

IMPERIAL

NWTF AI-Enabled Wind-Tunnel Experiments Forum 2026

Physics-informed neural networks for super-resolution of PIV data and flow reconstruction

R. Klopsch, Y. Patel, G. Rigas

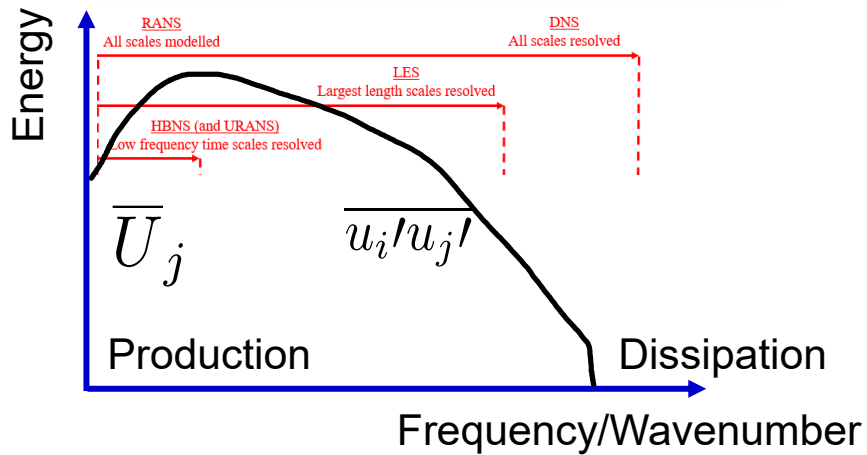
Department of Aeronautics, Imperial College London

14/09/2026

Partial Physics

Underdetermined RANS, ...

- Navier-Stokes equations ($\mathbf{u}, p$).
 - Direct numerical **simulation** (DNS) of industrial flows **intractable**.
 - Modelling is required (RANS, LES, ...) which relies on **empirical closures**.



Partial Data

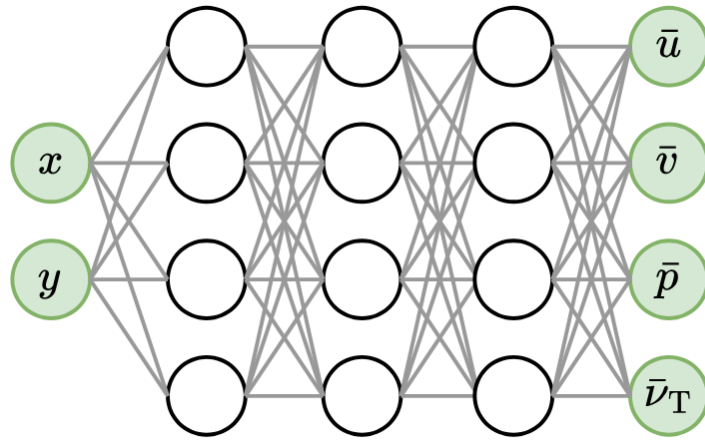
Sparse experimental data

- Non-intrusive high-fidelity **experimental** data is limited:
 - **Pressure** can only be measured at the wall
 - **Restrictions** on **velocity resolution** (space vs time)



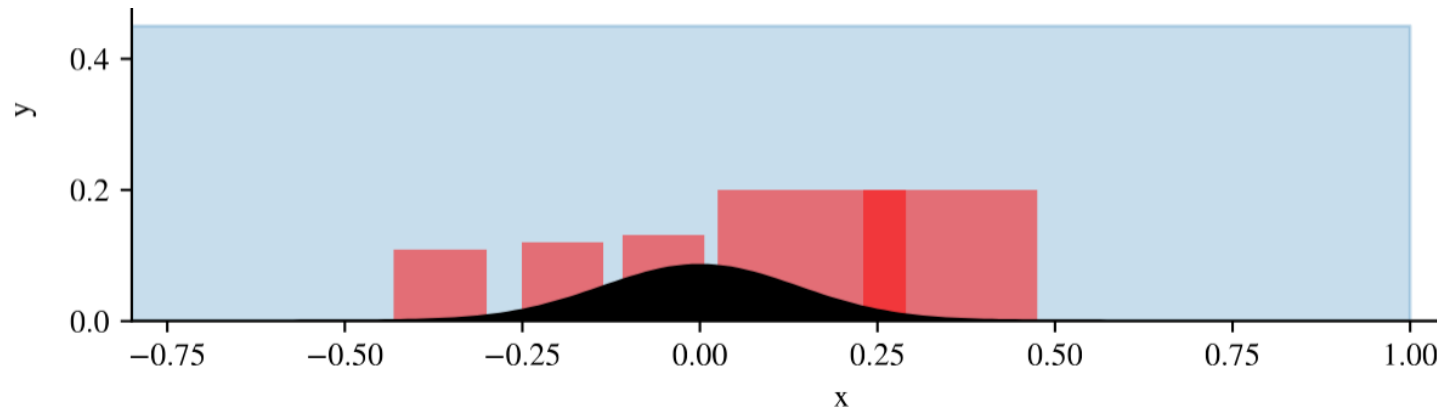
Combining partial physics with partial data

Mean field data assimilation with physics-informed neural networks



Data loss
(deviation from the data)

Physics loss
(residual of the equations)



Learning objective:

$$\min_{u,v,p,\dots} J_{\text{Data}} + J_{\text{Physics}}$$

RANS mean flow model

$$\epsilon_{\text{RANS}} = (\bar{\mathbf{u}} \cdot \nabla) \bar{\mathbf{u}} + \nabla \bar{q} - \nabla \cdot \left[\left(\frac{1}{\text{Re}} + \nu_t \right) \bar{\mathbf{S}} \right]$$

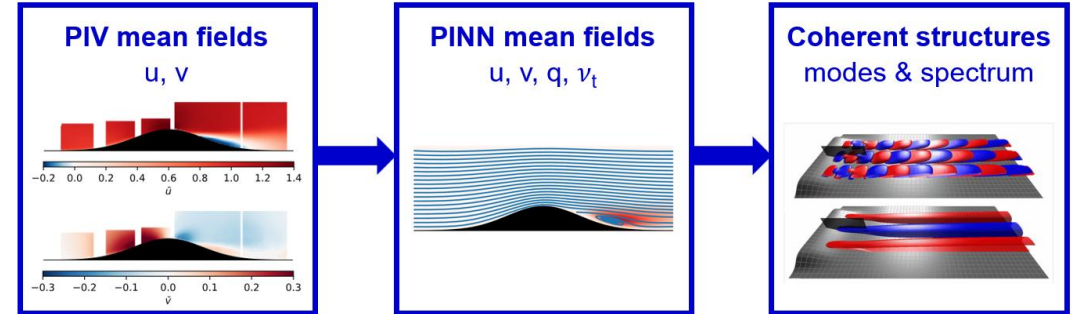
$$\epsilon_{\text{cont}} = \nabla \cdot \bar{\mathbf{u}}$$

+ eddy viscosity turbulence model

+ no-slip wall

Application examples

1. Modelling flow dynamics from mean measurements



2. 3D reconstruction and mitigation of measurement errors

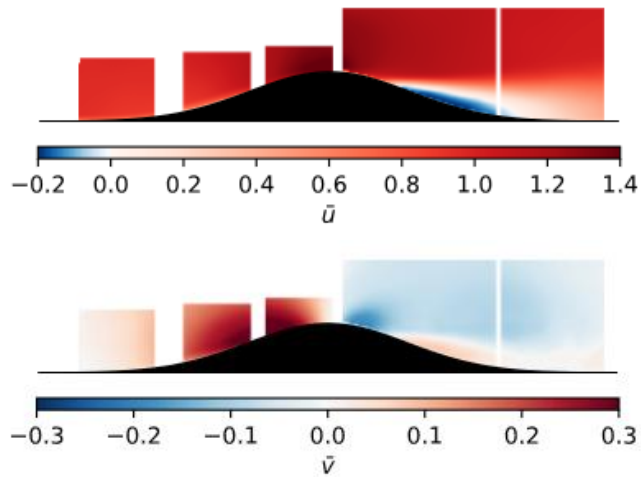


Workflow

From PIV mean fields to coherent structures

PIV mean fields

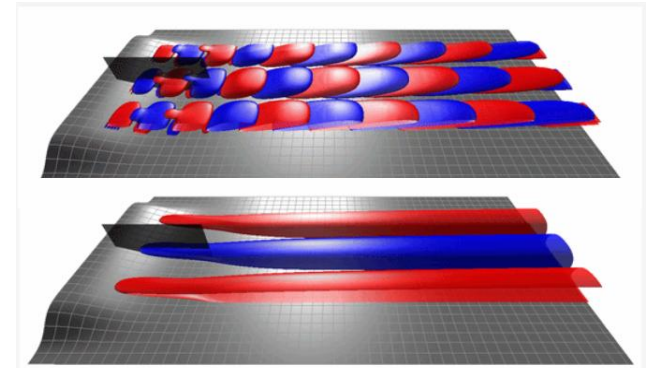
u, v



Dataset: Gray *et al.* 2021, 2022, 2023;
Straccia and Gray / NASA

Linear mean field methods:
stability & resolvent
analyses

Coherent structures modes & spectrum

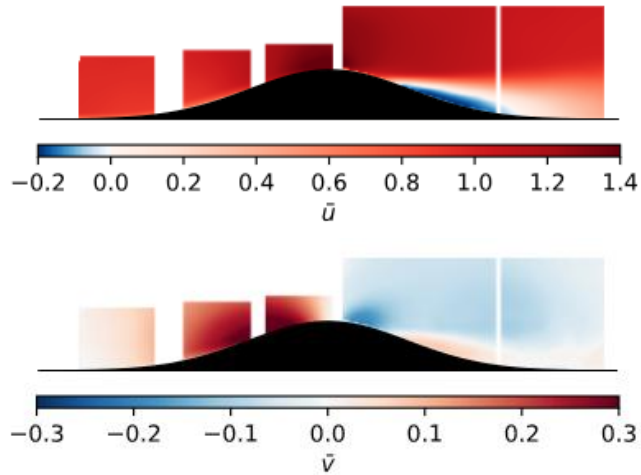


Workflow

From PIV mean fields to coherent structures

PIV mean fields

u, v



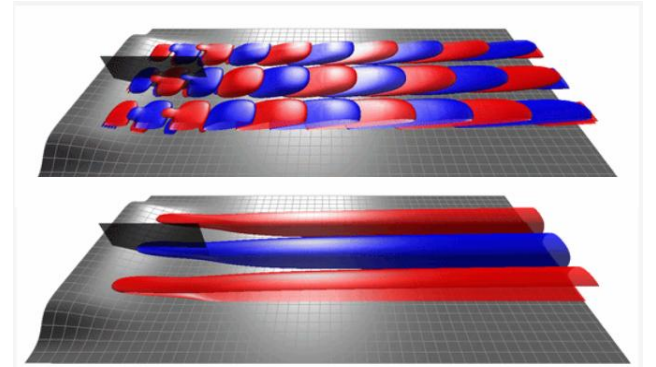
Dataset: Gray *et al.* 2021, 2022, 2023;
Straccia and Gray / NASA

- ✗ Sparse data
- ✗ Limited domain
- ✗ Missing closure term



Mean flow data assimilation with PINN

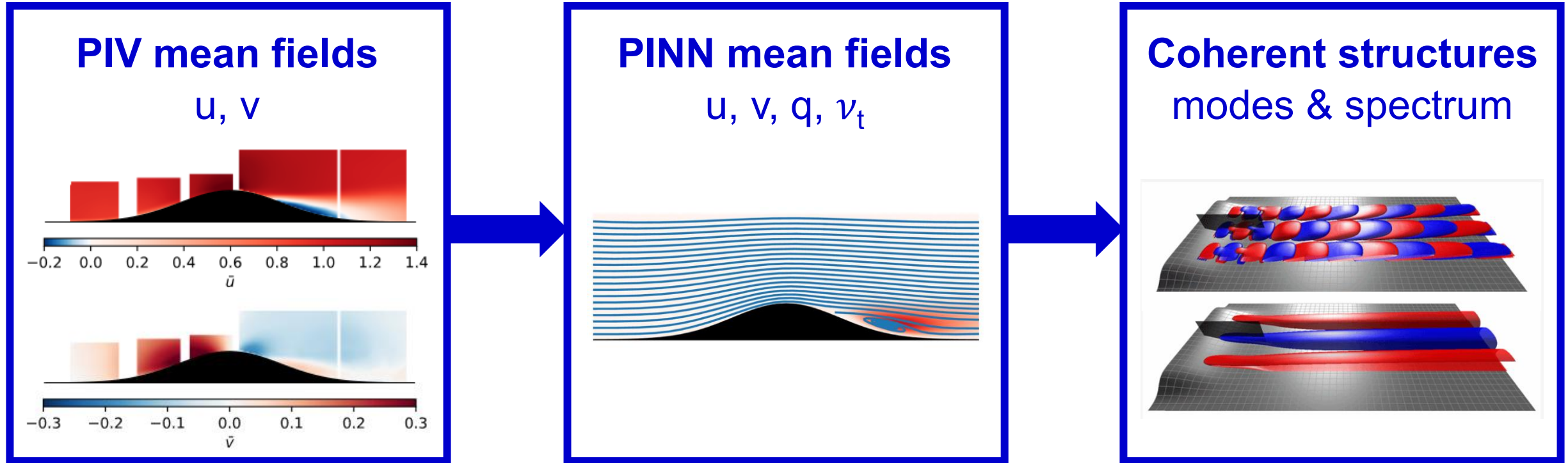
Coherent structures modes & spectrum



Klopsch et al. AVIATION 2025, JFM 2026

Workflow

From PIV mean fields to coherent structures

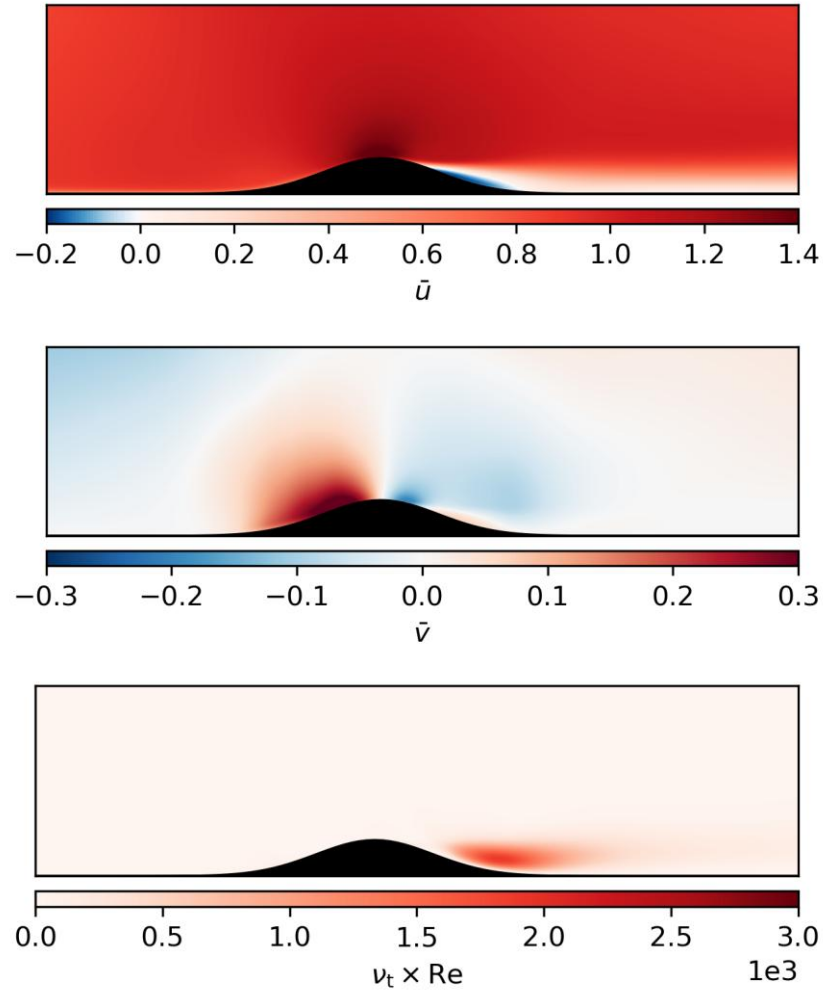


Dataset: Gray *et al.* 2021, 2022, 2023;
Straccia and Gray / NASA

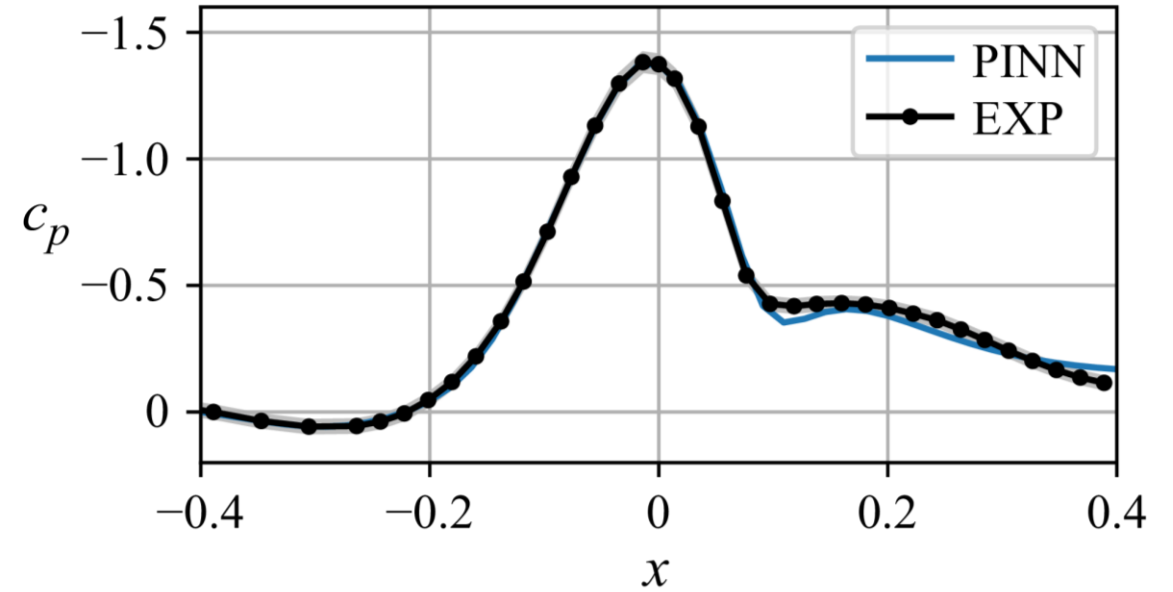
Klopsch et al. AVIATION 2025, JFM 2026

Results

Assimilated fields



Validation



Pressure was not included in training data

Results

Modelling of flow dynamics

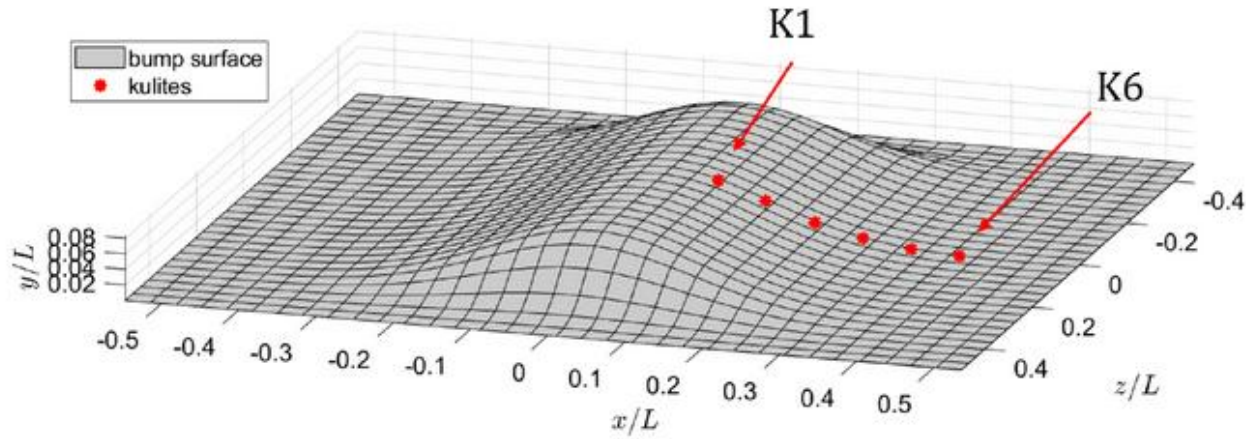
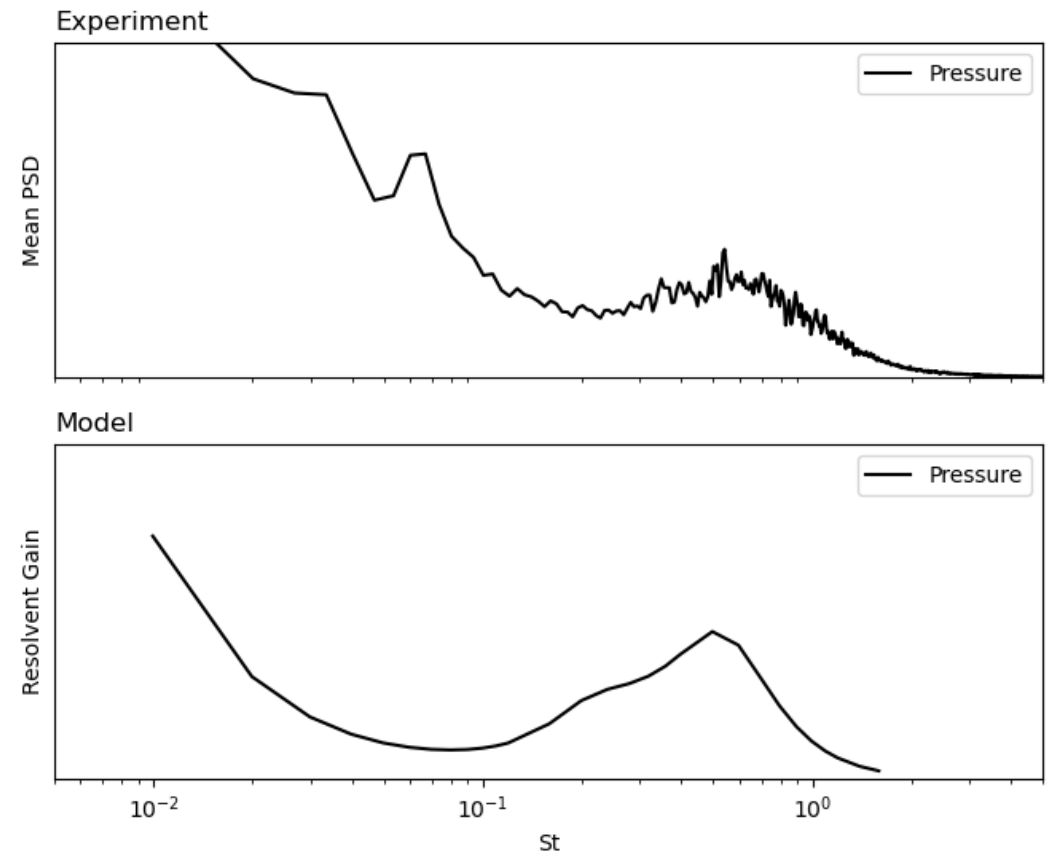
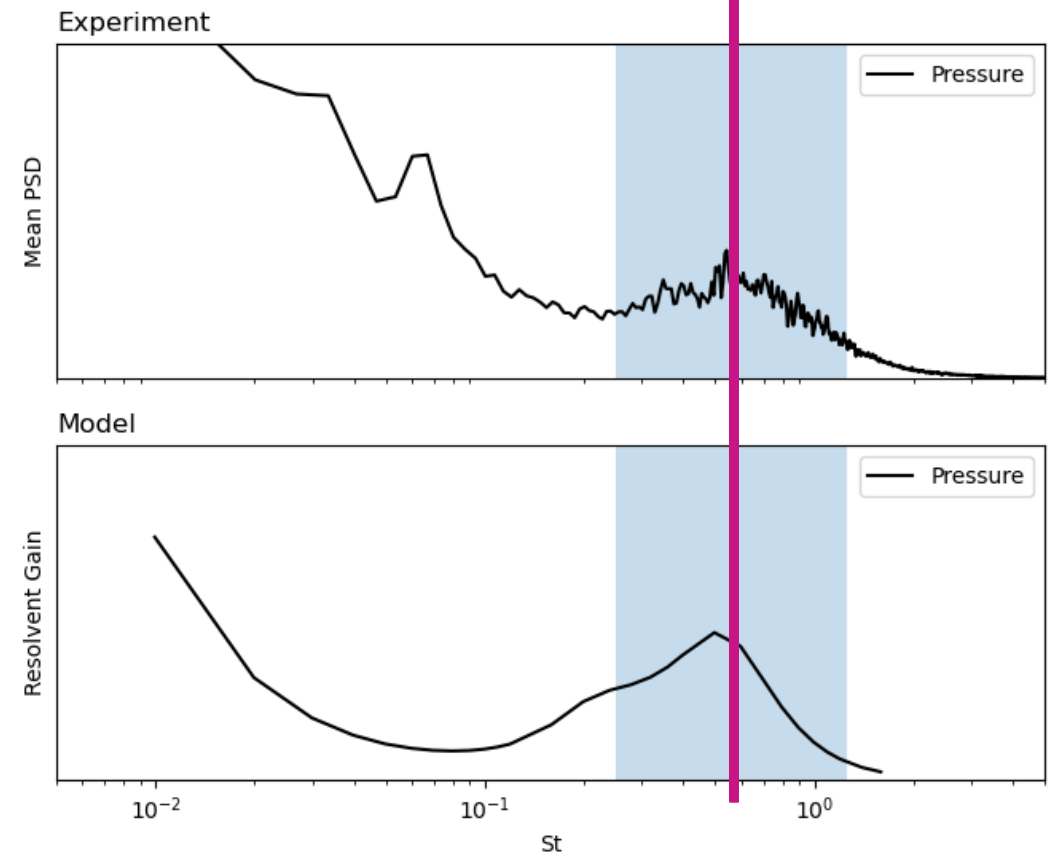
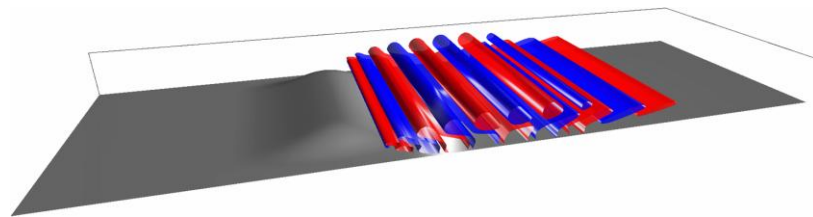
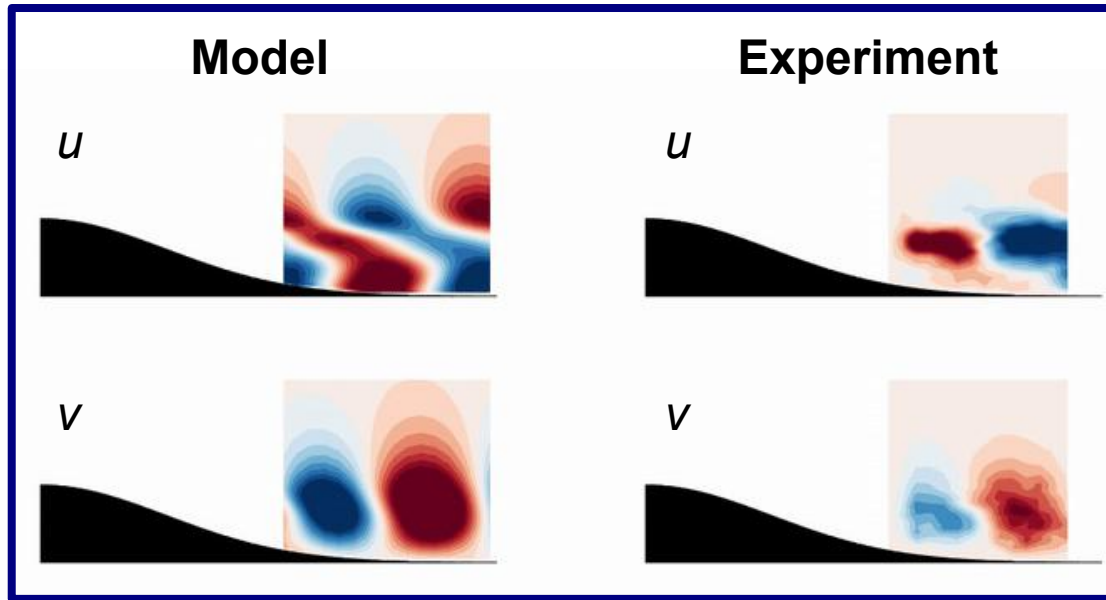


Image: Straccia and Gray / NASA



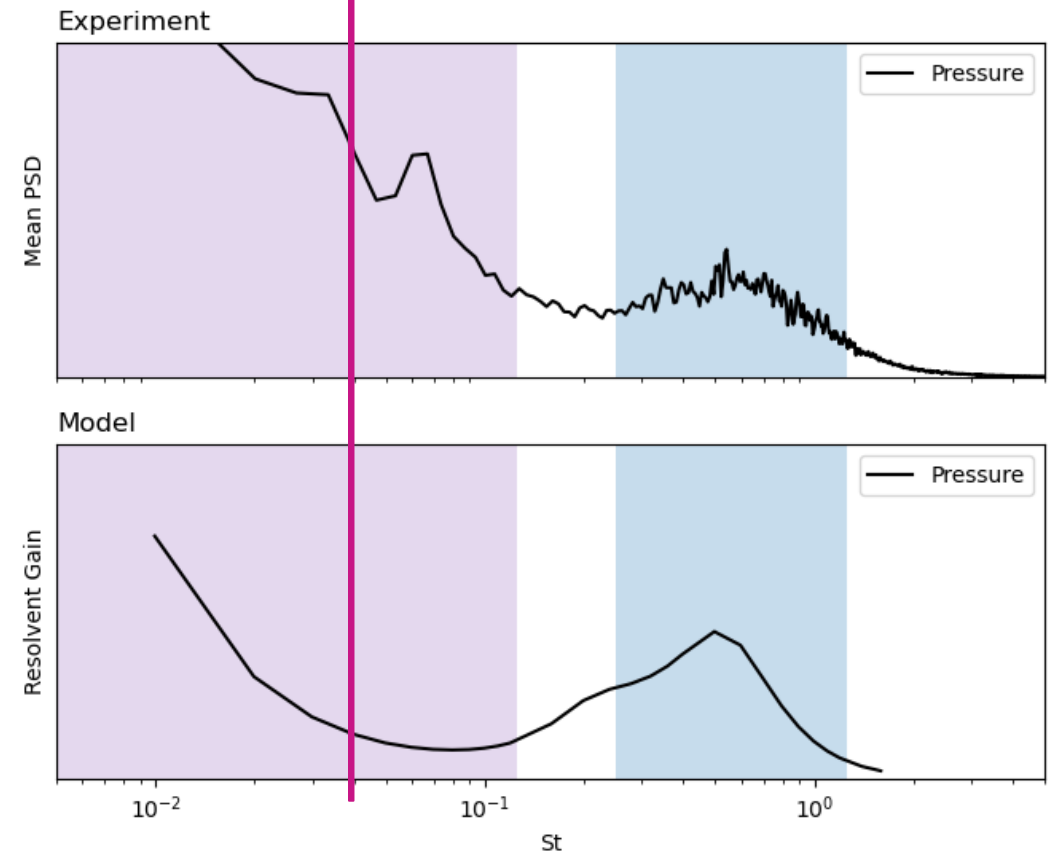
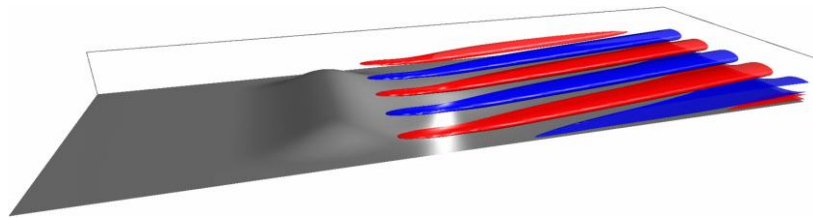
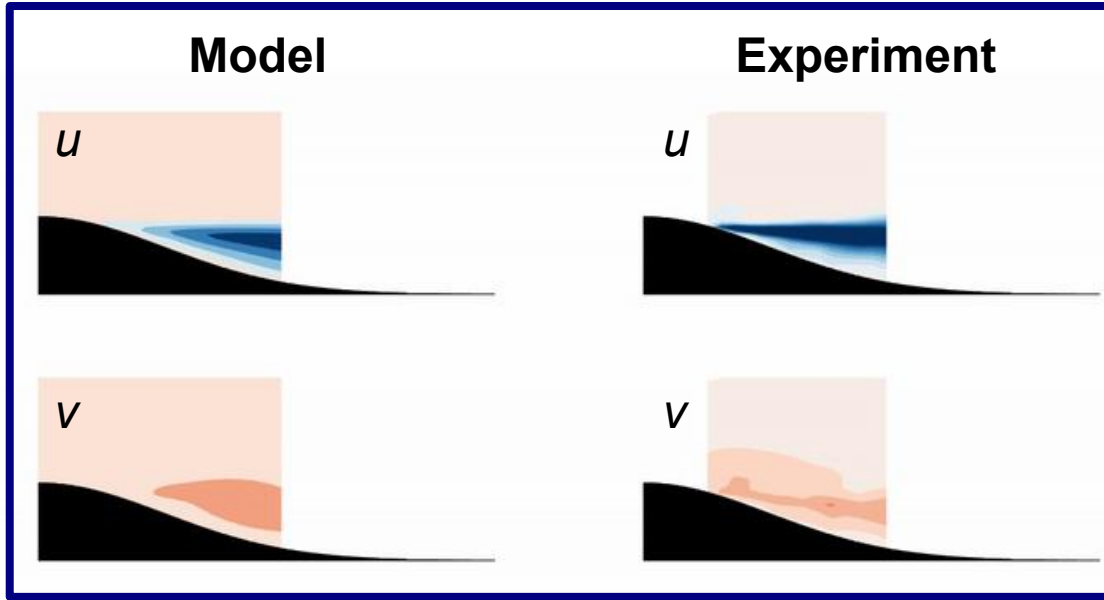
Results

Modelling of flow dynamics



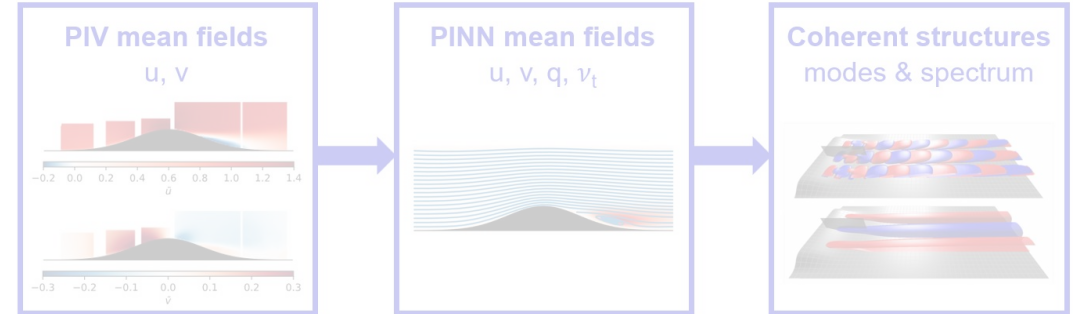
Results

Modelling of flow dynamics



Application examples

1. Modelling flow dynamics from mean measurements



2. 3D reconstruction and mitigation of measurement errors

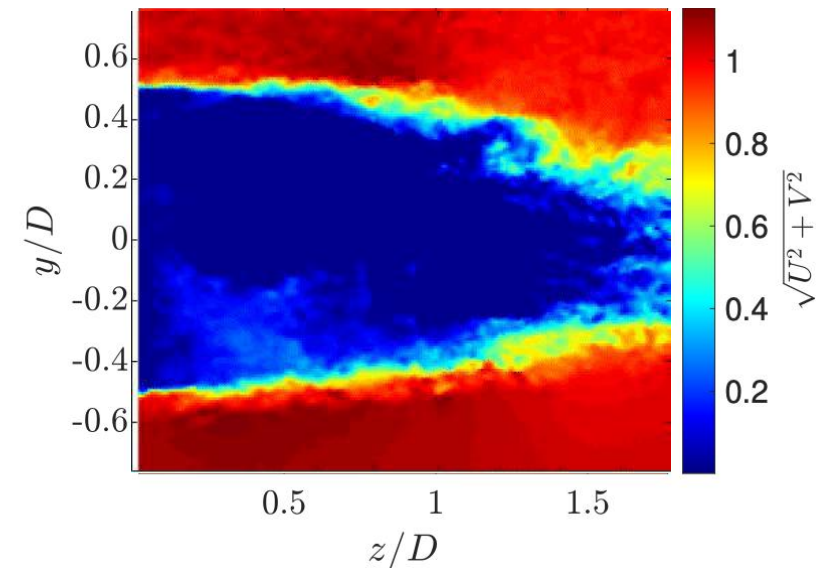
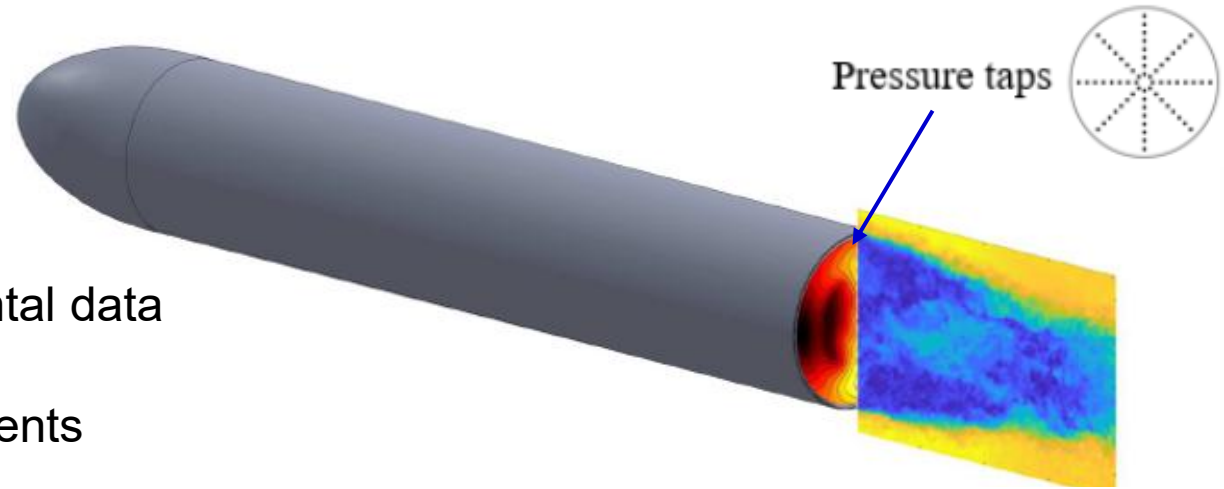


Super-resolution and pressure reconstruction

Of an axisymmetric bluff-body wake

Objectives:

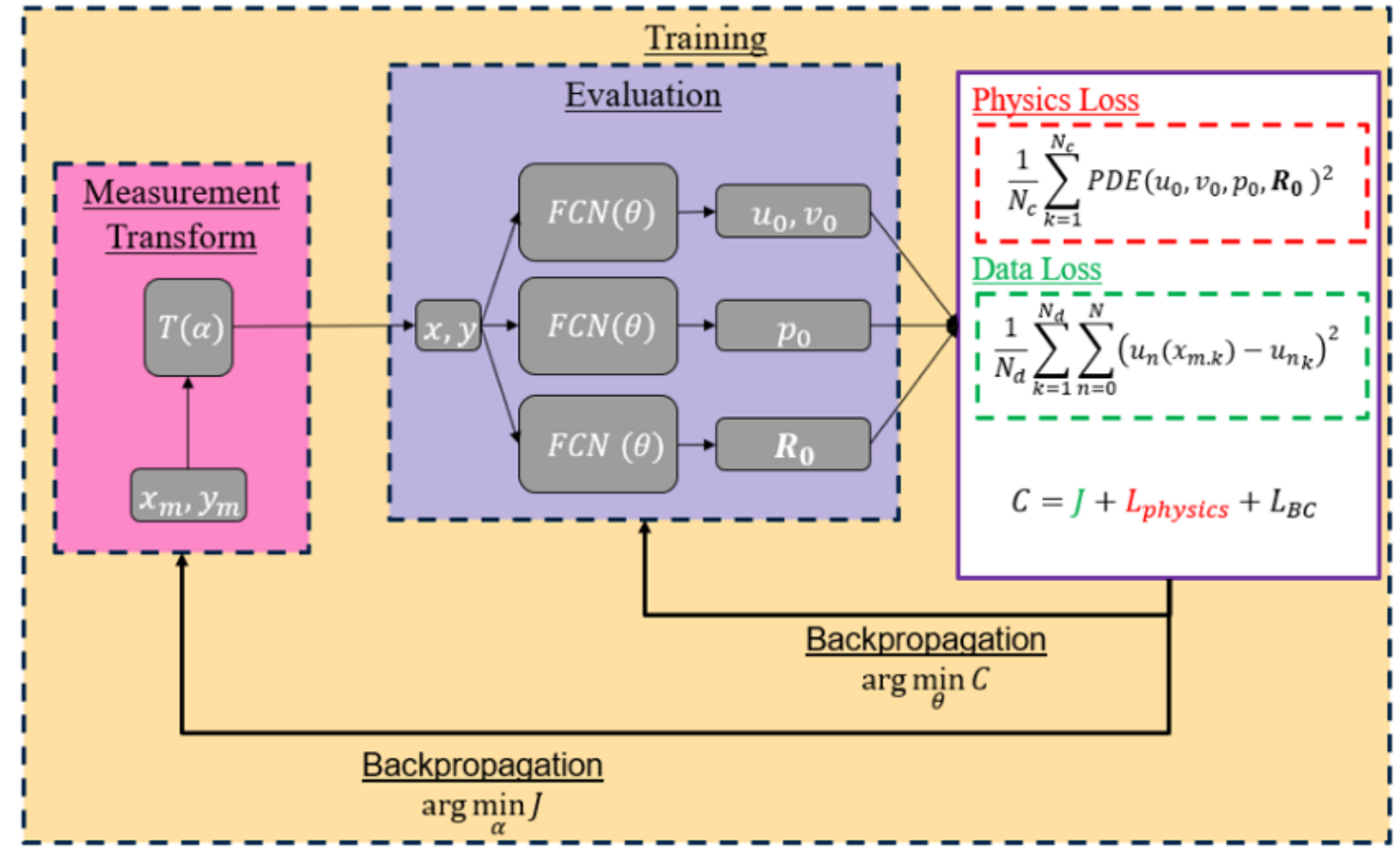
- reconstruct bluff body wake from experimental data
- super-resolve velocity data (interpolation)
- infer pressure field from velocity measurements



Super-resolution and pressure reconstruction

Of an axisymmetric bluff-body wake

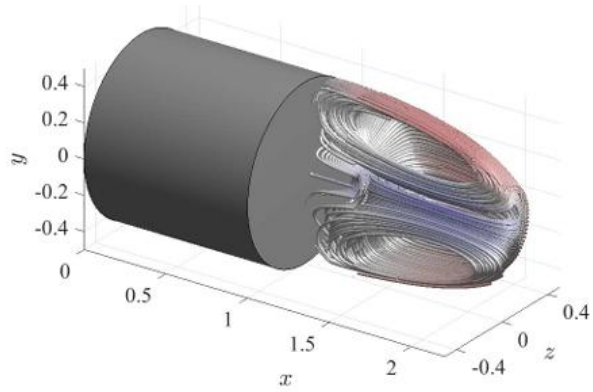
- Small errors in calibration or misalignment of data can affect the flow reconstruction
- Simultaneous optimisation of data, PDE and affine transformation (scaling and translations)



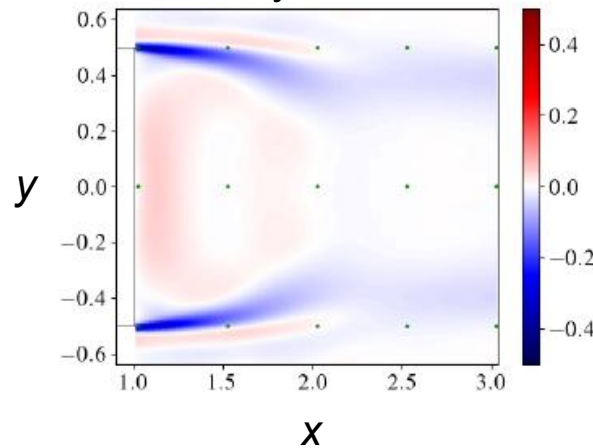
Super-resolution and pressure reconstruction

Of an axisymmetric bluff-body wake

Assimilated velocity field

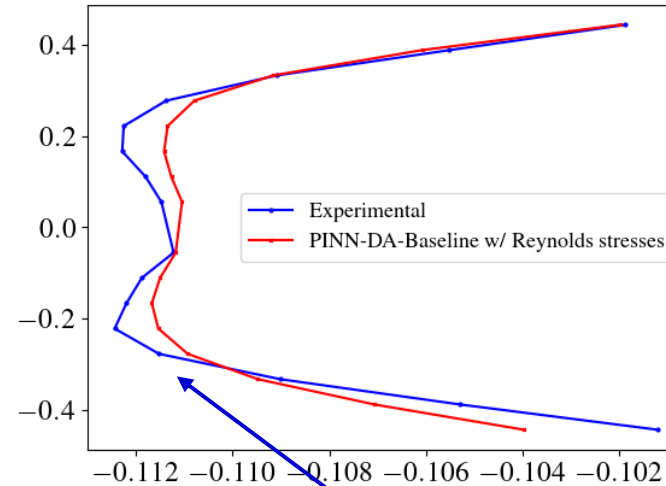


Velocity field error

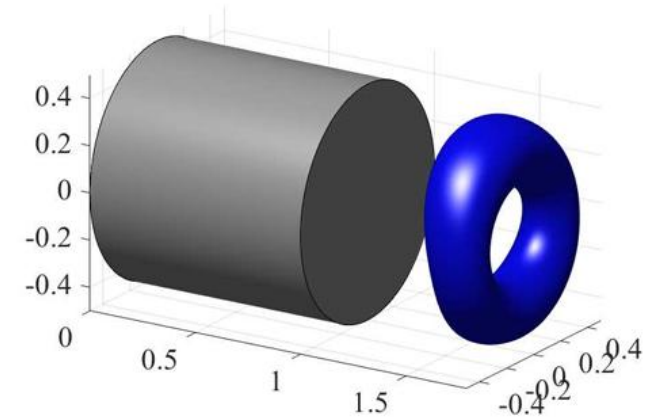


Assimilated pressure field

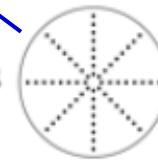
At the wall



In the wake



Pressure taps



Pressure was not included in training data

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PINNs offer a convenient approach to solving **inverse problems** by naturally utilizing automatic differentiation and GPU acceleration

Inverse problems include super-resolution, denoising and inference of missing fields or model parameters

This enables analysing fields that cannot directly be measured, as well as downstream operations (stability analyses, optimization, etc.)

PINNs for super-resolution and flow reconstruction

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25/06/2026

More in our papers:

Bump flow:

R. Klopsch, L. M. Fuchs, G. Rigas, K. Oberleithner, and J. G. R. von Saldern, "Spectral analysis...", *JFM*, 2026.

R. Klopsch, L. M. Fuchs, G. Rigas, K. Oberleithner, and J. G. R. von Saldern, "Enabling Resolvent Analysis...", *AIAA AVIATION*, 2025.

Bluff body wake:

Y. Patel, V. Mons, O. Marquet, G. Rigas, "Turbulence model augmented...", *PRF*, 2024.