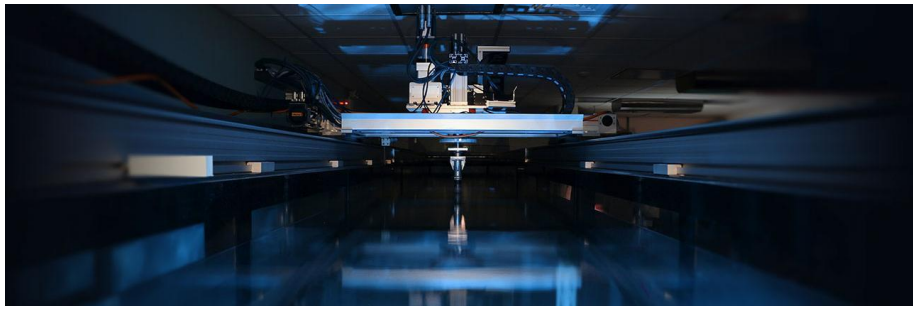
西湖大學
WESTLAKE UNIVERSITY

MATLAB Application in Intelligent and Bio-inspired Fluid Mechanics

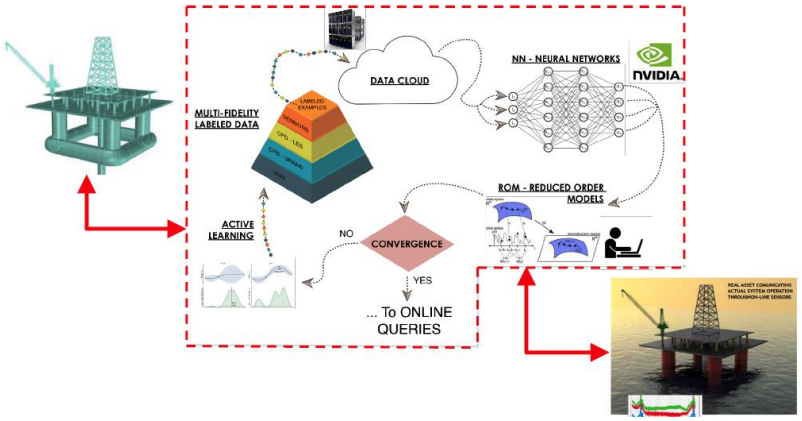
Dixia Fan, Westlake University

MATLAB EXPO

i^4 - FSI Lab at Westlake Univ.



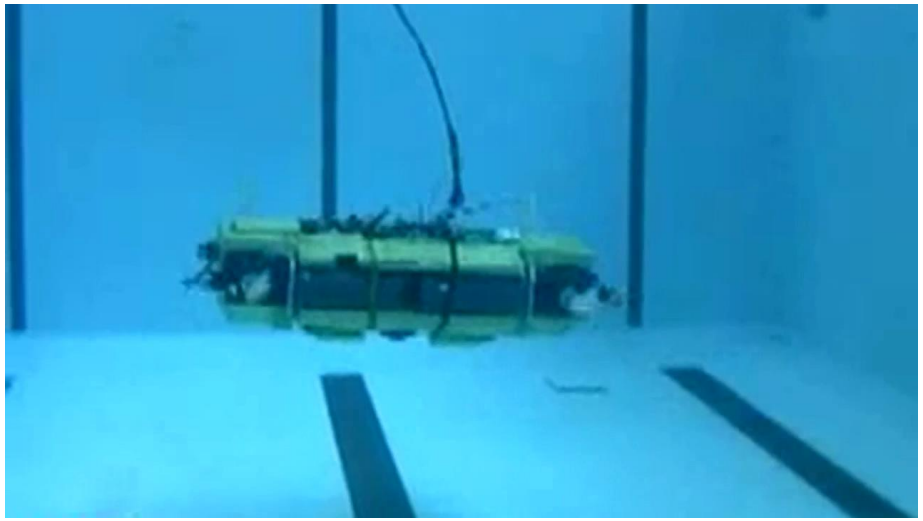
Intelligent Towing Tank



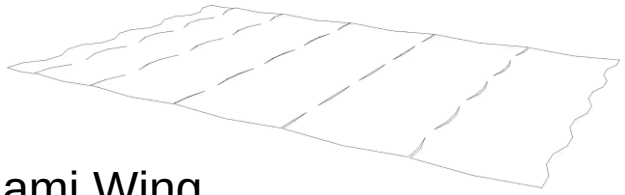
Digital Twin for Marine Risers

Invited ISOPE keynote

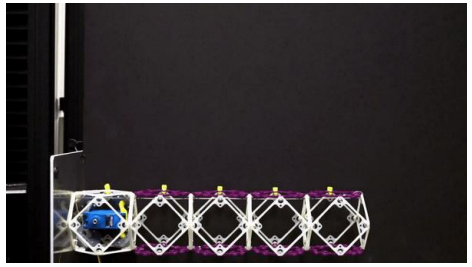
Intelligent,
Informational,
Integrative,
Interdisciplinary
Fluid-Structure Interaction



MIT Roboturtle



Origami Wing



Discrete Voxel Robot

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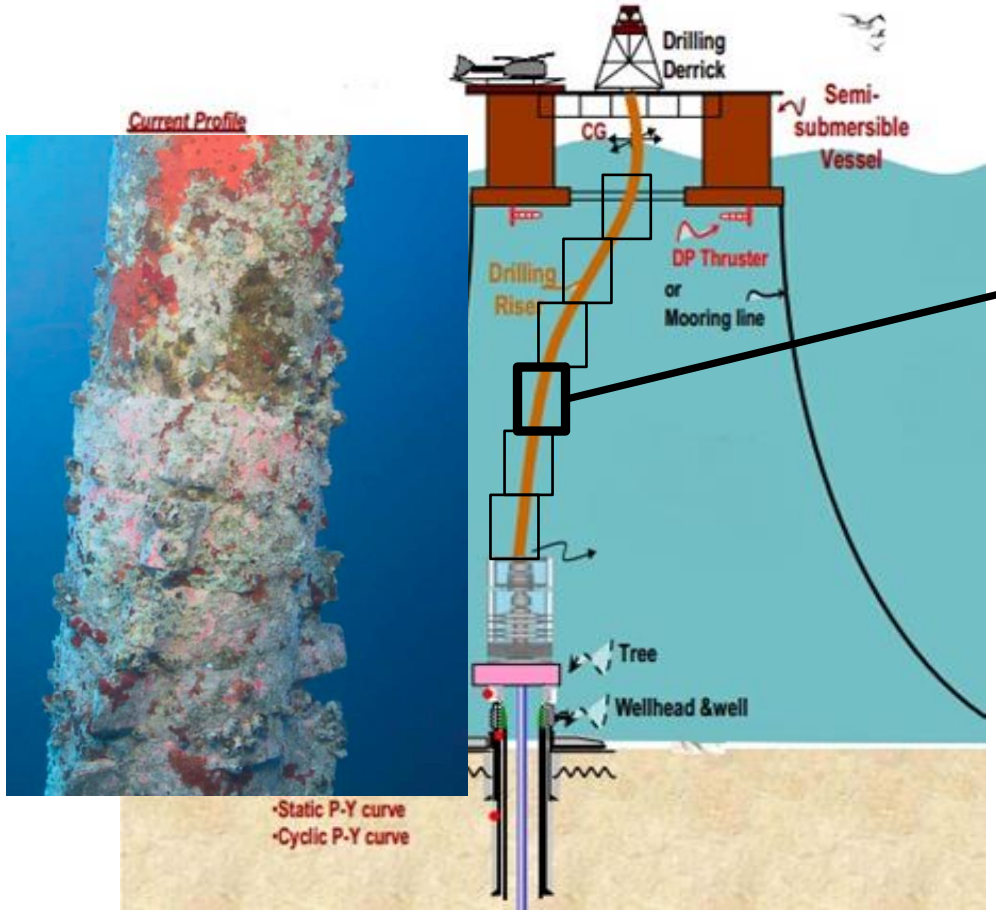
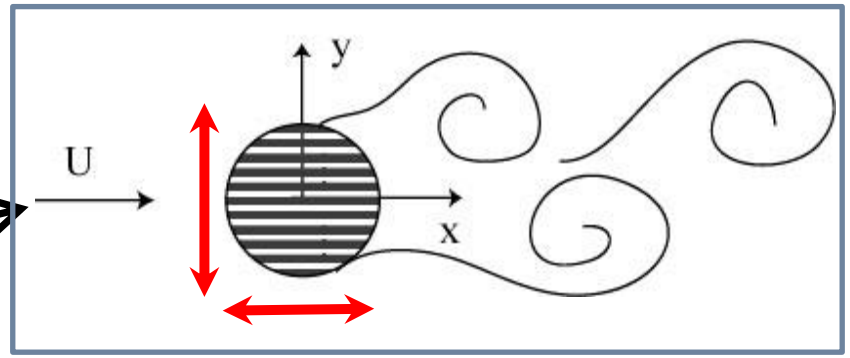
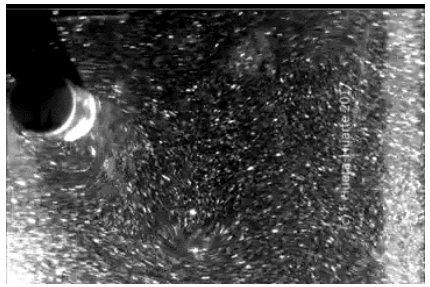
Motivation: Marine Riser Vortex-Induced Vibration (1/3)







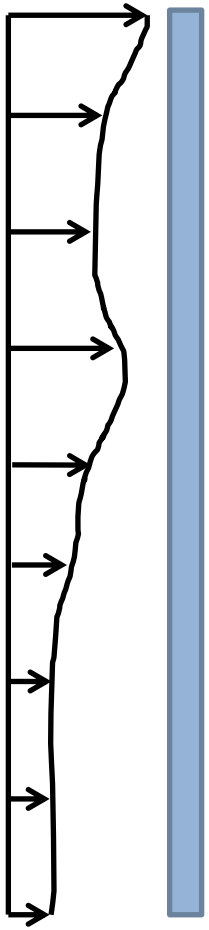
Key hydrodynamic coefficients C_d , C_{lv} , C_{my},

is affected by many parameters, such as

1. amplitude; 2. frequency; 3. roughness; 4. Reynolds number

$$C = \boldsymbol{C}(f_x, f_y, A_x, A_y, \theta, Re \ldots , \ x_n)$$

Motivation: Curse of Dimensionality (2/3)



$$C = \boldsymbol{C}(f_x, f_y, A_x, A_y, \theta, Re \ldots, x_n)$$

If n = 8, and 10 experiments each x_n:

$$\underbrace{10 \times 10 \times \cdots \times 10}_{} = 10^8$$

950 Years for 5 min each experiment.

Motivation: Dream of a lazy fluid enthusiast (3/3)

Confession by a “lazy” fluid enthusiast

Once He dreamed a smart machine that can replace him to

Perform, analyze and **design** experiments ***smartly and automatically***…

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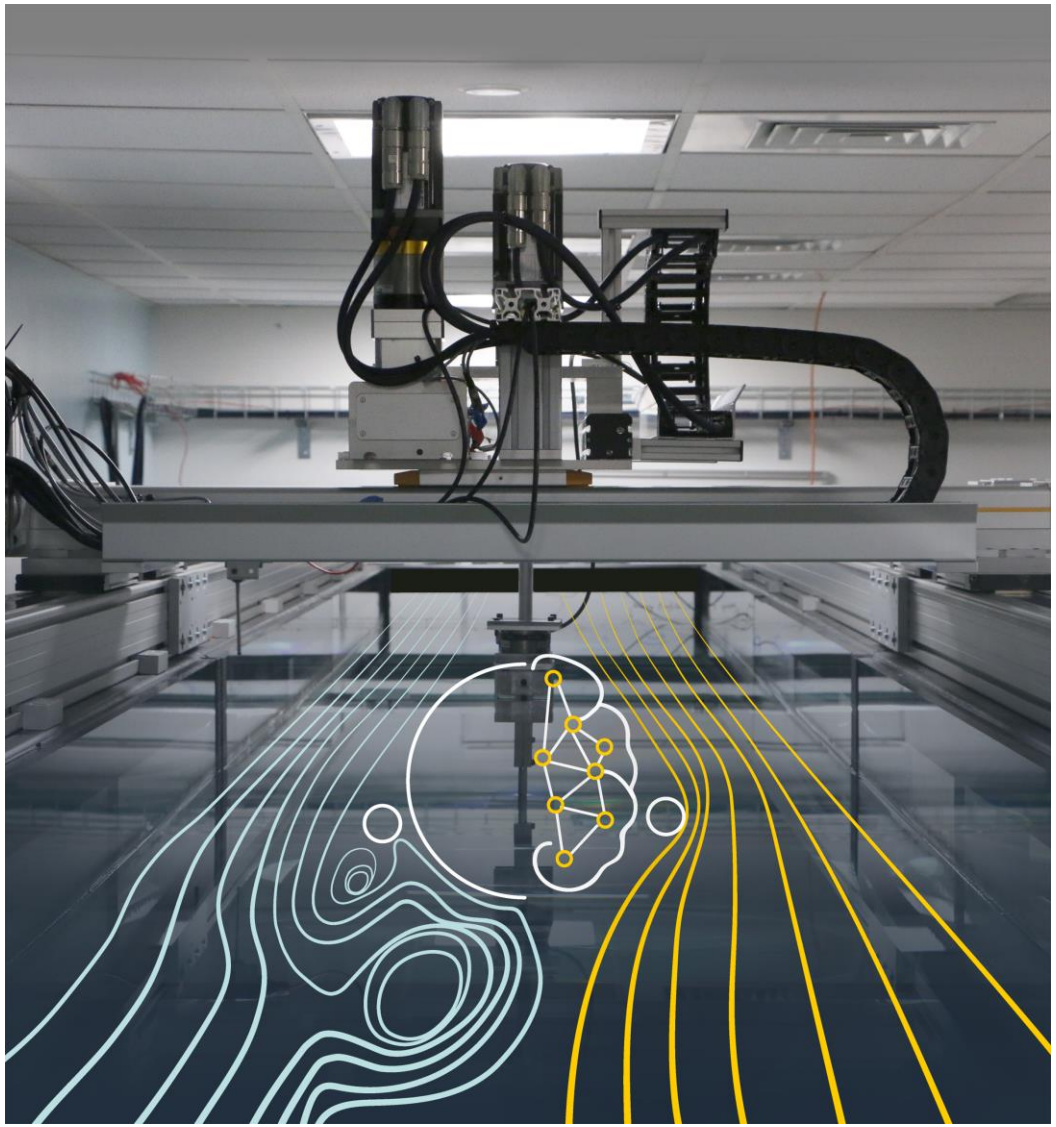


A Reflection on Research (1/4)

$$y \qquad x$$

$$k(x, x') = \sigma_f^2 exp(-\frac{(x, x')^2}{2\sigma_l^2})$$

$$\begin{bmatrix} y \\ f^* \end{bmatrix} \sim \mathcal{N}\left(0, \begin{matrix} K(X,X) + \sigma_n^2 I & K(X, X_*) \\ K(X, X_*) & K(X_*, X_*) \end{matrix}\right)$$

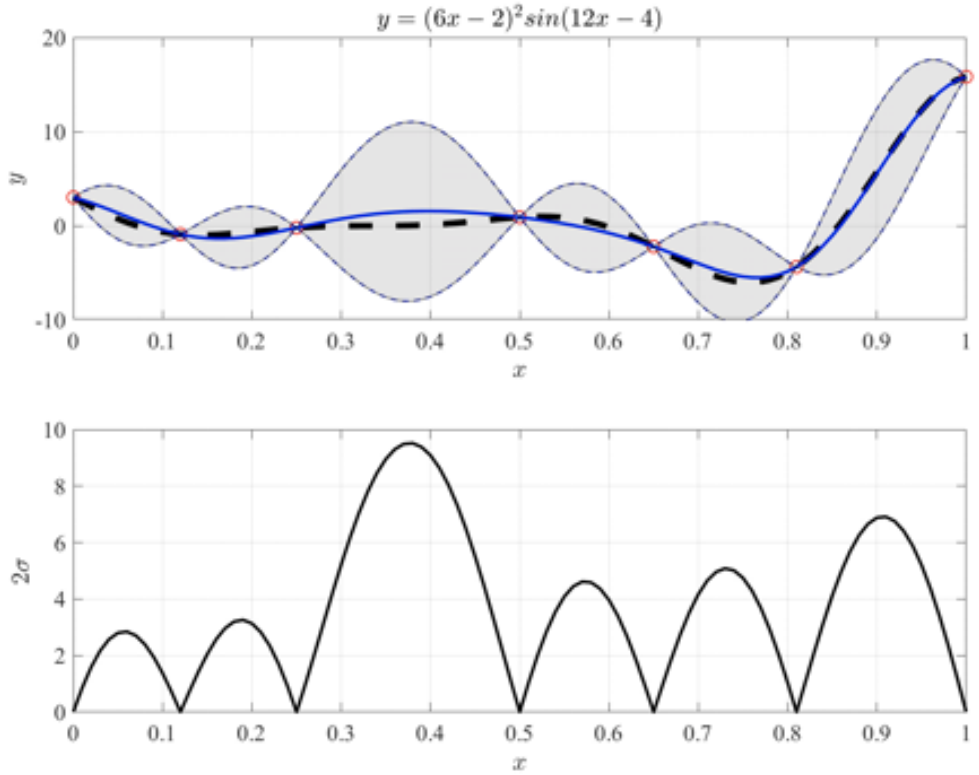
$$f^*|X, y, X^* \sim \mathcal{N}(\overline{f^*}, \mathrm{cov}(f^*))$$

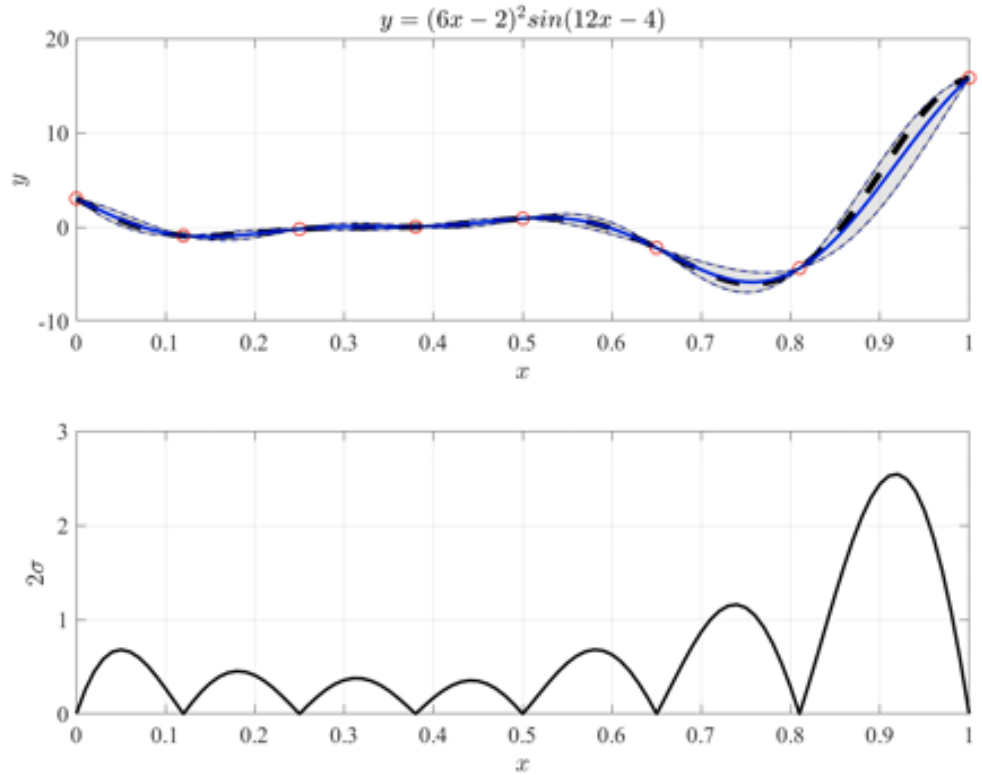
prediction ***uncertainty***

C. E. Rasmussen & C. K. I. Williams (2006)

A Quick Demo (2/5)

$$y = (6x-2)^2 \sin(12x-4)$$



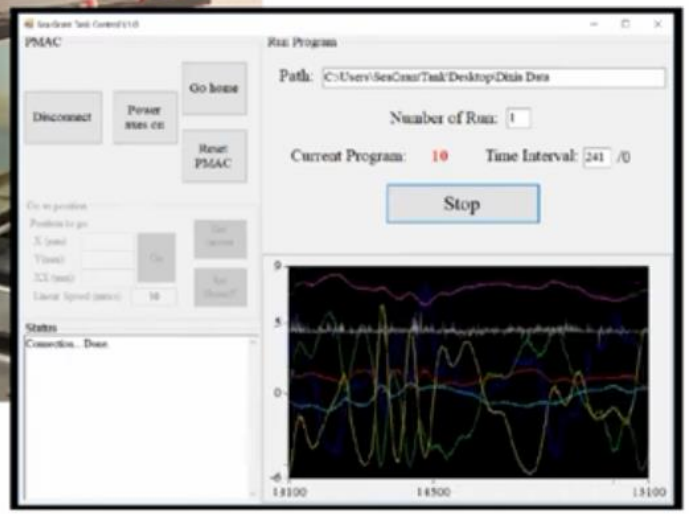


Intellige

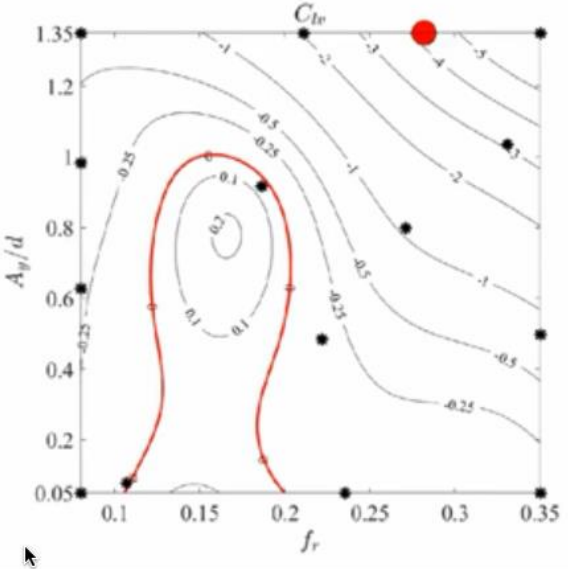
$$\varepsilon_t = \varepsilon_m$$

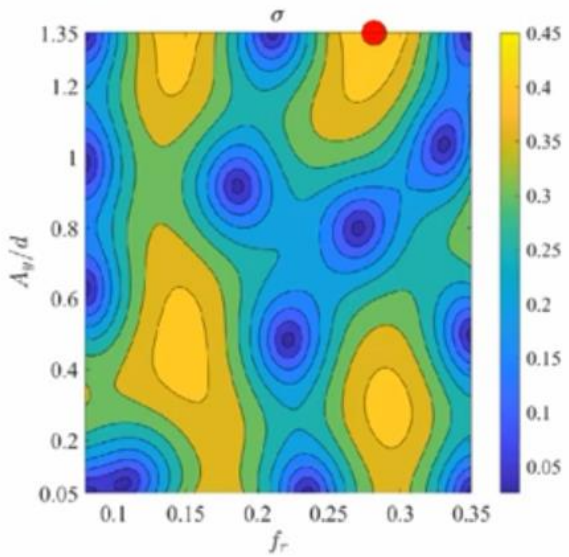
C_d

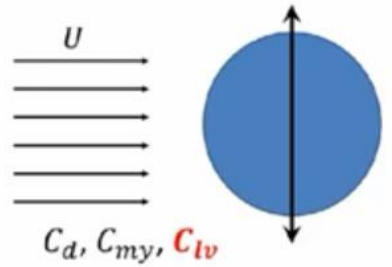
MIT Intelligent Towing Tank

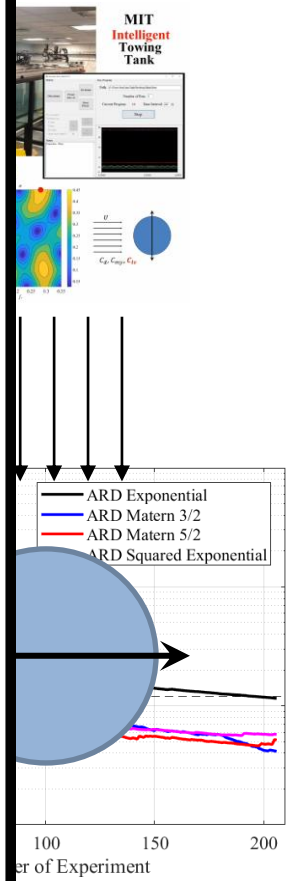


Current Run: 10, Samples: 14





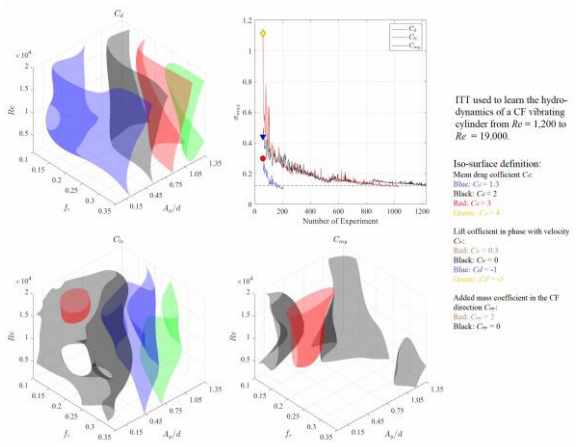




my, C_{lv}

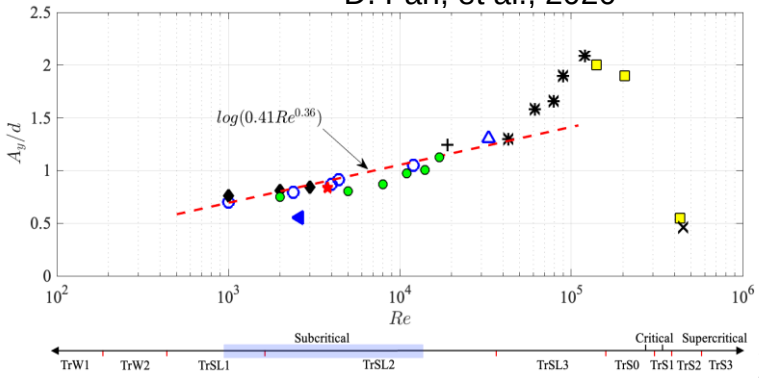
D. Fan, et al. 2019

ITT Applications (4/4)

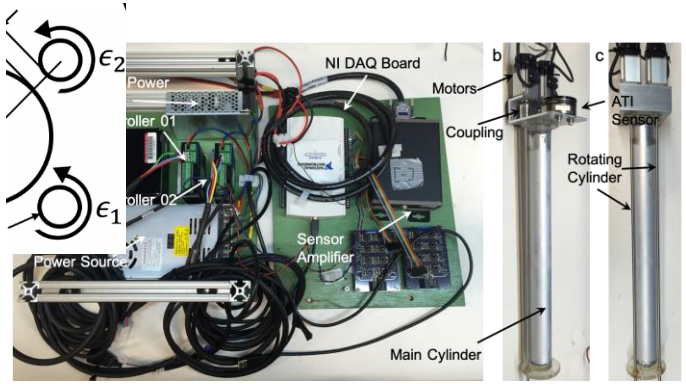


1. The first Reynolds effect CF databa

D. Fan, et al., 2020

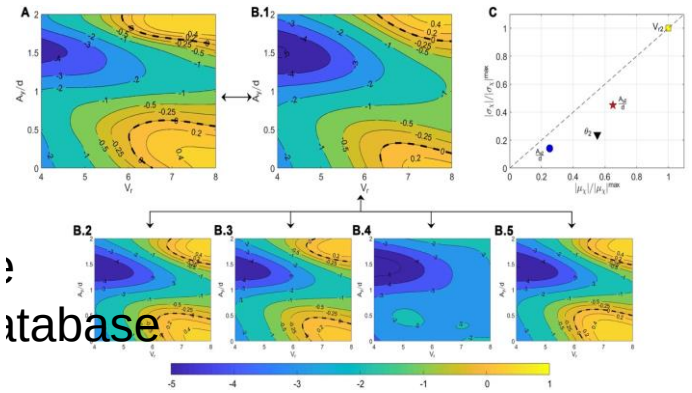


2.



4. The first DRL application in bluff body active flow control

D. Fan, et al., 2020



atabase

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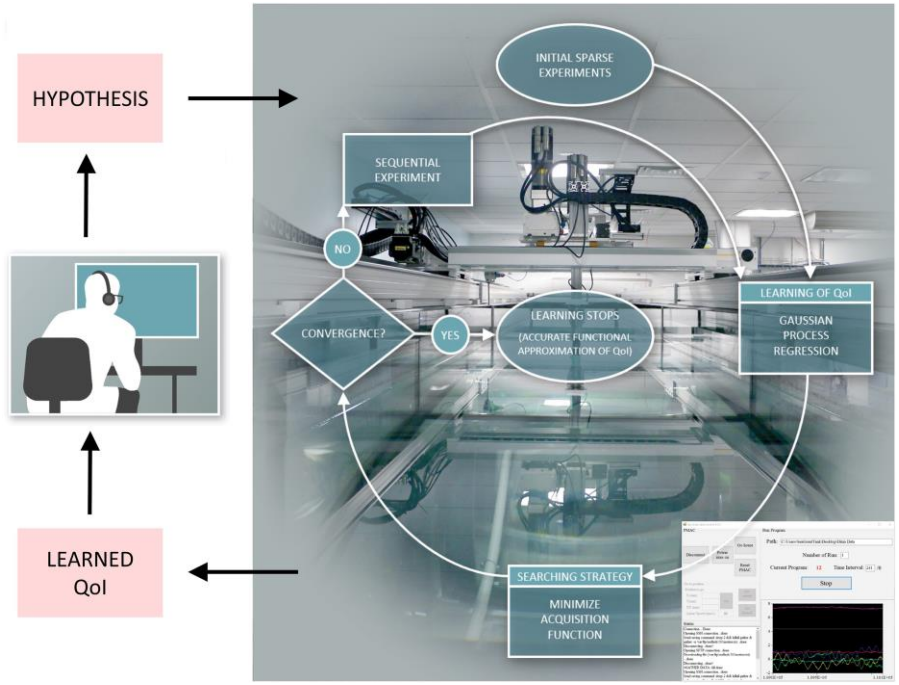
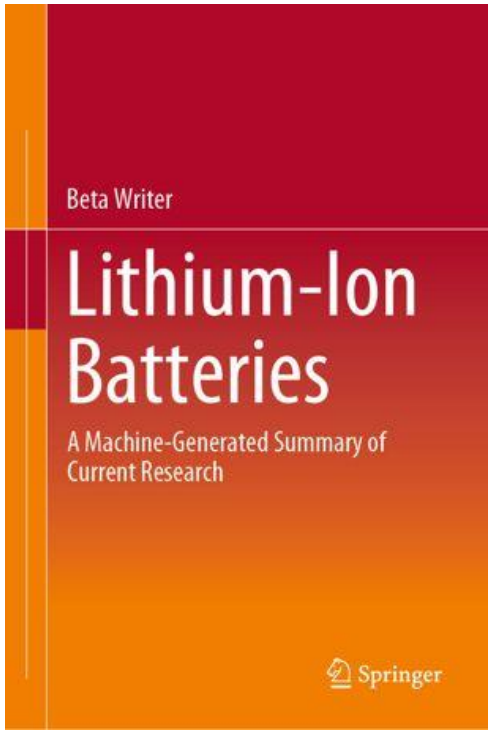
The Robot Scientists Are Coming. But That's Not a Bad Thing

---- By Discover Magazine

Dictator



Collaborator



Counselor

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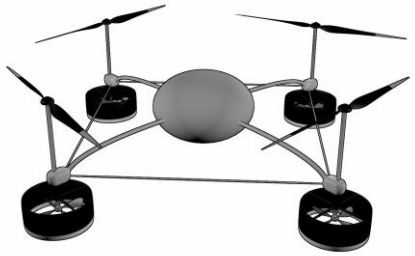
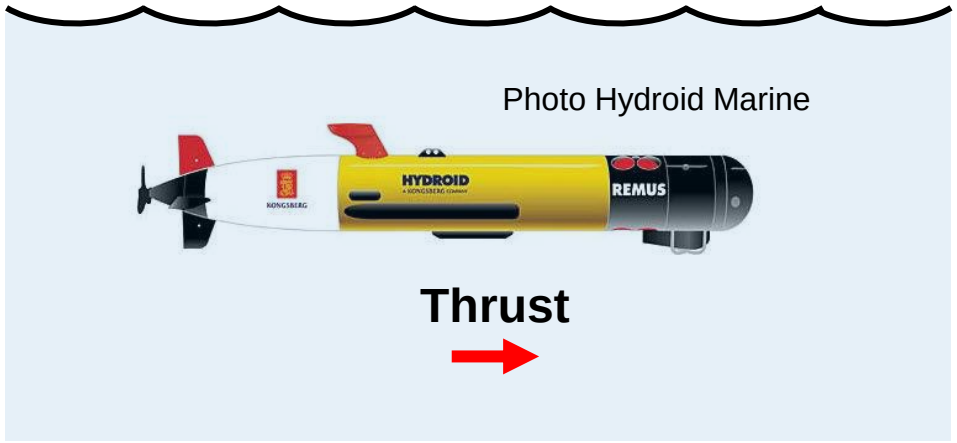
Motivation: Aerial / Aquatic Transportation



Drews et al. 2014

NRL 2015

Lift



Inspiration from Nature

Flying-Only

Swimming-Only

Dual Aerial/Aquatic

Flying Underwater

Puffin's Strategy on Flapping Wings

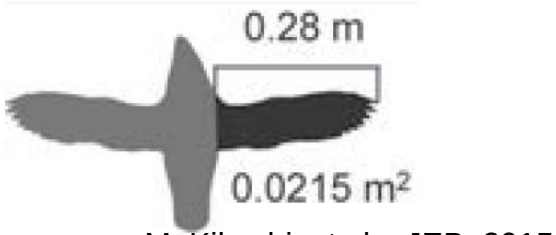
- Air: enough lift to balance weight (undersized wing)
- Water: enough thrust to overcome drag (oversized wing)

Wing Trajectory Figure-Of-Merit:

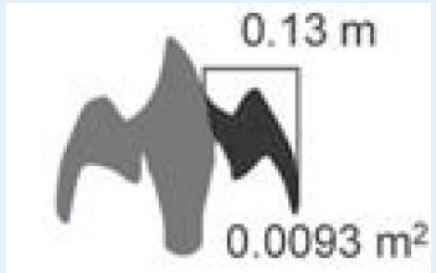
$$\frac{F_L \sim A_{\text{air}} C_{\text{L,air}}}{F_T \sim A_{\text{water}} C_{\text{T,water}}} \geq 10$$

~3 – 5

$$\text{Thrust} = \tfrac{1}{2}\rho_{\text{water}} U^2_{\text{water}} A_{\text{fuselage}} C_{Df}$$



M. Kikuchi, et al., JEB, 2015



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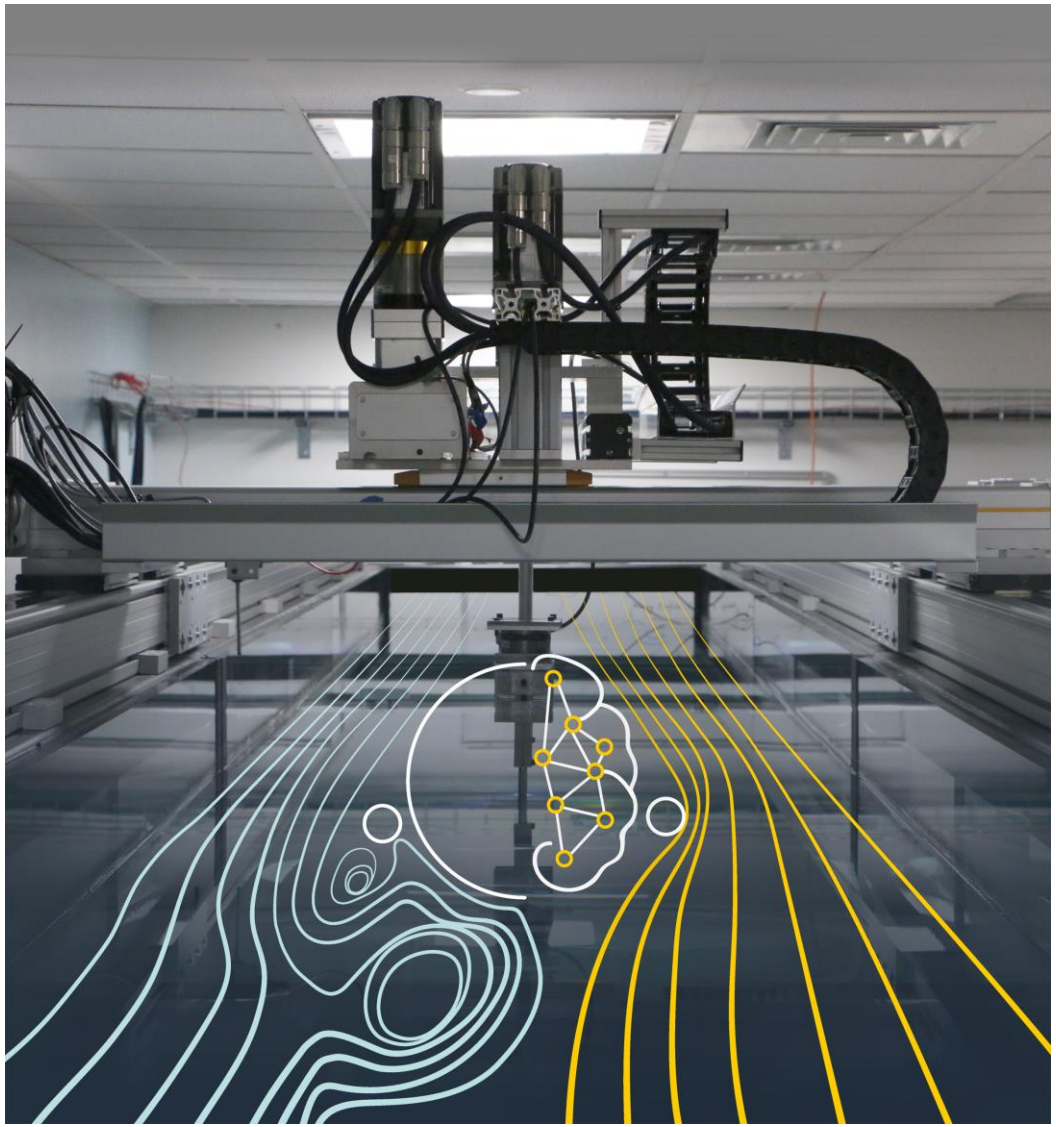
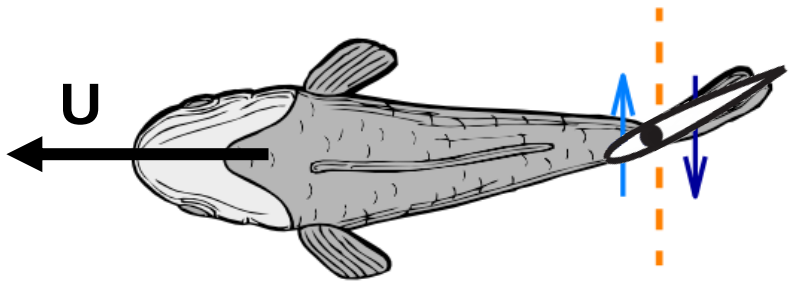
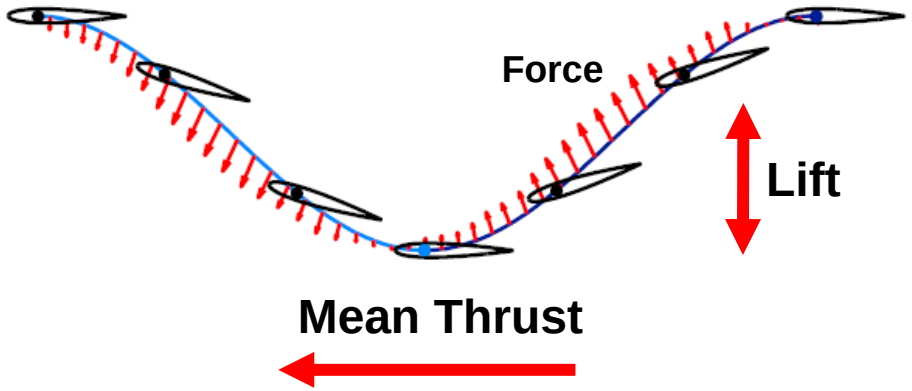
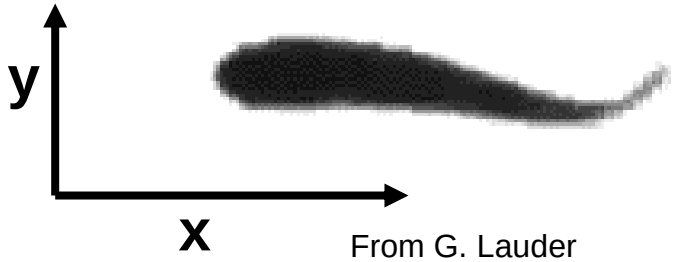


One Minute Flapping Foil Theory: Symmetric Flapping



Heaving & Pitching Foil Tail

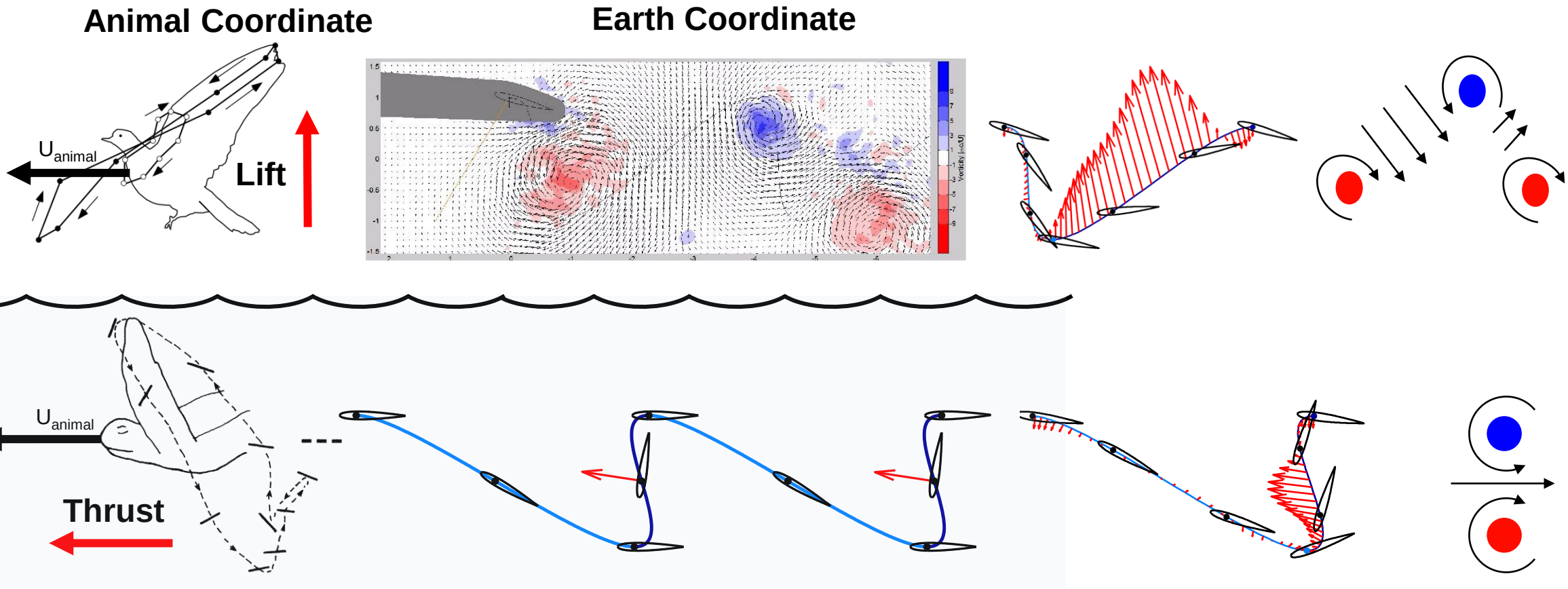




From G. Lauder

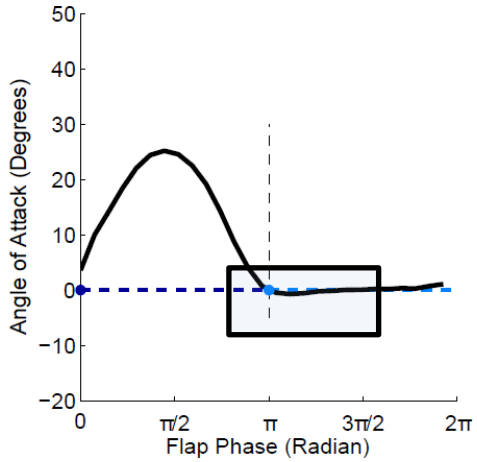
rms(**Lift**) ≈ mean(**Thrust**)

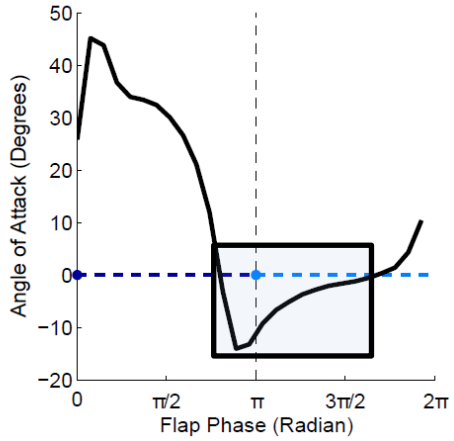
Non-Symmetric Flapping

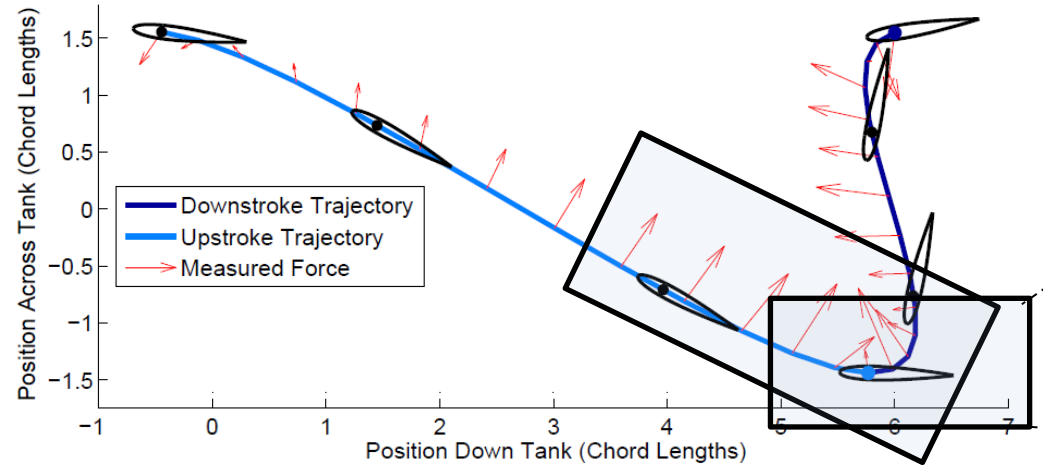


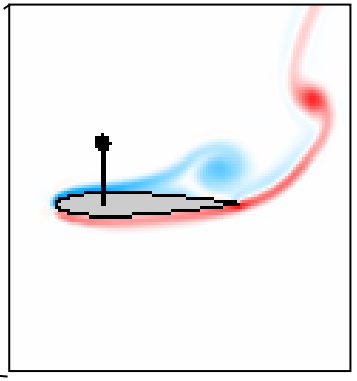
Izraelevitz, et al. 2014

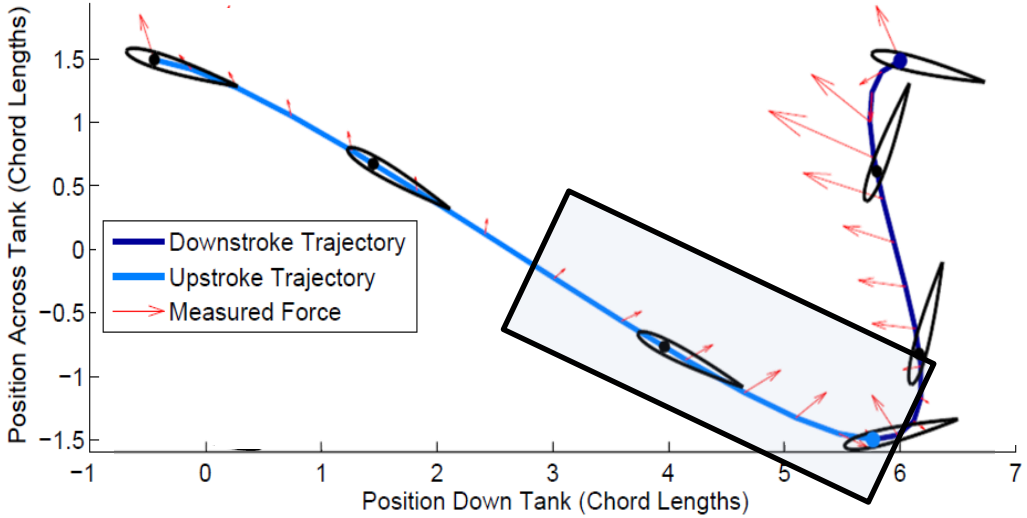
Challenges in Flapping Foil Vortical Flow Control











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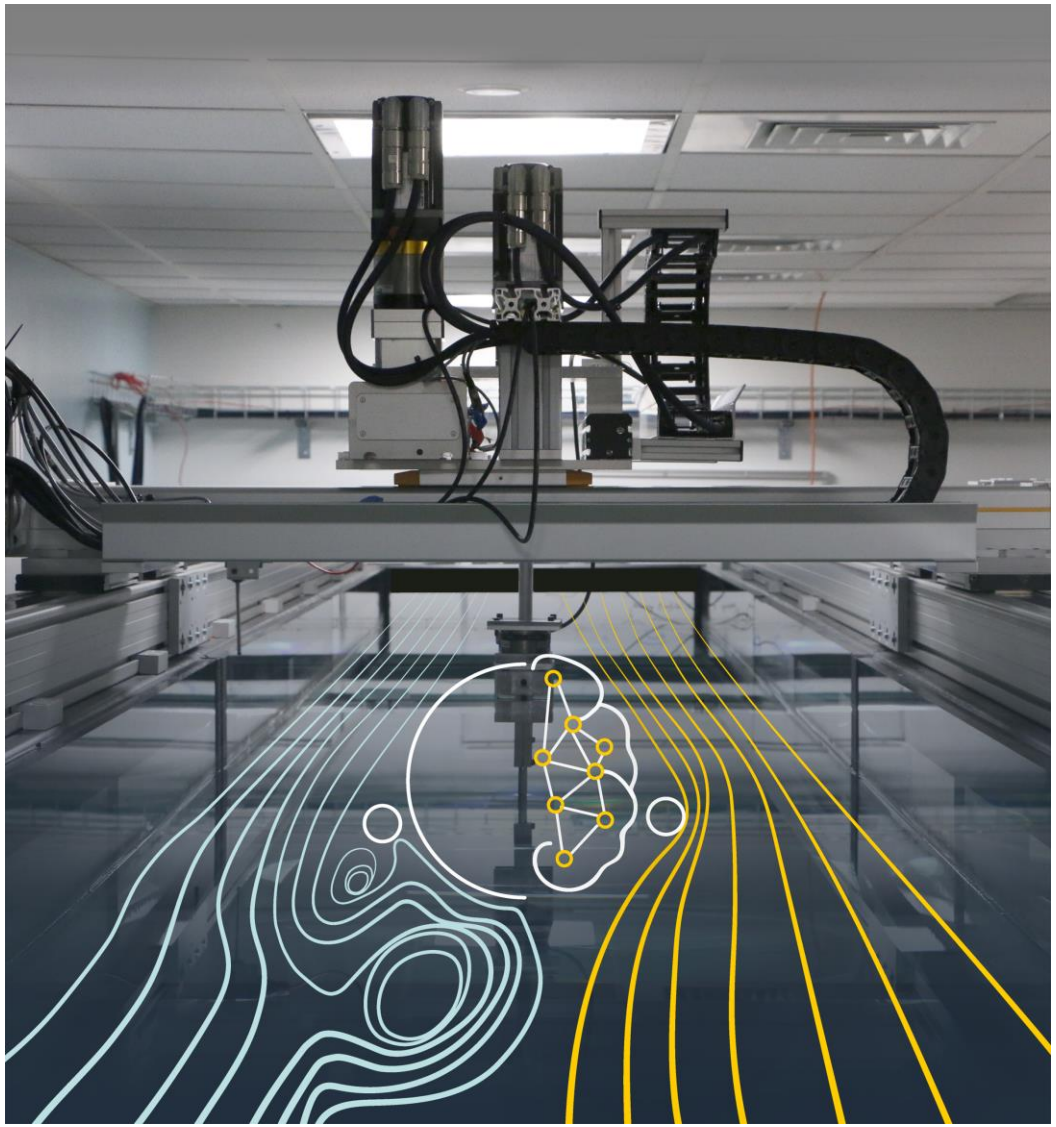
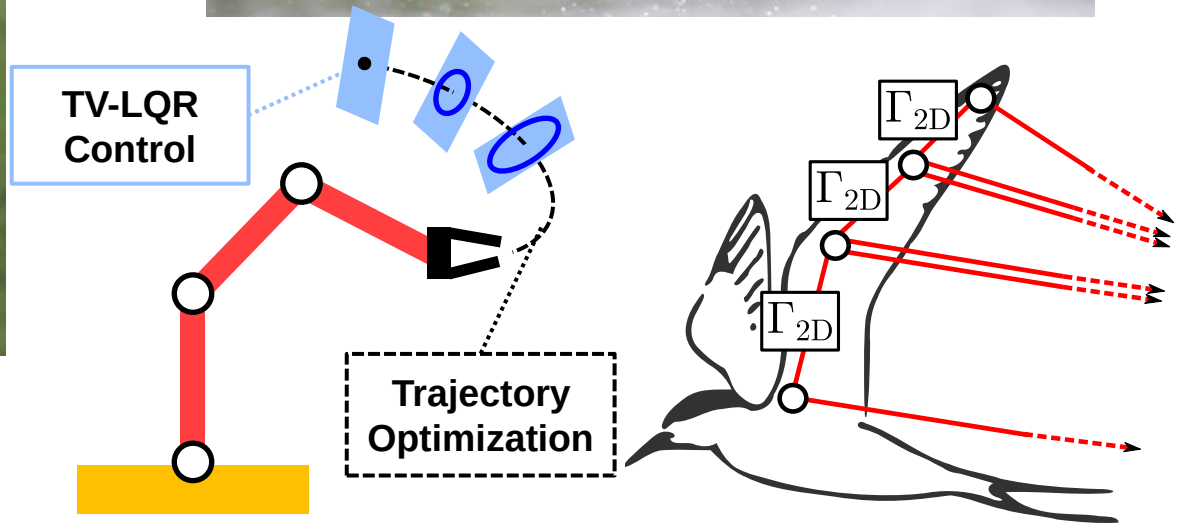
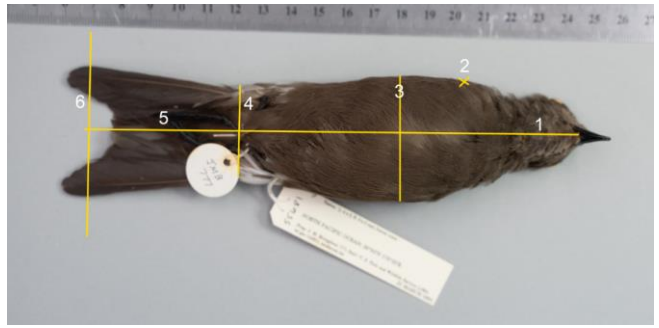
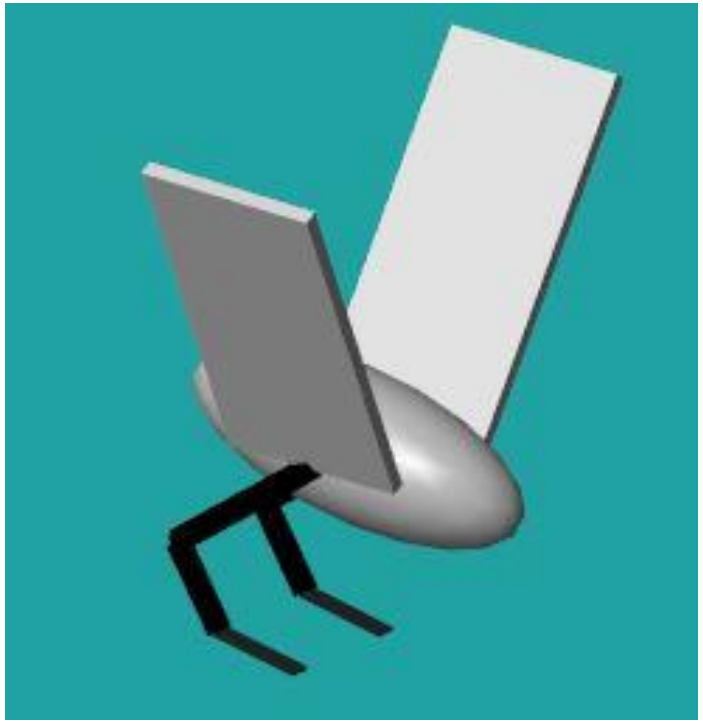


Future challenges: Robotic Control

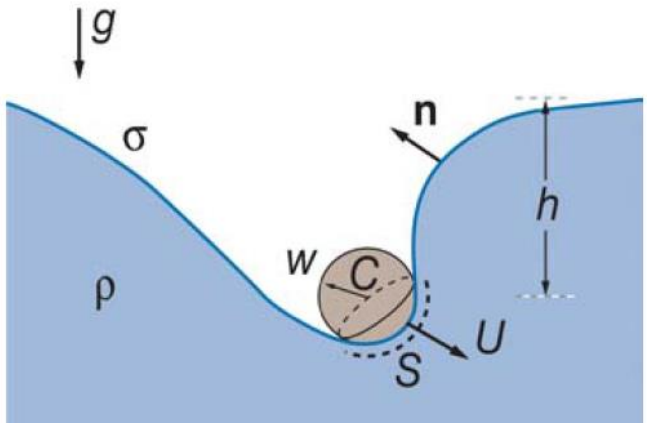


A cute example: a gentle touch on the water

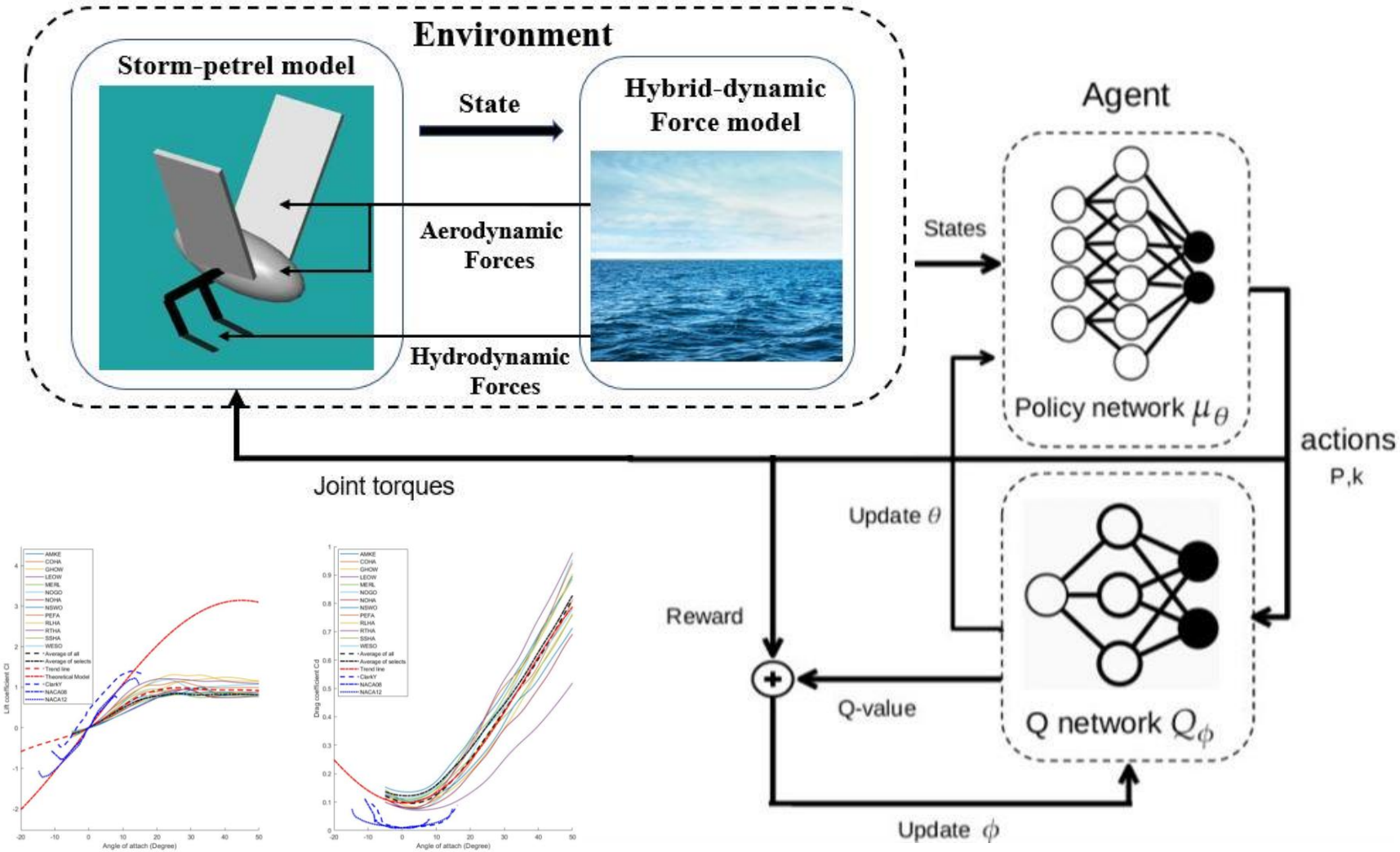




A cute example



a) **Hydrodynamic force on webs;**
b) **Aerodynamic force on wings;**
c) **Aerodynamic force on the body;**
d) **Aerodynamic force on the tail.**



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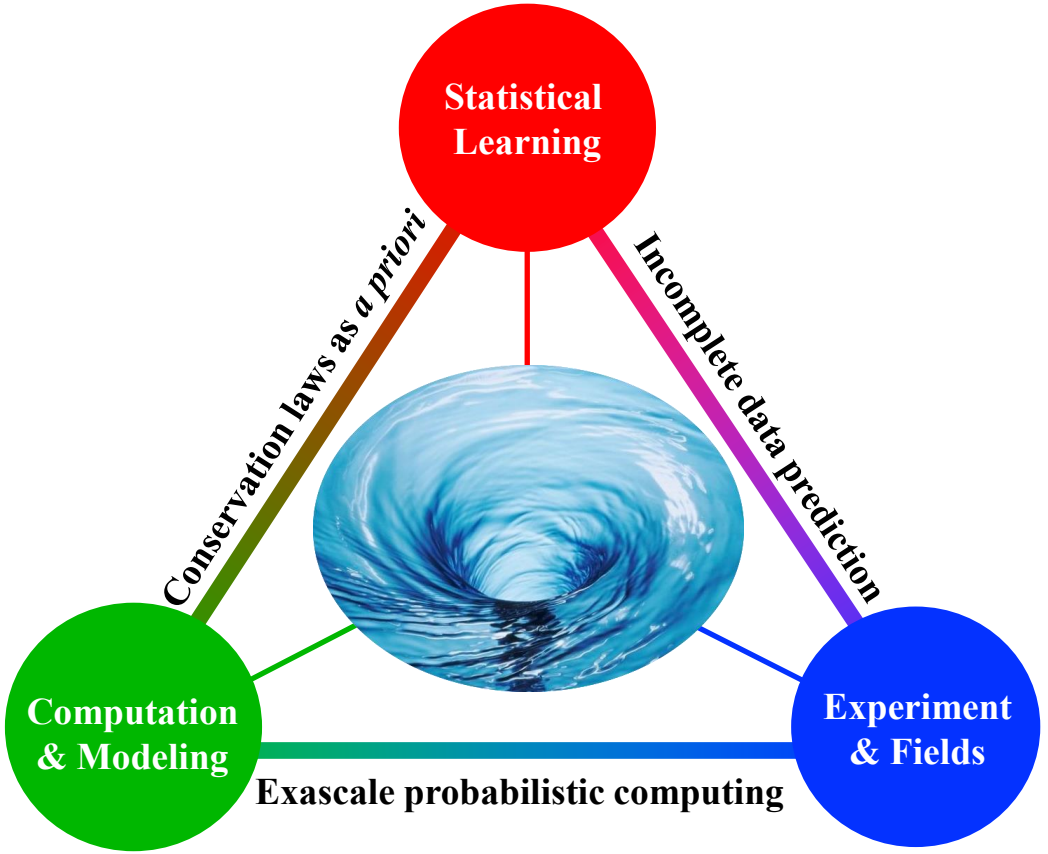
- Next-Gen Bio-Inspired Aero/Aquatic Vehicles
  - Challenges in Dual Aerial / Aquatic Propulsion
  - Flapping foil vortical flow control
  - Inspired by nature: a peak into the future flapping foil/wing actuator
- **Bottom up: AI for Fluid Experimentation**

Physics-informed (and -informative) Learning for Fluid Mechanics



MATLAB EXPO

Thank you

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