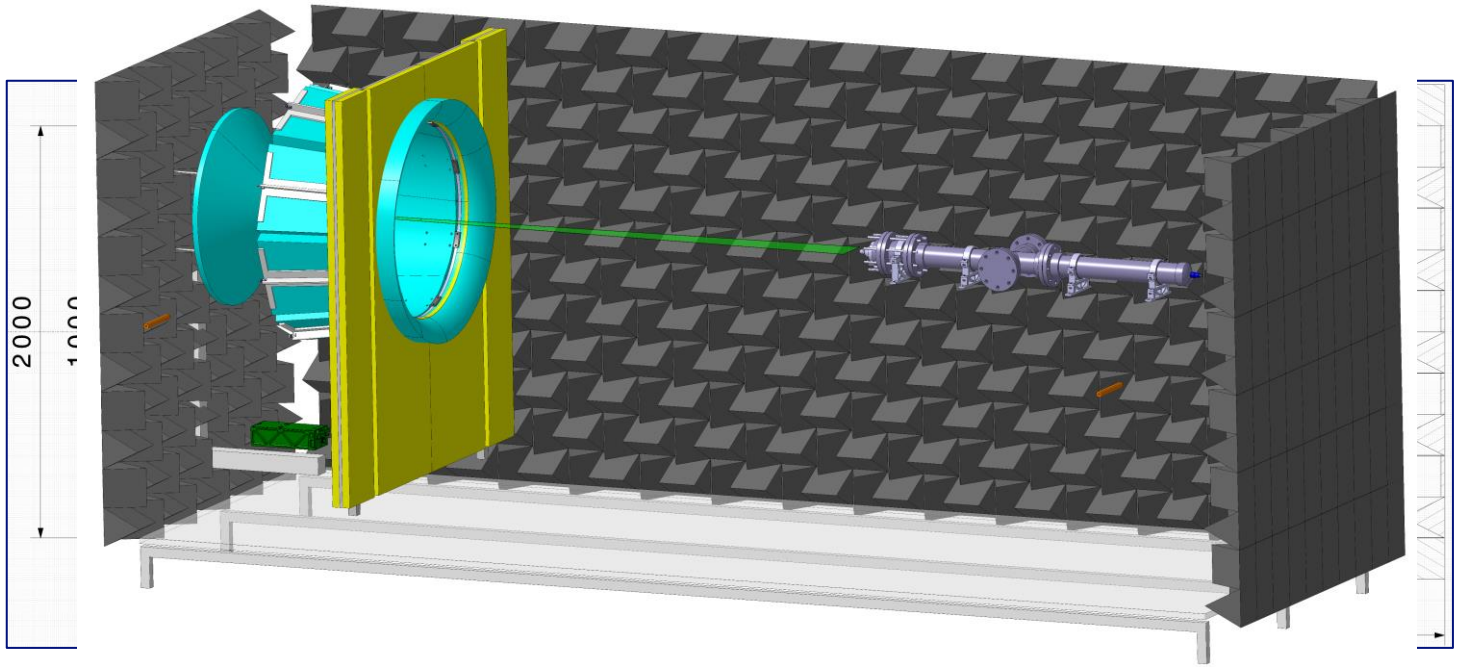
Daniel de la Prida ‡
Technical University of Madrid, Madrid, Madrid, 28031, Spain

Luis A. Azpicueta-Ruiz § and Marco Raiola ¶
Universidad Carlos III de Madrid, Leganés, Madrid, 28911, Spain

Fluidic

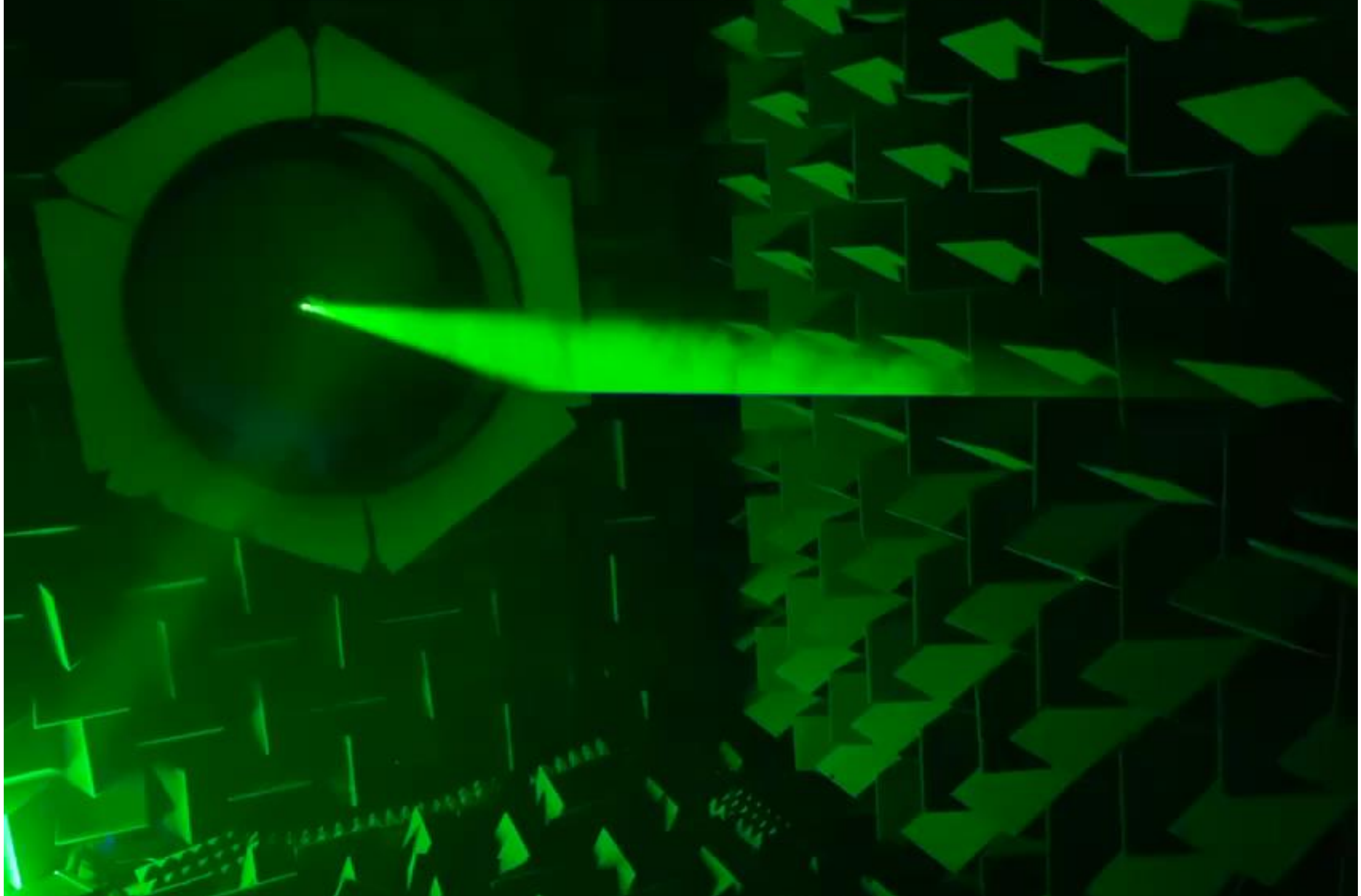
No flow-ricirculation ✓

- Flow dissipation via secondary room

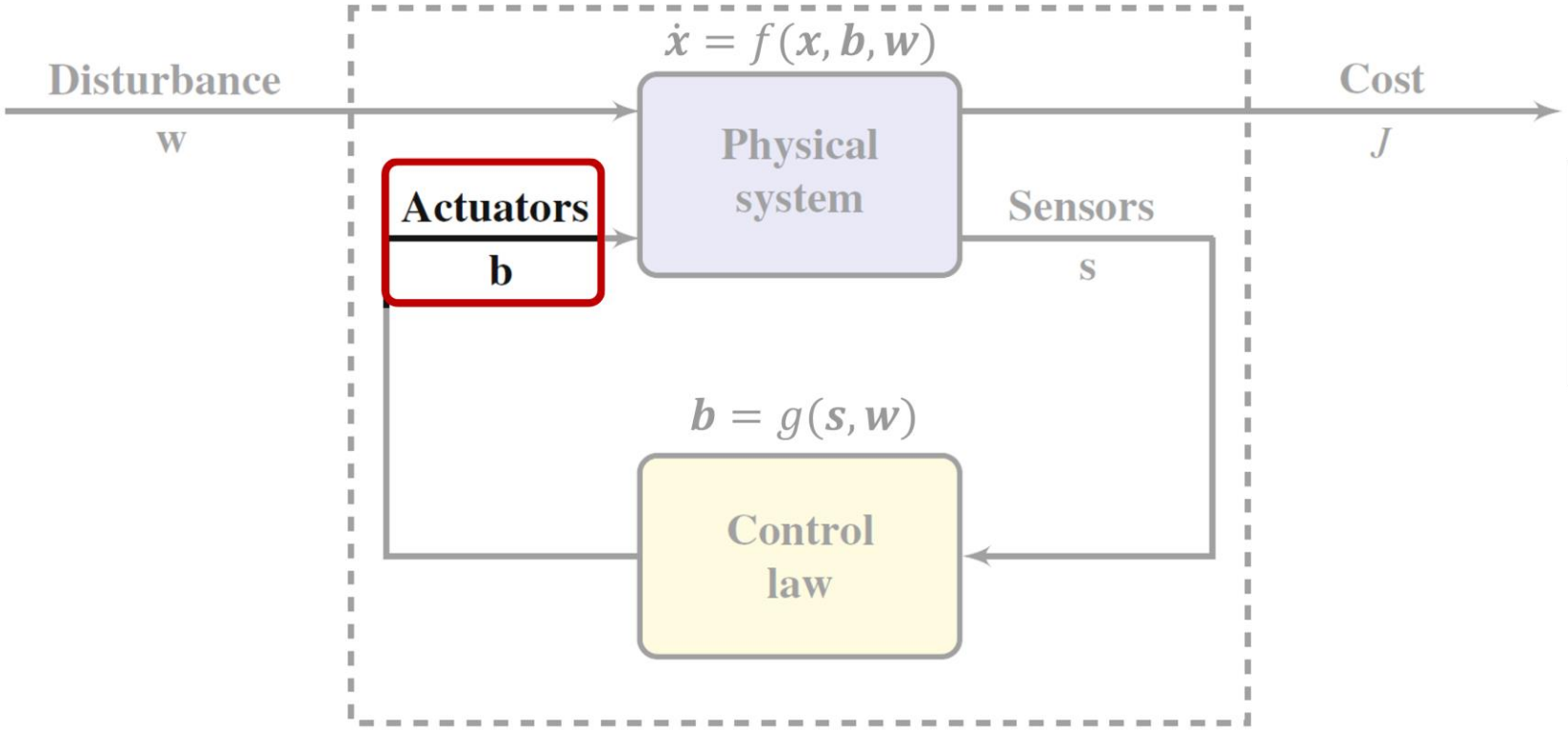


Merino-Martinez, R. et al., “Aeroacoustic design and characterization of the 3D-printed, open-jet, anechoic wind tunnel of Delft University of Technology”, 2020

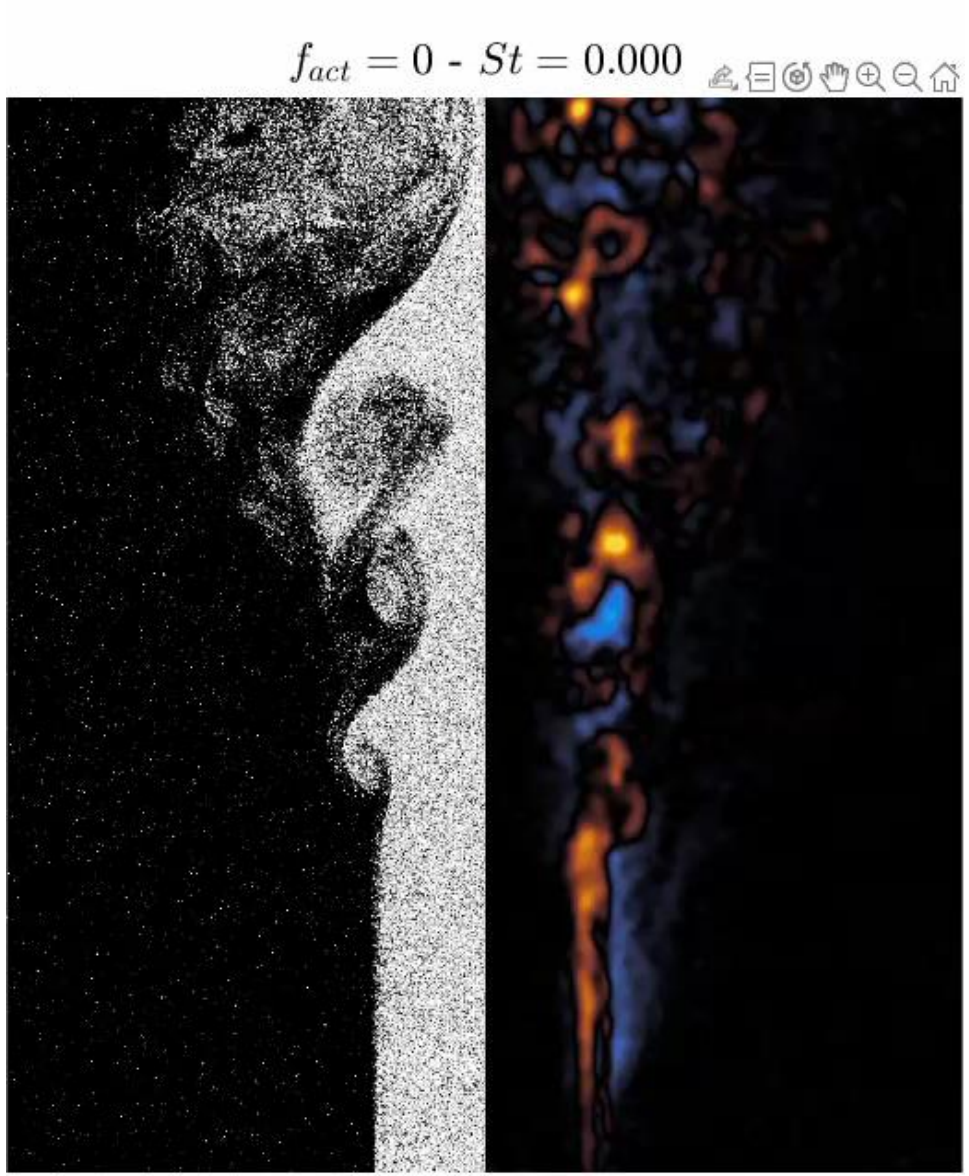
Ahuja, K. K., “Designing Clean Jet-Noise Facilities and Making Accurate Jet-Noise Measurements”, 2003

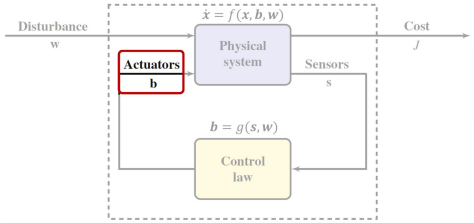


Actuation Design

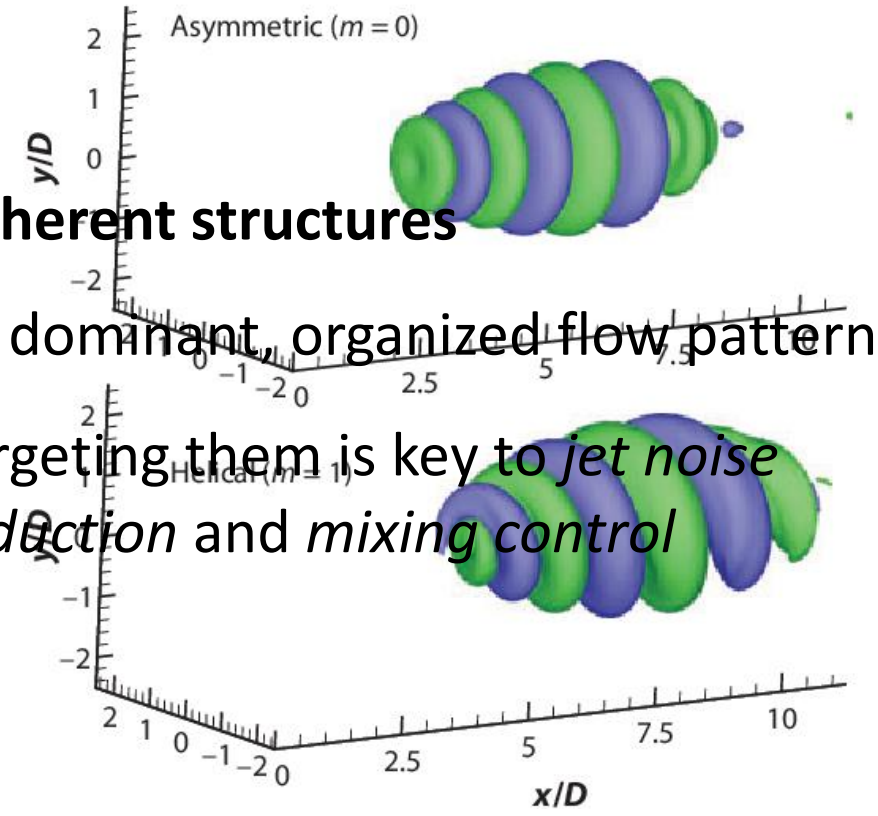


What do we want to control?





Most energetic structures in a jet



- **Coherent structures**

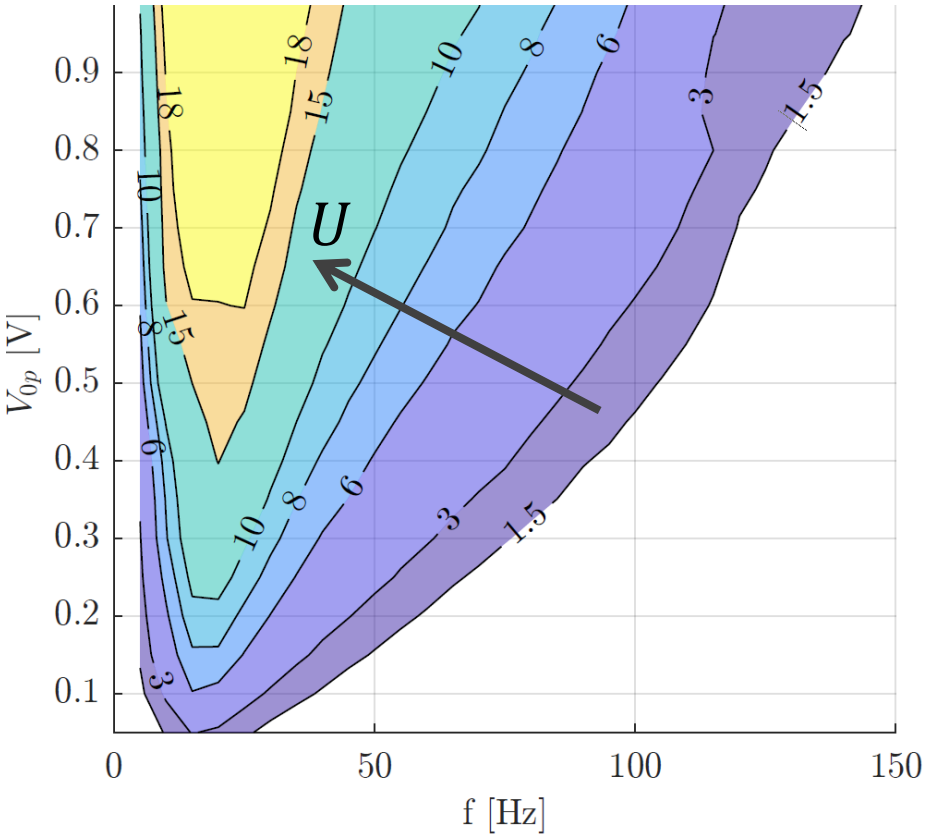
  → dominant, organized flow patterns

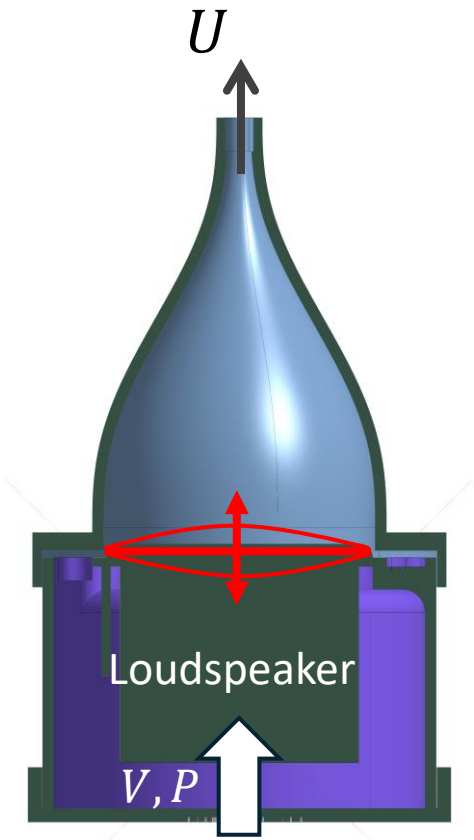
- Targeting them is key to *jet noise reduction* and *mixing control*

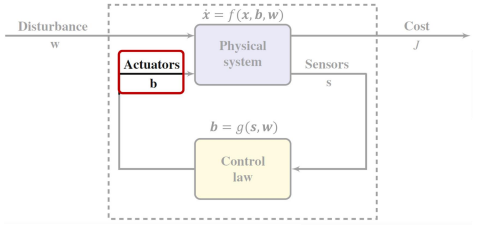
Jordan P, Colonius T, “Wave Packets and Turbulent Jet Noise”, 2013

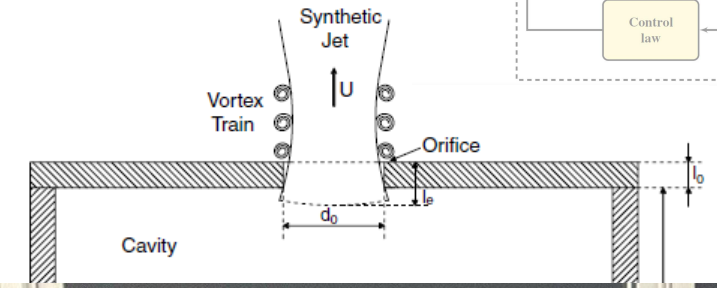
How to act on these structures: Synthetic jet actuators

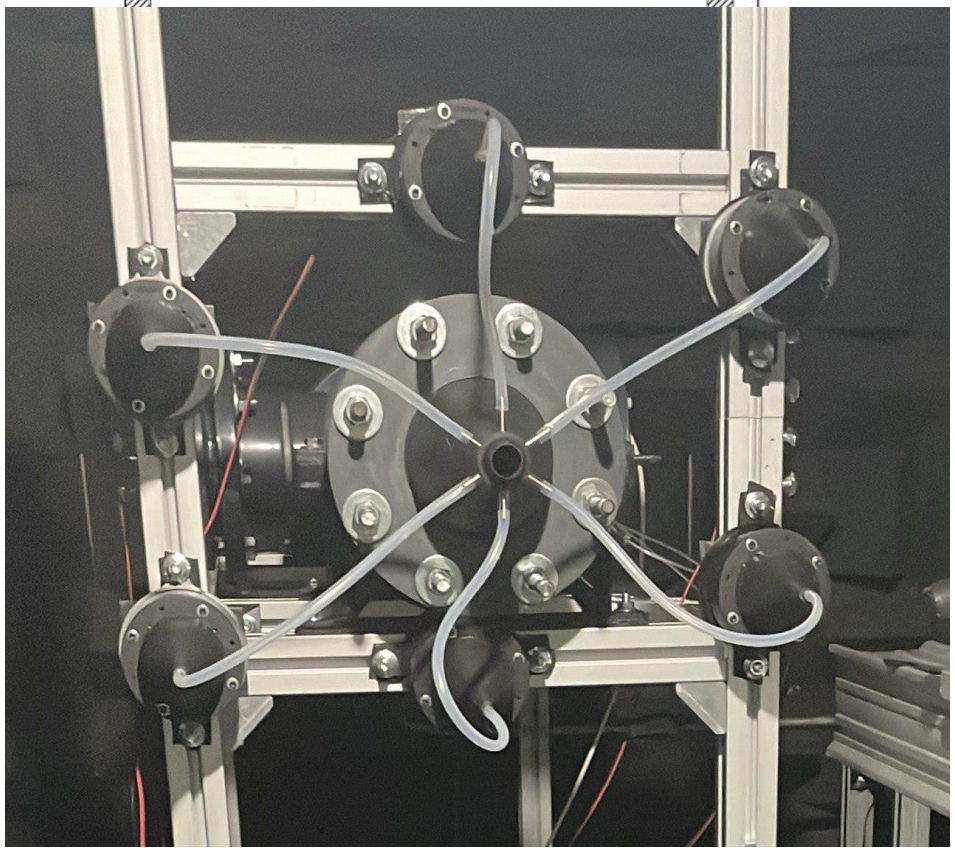
- Zero net mass flow actuation
- No external air supply required
- Compact, cost-effective and easily integrated





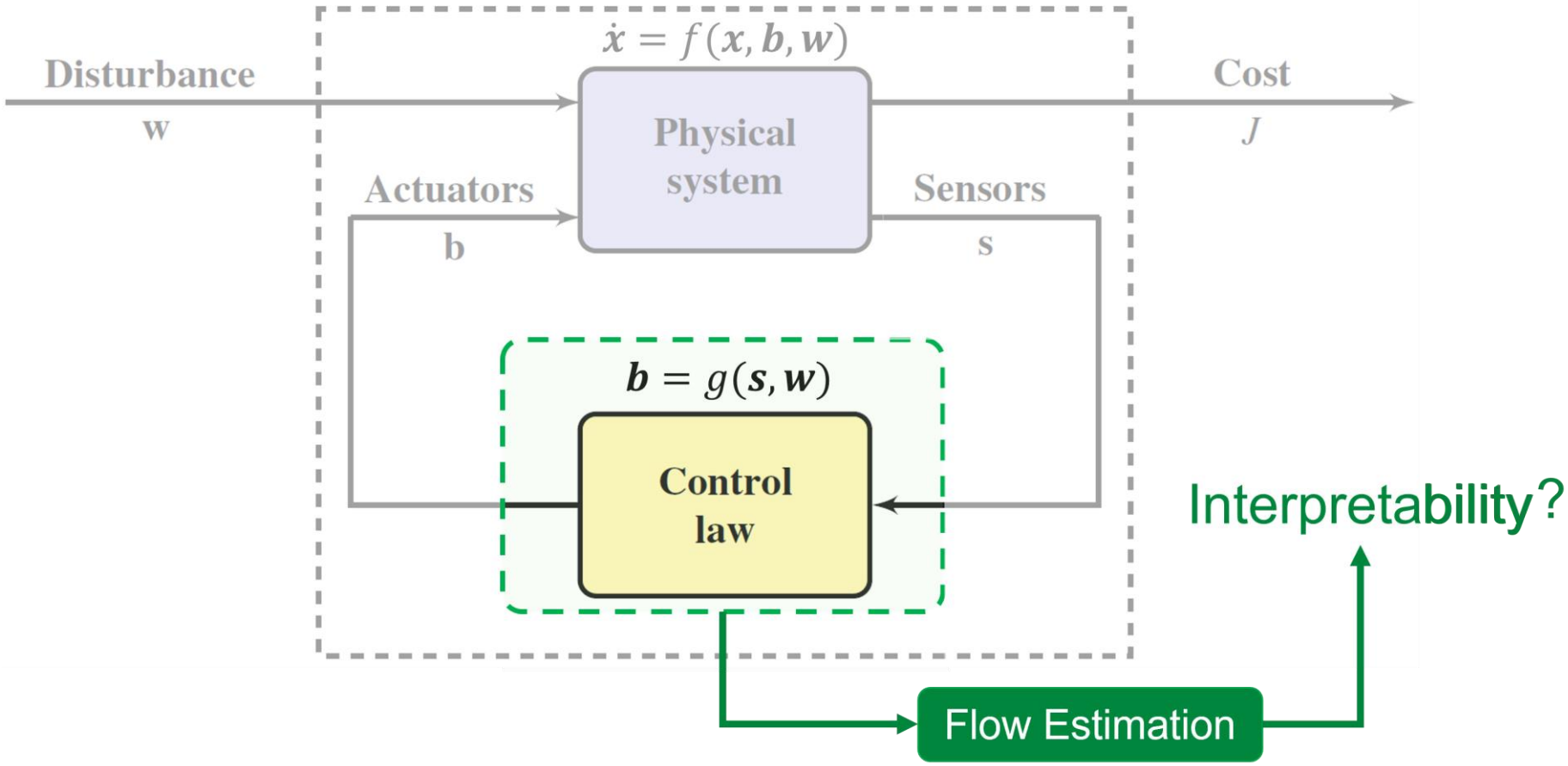




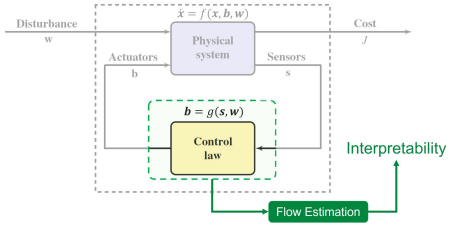


Chiatto M et al., “Design approach to predict synthetic jet formation and resonance amplifications”, 2019

Control Law Interpretability

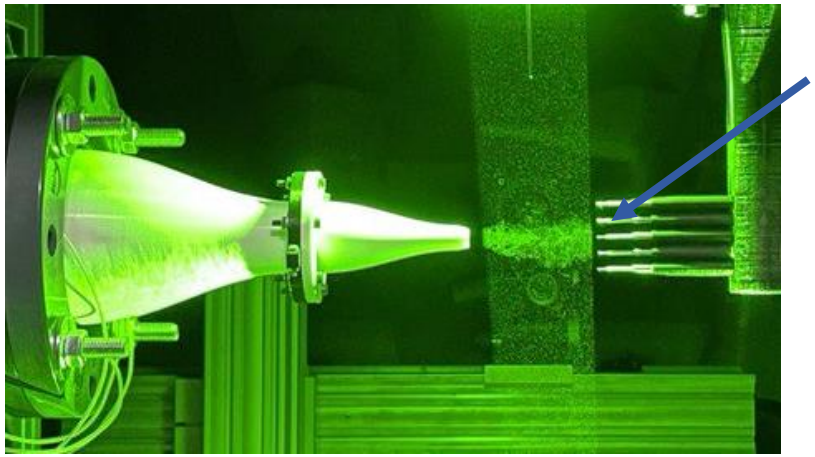


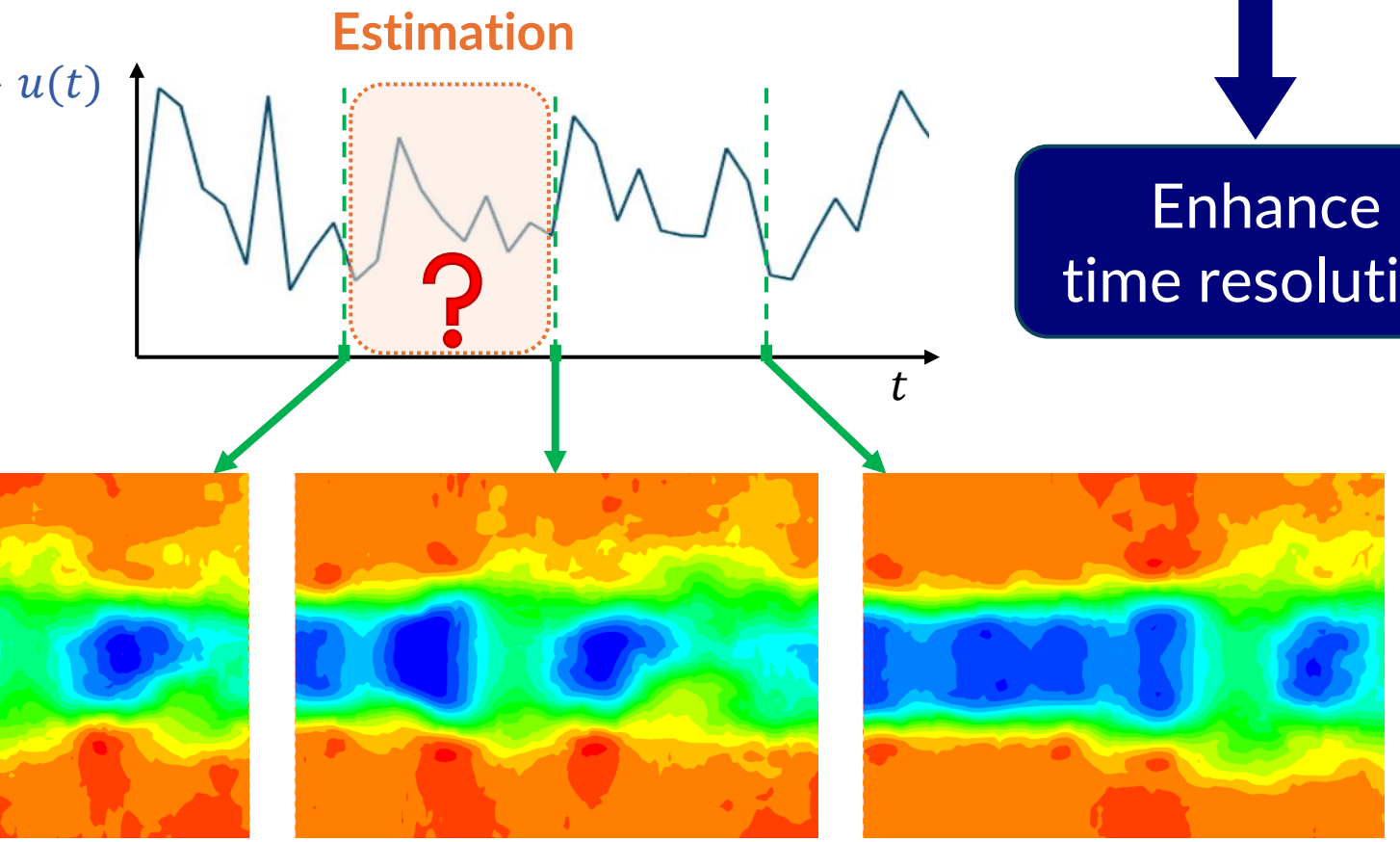
Flow Field Estimation from fast-response probes



✓ Fast response probes → ~~Point-wise measurement~~, high temporal resolution

✓ Snapshot PIV → Instantaneous Flow-field, ~~no temporal resolution~~

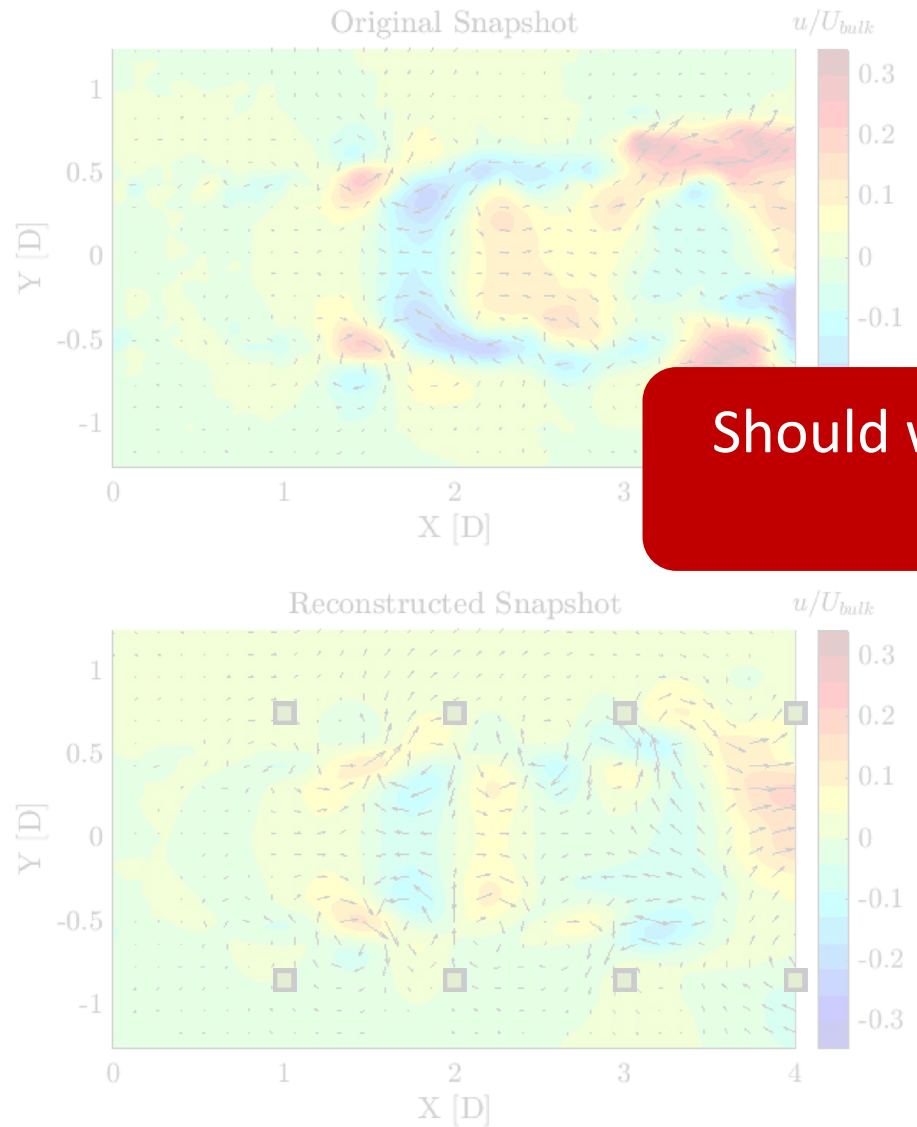




Enhance time resolution

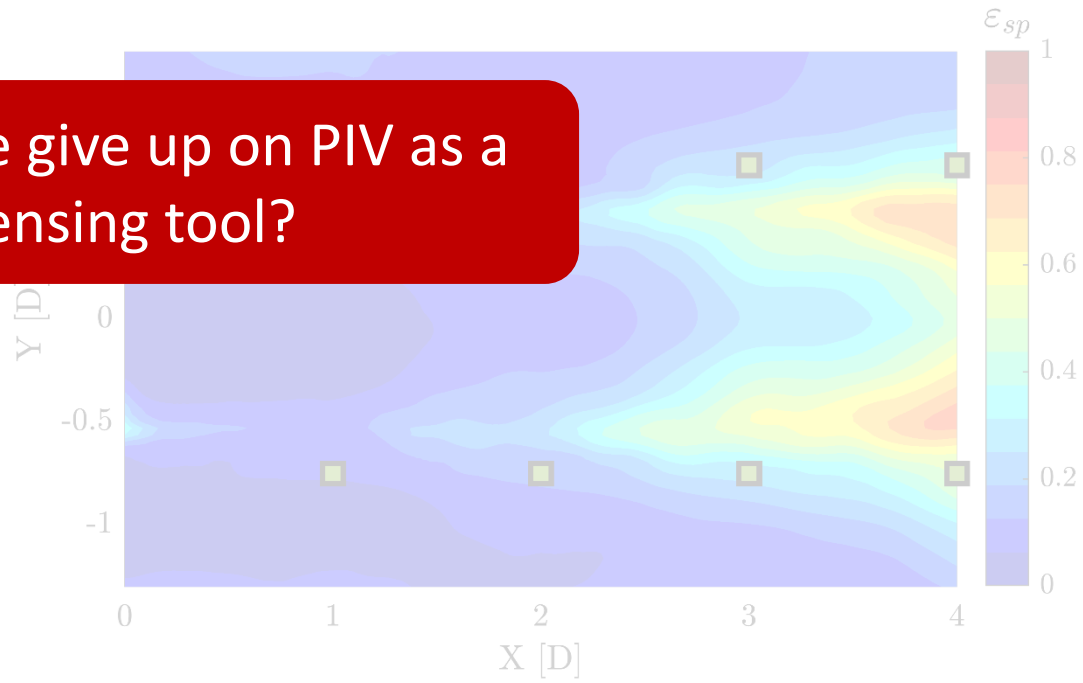
Borée J, “Extended proper orthogonal decomposition: a tool to analyse correlated events in turbulent flows”, 2003

Flow Estimation via EPOD – 8 Virtual Microphones



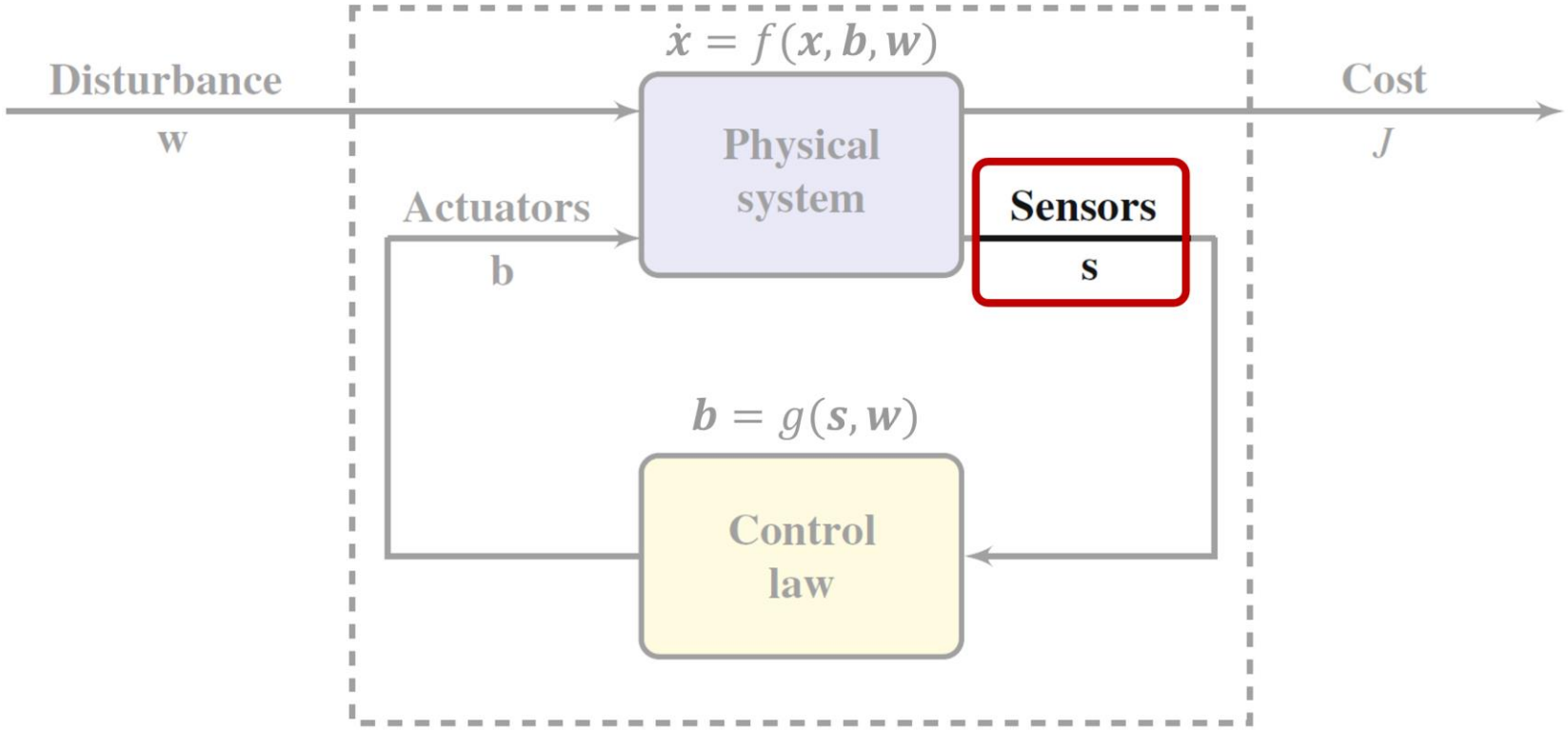
$$\varepsilon_{sp}(\boldsymbol{x}) = \frac{RMSE(\boldsymbol{x})}{2 \cdot TKE_{\max}} = \frac{1}{2 \cdot TKE_{\max}} \sqrt{\frac{\sum_{i=1}^{2} \sum_{j=1}^{N_t} (\tilde{u}_{i,j} - u_{i,j})^2}{N_t}}$$

Should we give up on PIV as a sensing tool?



"Jet flow feature estimation with snapshot PIV and fast probes", presented at ISPIV and ETC 2023

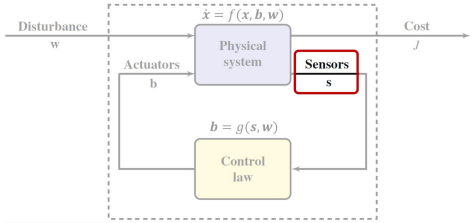
Close the loop: how to “sense” the flow



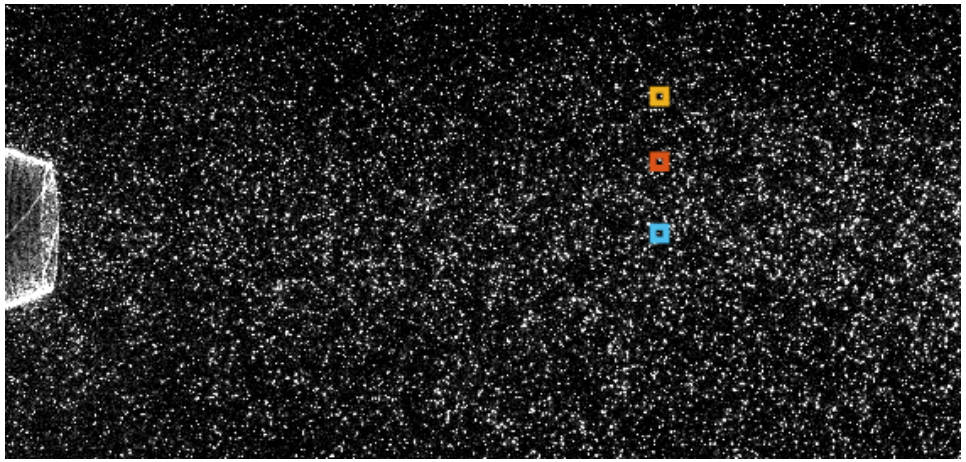
Need to act fast $\mathcal{O}(\geq 10^2 Hz)$

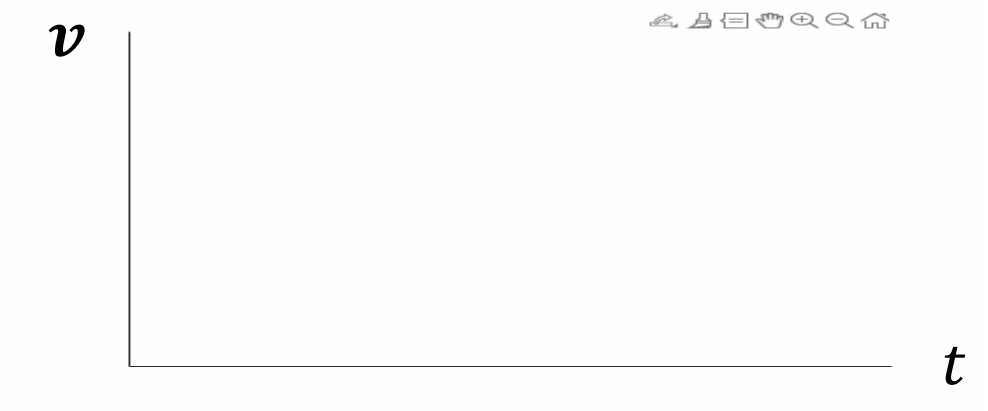
Sense faster

Can we use PIV as sensor?

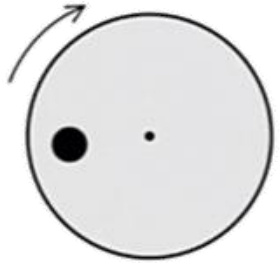


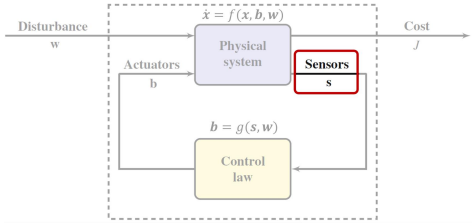
- Point-wise sensors usually implemented: microphones, hot-wires, …
- PIV → flow diagnostic, but not fast enough for flow control
- Bottleneck: image acquisition process, data rate, cost



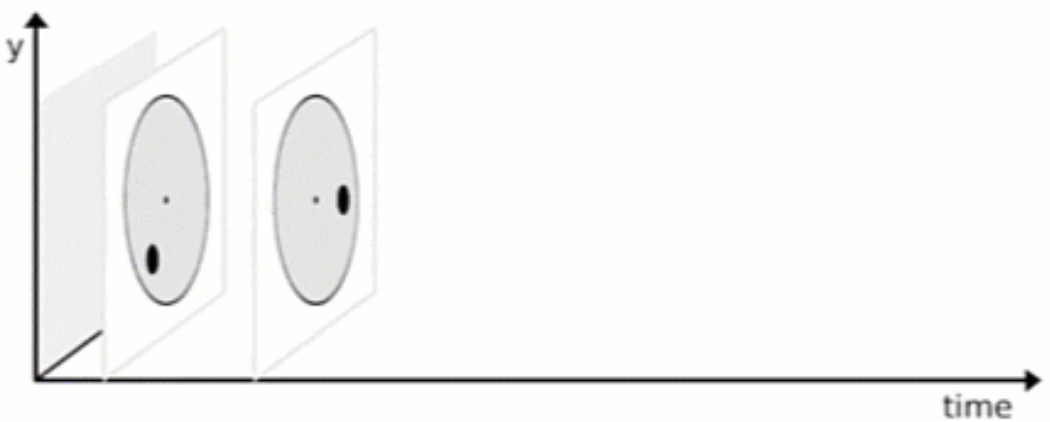


Event-based vision (EBV)





Frame-based camera



- Generates sequential frames
- Clock-driven → pre-defined frame-rate
- User-defined exposure time
- Synchronous read-out of the sensor

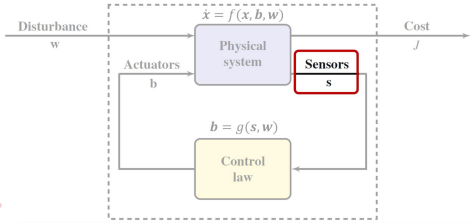
Neuromorphic camera

Is it good enough to catch the flow dynamics?

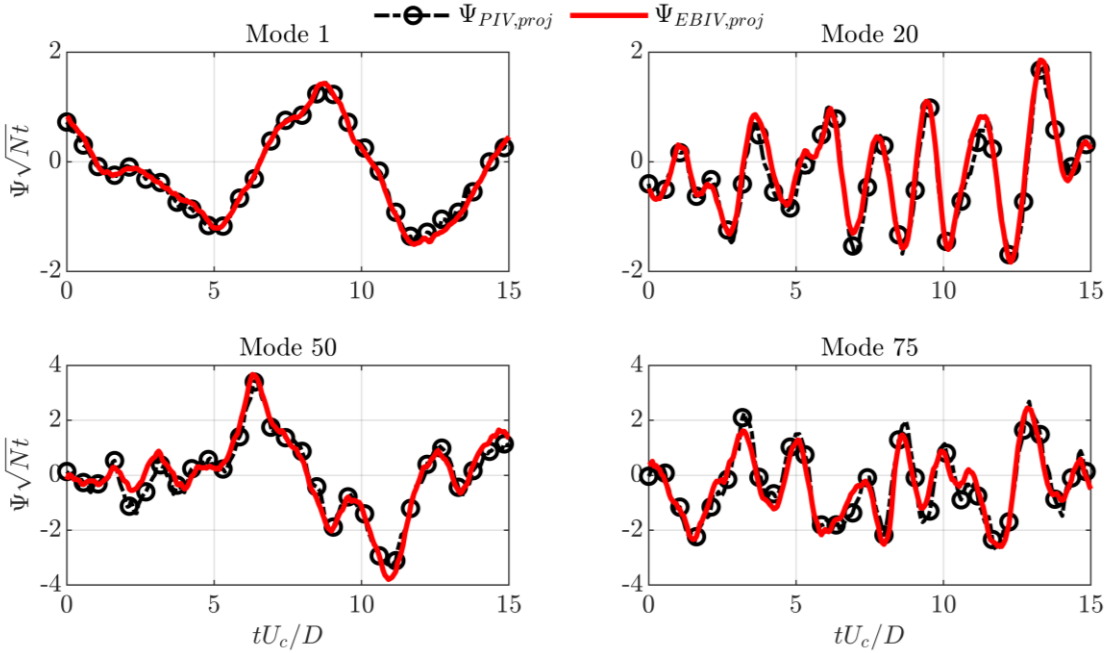
- **Continuous** data-stream from pixels
- **Adaptive** scene-driven sampling rate
- **Sparse data**
- **Logarithmic sensitivity** → High dynamic range

Gallego G. et al., “Event-Based Vision: A Survey”, 2020

EBIV (Event-based Imaging Velocimetry) as sensor



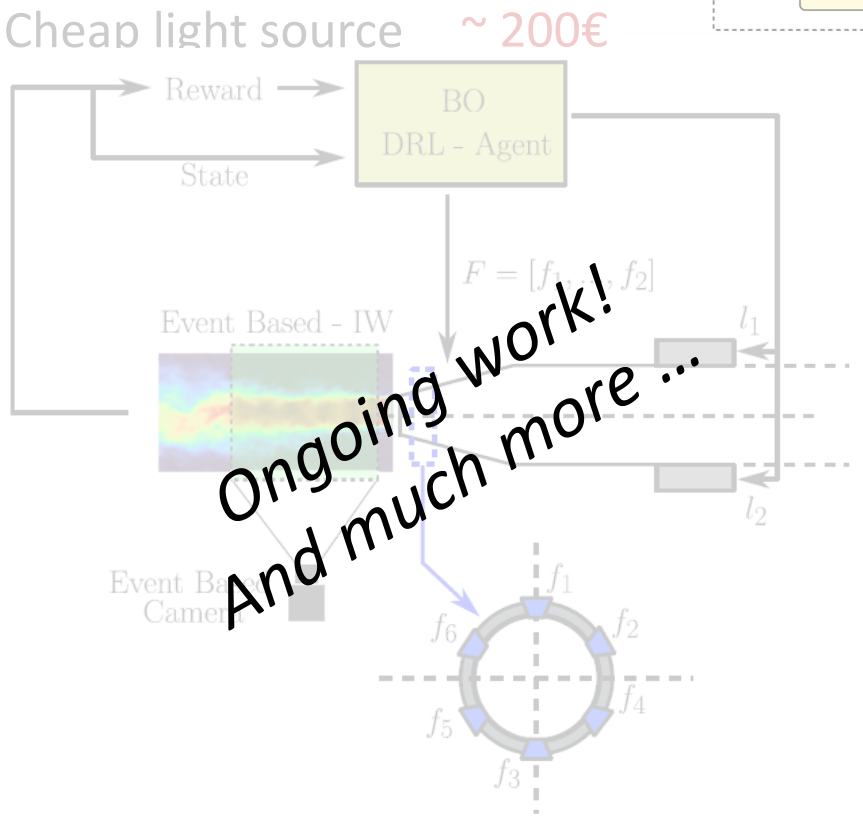
Comparison EBIV with Conventional PIV



2) EBV camera *~ 1'000€*

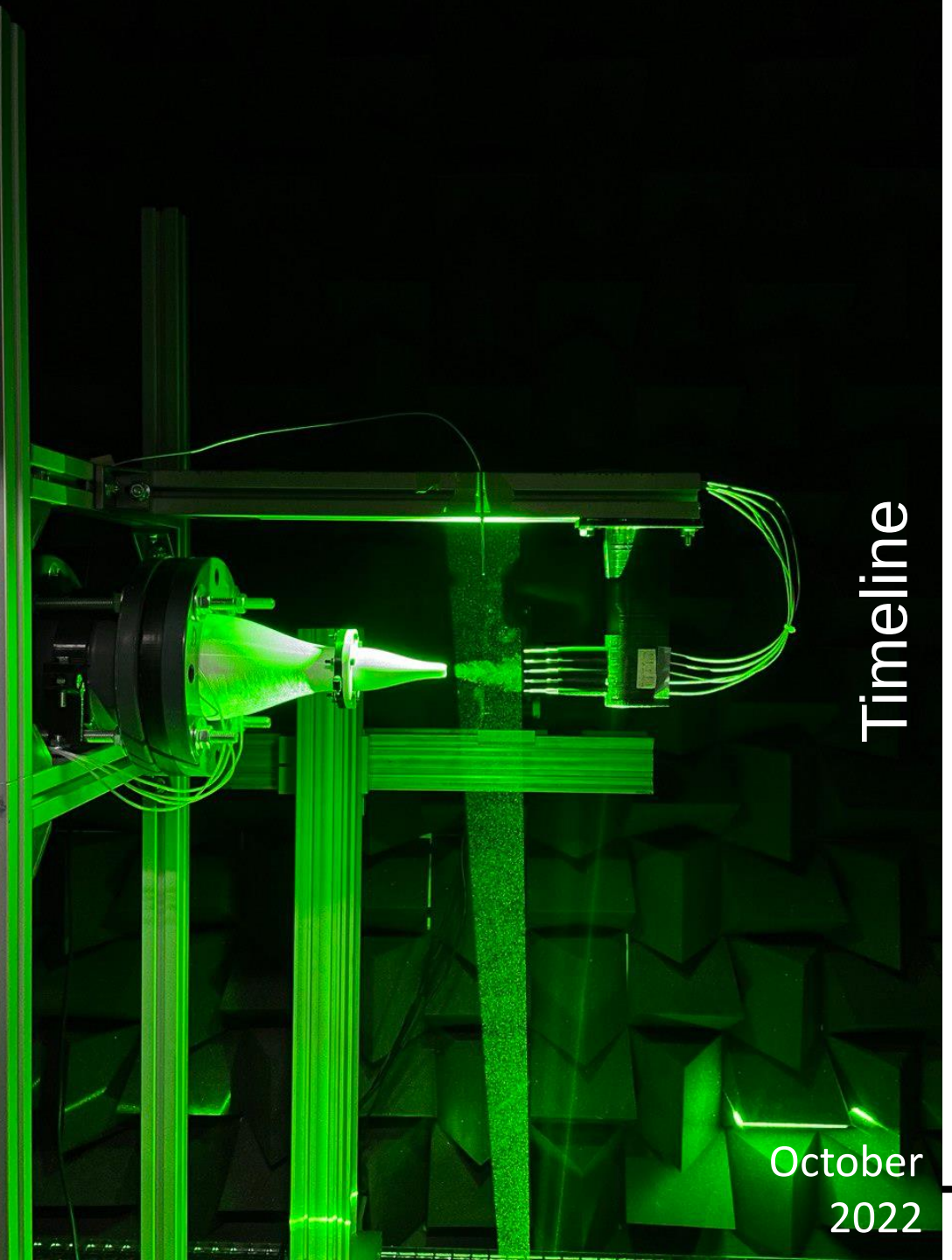
3) High-speed camera *~ 200'000€*

EBIV is capable of correctly identifying the dynamics of flow structure



EBIV data as reward J of the optimization

Implementation of EBIV in the control loop



Timeline

October 2022

Research stay at TU Delft under the supervision of Prof. Daniele Ragni (Sept–Dec 2025)

Year III

- ☐ Imaging-based closed-loop control
- ☑ Jet-Flow optimization using imaging-based reward
- ☑ Actuation manifold of a controlled jet
- ☑ event-based sensing for flow control

Year II

- ☑ Upgraded jet facility and characterization
- ☑ Implementation of flow actuation
- ☑ Evaluation of event-based imaging for real-time PIV

Year I

- ☑ Preliminary jet facility
- ☑ Flow estimation via EPOD

Outcomes

Journal Paper

- Franceschelli, Luca, et al. "An assessment of event-based imaging velocimetry for efficient estimation of low-dimensional coordinates in turbulent flows." *Experimental Thermal and Fluid Science* (2025): 111425.

Conference papers

- "Jet flow feature estimation with snapshot PIV and fast probes", Franceschelli L., Raiola M., Discetti S., presented at ISPIV15 (San Diego, 19th – 21st June 2023), iTi-X (Bertinoro, 24th – 26th July 2023) and ETC18 (Valencia, 4th – 6th Sept 2023)
- "Experimental investigation of turbulent swirling jets", Cuellar A. et al., Spanish Fluid Mechanics Conference (Barcelona, 2nd – 5th July 2023)
- "Implementation of a Jet Collector and Dissipation Cavity into a Closed Anechoic Chamber for jet noise studies", Moreno et al., AIAA Aeroacoustics (Rome, 4th – 7th June 2024)
- "An assessment of event-based imaging velocimetry for dimensionality reduction in turbulent flows", Franceschelli et al., LXLASER (Lisbon, 8th – 11th July 2024)
- "Open-Loop Control for Jet Mixing Enhancement Using Acoustic Excitation.", Franceschelli et al., APS Division of Fluid Dynamics (Salt Lake City, 24th – 26th November 2024)
- "Identification of an actuation manifold for open-loop control of subsonic jet noise with acoustic-based excitation", Franceschelli et al., Forum Acousticum Euronoise (Malaga, 23rd – 26th June 2025)
- "Event-based imaging velocimetry for jet flow control", Franceschelli et al., ISPIV16 (Tokyo, 26th – 28th June 2025) and Flucome (Delft, 4th – 7th November 2025)
- "A POD-based spatial resolution enhancement method for real-time event-based imaging velocimetry", Franceschelli et al., ISFV21 (Tokyo, 21st – 25th June 2025)

Thank you for your attention!

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (grant agreement No 949085).