



# Upcoming Events at KITP

**Sep 19**  
5:30 pm

**Chalk Talk: Rahul Nandkishore at KITP**  
**"Quantum Glass"**

**Oct 24**  
7:00 pm

**Public Lecture: Stephen Shenker at KITP**  
**"TBA"**

**Nov 28**  
5:30 pm

**Chalk Talk: Louis Kauffman at KITP**  
**"Knots and Physics"**

# The tao of fish swimming



**KITP Chalk Talk**  
August 7<sup>th</sup>, 2018

**James C. Liao**  
Associate Professor  
Department of Biology  
UF Term Professor

**UF** UNIVERSITY of  
FLORIDA



THE WHITNEY LABORATORY  
for MARINE BIOSCIENCE

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# ARISTOTLE

## PARTS OF ANIMALS

WITH AN ENGLISH TRANSLATION BY  
A. L. PECK

## MOVEMENT OF ANIMALS PROGRESSION OF ANIMALS

WITH AN ENGLISH TRANSLATION BY  
E. S. FORSTER



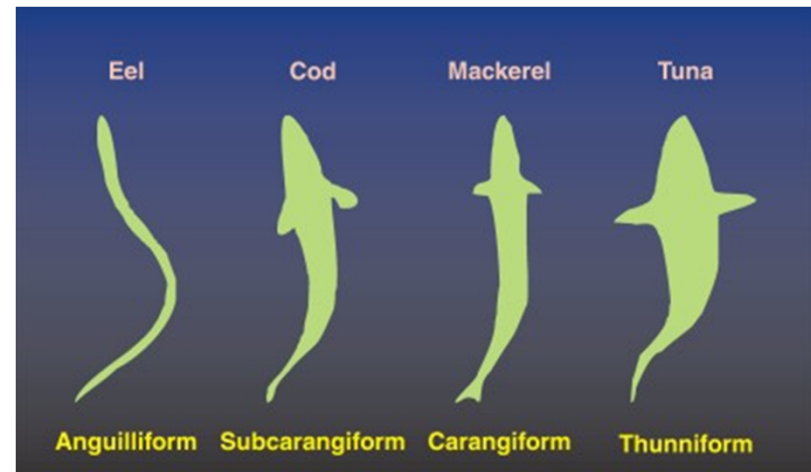
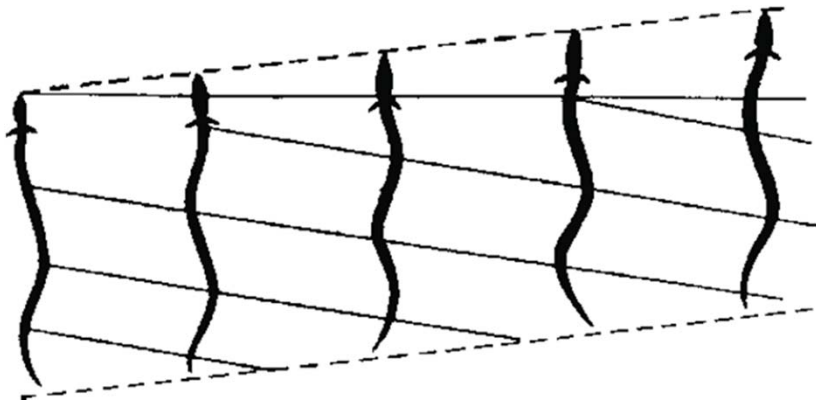
HARVARD UNIVERSITY PRESS  
CAMBRIDGE, MASSACHUSETTS  
LONDON, ENGLAND



JOH. ALPHONSI BORELLI  
*Neapolitani Mathematici Professoris*  
DE  
**MOTU  
ANIMALIUM**  
*PARS PRIMA.*  
EDITIO NOVISSIMA,  
*Ab innumeris mendis & erroribus repurgata.*  
*Addita sunt post finem Partis Secundae*  
JOHANNIS BERNOULLII  
*Prof. Mat. Dnl.*  
Meditationes Mathematicae  
**DE MOTU MUSCULORUM.**



LUGDUNI BATAVORUM,  
Apud **PETRUM VANDER A.**, Bibliopolam.  
ANNO M DCC X.







Traveling wave equation for undulatory swimming.

$$h(x, t) = A(x) * \sin(kx - \omega t + \phi)$$



1980

1996

1999

2016

1986

1992

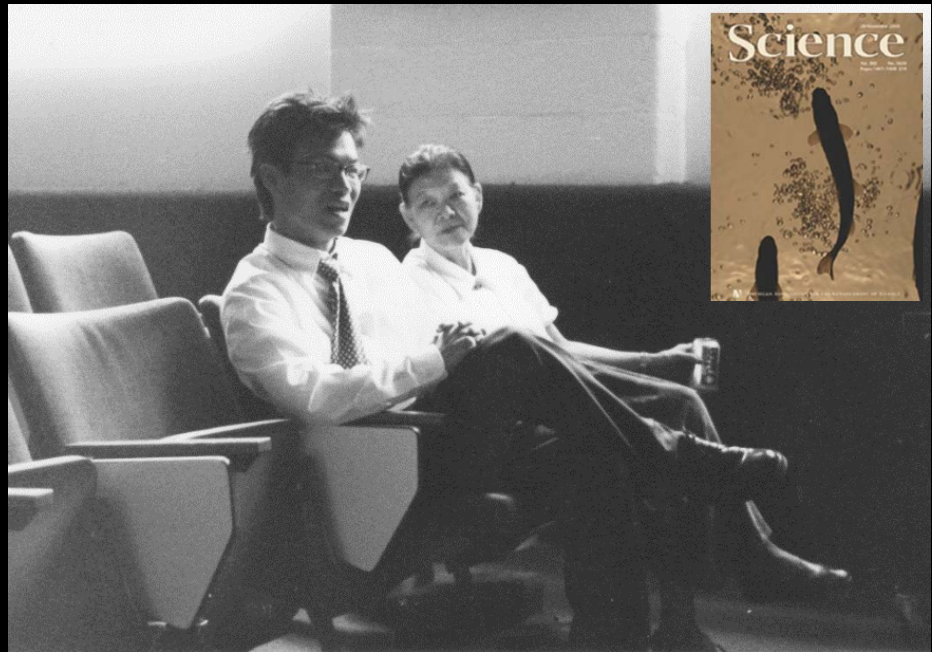
2004

2009







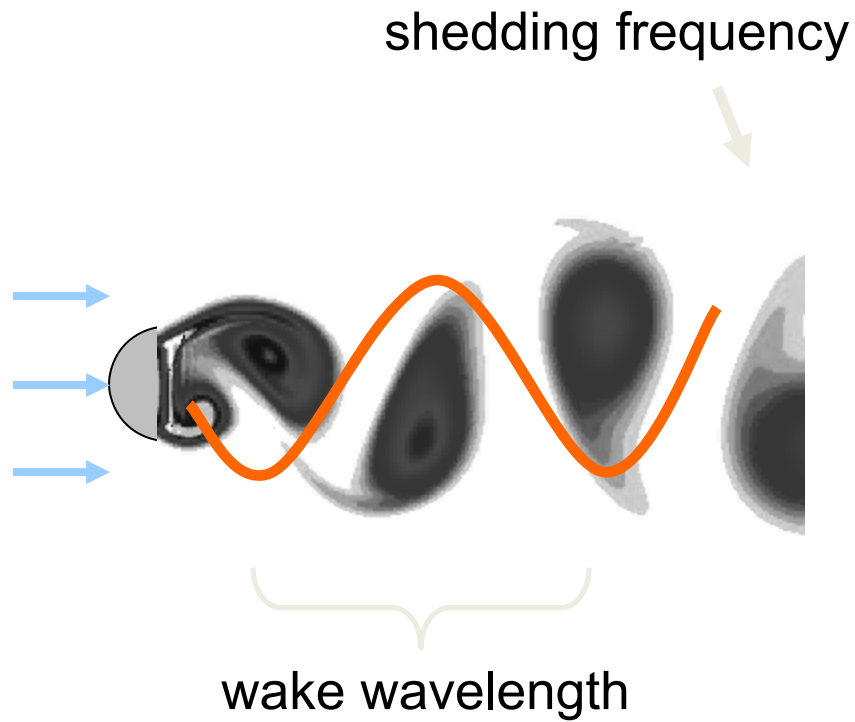




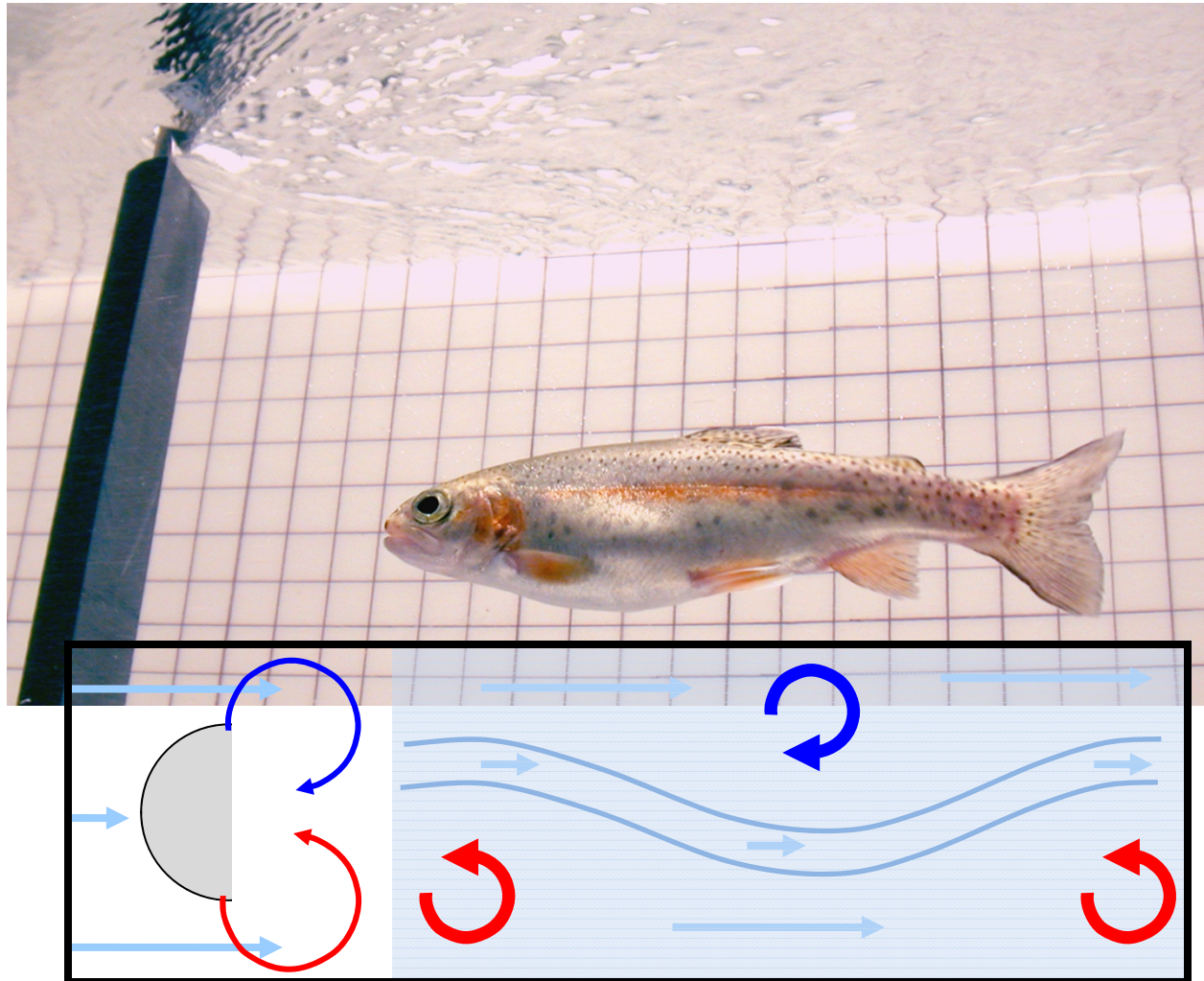




# Kármán vortex street



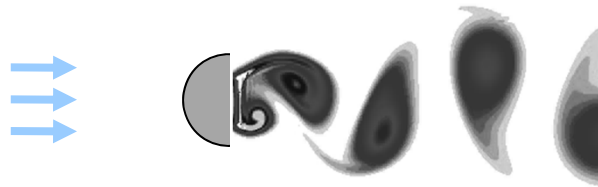
# Fish in a Kármán vortex street



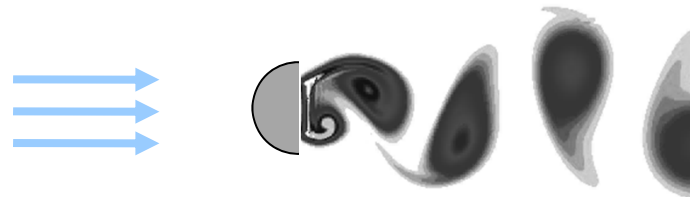
# Kármán vortex street

$$\text{Strouhal number} = (L \cdot f) / v$$

$$\lambda = v/f$$



$$\lambda = 11 \text{ cm}$$
$$f = 2.2 \text{ Hz}$$

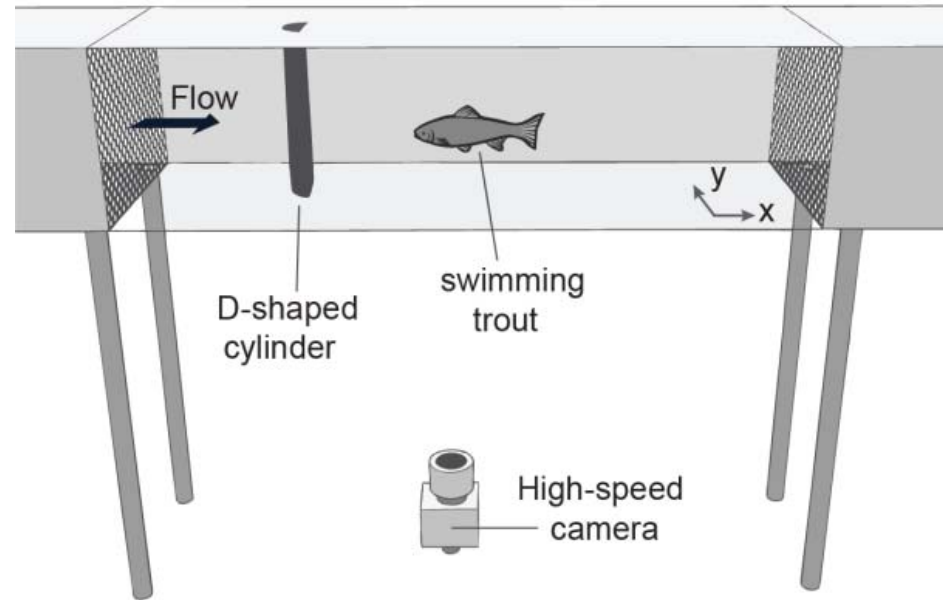


$$\lambda = 11 \text{ cm}$$
$$f = 4.0 \text{ Hz}$$



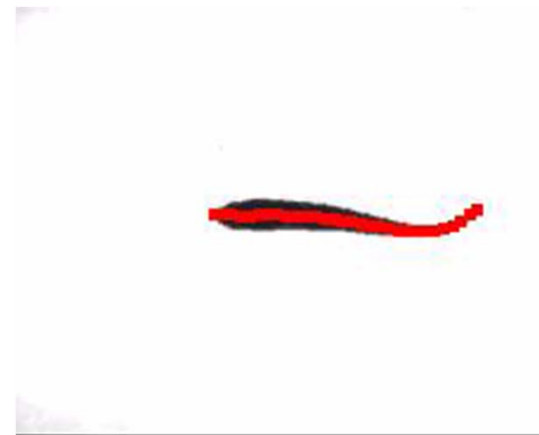
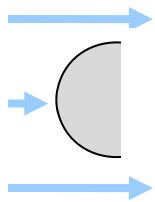
$$\lambda = 20 \text{ cm}$$
$$f = 2.2 \text{ Hz}$$

# The Kármán Gait



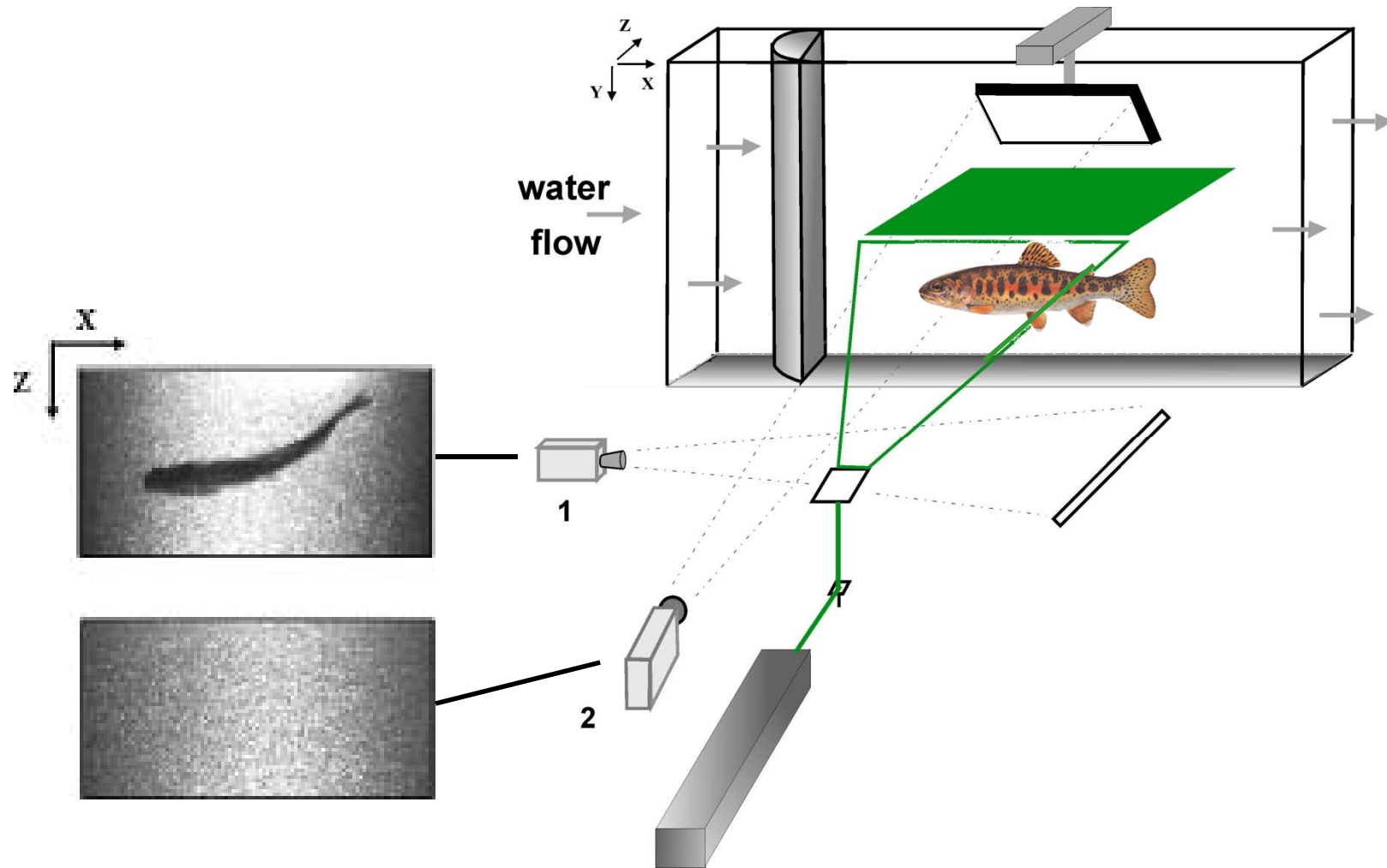
**Kármán gait**

**no cylinder**





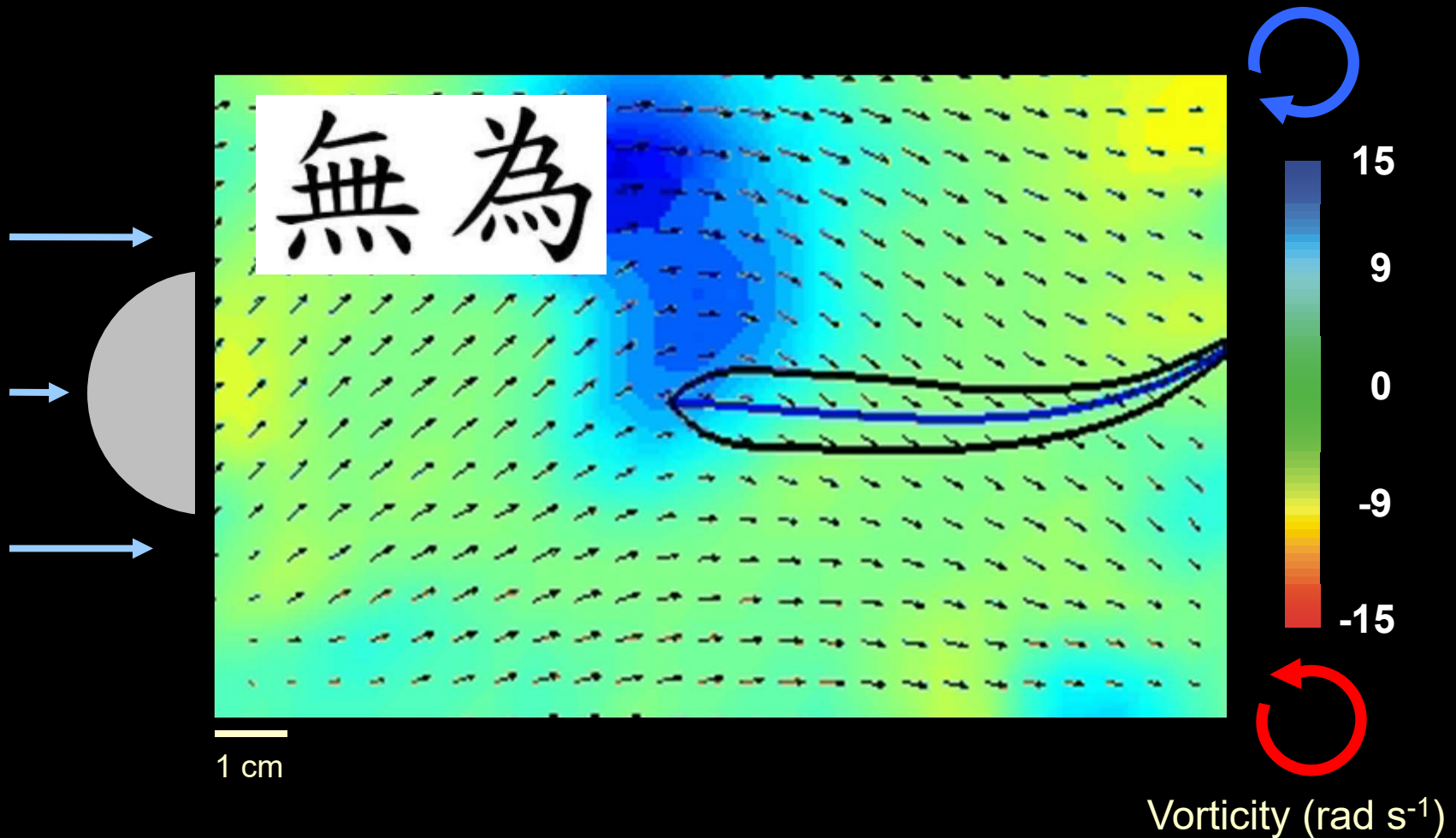
# Digital Particle Image Velocimetry



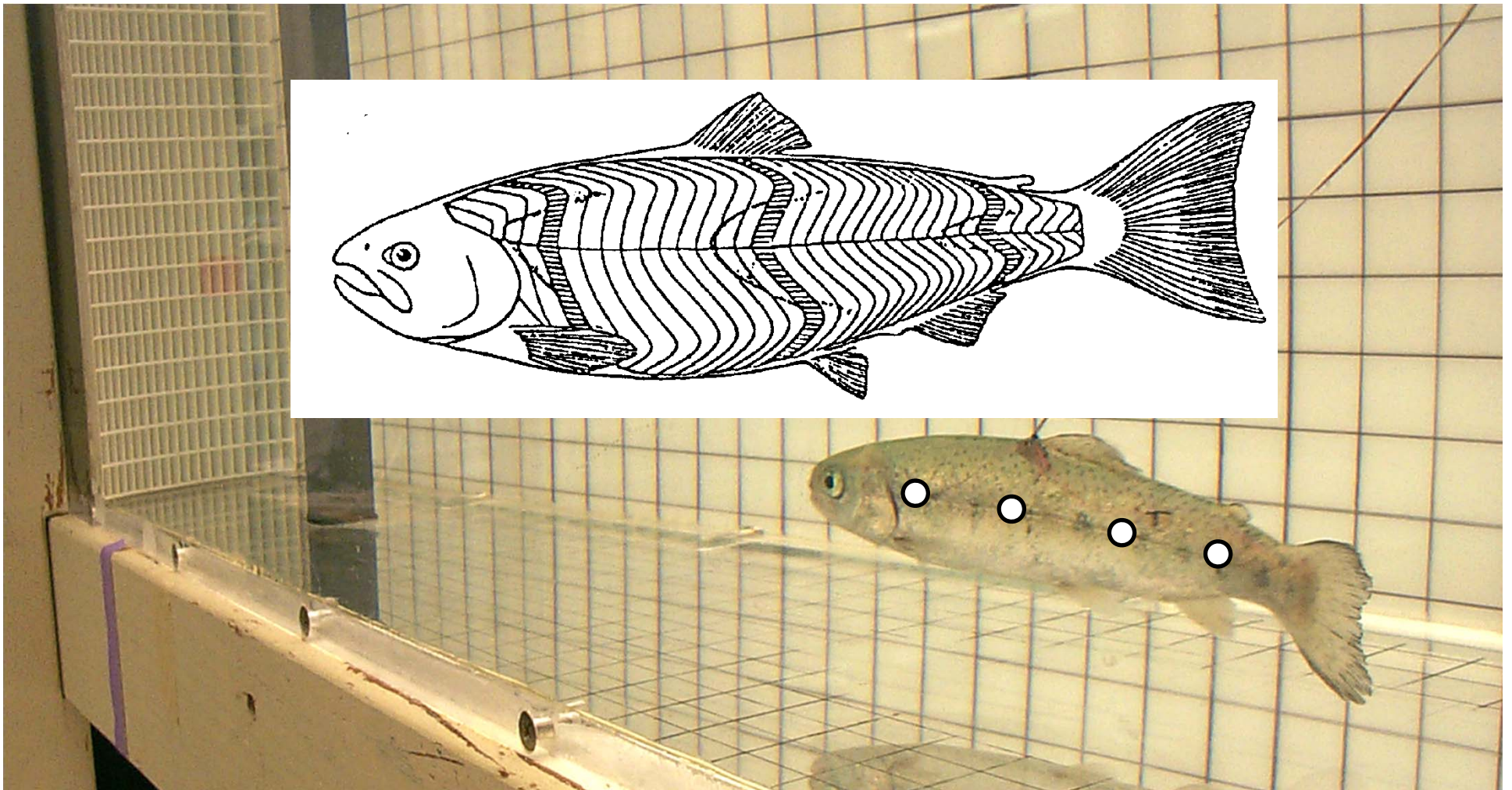
# Digital Particle Image Velocimetry



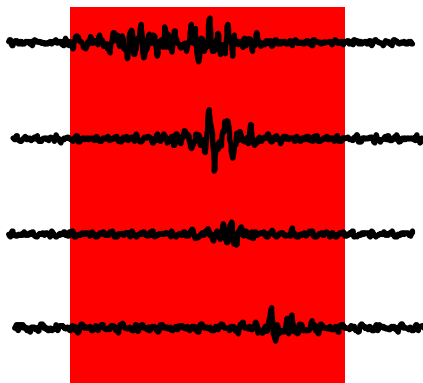
# Digital Particle Image Velocimetry



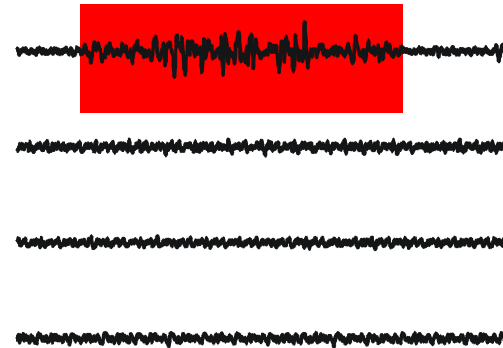
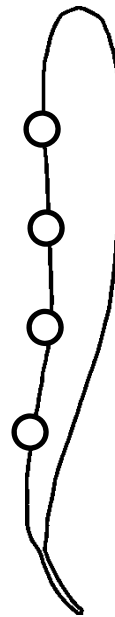
# Muscle activity



# Muscle activity

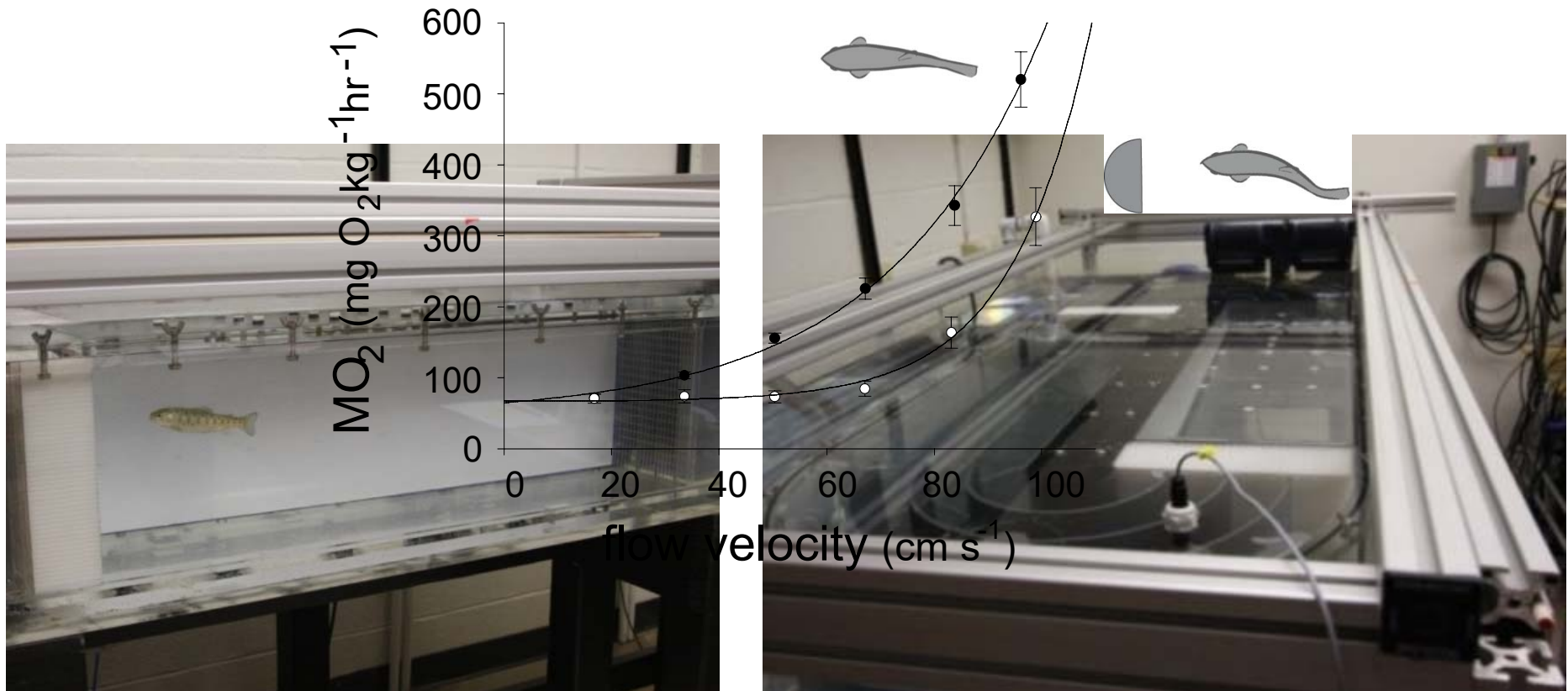


swimming



Kármán gait

# Kármán gaiting saves energy



# Dead trout swimming



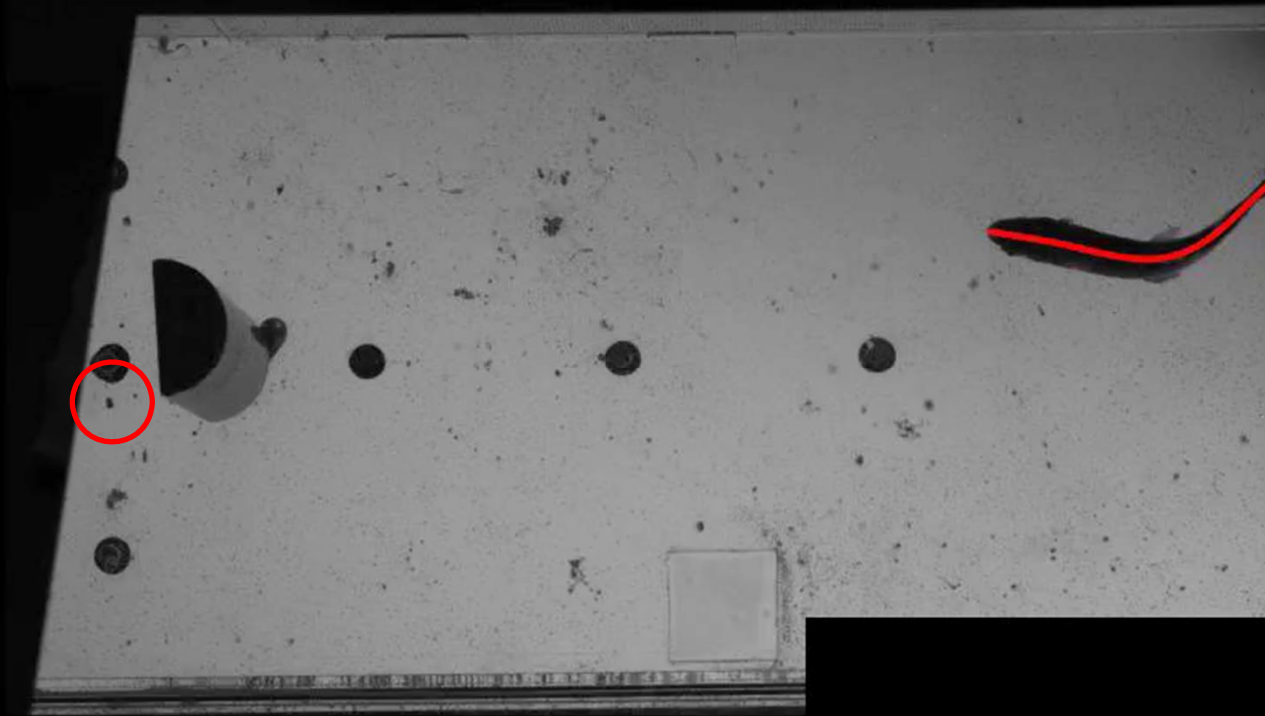
Beal, Liao et al. *Journal of Fluid Mechanics* 2006





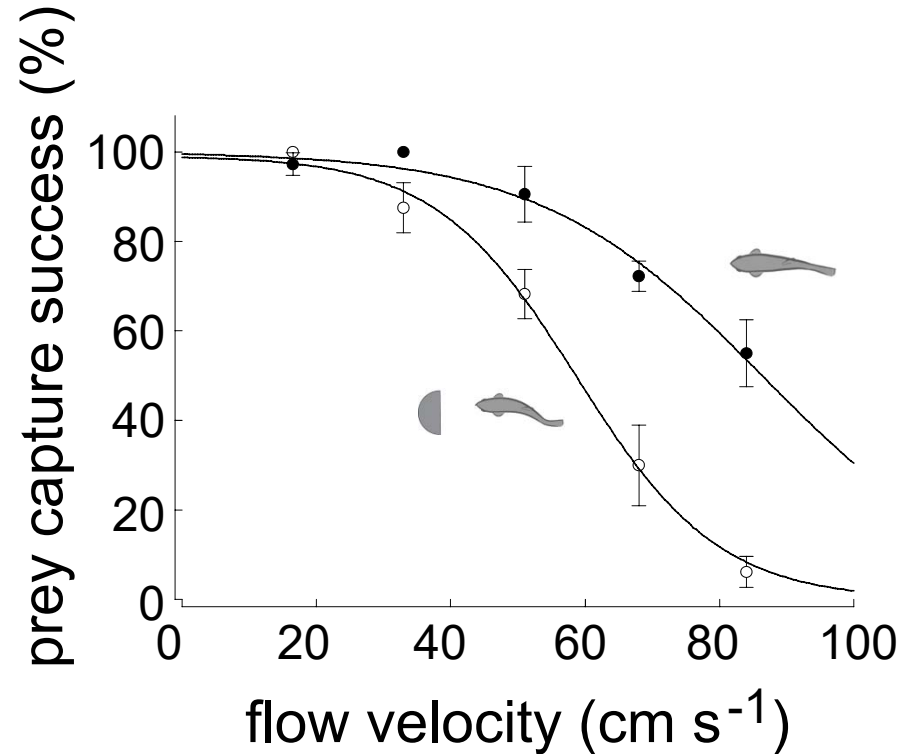
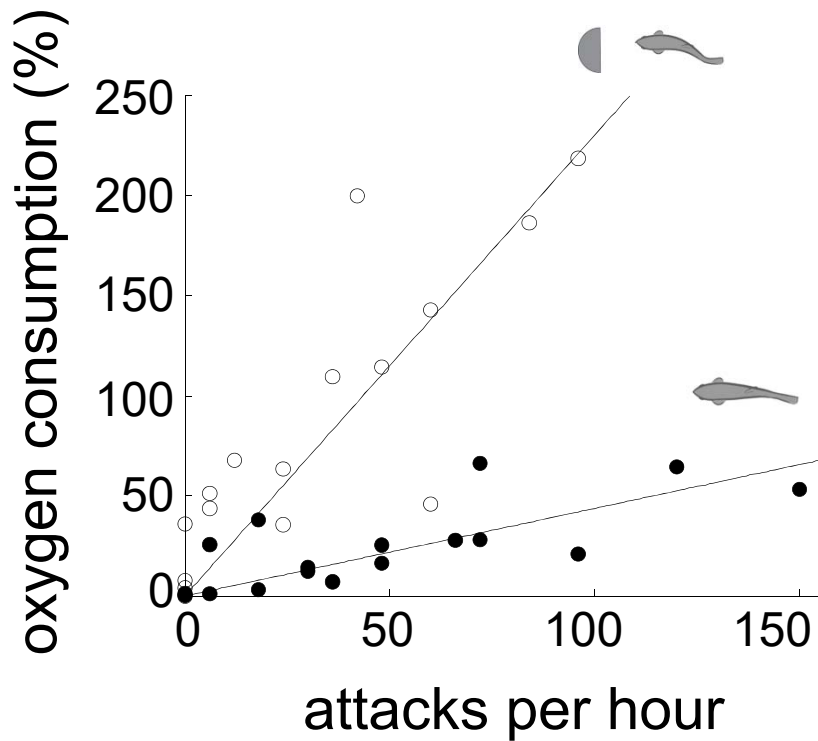


# Drift Feeding



# Feeding in unsteady flows

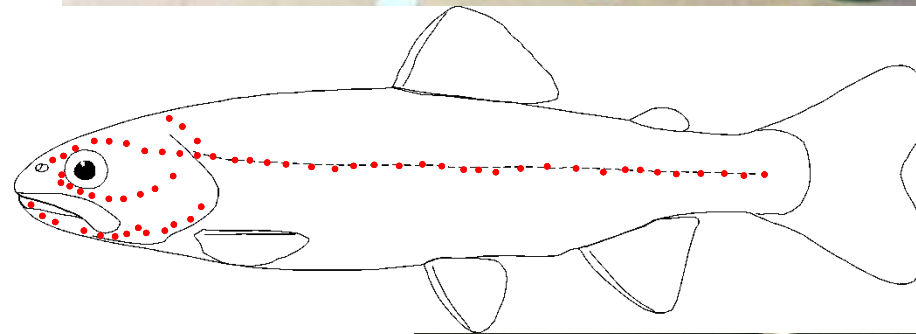
1. more costly
2. less successful



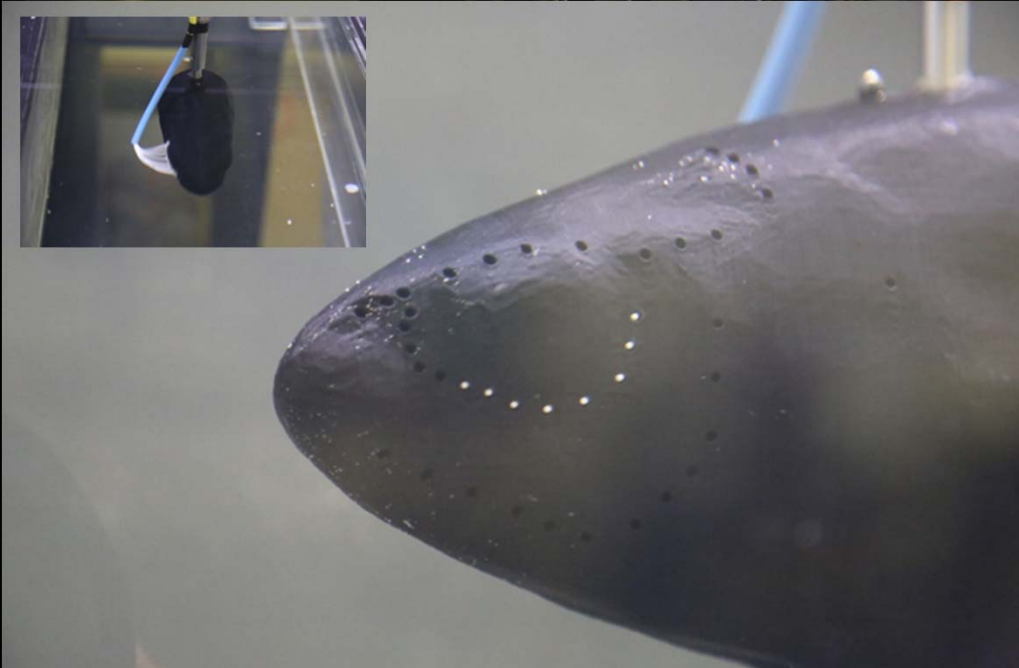
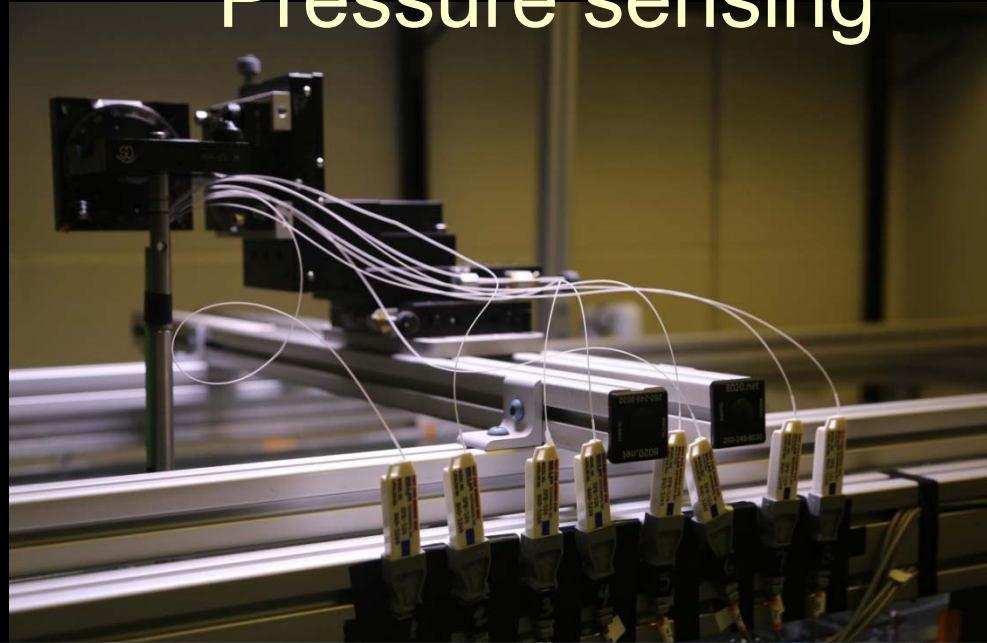
What is the role of the flow sensing lateral line system?

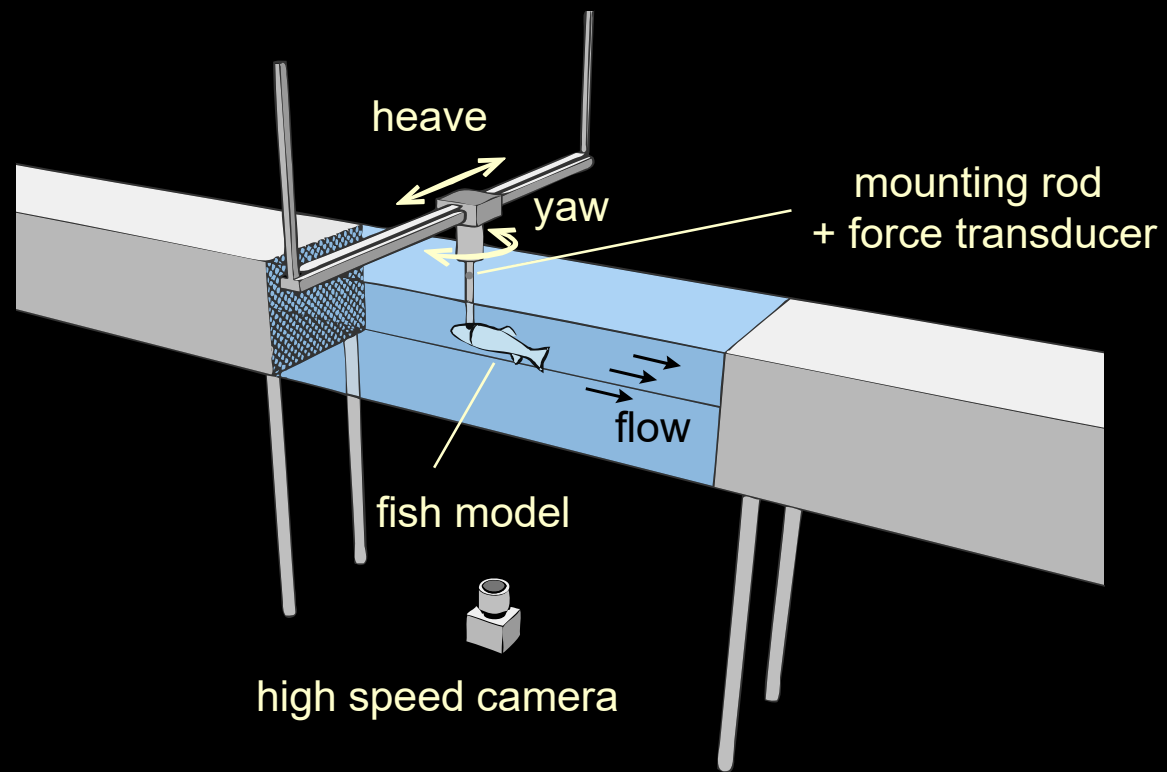


# Can the lateral line optimize swimming?

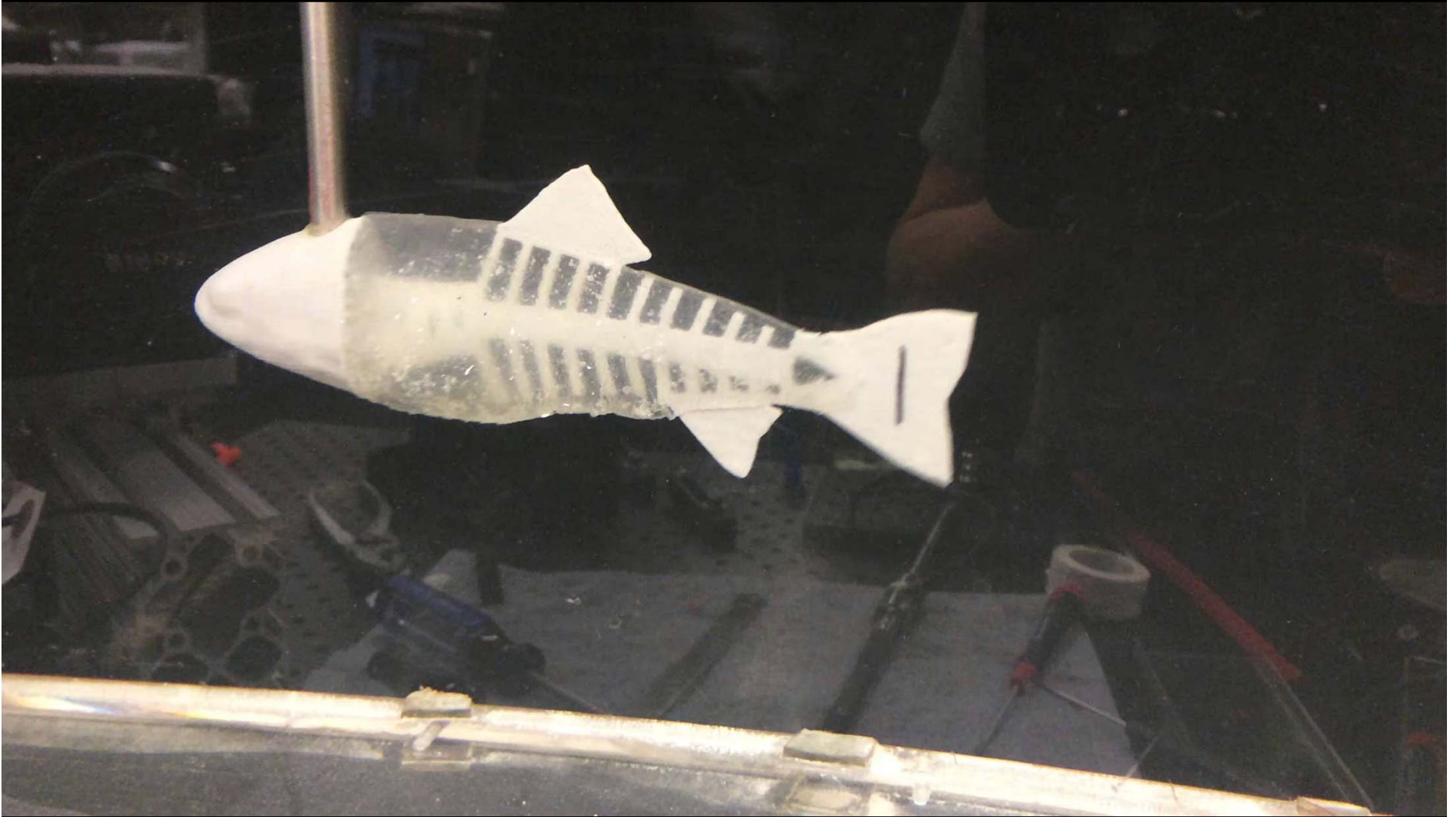


# Pressure sensing





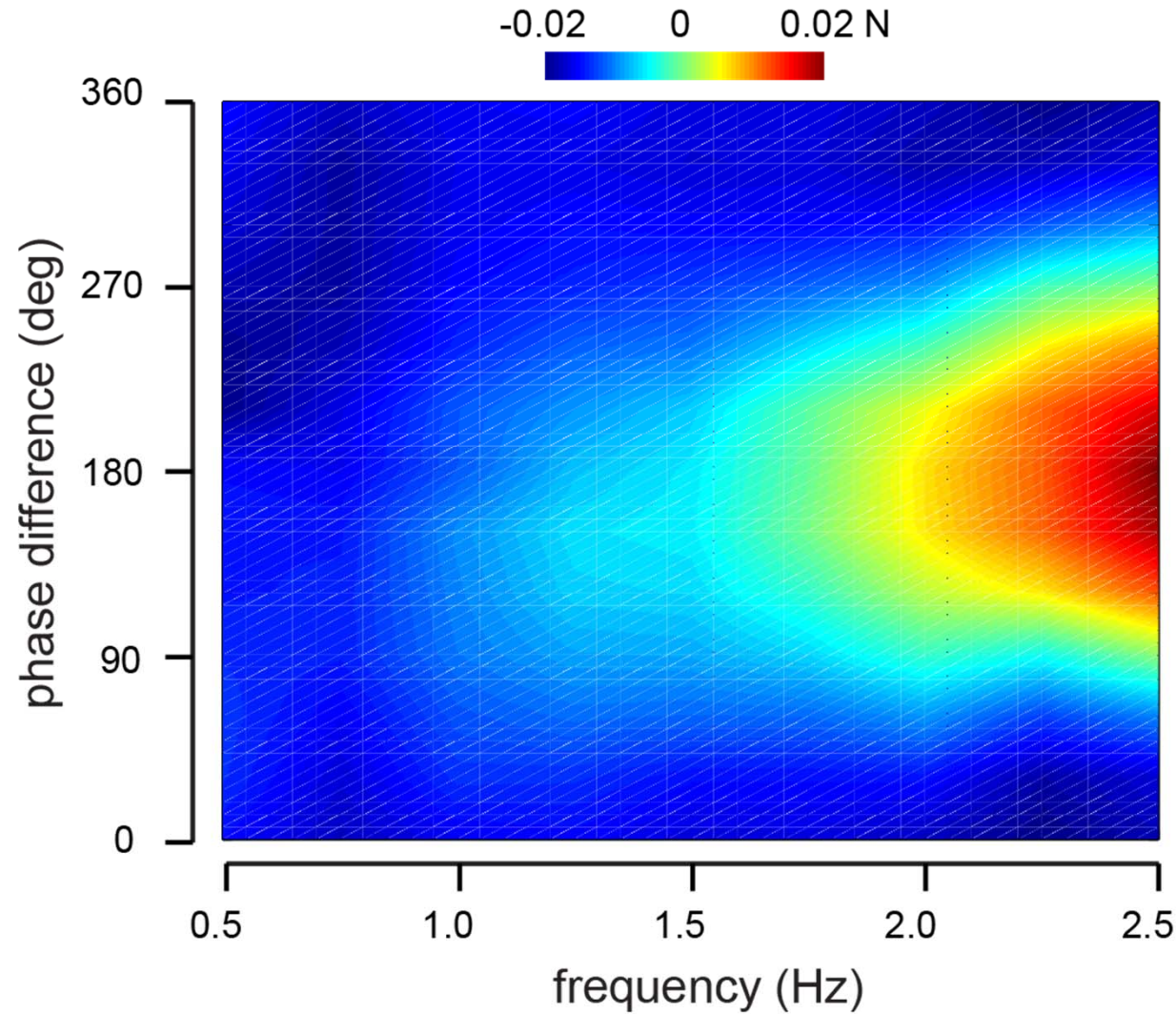
# Soft robotics



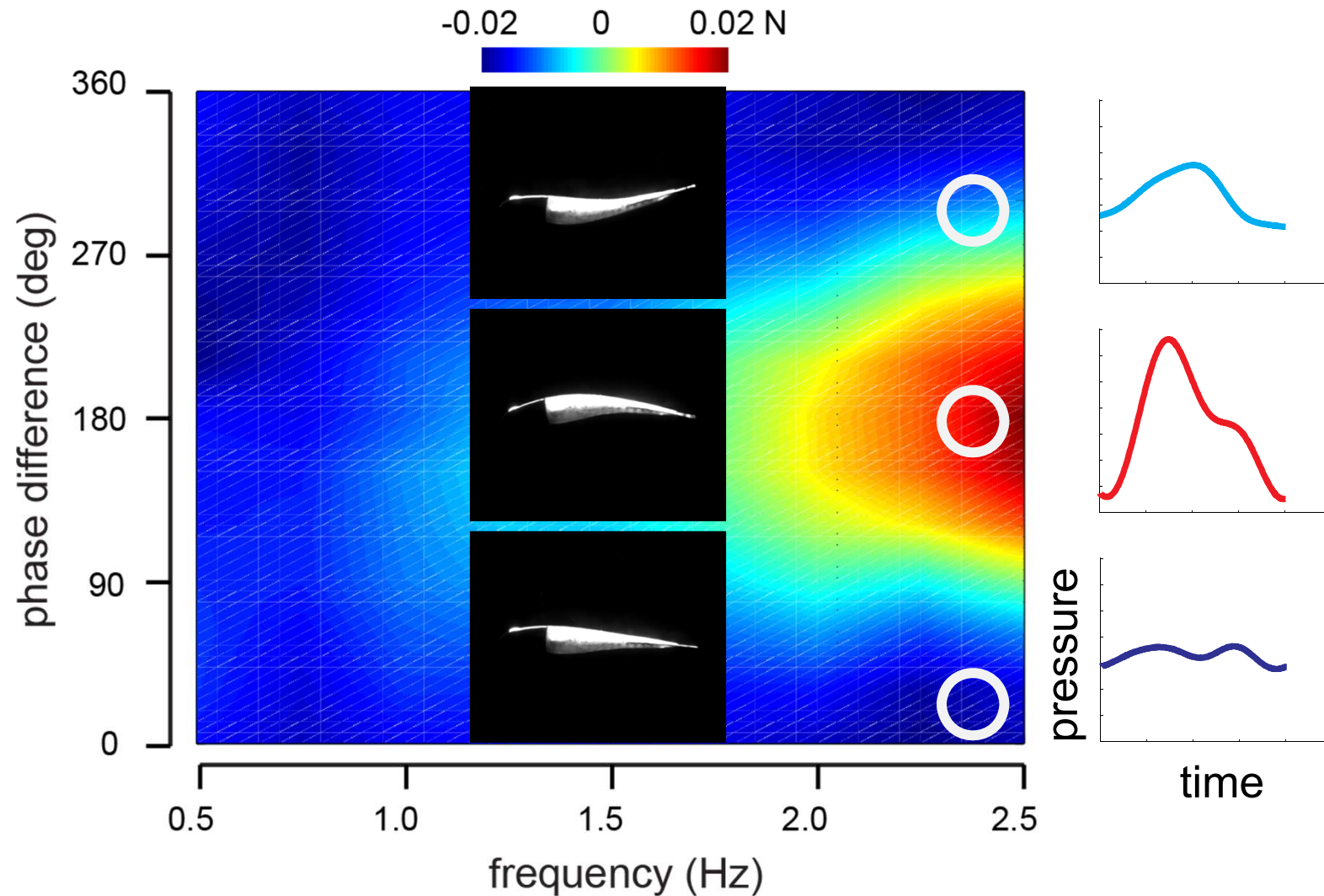
Akanyeti, Putney, Yanagitsuru, Lauder, Stewart and Liao **PNAS** 2017



# Thrust correlated to unique pressure profiles



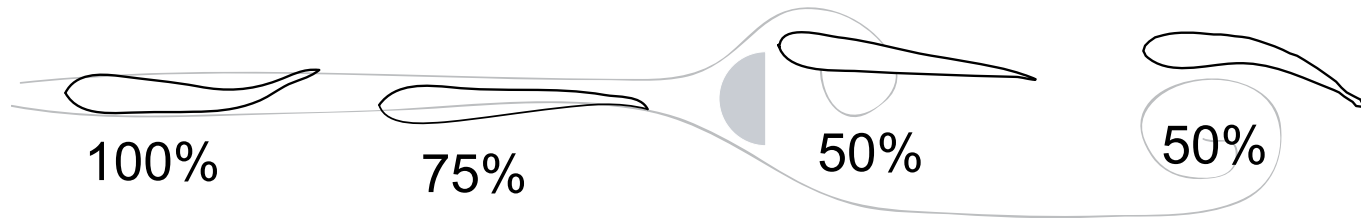
# Thrust correlated to unique pressure profiles



# Summary

How and why do fish swim in unsteady flows?

# Behavioral complexity

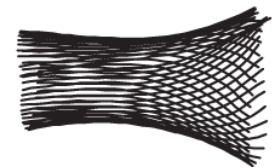
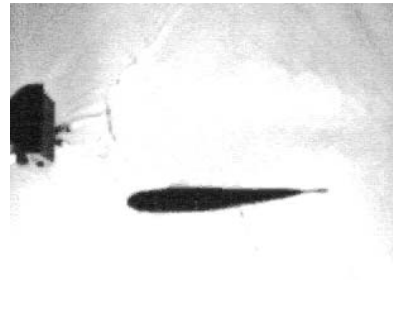


swimming

bow waking

entraining

Kármán gaiting



# Acknowledgments

## Whitney Lab/U. Florida

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- Yuzo Yanagitsuru

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- Christina Walker

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