

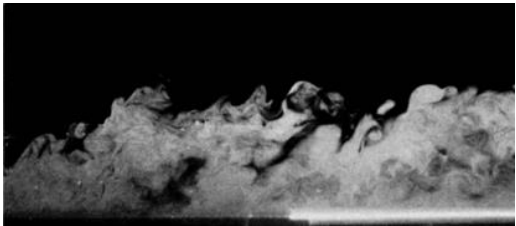
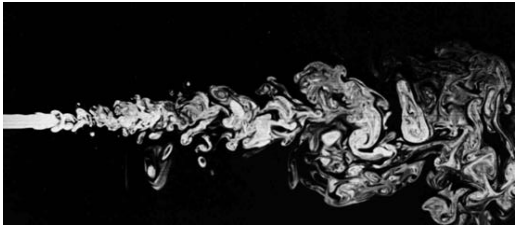
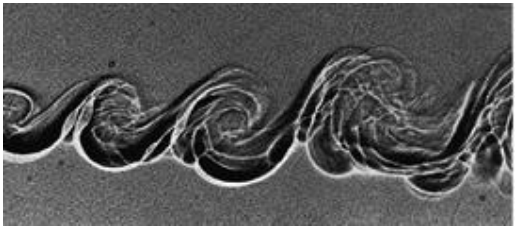
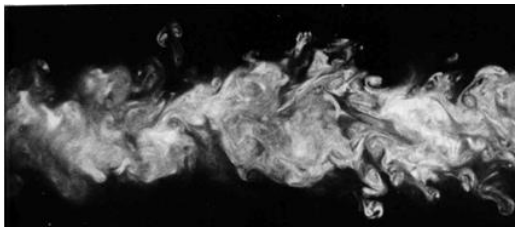
Data-driven modelling of turbulent flows under active flow control

Candidate: Qihong L. Li-Hu

Supervisors: Prof. Andrea Ianiro, Prof. Stefano Discetti



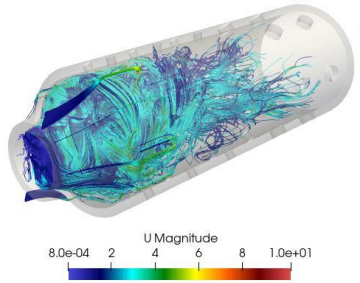
Turbulence is
Everywhere



Milton Van Dyke



Andretti Autosport



aeroengineering



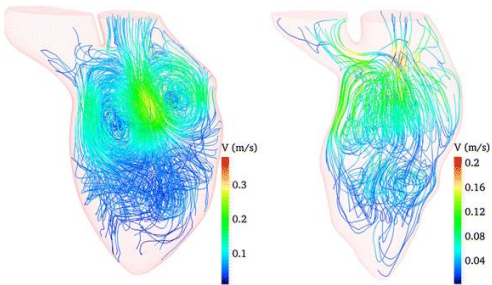
Airtecnics



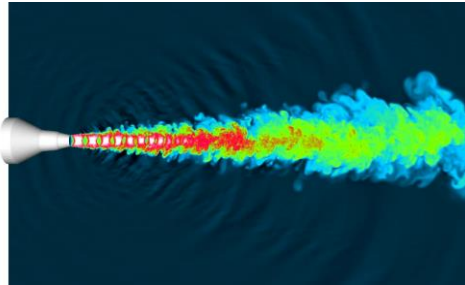
Grupo One Air



Ryoh Ishihara



Doost. S. N. et all (2016)



Mendez S. et al (2020)



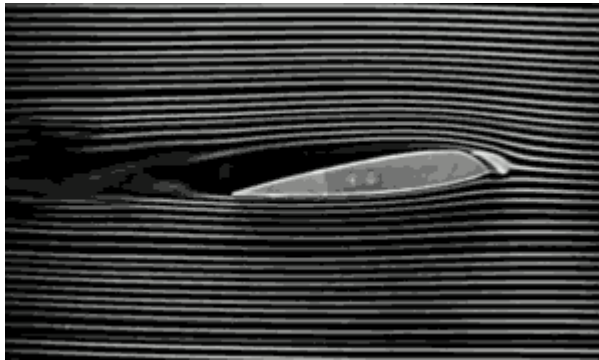
NASA



Eyink G. (2024)

Turbulent flows

Navier-Stokes Eqs
Dynamical models
Flow Control



Limitations

No analytical solution
Nonlinear dynamics
High-dimensionality
Technological limitations

Turbulent flows

Limitations

Reduced-order data-driven models



Technological limitations

Literature review

- Dimensionality reduction

Proper Orthogonal
Decomposition (POD)

$$U = \Phi \Sigma \Psi^*$$



Full order

$n_r = 10$

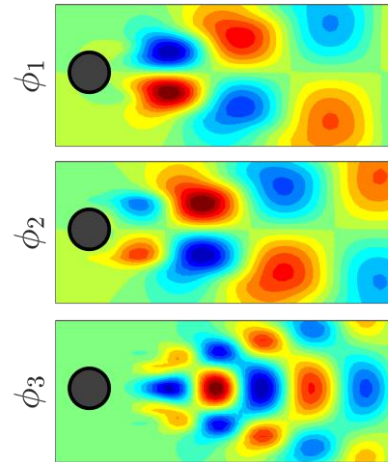


100

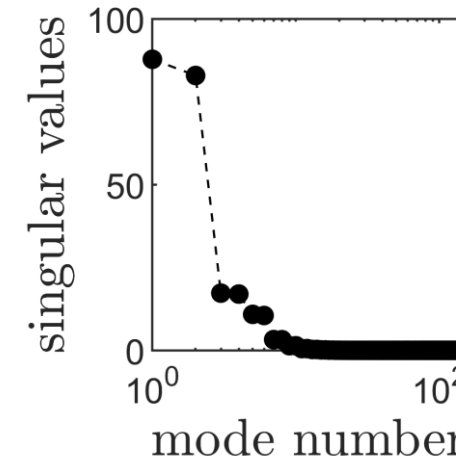


1000

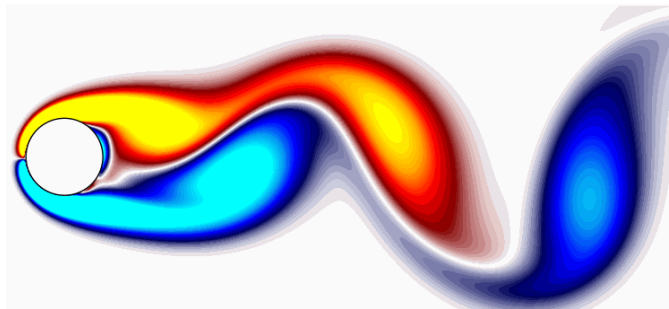
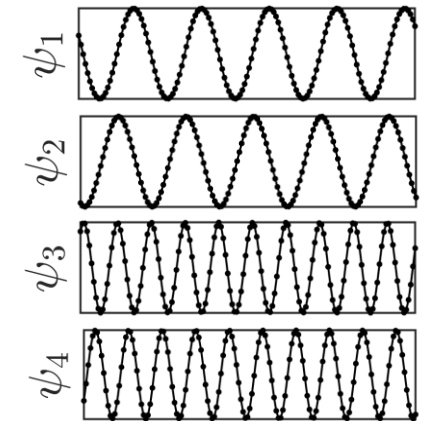
Spatial modes



Singular values



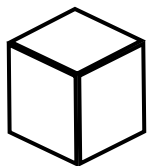
Temporal modes



Medium

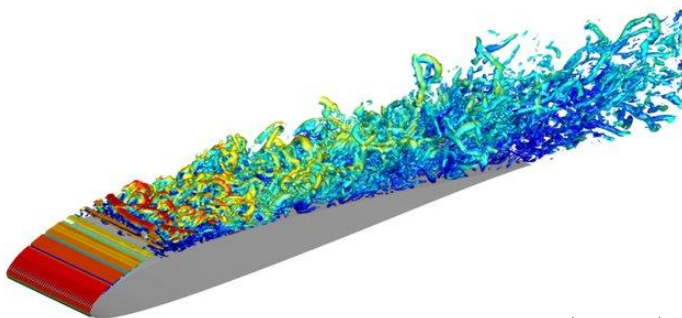
Literature review

- Dimensionality reduction
- Data-driven models



White-box

Navier-Stokes
equations

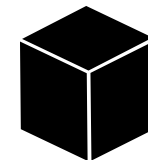


Marten D. (2020)



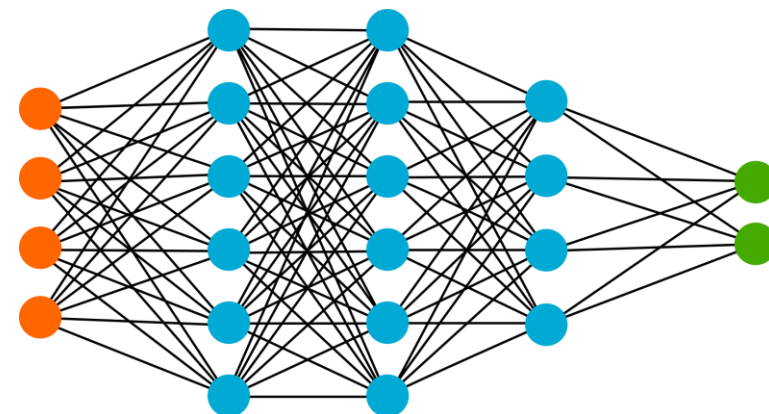
Grey-box

Reduced Order
Models
&
Physics

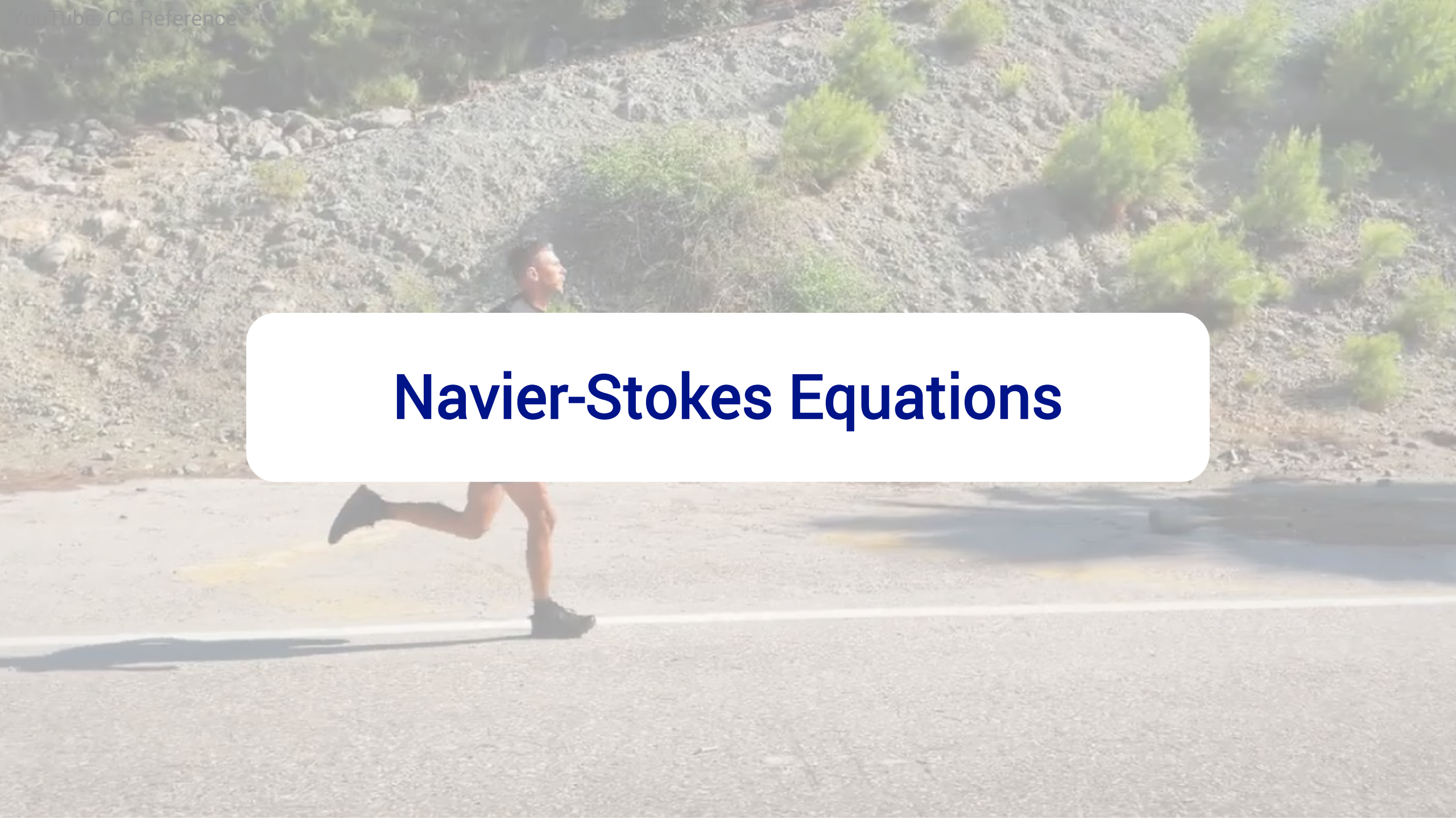


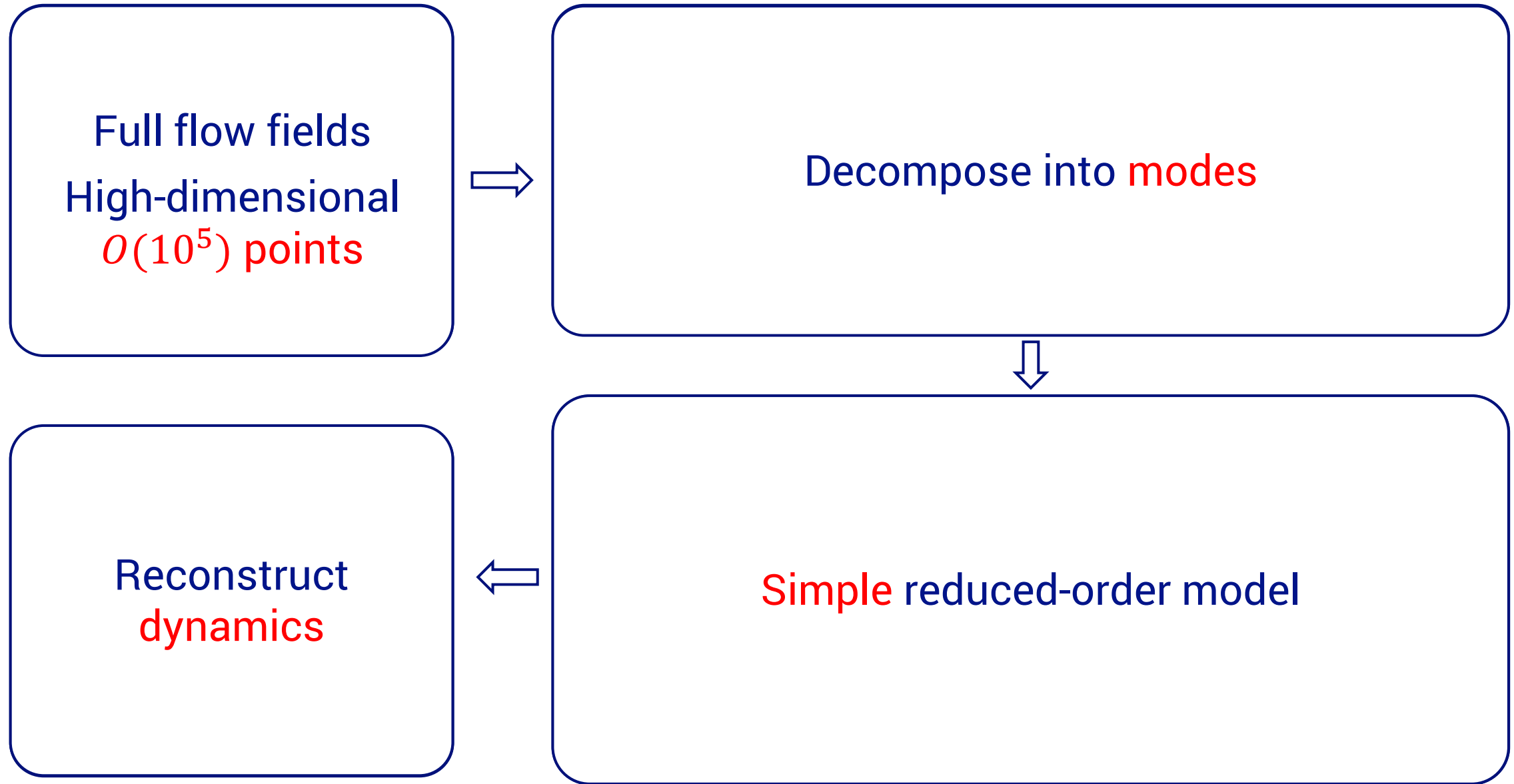
Black-box

Machine learning



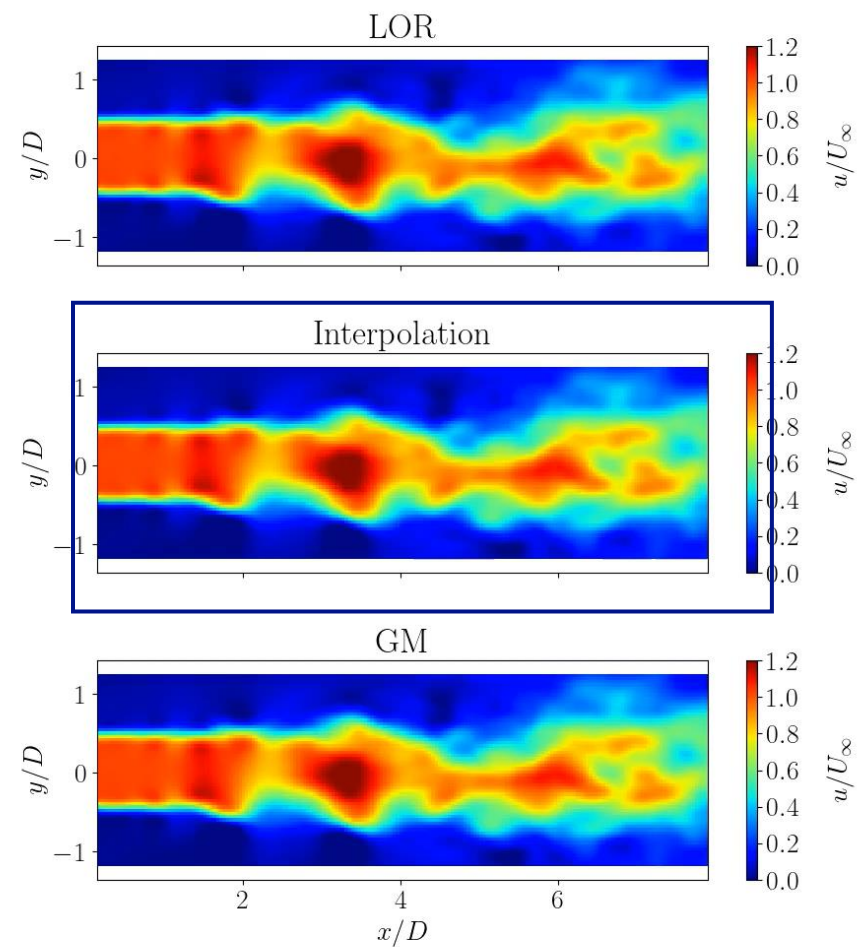
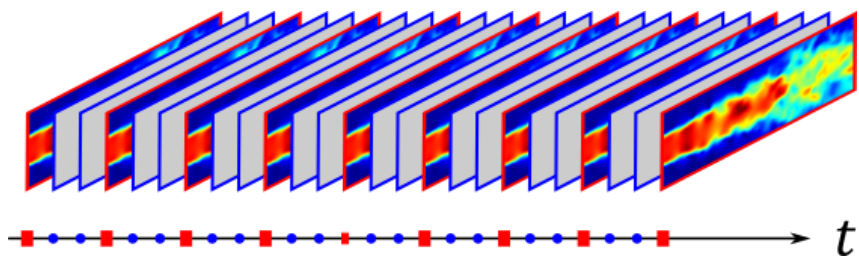
Navier-Stokes Equations

A person is running on a paved road, captured in a side profile. The runner is wearing dark athletic shoes and shorts. The background features a steep, rocky hillside with sparse green shrubs. A white line is visible on the road surface. The overall scene is brightly lit, suggesting a sunny day.



$$\Delta t = 1.6t_c$$

$$S_r = 10$$



Galerkin model



Journal publication under review

Meshless Galerkin
model



Spatio-temporal model

Multi-manifolds
model



Multi-scale problem
Local dynamical models

Hybrid model for
controlled flow



Collaboration with Scott D.
Possible Research Stay

- Journal articles and code/datasets
 - ✓ Li-Hu Q. L., García-Caspueñas, P., Ianiro, A., & Discetti, S. (2025). Model-based time super-sampling of turbulent flow field sequences. arXiv preprint arXiv:2502.14722. (Dataset pending of publication)
- Conference contributions
 - ✓ **21st International Symposium on Applications of Laser and Imaging Techniques to Fluid Mechanics**, Jul 8 – 11, Lisbon, Portugal
 - ✓ **2nd International Conference on Mathematical Modelling in Mechanics and Engineering (ICME)**, Sep 12 – 14, 2024, Belgrade, Serbia
 - ✓ **APS Division of Fluid Dynamics Annual Meeting 2024**, Nov 22 – 24, 2024, Salt Lake City, UT, USA
 - ✓ **7th International Conference on Turbulence and Interactions**, Mar 30 – Apr 4, 2025, La Palma, Spain

- Courses/Workshops Attended
 - ✓ **Machine Learning for Fluid Mechanics: Analysis, Modeling, Control and Closures**, Von Karman Institute and ULB Lecture Series, Jan 29 – Feb 2, 2024 , Brussels, Belgium
 - ✓ **Particle Image Velocimetry**, Von Karman Institute Lecture Series, Dec 2 – 5, 2024, Brussels, Belgium
 - ✓ **Workshop on Machine Learning for Complex Flows – CYPHER**, Feb 6 – 7, Madrid, Spain
- Dissemination Activites
 - ✓ Li-Hu Q.L., Franceschelli L., Discetti S., *Desvelando la fluidodinámica para una aviación más sostenible*, La Noche Europea de los Investigadores e Investigadoras de Madrid 2023
 - ✓ Li-Hu Q.L., Franceschelli L., *Mata el ruido de los aviones diseñando tu propia ala*, XXIII SEMANA DE LA CIENCIA Y DE LA INNOVACIÓN 2023
 - ✓ Li-Hu Q.L., Franceschelli L., *Cámaras neuromórficas, qué son y cómo usarlas en fluidodinámica*, La Noche Europea de los Investigadores e Investigadoras de Madrid 2024
 - ✓ Li-Hu Q.L., Franceschelli L., *Descubriendo los secretos ocultos de los jets*, XXIV SEMANA DE LA CIENCIA Y DE LA INNOVACIÓN 2024
 - ✓ Li-Hu Q.L., Tirelli I., Discetti S., *¡Aprende a volar con aviones de papel!*, XXIV SEMANA DE LA CIENCIA Y DE LA INNOVACIÓN 2024

- **1st year**
 - ✓ Literature review
 - ✓ Galerkin model
- **2nd year**
 - ✓ Journal paper under review
 - Meshless Galerkin model
 - Multi-manifolds model
 - Collaboration
- **3rd & 4th years**
 - Research stay
 - Publish/submit papers of new work
 - PhD defense

Questions?

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).

