Identification of actuation manifolds in wall-bounded turbulent flows with active control

PhD Student: Alicia Rodríguez Asensio
Supervisor/s: Stefano Discetti, Andrea Ianiro

PhD Aerospace Engineering UC3M
Doctoral Meetings 2026
2nd and 3rd June 2026

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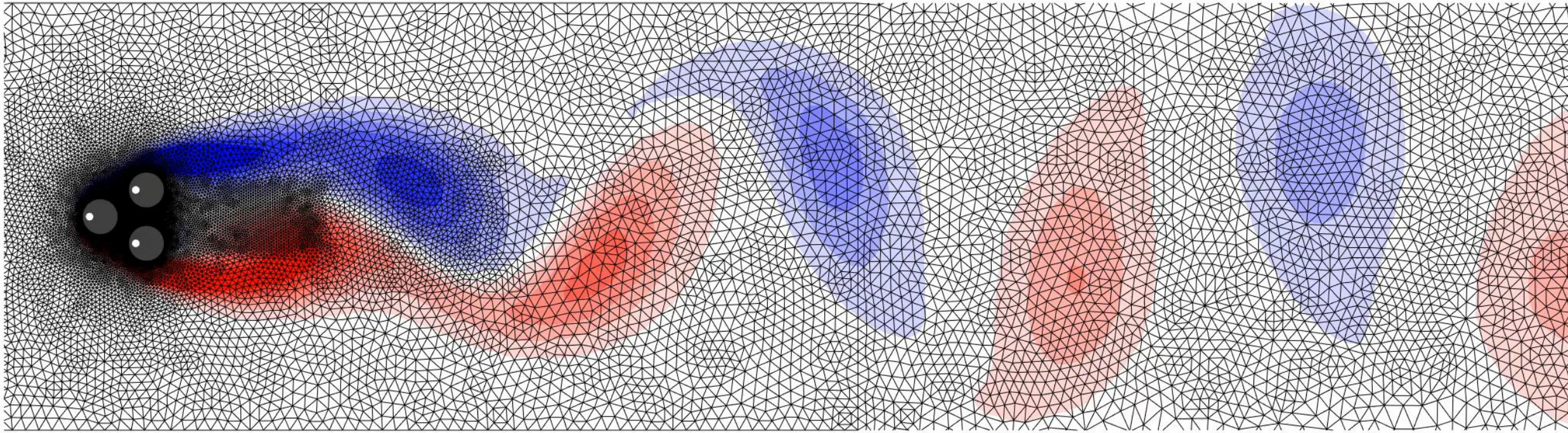
Motivation



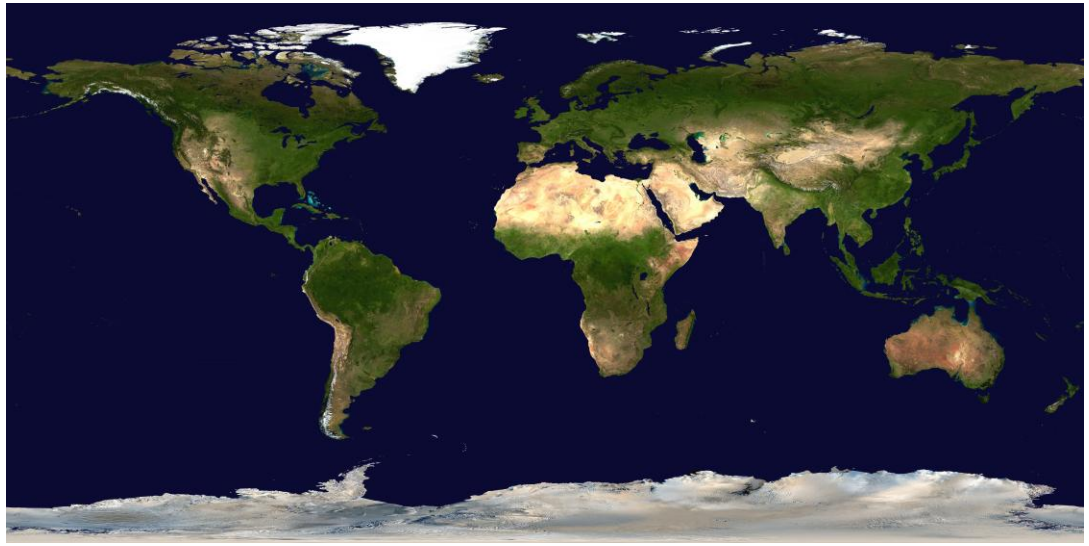
~~Characterization and closed-loop control~~

→ Manifolds to build a control-oriented model

State of the art: What are manifolds?

A low-dimensional surface embedded in a high-dimensional space that contains the physically relevant flow states

3D

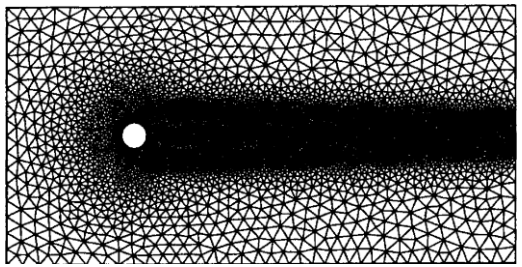


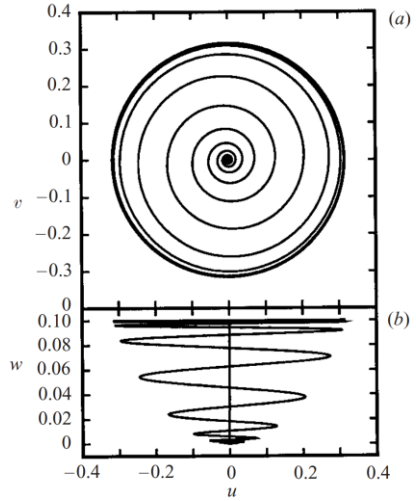
2D

Manifolds do the same thing for flows

State of the art: What are manifolds?

Unactuated wake

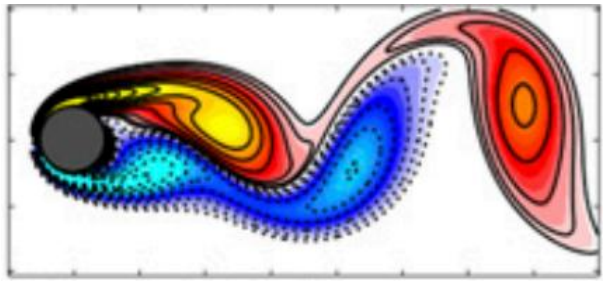


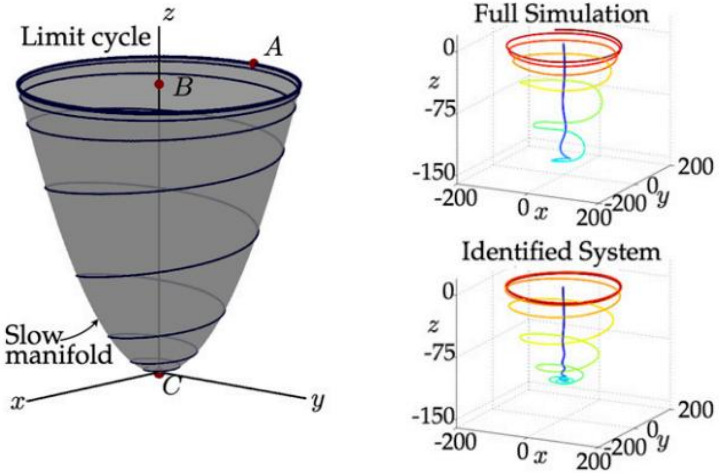


3 variables describe wake evolution

[1] Noack et al. (2003)

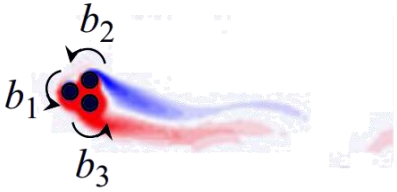
Data-driven approaches

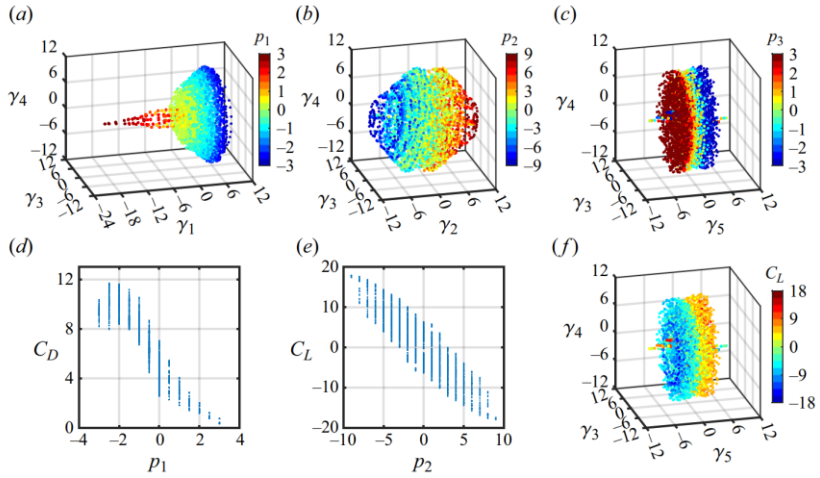




[2] Brunton et al. (2016)

Steadily-actuated wake





5 physically-meaningful variables compose the steady actuation manifold

[3] Marra et al. (2024)

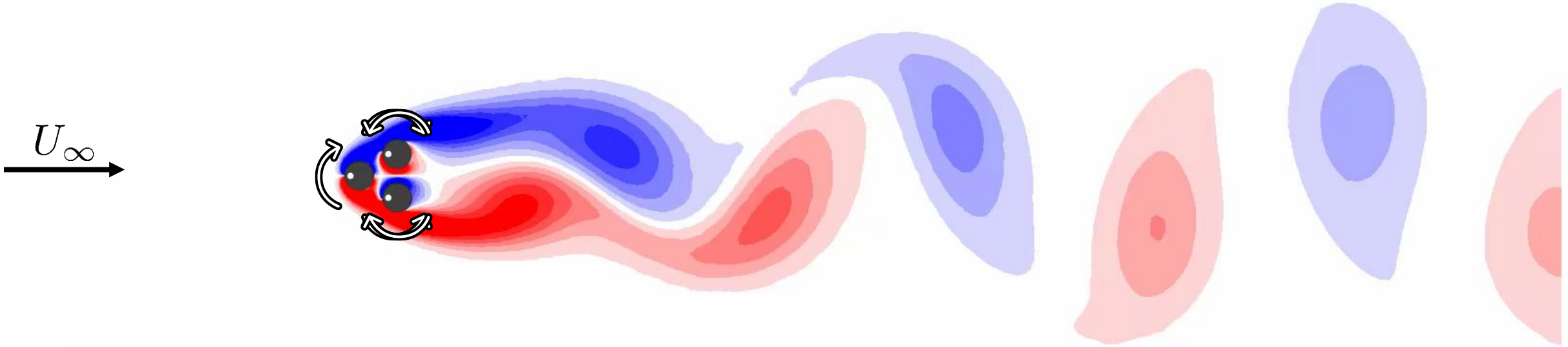
Open challenges

We have identified our steady states in our wake manifold

Proof existence of these manifolds in more challenging cases (turbulent flow)

Predict evolution for time-varying actuation

Flow configuration: The fluidic pinball



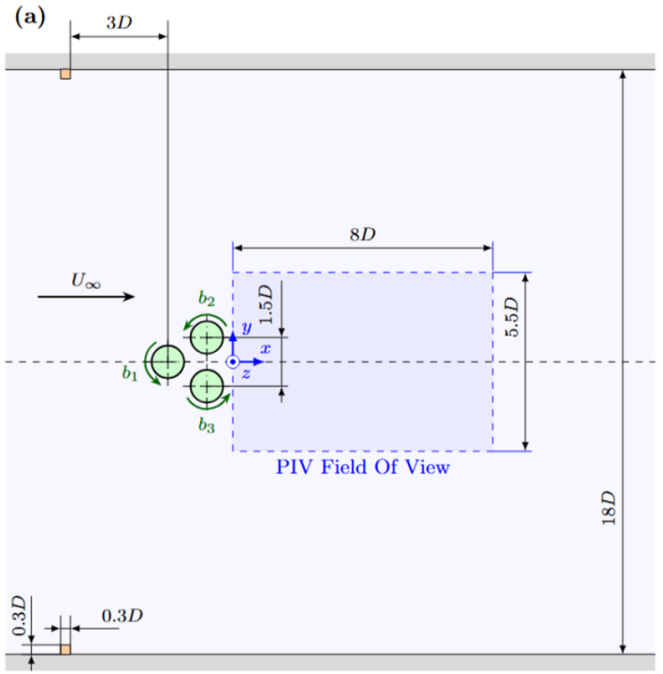
6 wake manipulation mechanisms

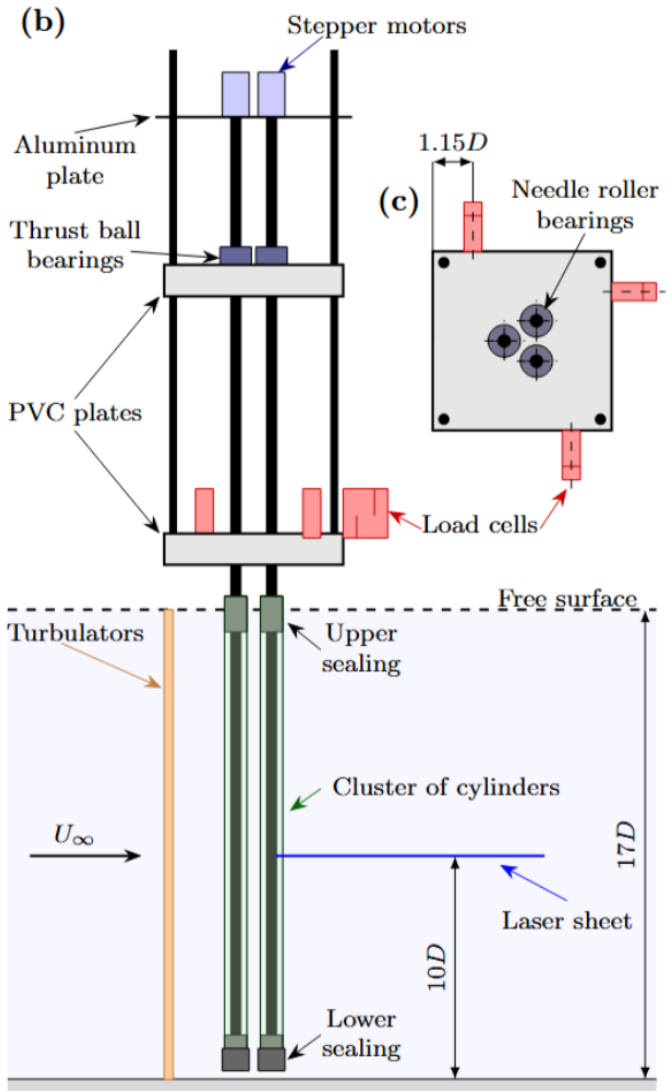
Encapsulates the main features of wake flows

- Wake stabilization → Boat tailing
- Wake destabilization → Base bleeding

Challenge 1: Proof existence of steady actuation manifold in turbulent wake flows

- Experimental setup
- Turbulent regime at $Re = 9100$
- Velocity + force measurements
- Modal analysis
- Near-cylinder flow inspection through simulations





Challenge 1: Proof existence of steady actuation manifold in turbulent wake flows

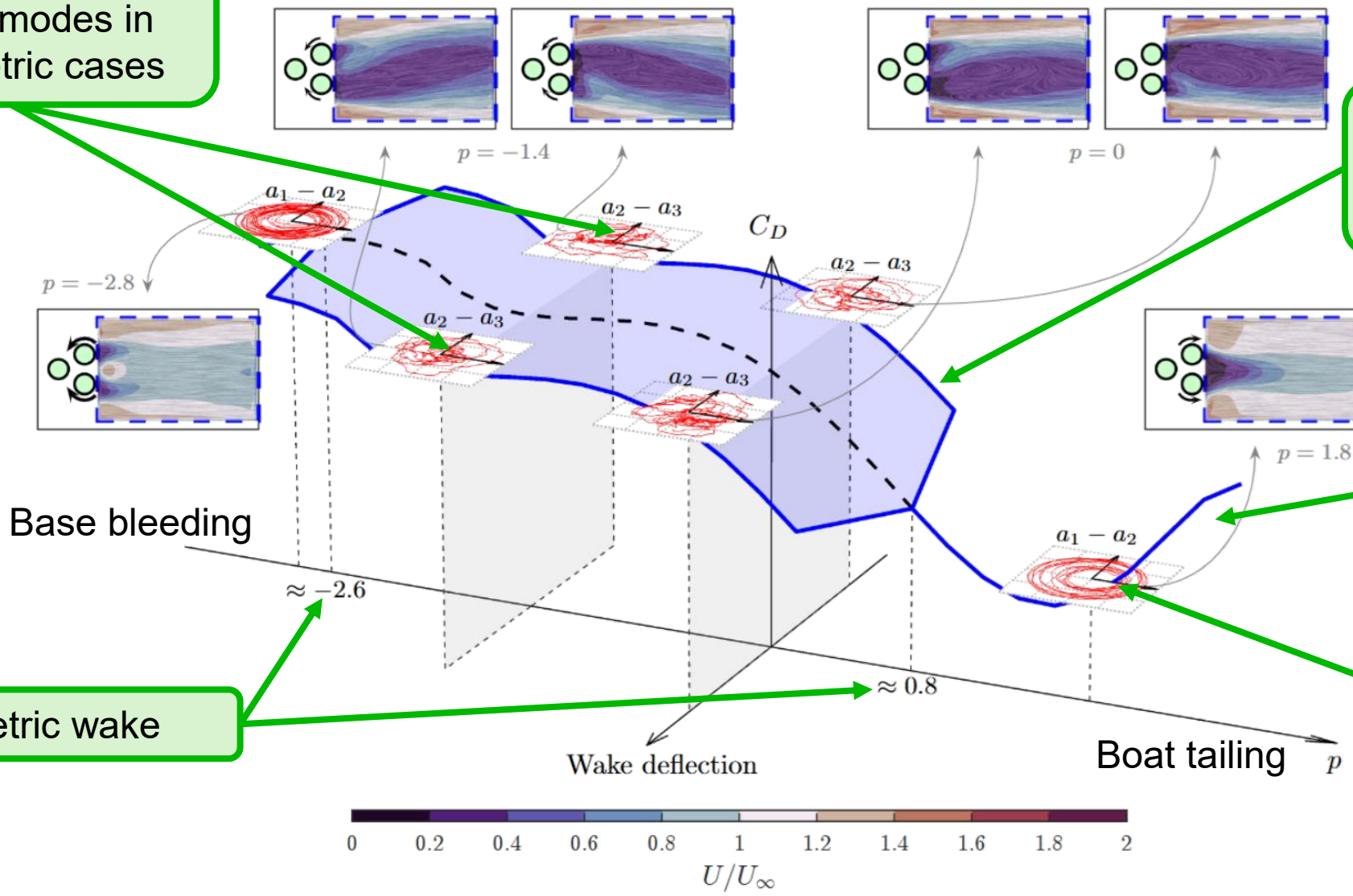
Oscillatory pair in 2nd and 3rd modes in asymmetric cases

Wake asymmetry despite symmetric actuation

Loss of control authority for high boat tailing

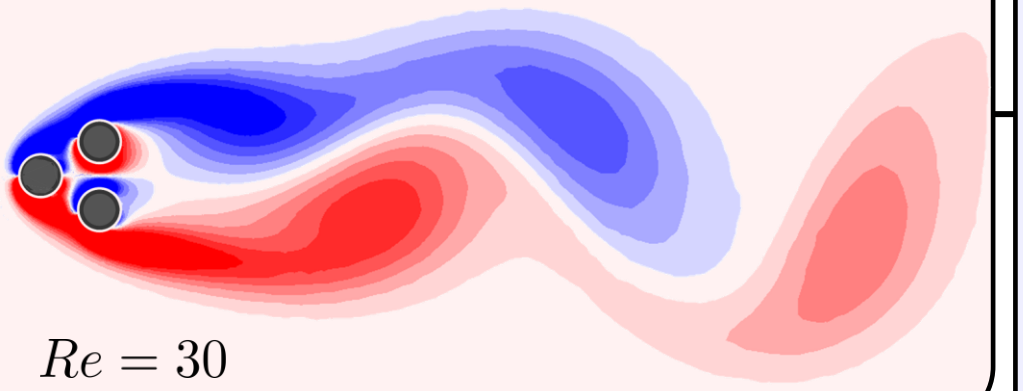
Oscillatory pair in 1st and 2nd modes in symmetric cases

Symmetric wake

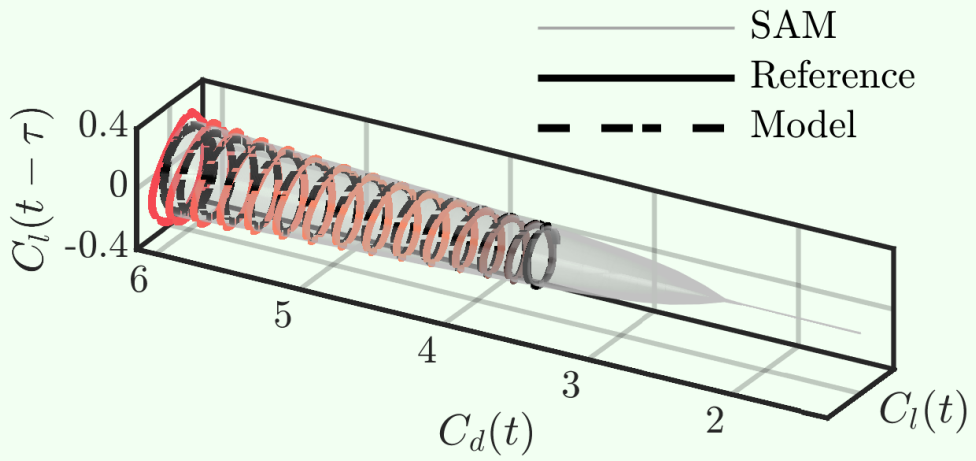


Challenge 2: Predict wake evolution under time-varying actuation

Flow configuration

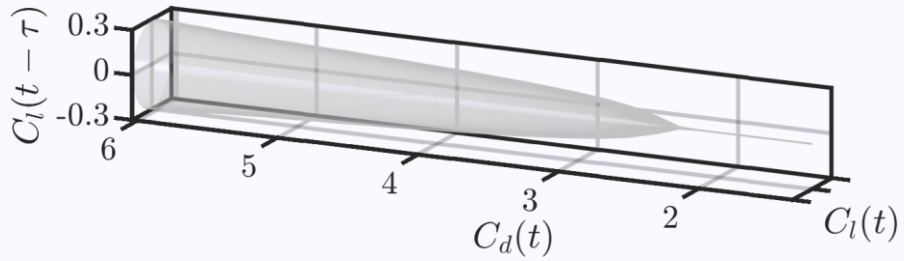


Predicted feature evolution



Feature-based manifold model

Steady Actuation Manifold (SAM)



Lift subsystem

Drag response

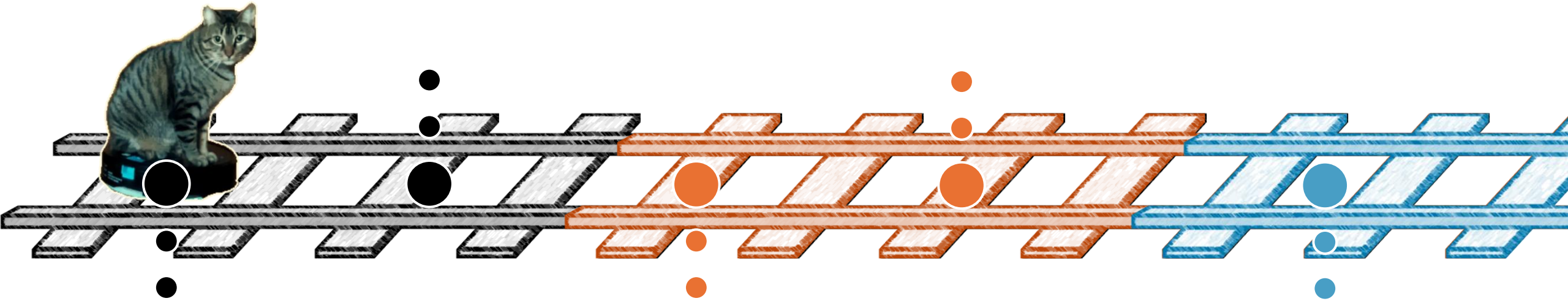
Full model vector

state + output

Outlook: What I have done in my ongoing PhD journey

Comparative analysis of data-driven manifold learning techniques

Feature-based manifold model for predicting wake evolution under time-varying actuation



Literature review

Low-dimensional framework for turbulent wake flows

Extend feature-based manifold model turbulent flows

Achievements

Journal articles

- Rodríguez-Asensio A., Marra L., Andreu-Angulo I., Meilán-Vila A., Alfaro J., Cornejo Maceda G. Y., Noack B. R., Ianiro A., Discetti S. **On the turbulent wake of the actuated fluidic pinball: dynamics, bifurcations and control authority**. Experimental Thermal Fluid Science. 2026, in press.
- Rodríguez-Asensio A., Cornejo Maceda G. Y., Noack B. R., Discetti S., Ianiro A. **Feature-based manifold model of actuated wakes**. TBD. 2026.

Conference contributions

- **2nd International Conference on Mathematical Modelling in Mechanics and Engineering.** September 12-14, 2024, Belgrade, Serbia
- **APS Division of Fluid Dynamics Annual Meeting 2024.** November 24-26, 2024, Salt Lake City, UT, USA
- **EuroMech Colloquium on Data-Driven Fluid dynamics and 2nd ERCOFTAC Workshop on Machine Learning for Fluid Dynamics.** April 2-4, 2025, London, United Kingdom
- **1st International Symposium AI and Fluid Mechanics.** May 27-30, 2025, Chania, Greece.
- **FLUCOME 2025 - 17th International Conference on Fluid Control, Measurements, and Visualization.** Nov 4-7,2025, Delft, The Netherlands.
- **Colloquium 665 - Data-driven active control in flows: from model-based to reinforcement learning methods.** June 8-10, 2026, Paris, France.

Dissemination activities

- Descubriendo patrones desconocidos en la turbulencia: secretos detrás de los datos. **Noche Europea de los Investigadores 2024.** September 27, 2024.
- ¿En qué se parece un globo a un motor de avión? Descubre la magia de un aerorreactor. **Semana de la Ciencia 2024.** November 14, 2024.
- Ciencia del empuje en acción: cómo funciona un motor de avión. **Semana de la Ciencia 2025.** November 11, 2025.
- Todos somos entrenadores: descubre cómo aprende una inteligencia artificial. **Semana de la Ciencia 2025.** November 12, 2025.

Courses attended

- **Particle Image Velocimetry.** Von Karman Institute. December 2-5, 2024, Brussels, Belgium.
- **WG3/WG4 Meeting – Workshop: Machine Learning for Complex flows.** CYPHER. February 6-7, Madrid, Spain
- **Flow control 2026.** Von Karman Institute. February 23-27, 2026, Brussels, Belgium.

Thank you!
Questions?

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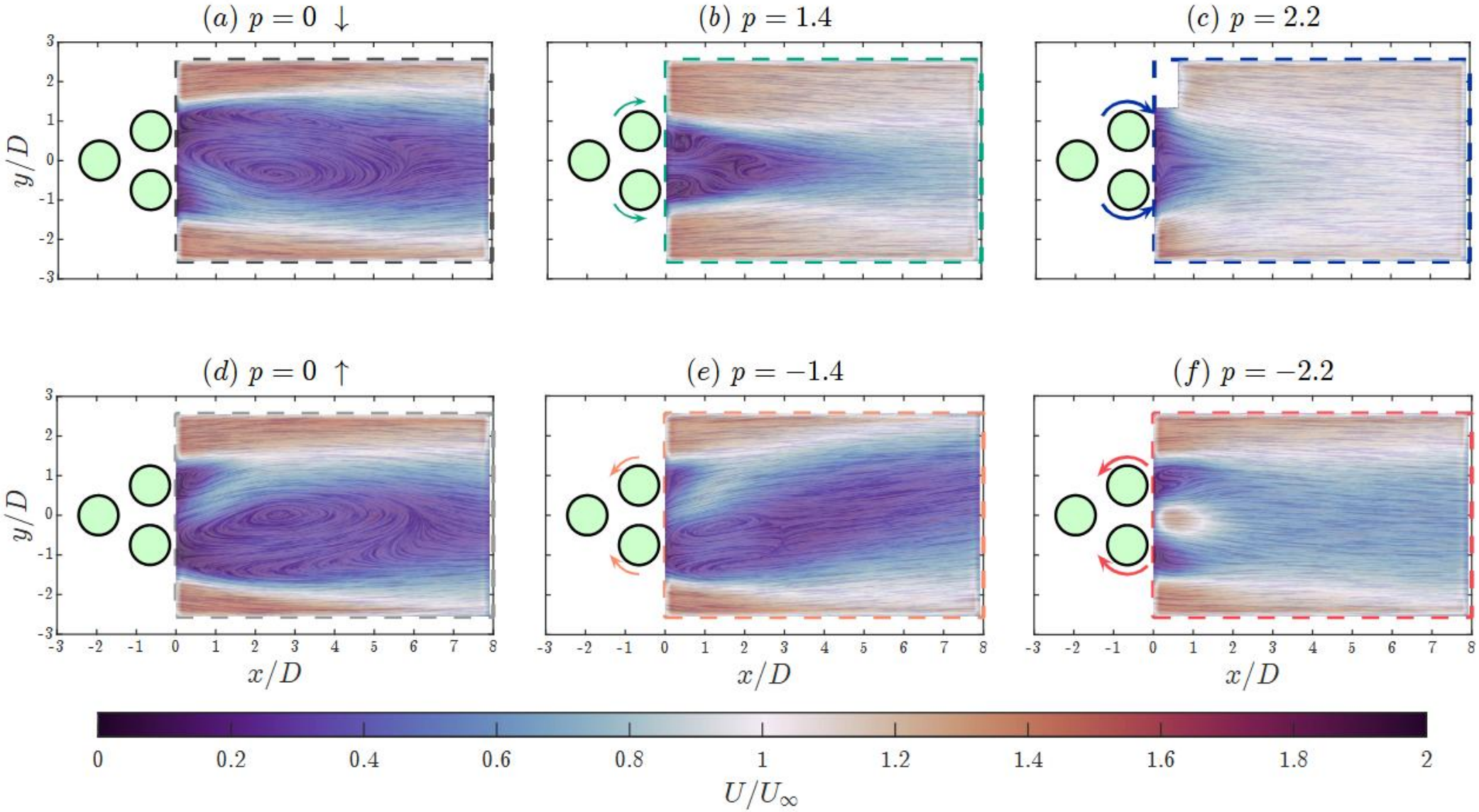
It is also part of the Grant PREP2022-000200 funded by MICIU/AEI/10.13039/501100011033 and by ESF+.

Back-up slides

Challenge 1: Proof existence of steady actuation manifold in turbulent wake flows



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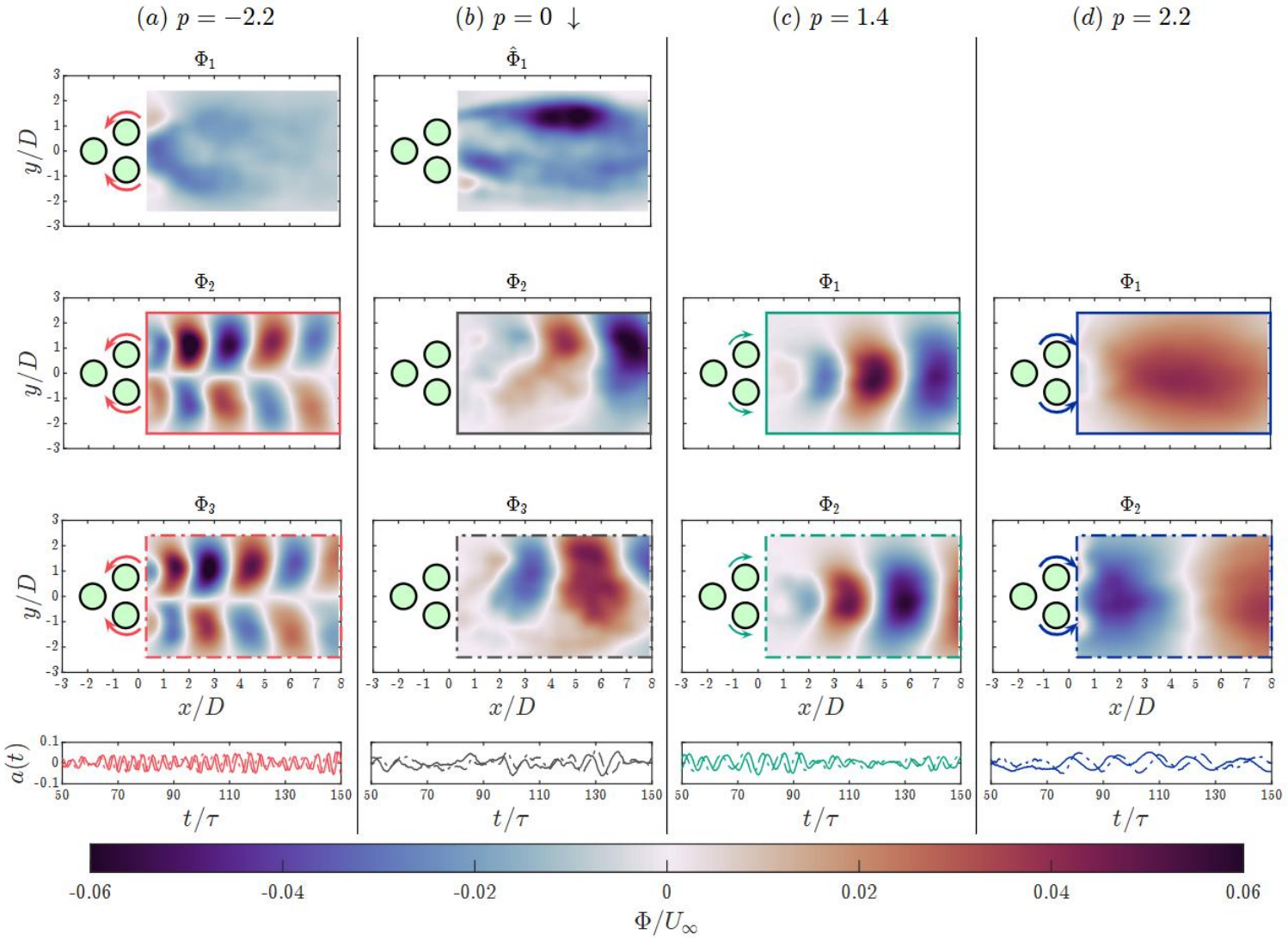

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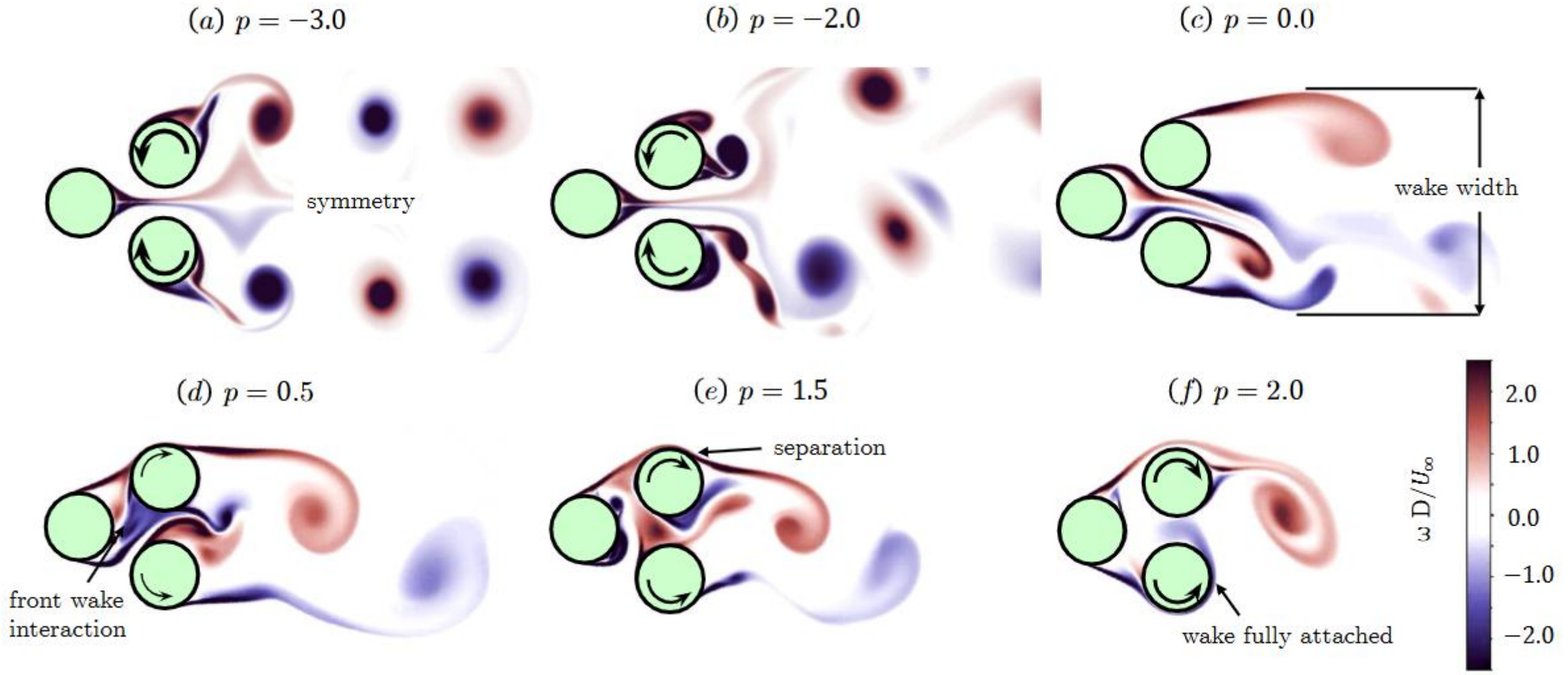


Steady Actuation Manifold (SAM) – Manifold of the post-transient dynamics

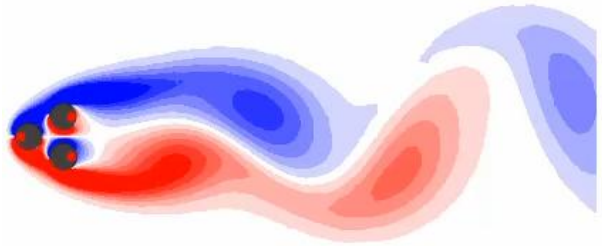
Manifold space

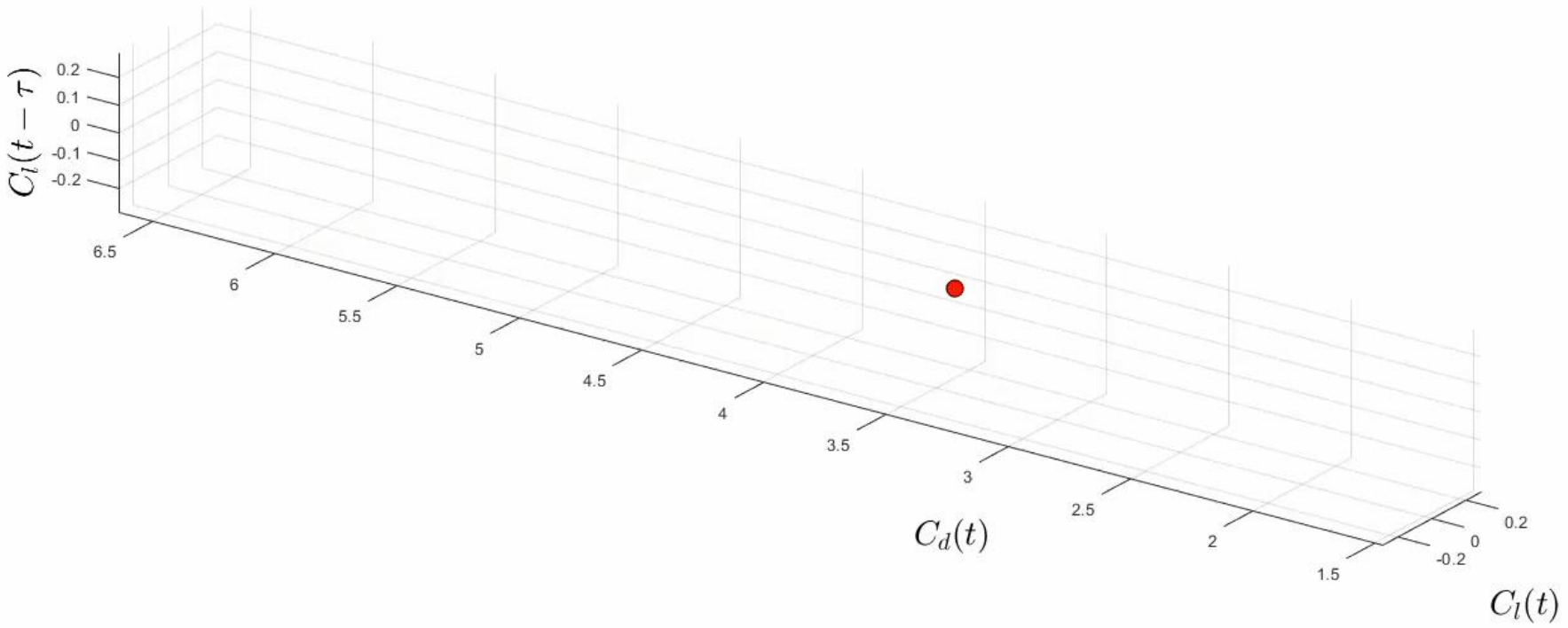
$$C_l(t) - C_l(t-\tau) - C_d(t) \iff A(t) - \phi(t) - C_d(t)$$

$$A(t) = \sqrt{C_l(t)^2 + C_l(t-\tau)^2}$$

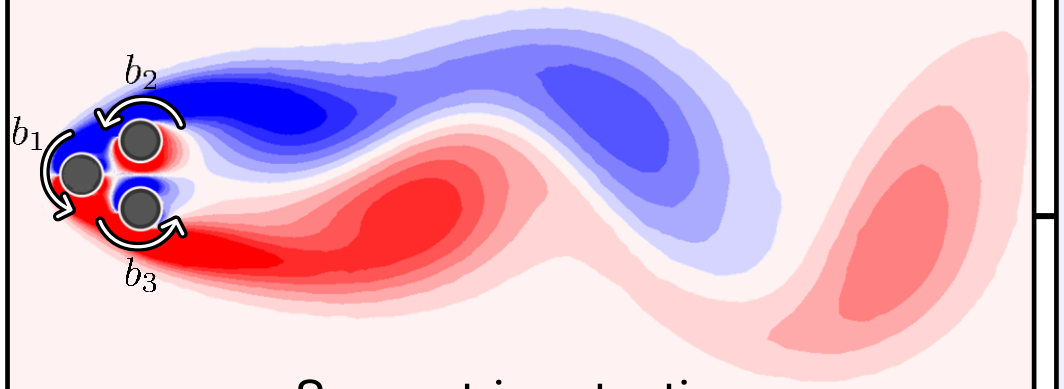
$$\phi(t) = \tan^{-1}\left(\frac{C_l(t-\tau)}{C_l(t)}\right)$$

$$\tau = \frac{T(p)}{4}$$





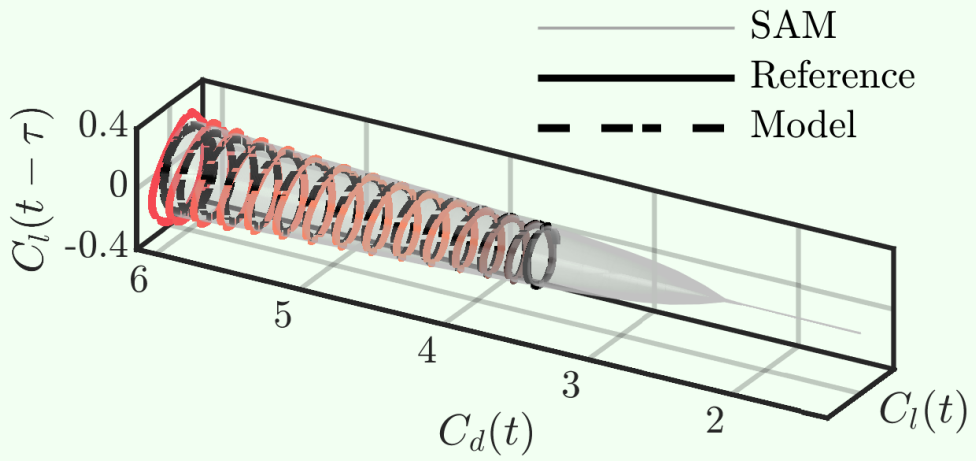
Flow configuration



Symmetric actuation

$$b_1 = 0, \;\; b_2 = -b_3 = p(t)$$

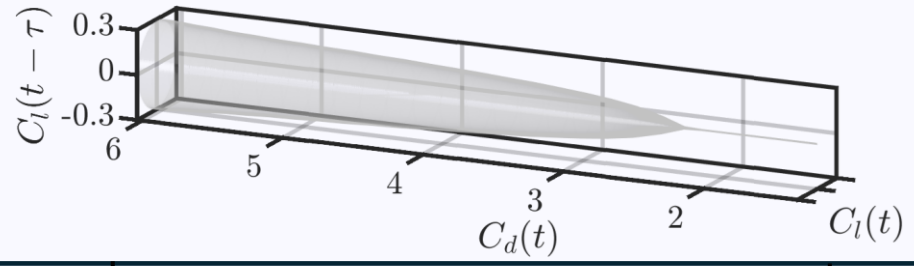
Predicted feature evolution



Feature-based manifold model

Steady Actuation Manifold (SAM)

$$\{A_{\mathrm{SAM}}(p),\, T(p),\, C_{d_{\mathrm{SAM}}}(p)\}$$



Lift subsystem

$$\dot{A} = \alpha\left(A^2_{\mathrm{SAM}}(\tilde{p}) - A^2\right)A$$
$$\dot{\phi} = 2\pi/T(p)$$
$$\dot{\tilde{p}} = (p - \tilde{p})/k$$

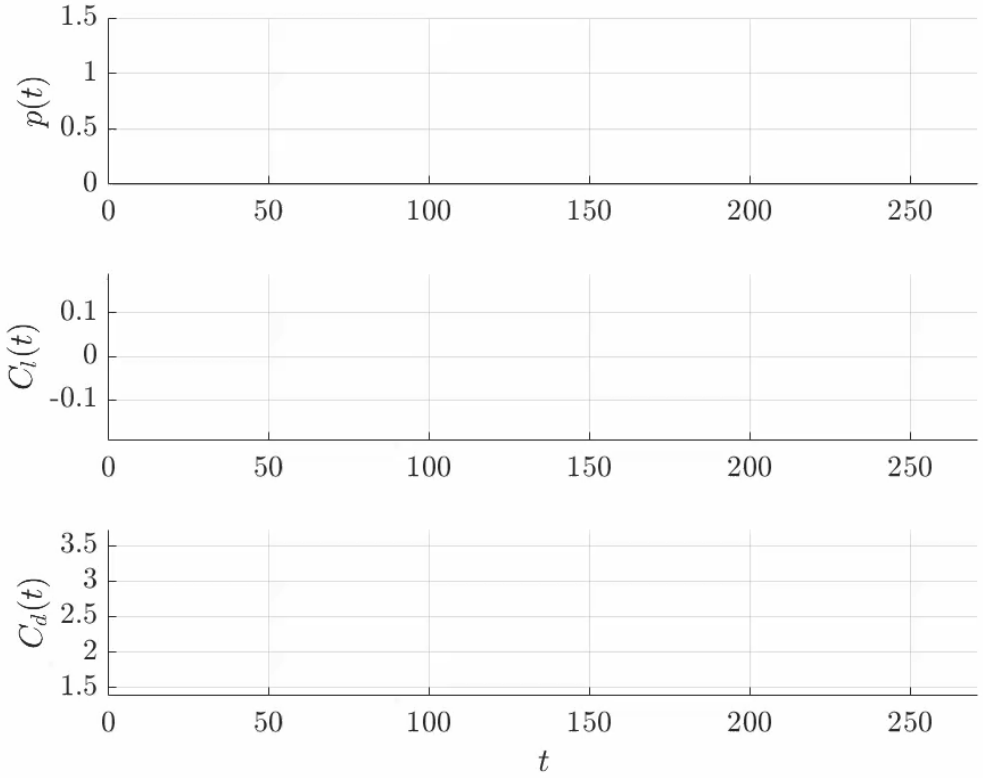
Drag response

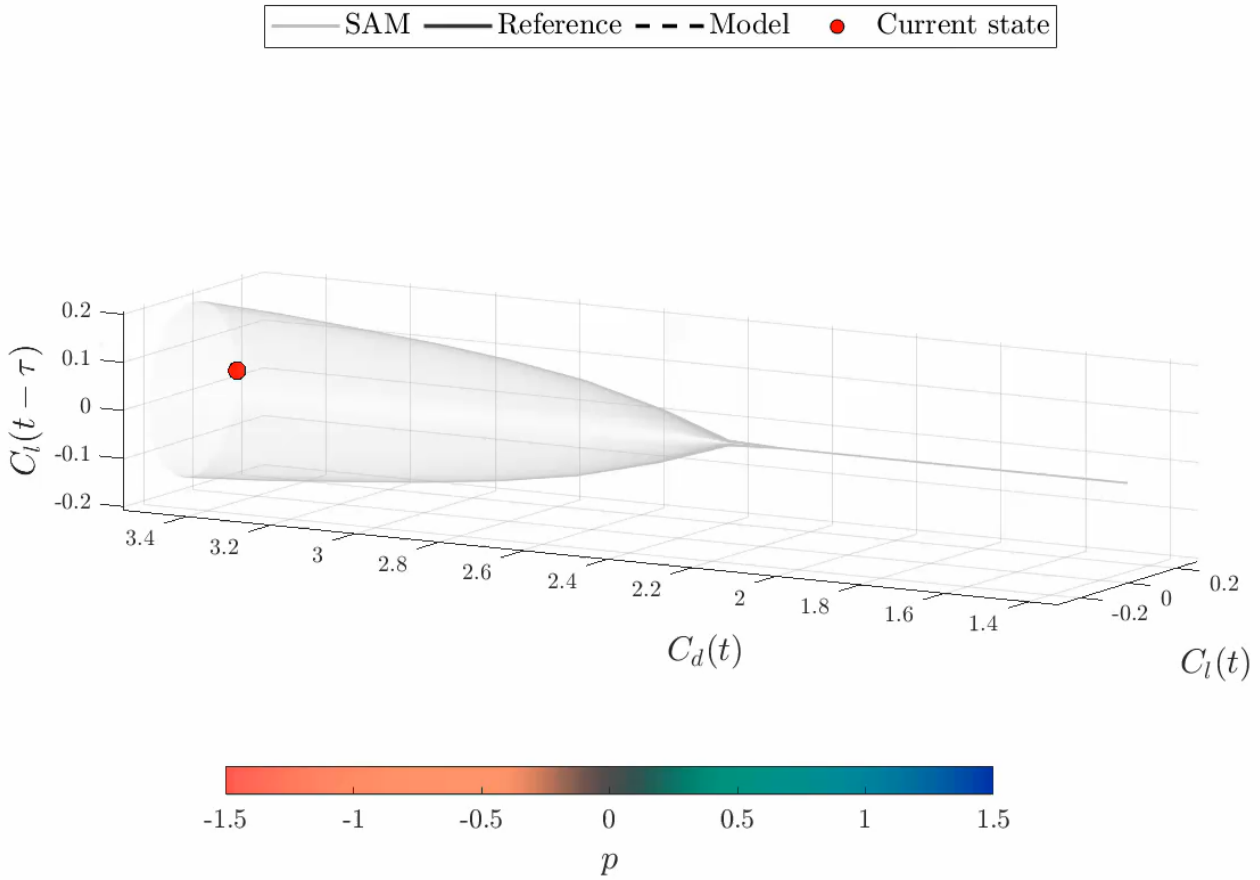
$$\dot{C}_d = \beta\left(C_{d_{\mathrm{SAM}}}(p) - C_d\right) - \gamma\left(A^2_{\mathrm{SAM}}(p) - A^2\right)$$

Full model vector

$$\mathbf{q} = [A, \phi, \tilde{p} \mid C_d] \longrightarrow \text{state + output}$$

Challenge 2: Predict wake evolution under time-varying actuation





$E_A(\%)$	$E_{C_d}(\%)$	$E_\phi(\%)$
6.61	1.30	2.87