



Data-driven predictions of unsteady flows

From Learning to Feel to Learning to Swim

Bharath Ganapathisubramani

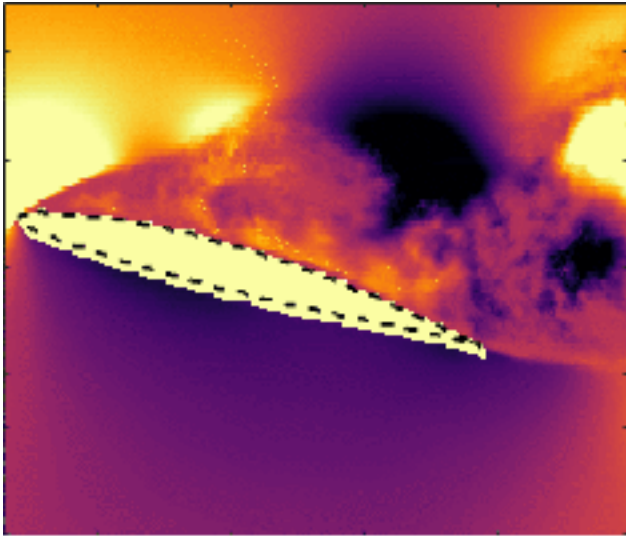
Department of Aeronautics & Astronautics
University of Southampton

Disclaimer

Only presenting work
I am involved in...

Motivation

Learning to feel



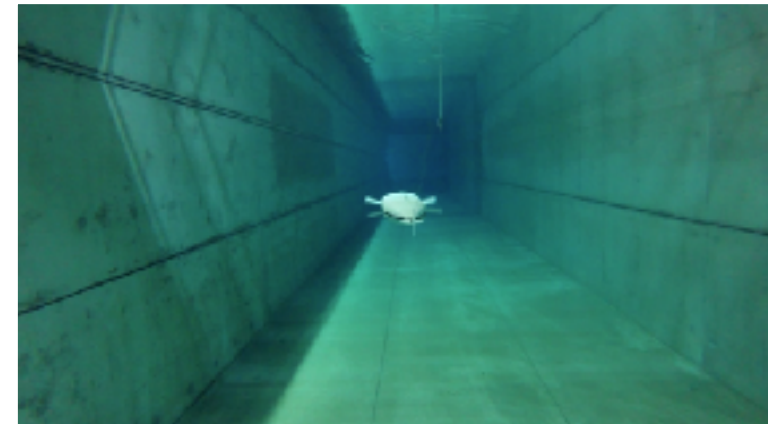
How does flow field affect the performance of my vehicle

Do surface
tuft motions
have links to
forces/
moments?

Can we
optimize
kinematics
with limited
information?

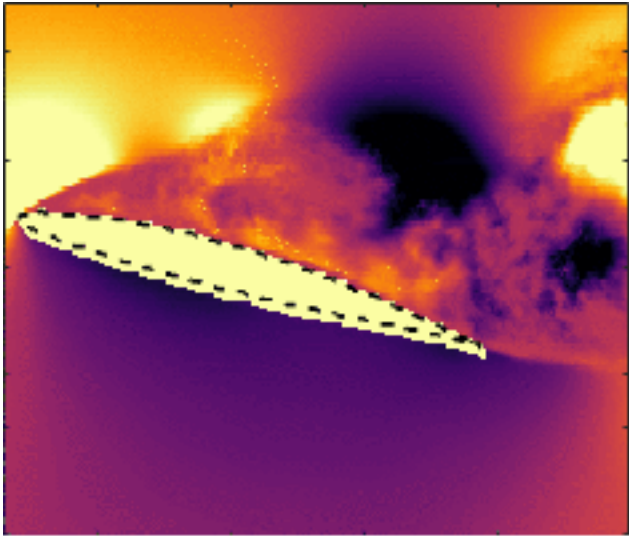
Predict **skin-friction** and
Force/moment fluctuations

Learning to swim



Credit

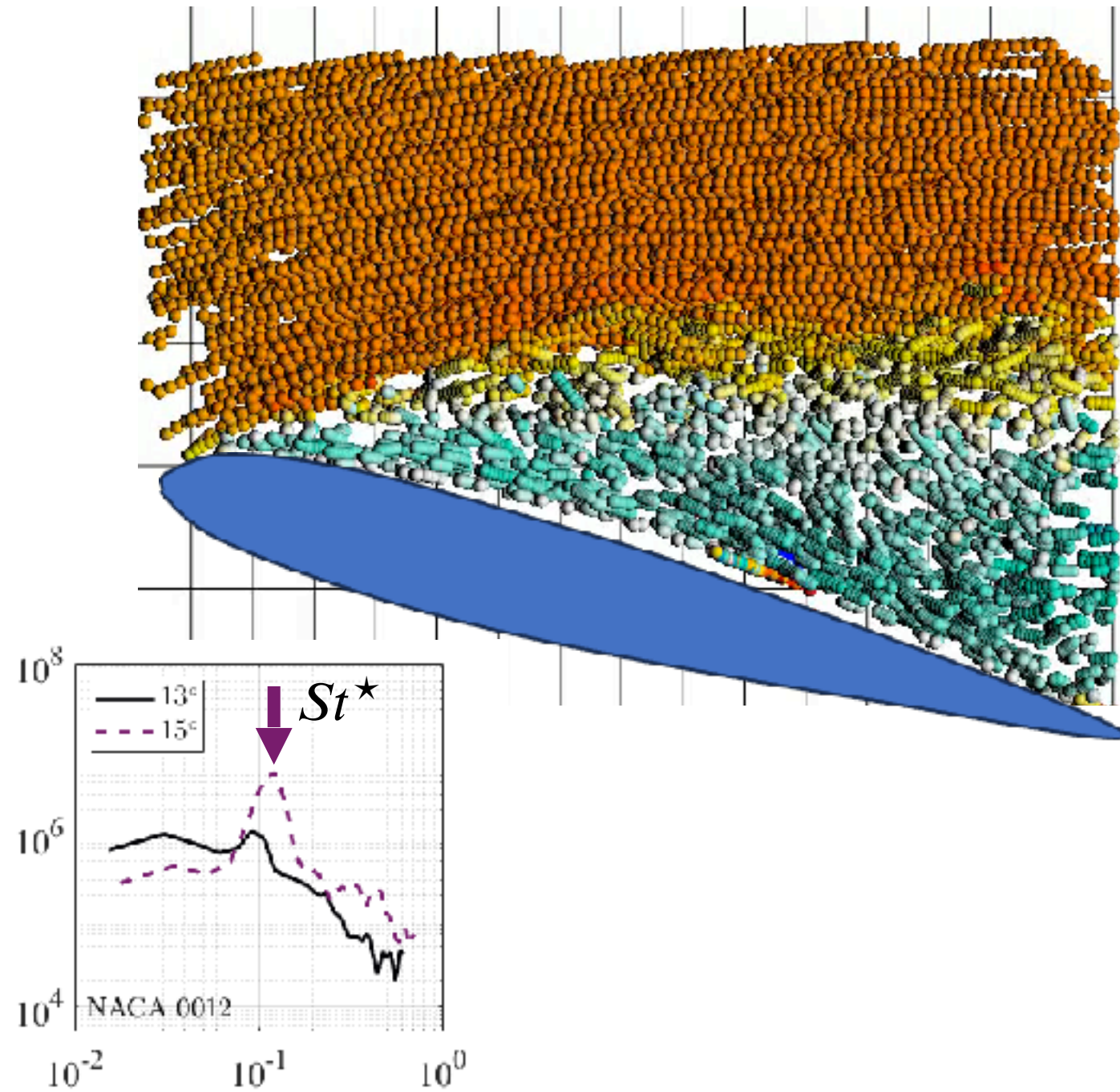
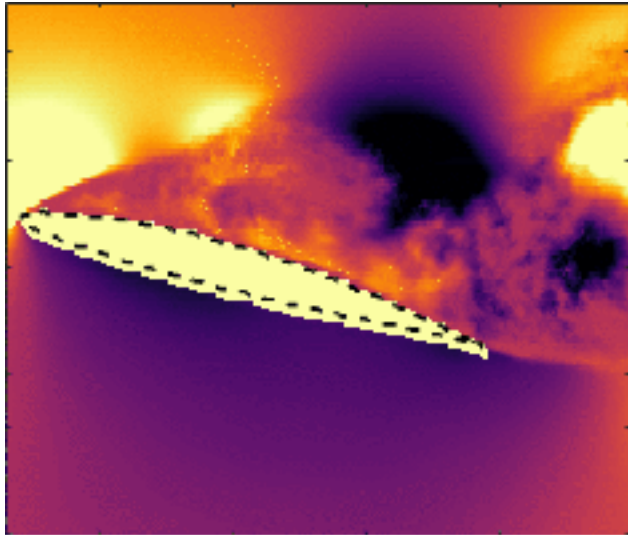
Learning to feel



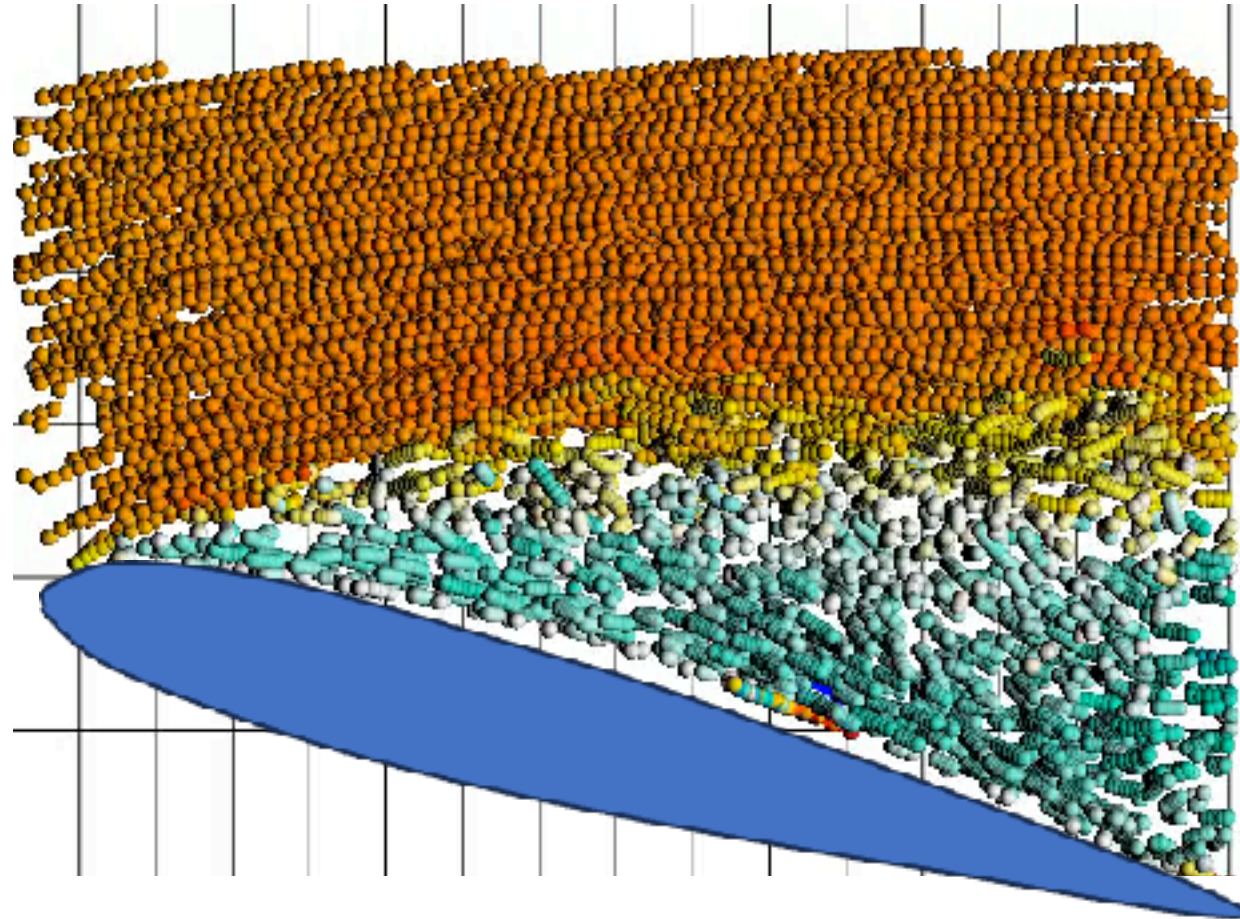
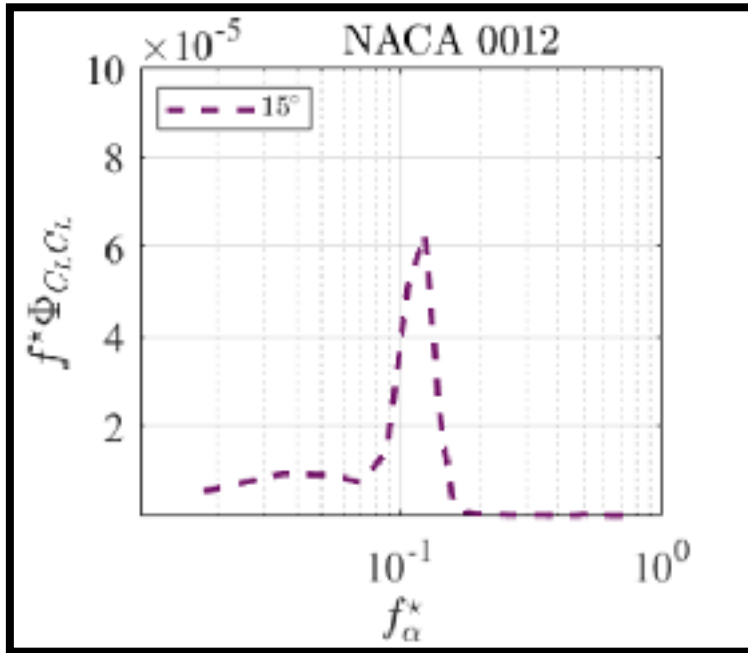
Francis de Voogt



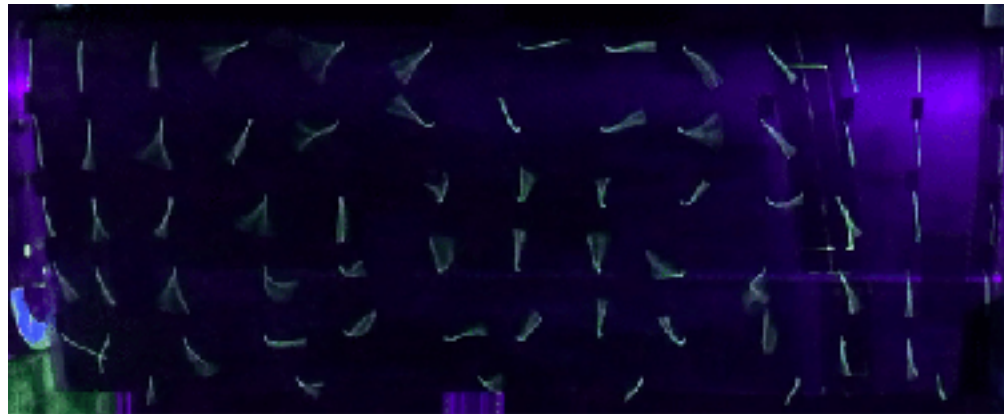
Separated flows



Separated flows



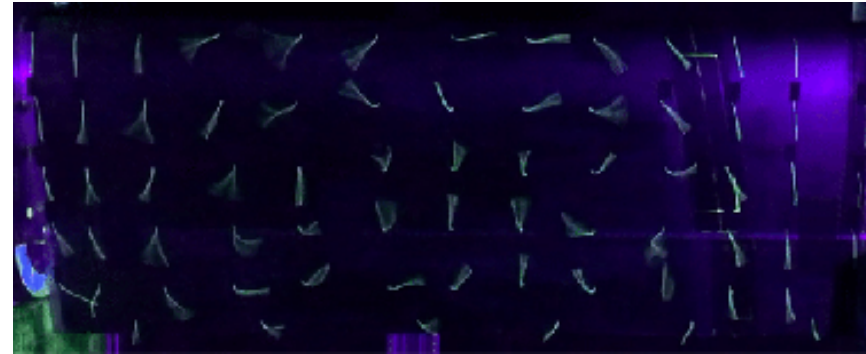
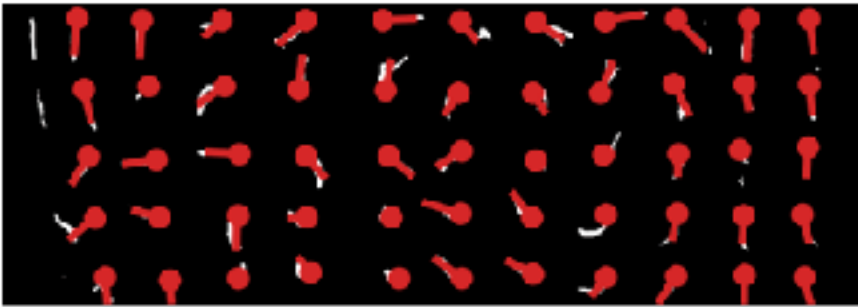
Can we relate surface signature to forces and moments?



Unsteady wing loading from tufts

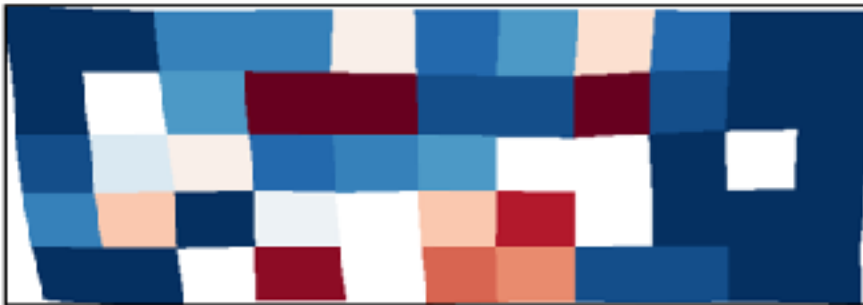
Angle of attack 15° and Reynolds number 400,000

BW image
with final tufts

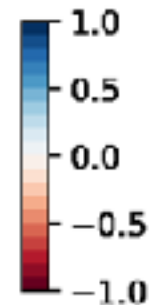
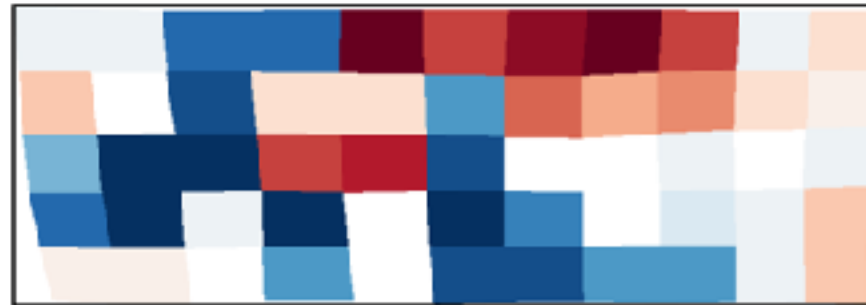


Encode
force data in
to tuft motion

tuft angle cosine
(chordwise flow)

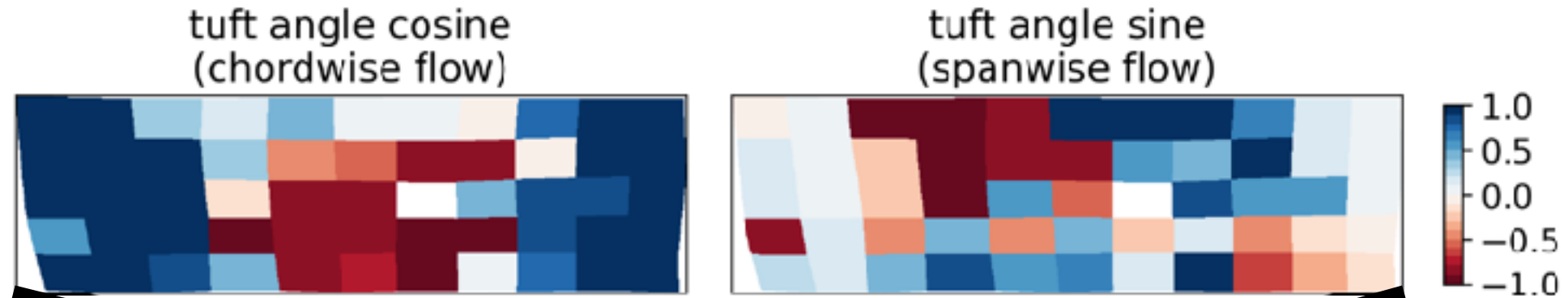


tuft angle sine
(spanwise flow)



Simultaneous force measurements synchronised with tuft visualisations

Unsteady wing loading from tufts



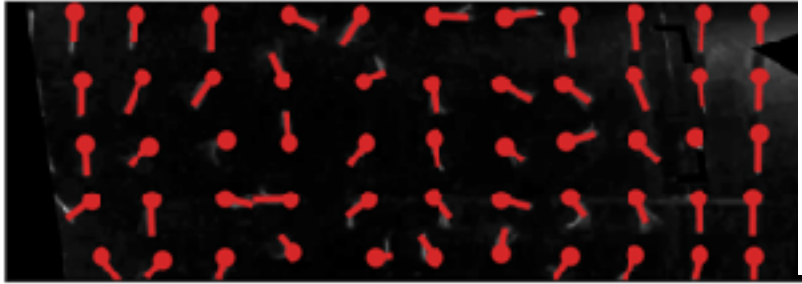
Mean comes from
Potential flow model or
steady lift/moment data

Deviations from ML model

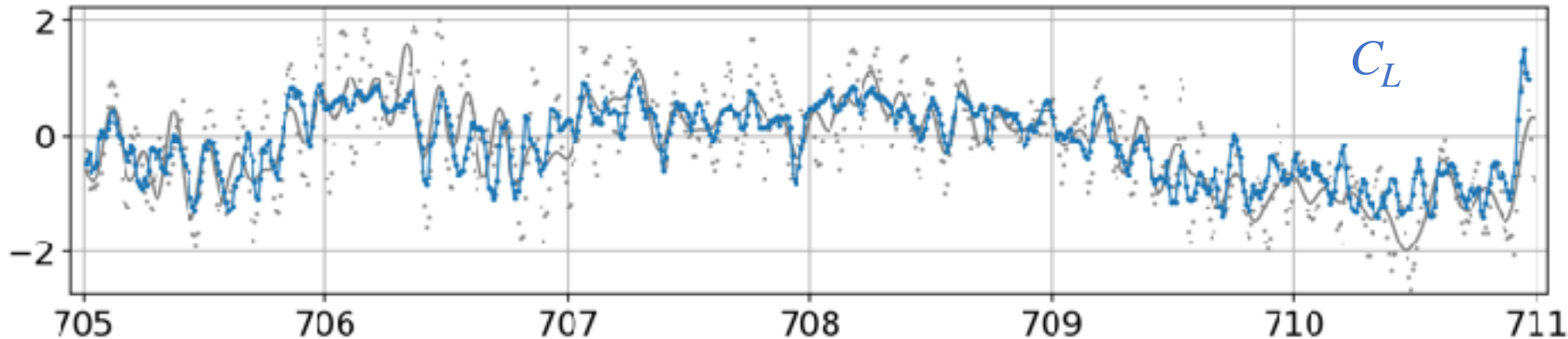
C_L C_M

Unsteady wing loading from tufts

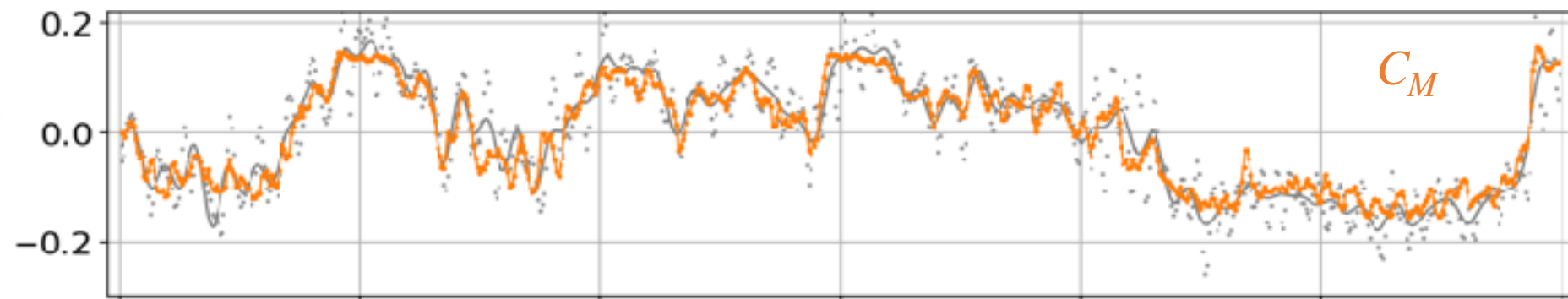
Angle of attack 17° and Reynolds number 500,000



Decode tuft motion to
infer force/moment data



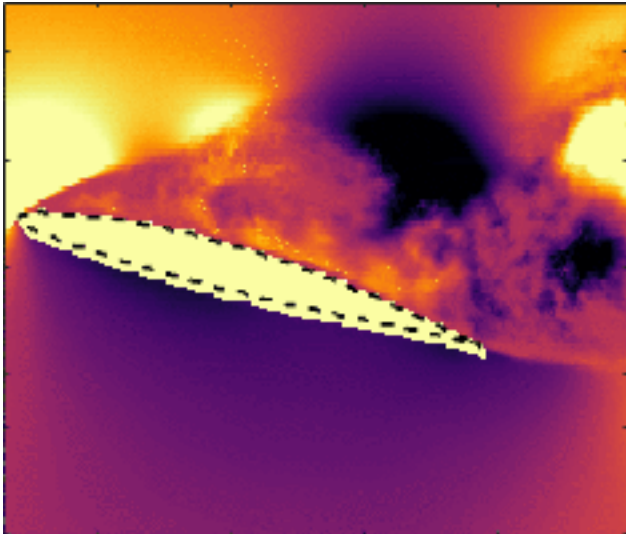
Works in realtime!



Can extend to
sensors in the flow

Motivation

Learning to feel



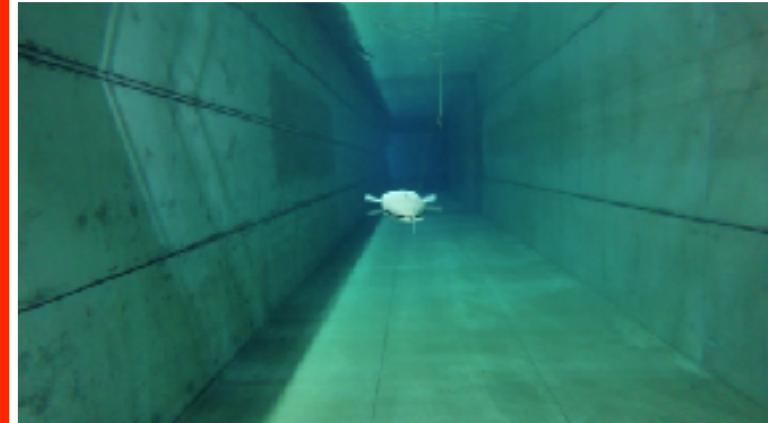
How does flow field affect the performance of my vehicle

Do surface tuft motions have links to forces/moments?

Can we optimize kinematics with limited information?

Predict **skin-friction** and **Force/moment fluctuations**

Learning to swim



Credit



Engineering and
Physical Sciences
Research Council



Rodrigo Vilumbrales

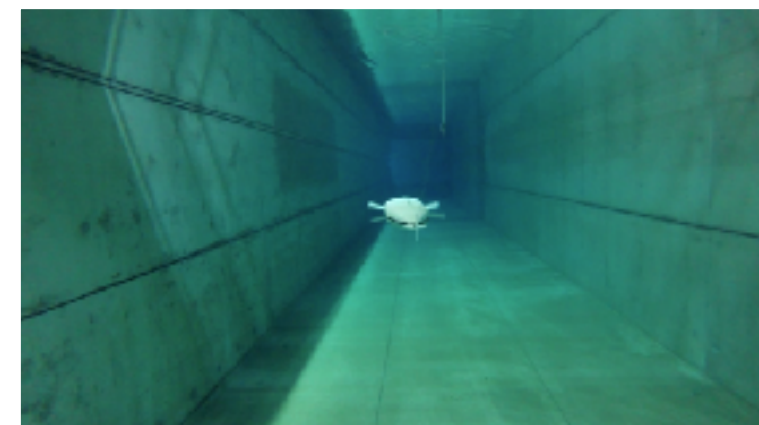


Bailey McAtee



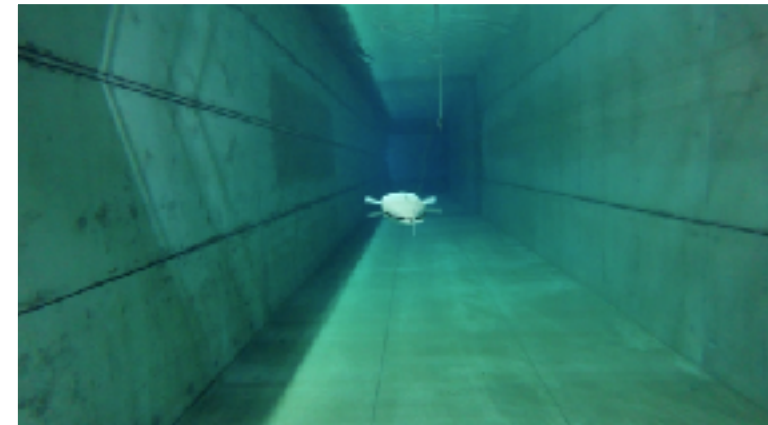
G. D. Weymouth

Learning to swim



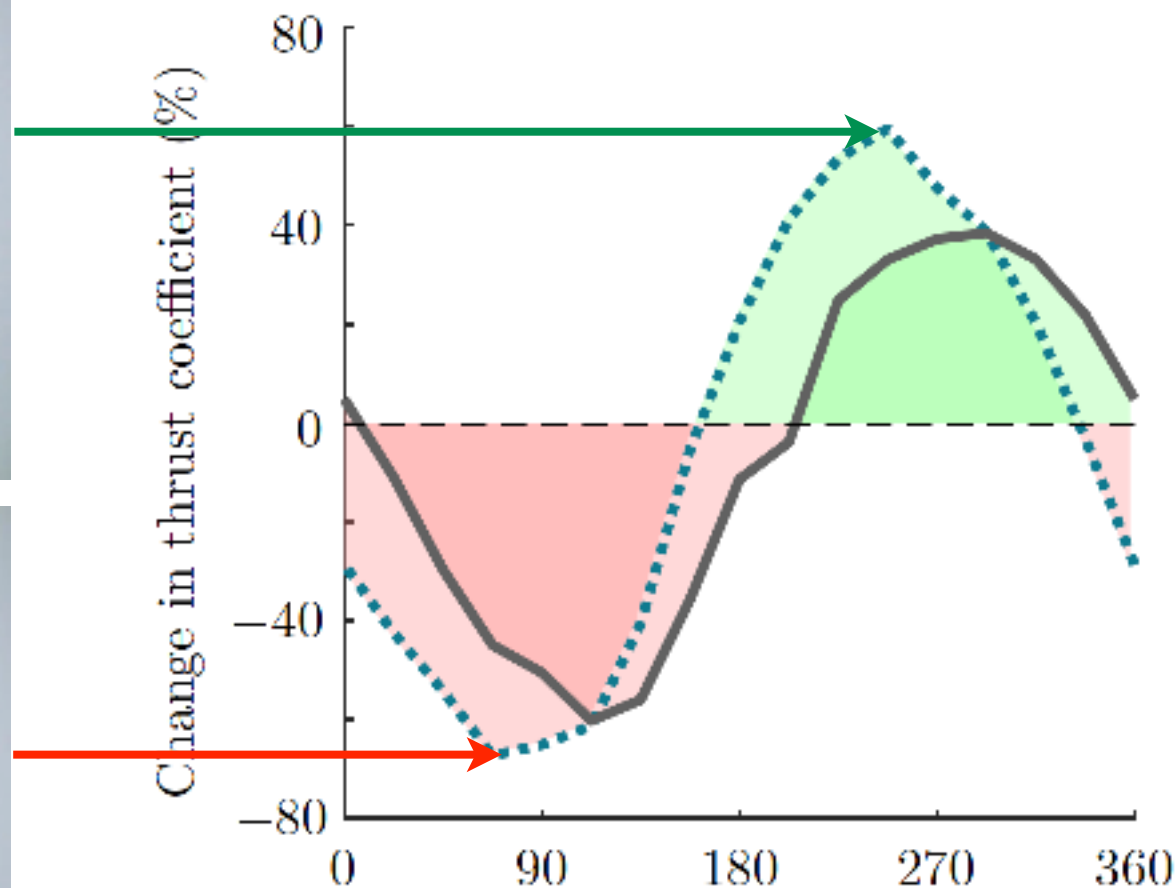
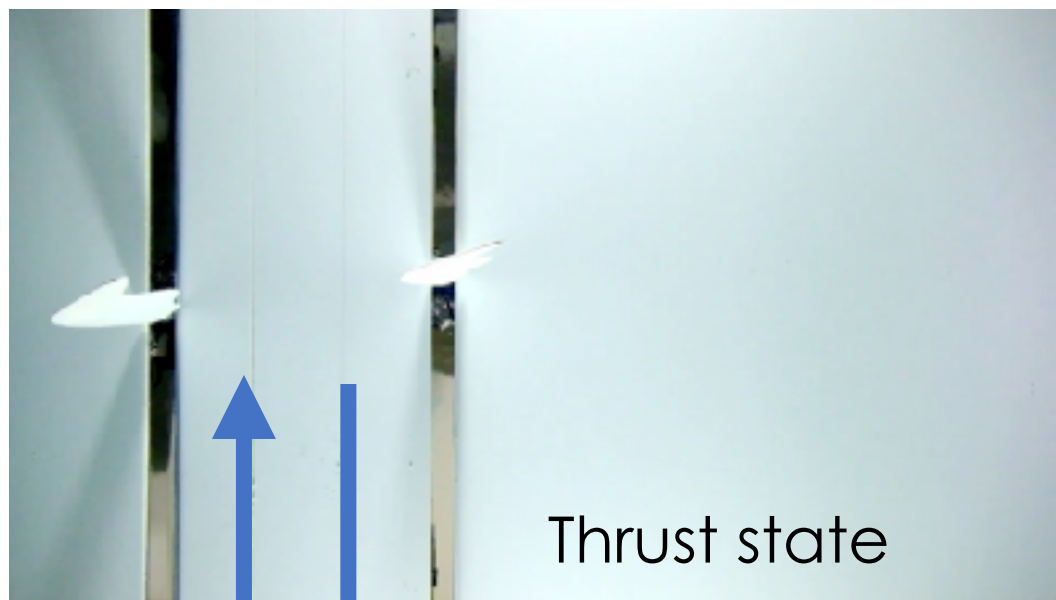
ATLANTIS: Underwater vehicle

- Fully autonomous
- Cruising speed of 0.6 m/s
- Turns in place
- At speed circle $\sim 0.5L$



How is this possible?

Learning to swim

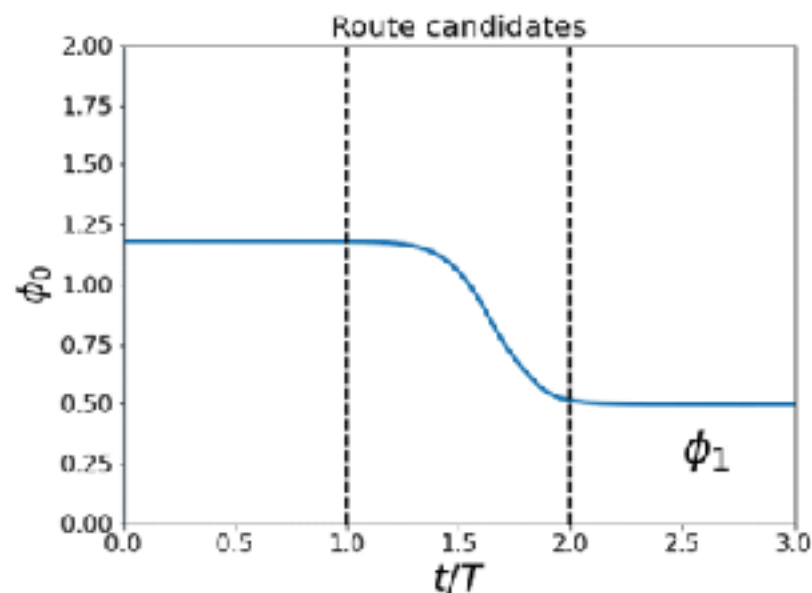
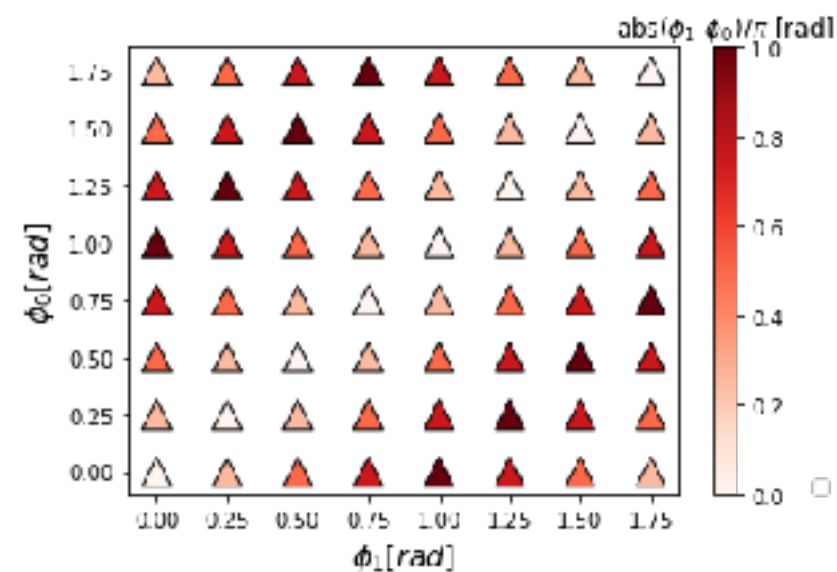


Identify manoeuvres from **drag** to **thrust**
(and vice-versa)

Optimisation

Surrogate model for loads with various kinematics...

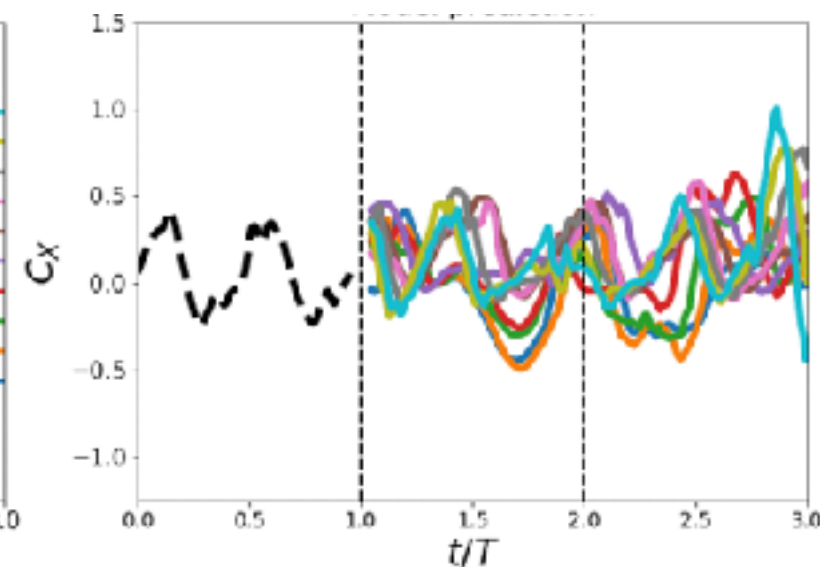
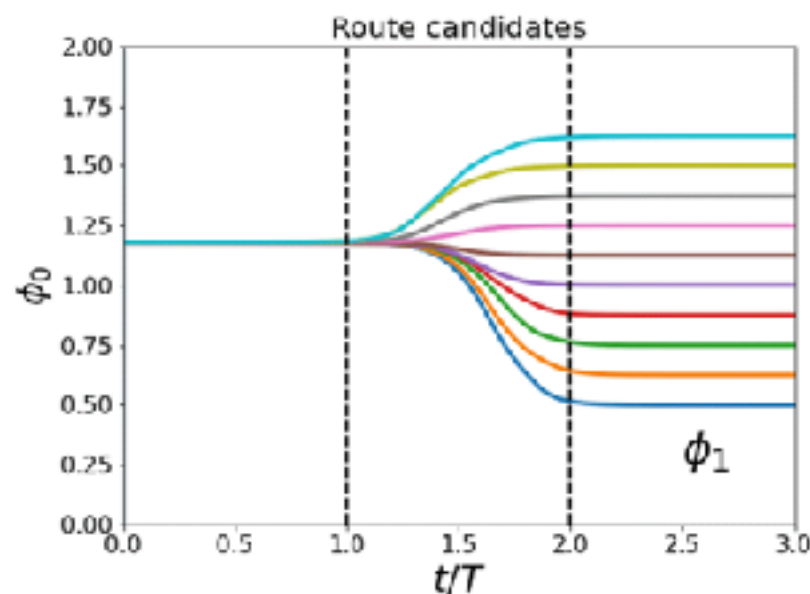
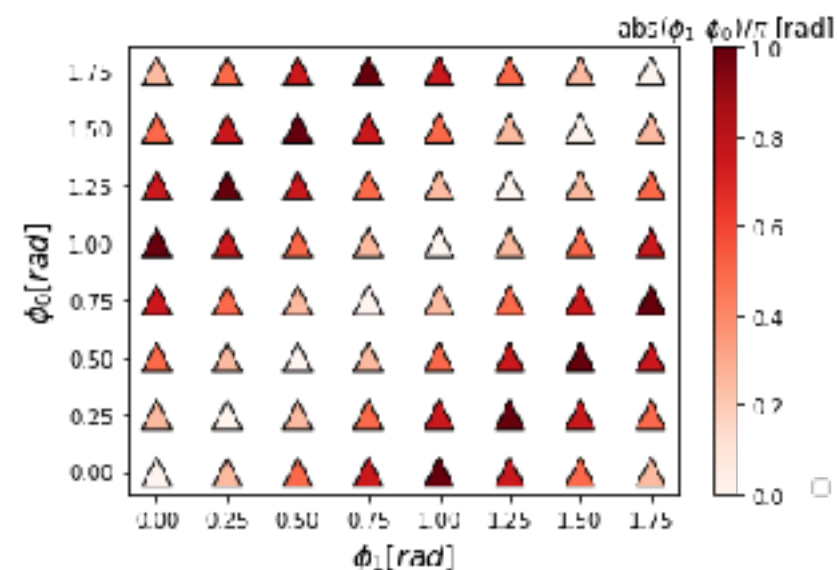
Numerical data for multiple start/end states with a given manoeuvre



Optimisation

Surrogate model for loads with various kinematics...

Numerical data for multiple start/end states with a given manoeuvre



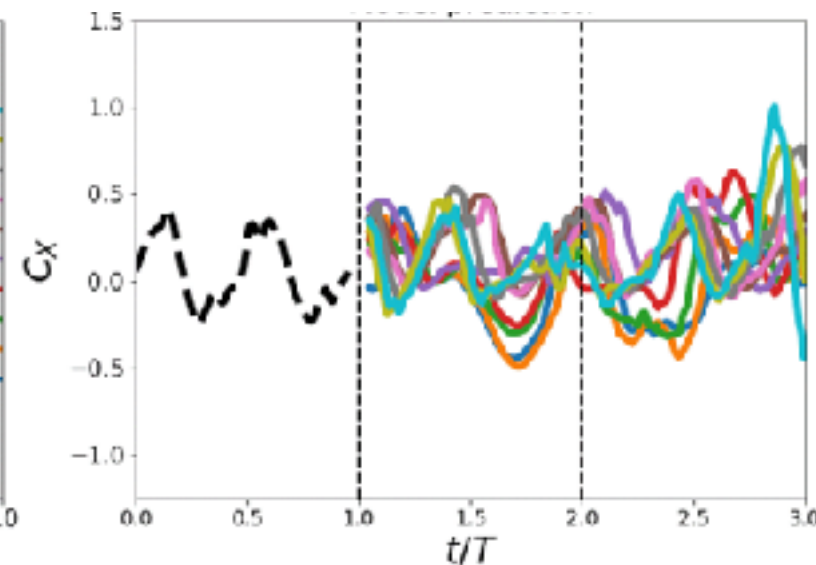
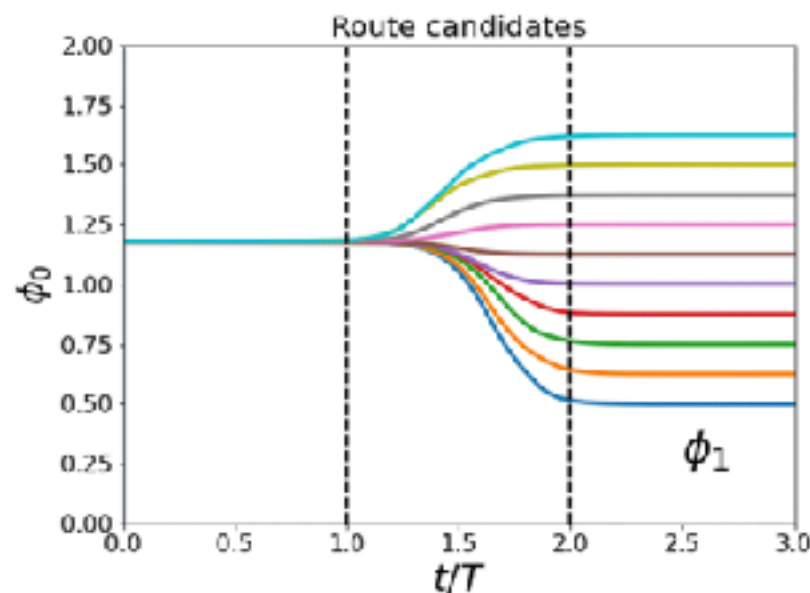
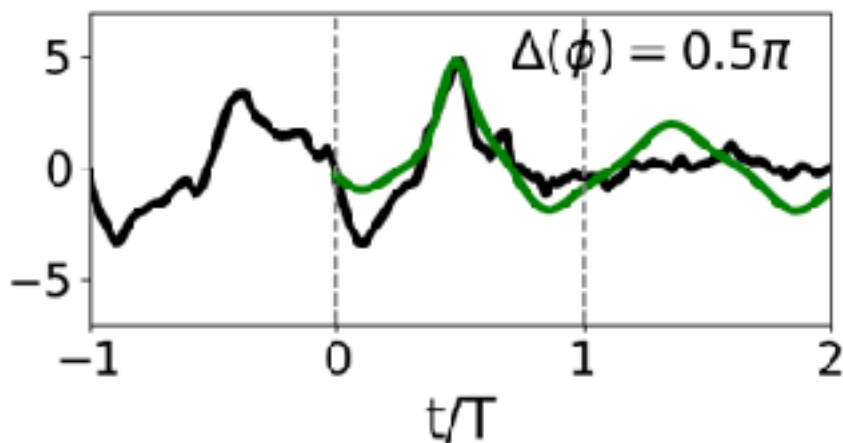
Optimisation

Surrogate model for loads with various kinematics...

Numerical data for multiple start/end states with a given manoeuvre

$$\frac{dC_L}{dt} = f(C_L, U)$$

U - Kinematics



Lasso $U = g(h, \dot{h}, \ddot{h}, \theta, \dot{\theta}, \ddot{\theta})$

SINDy (Brunton et al. 2016)

Optimisation

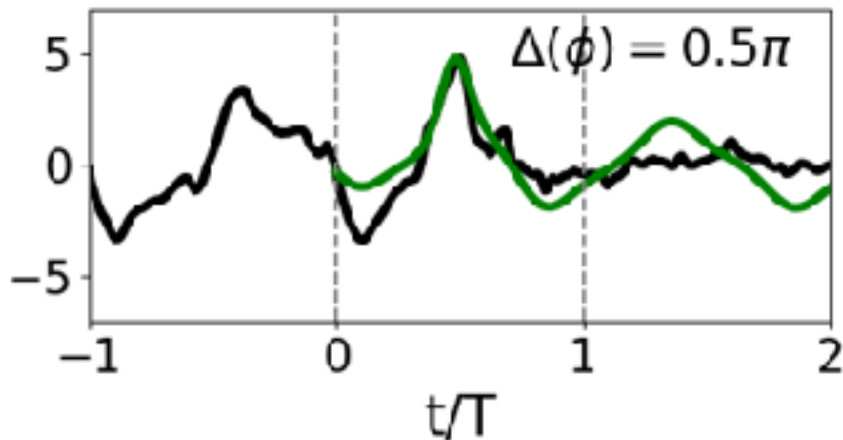
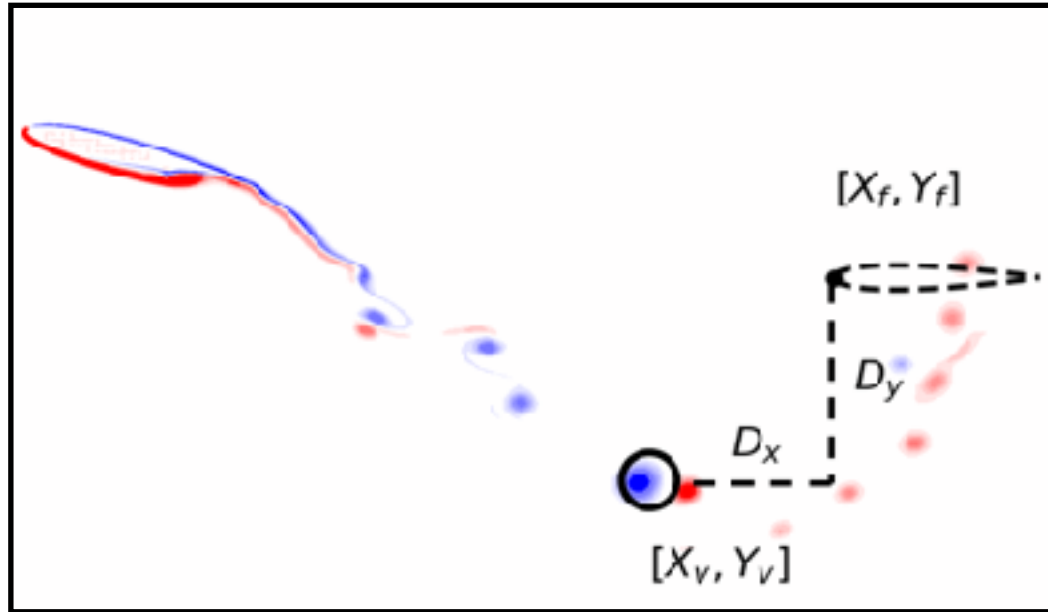
Surrogate model for loads with various kinematics...

Numerical data for multiple start/end states with a given manoeuvre

$$\frac{dC_L}{dt} = f(C_L, U)$$

U - Kinematics

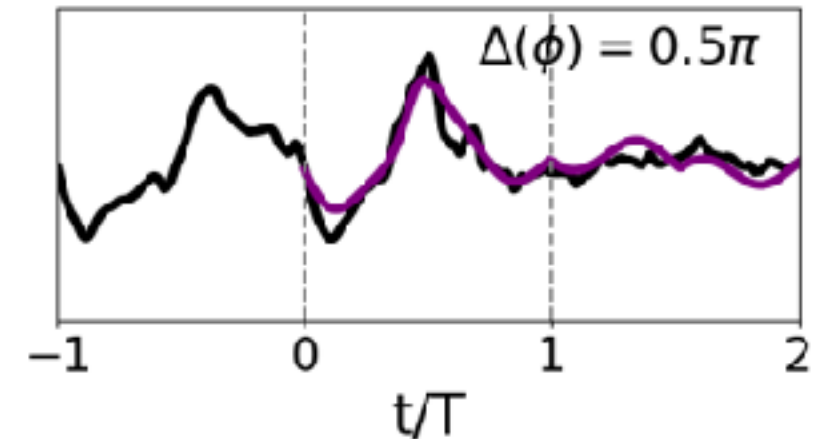
Vortex information



Lasso $U = g(h, \dot{h}, \ddot{h}, \theta, \dot{\theta}, \ddot{\theta})$
SINDy (Brunton et al. 2016)

Physics-infused

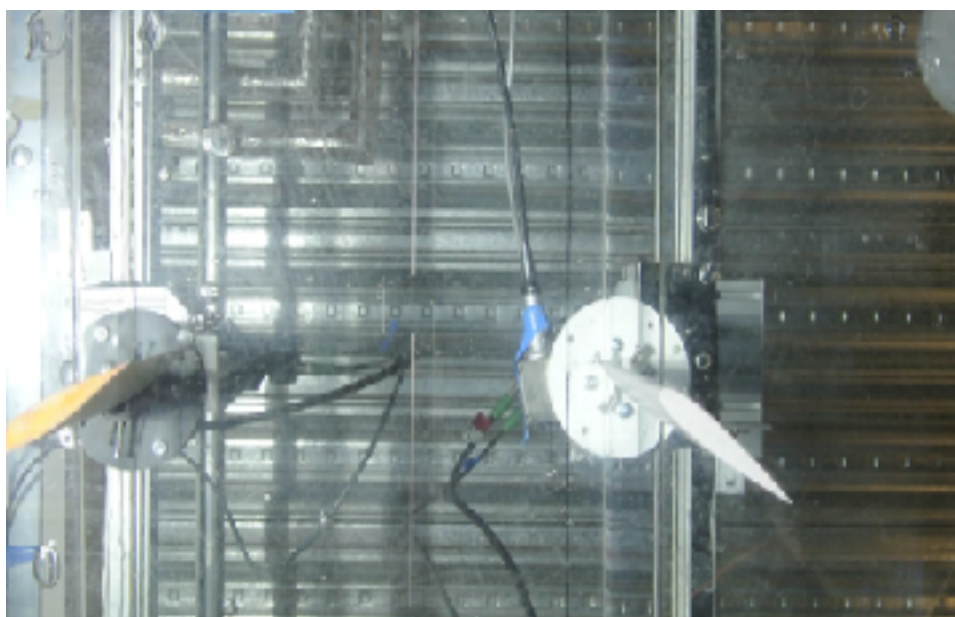
$$U = p(g, D_x, D_y, \dot{D}_x, \dot{D}_y)$$



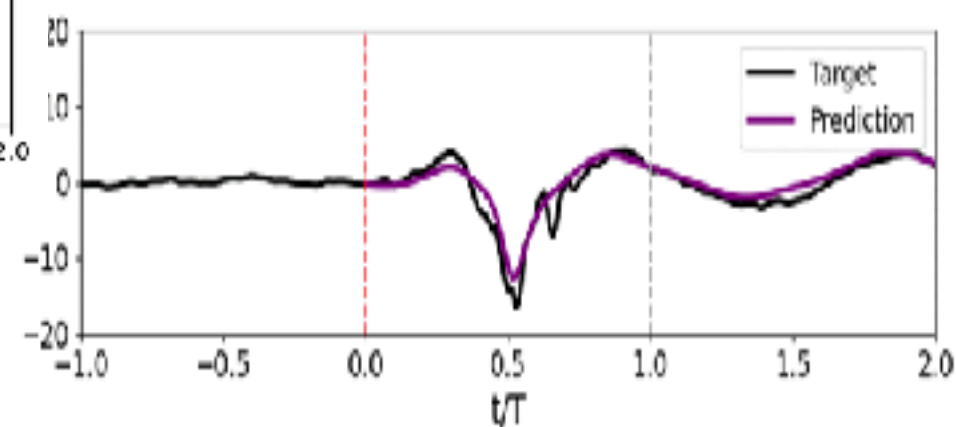
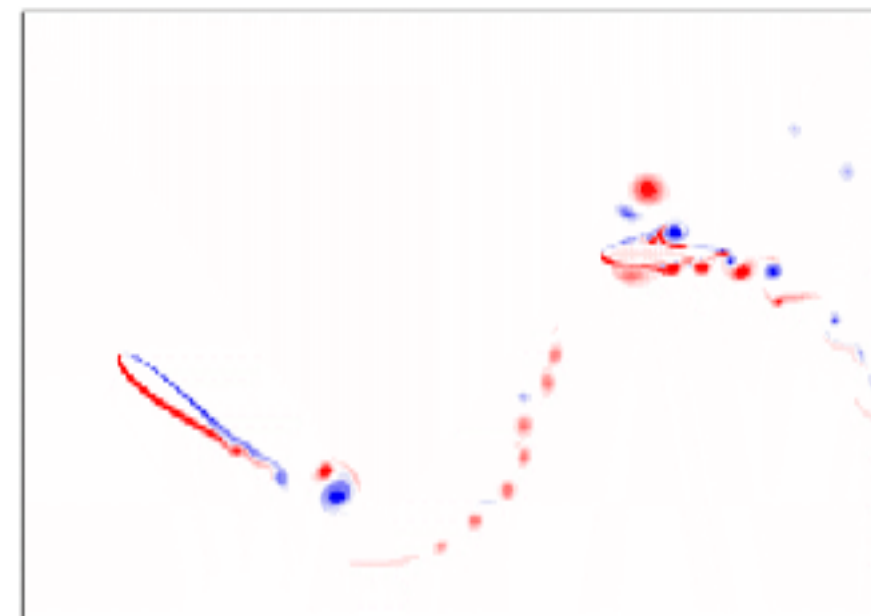
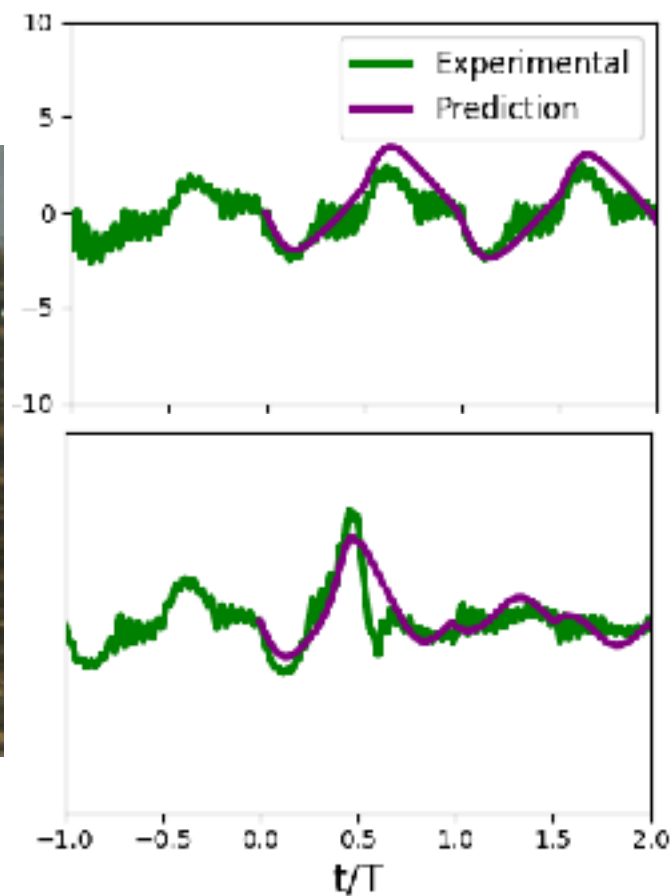
Optimisation

Surrogate model for loads with various kinematics...

Physics-infused Lasso



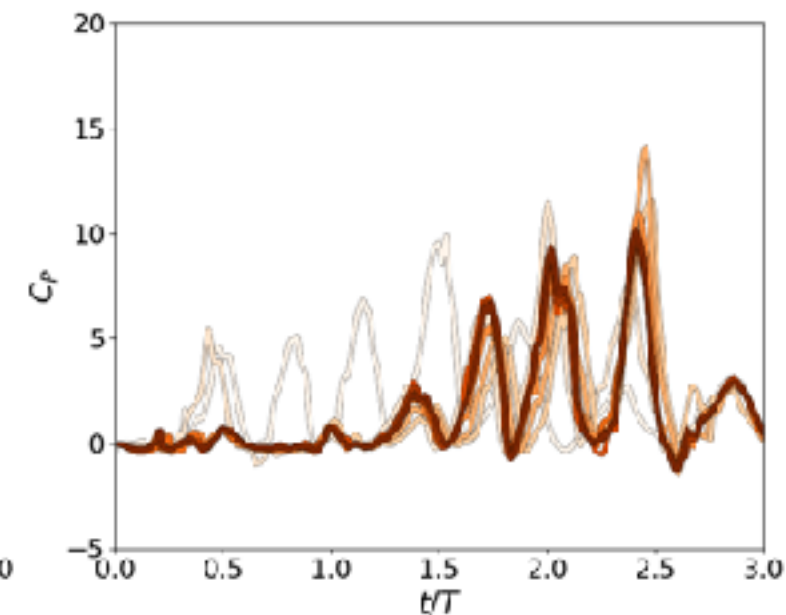
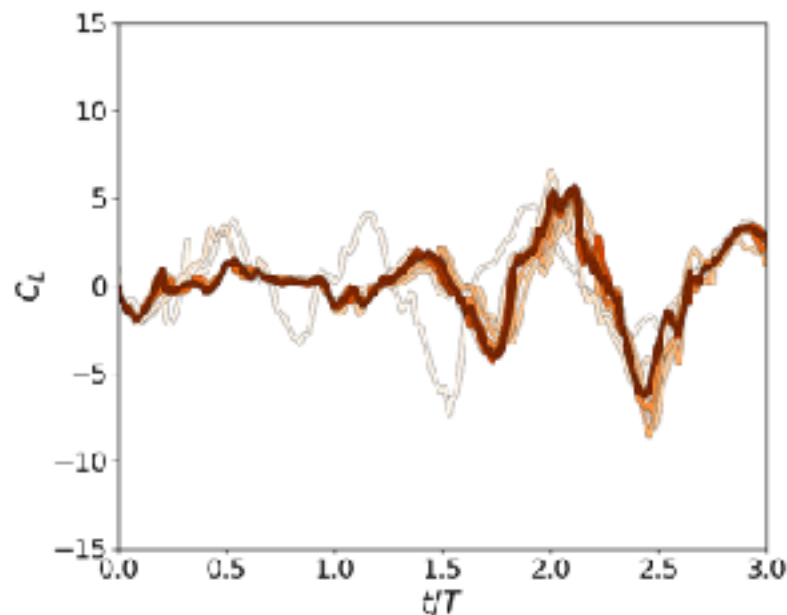
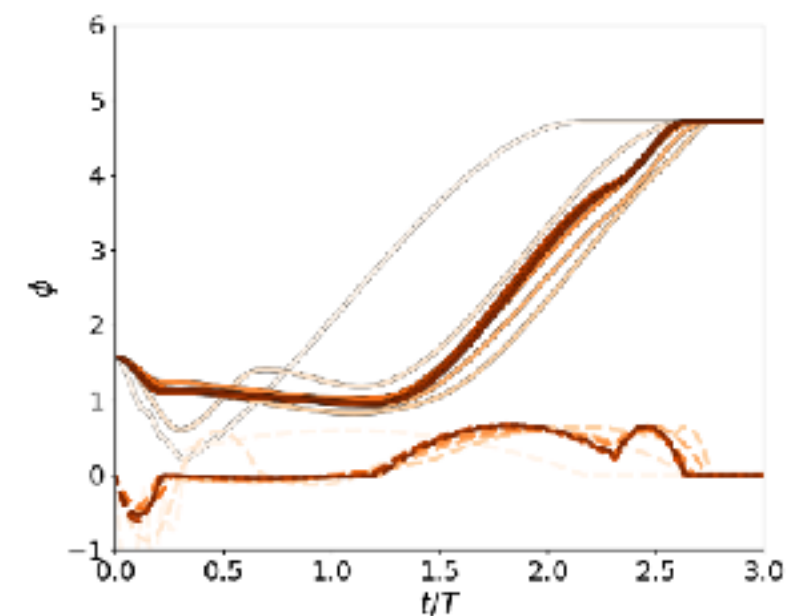
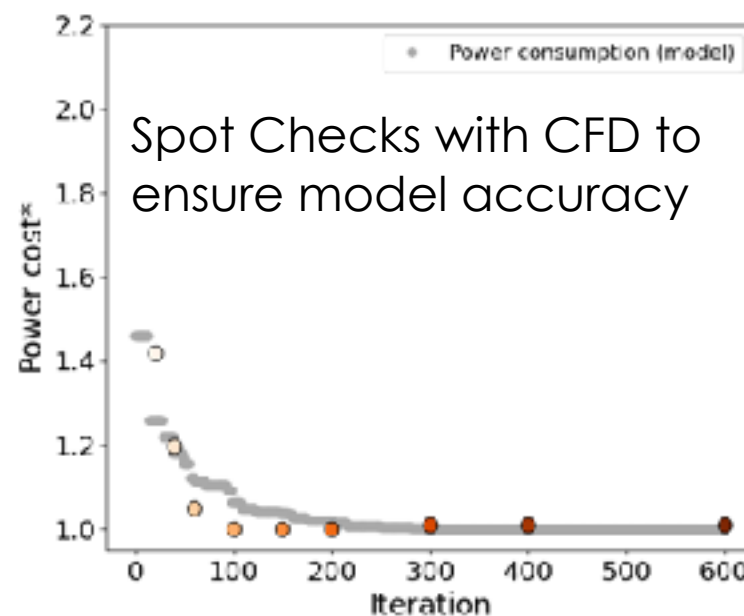
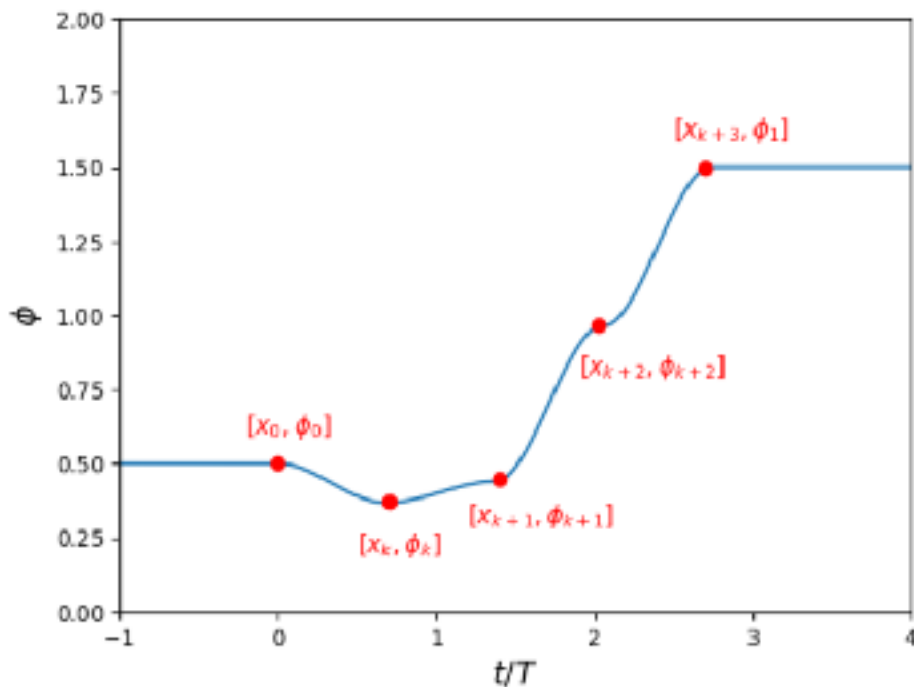
Use this model to generate
power efficient manoeuvres



Power efficient manoeuvres

Minimize power use during transition to best phase

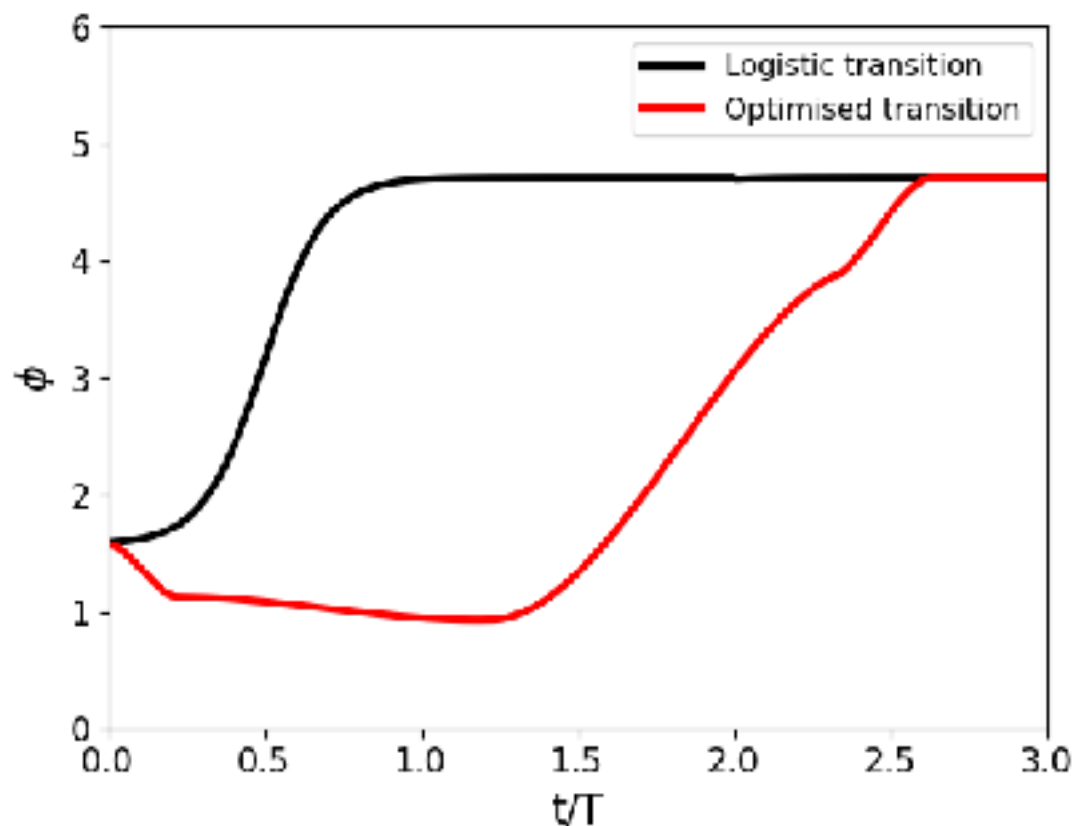
Genetic optimisation



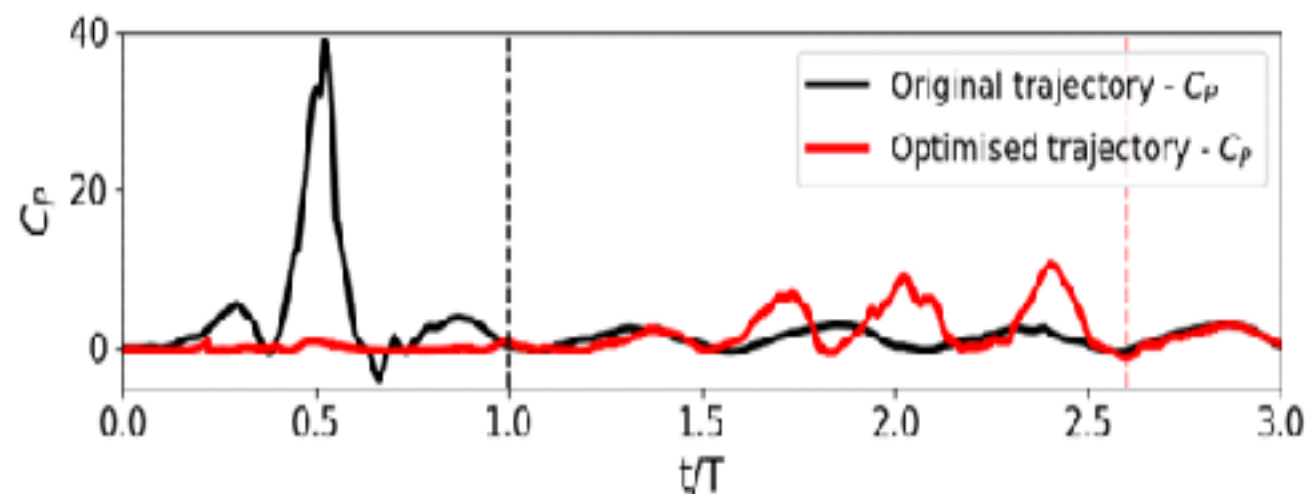
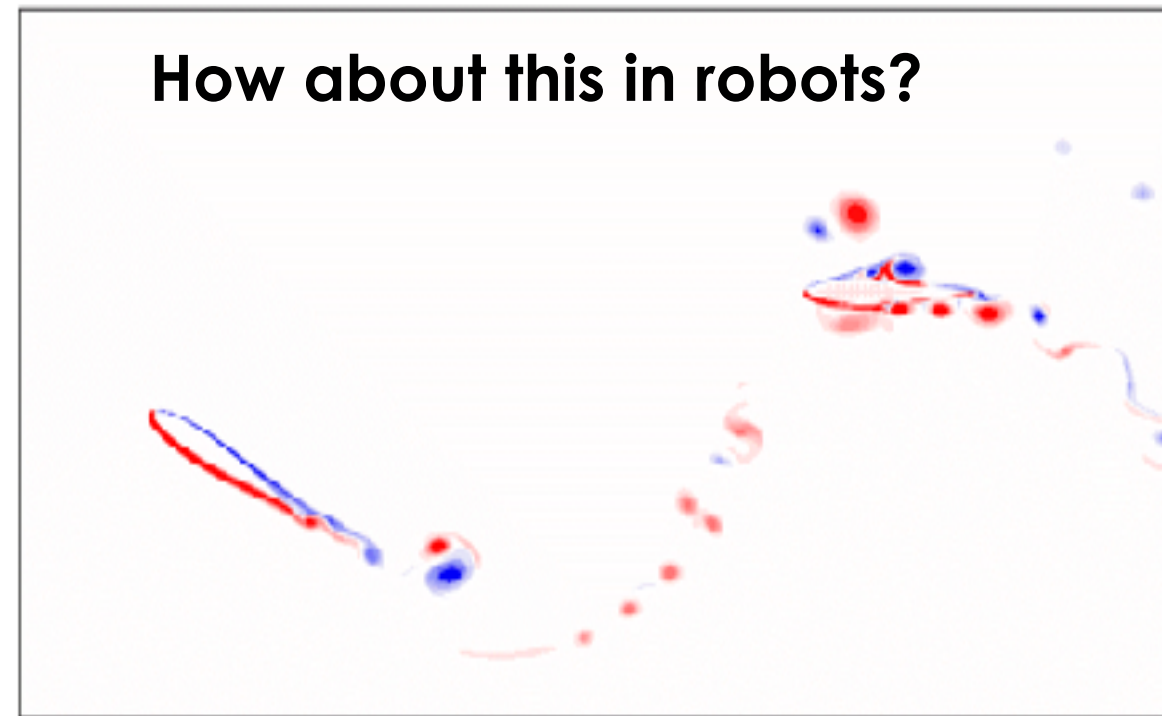
Power efficient manoeuvres

Two stages:

1. "Wait" or slow phase change
2. Accelerate phase - at the right time



How about this in robots?

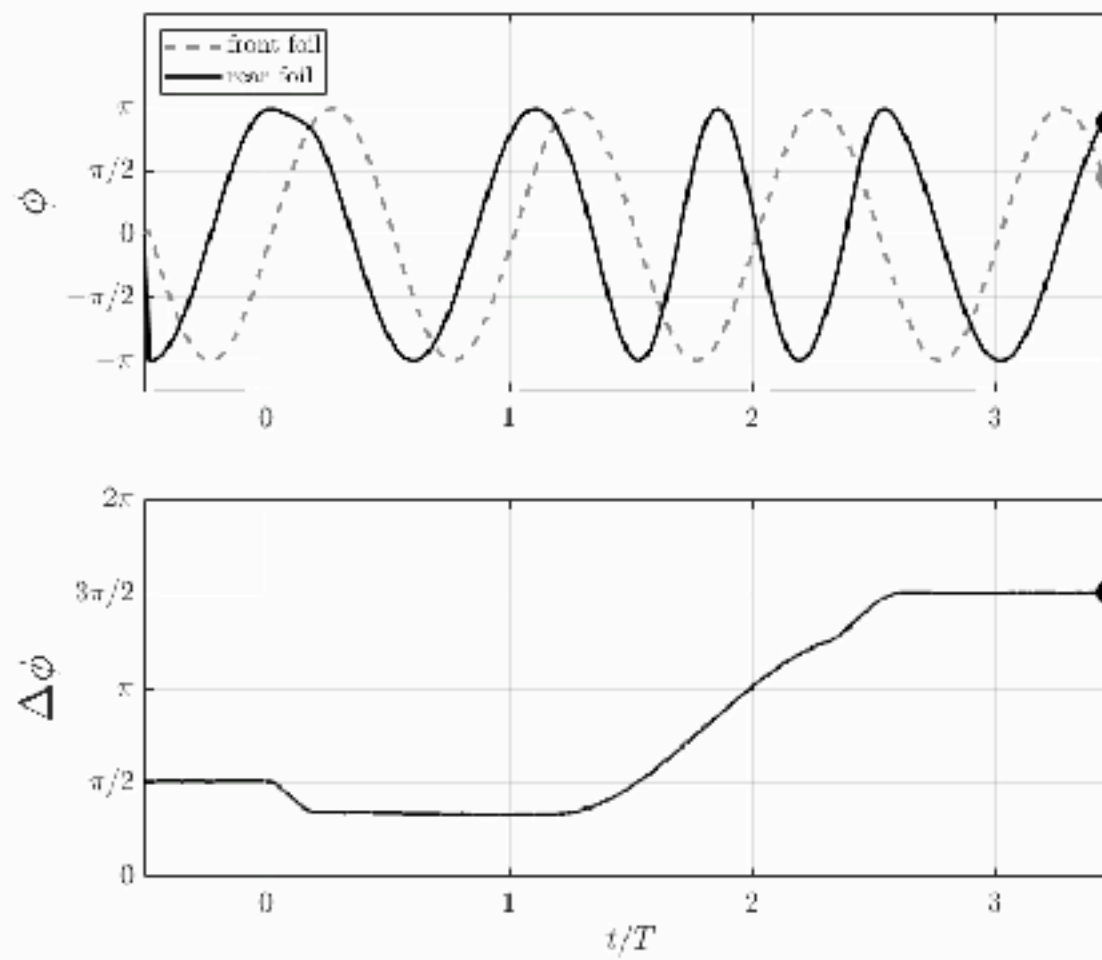
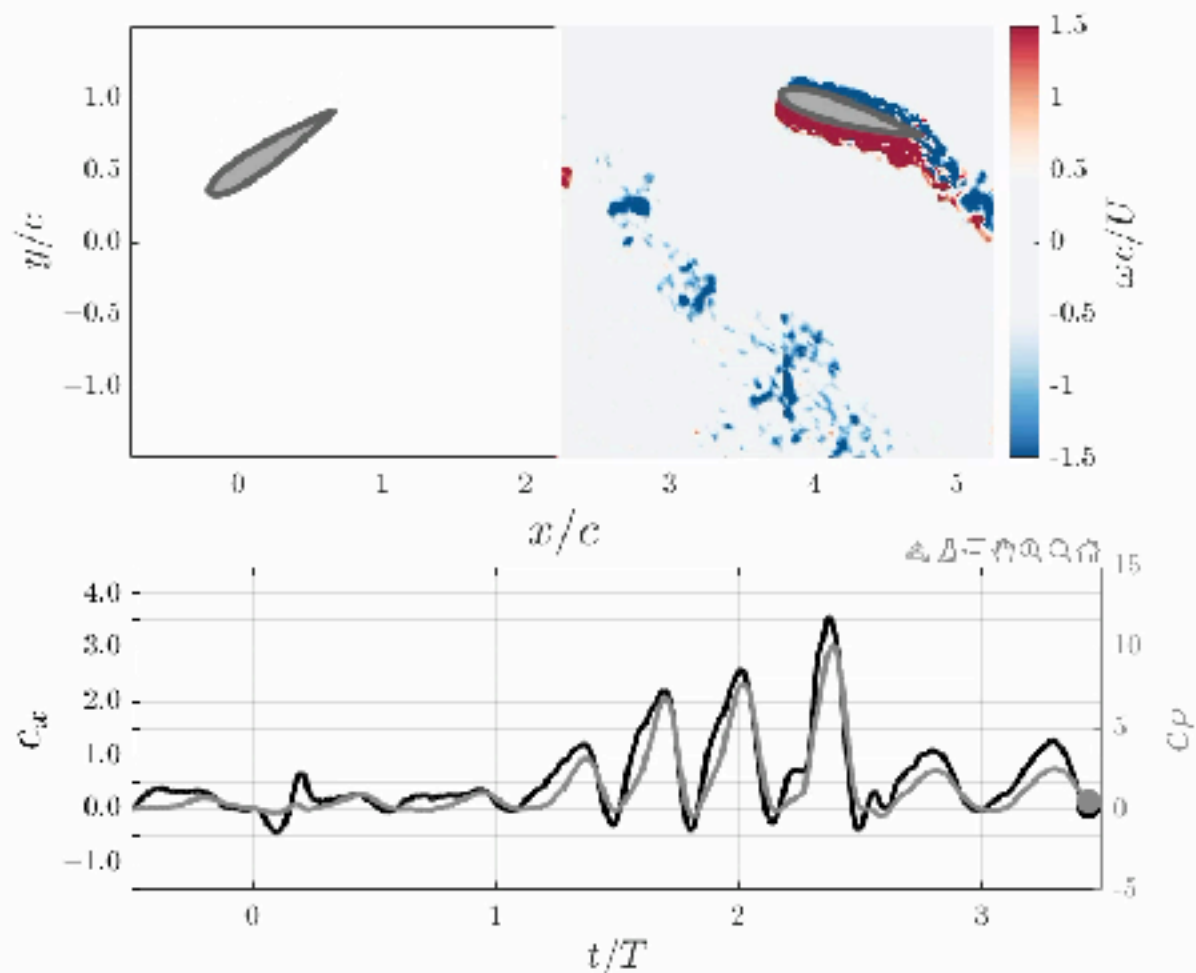


Experimental implementation

Two stages:

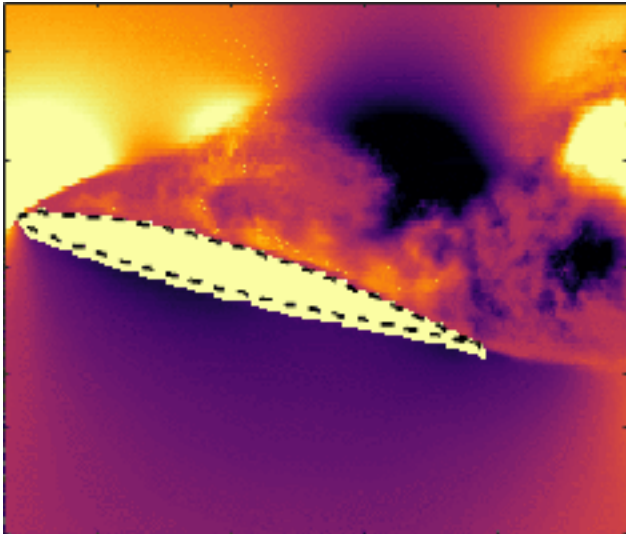
1. "Wait" or slow phase change
2. Accelerate phase - at the right time

This whole chain now automated in our new experiments...



Takeaways...

Learning to feel



Yes!

How does flow field affect the performance of my vehicle

Do surface tuft motions have links to forces/ moments?

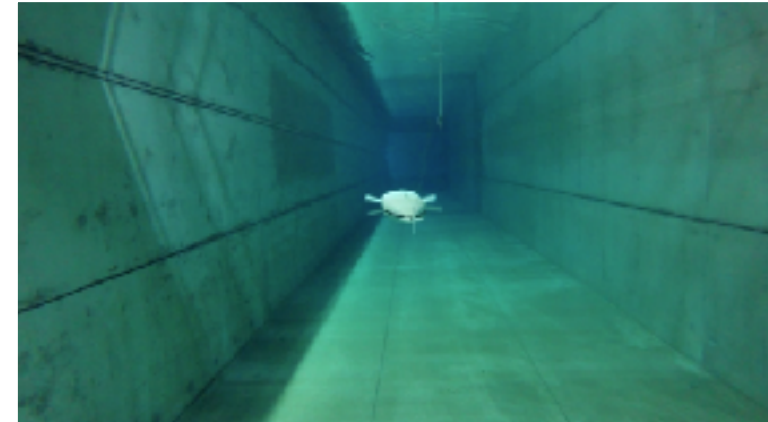
Can we optimize kinematics with limited information?

Need suitable formulations and varied data

THANK YOU!

g.bharath@soton.ac.uk
<http://www.bharath-lab.org/>

Learning to swim



Yes!