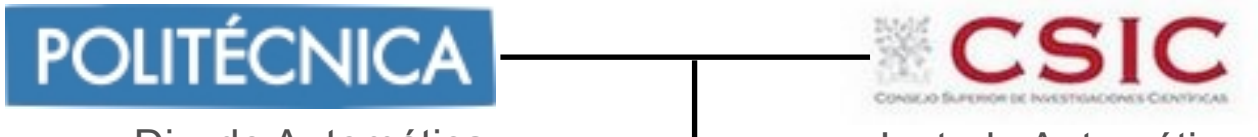

Universidad Politécnica de Madrid
POLITÉCNICA
Engineering the future



Div. de Automática (DISAM)

Inst. de Automática Industrial (IAI)

~50 staff
~100 researchers

Est. 2009

CENTRE FOR AUTOMATION AND ROBOTICS

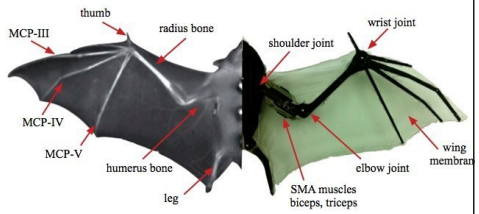
Robotics&Cybernetics Group

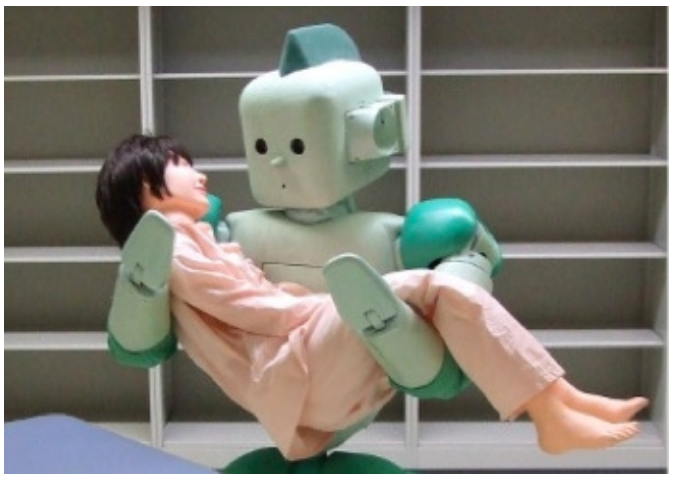
Est. 2010

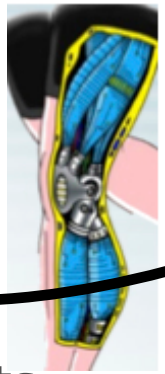
Bioinspired Systems Lab

1 staff (+2)
2 Ph.D. students
~4 undergrad

Testbed for alternative technologies







Long-term view

- ✴ ***motor-less*** and ***gear-less*** robots
  - devoid of "conventional" electro-magnetic/pneumatic/hydraulic technology, no rotating parts ➜ lighter, simpler, safer

Robot fishes' escape from flatland

Claudio Rossi, William Coral

***2nd FitFish workshop,* Barcelona, October 2013**

CAR

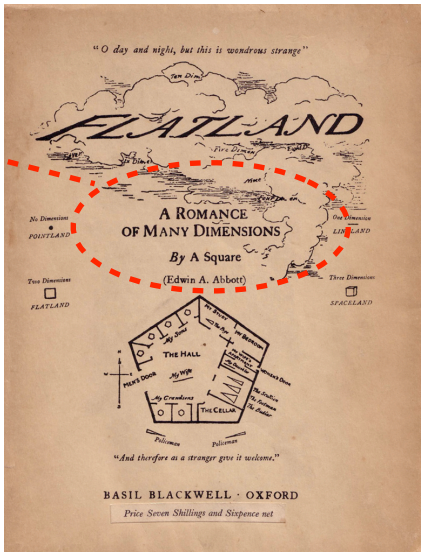
CENTRE FOR AUTOMATION AND ROBOTICS | bio-inspired systems lab

POLITÉCNICA

CSIC

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

*"A romance of **many dimensions**..."*

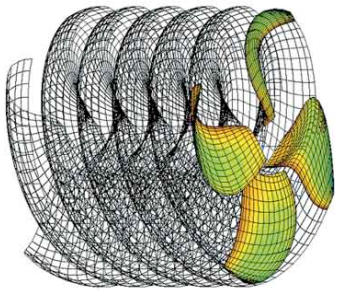


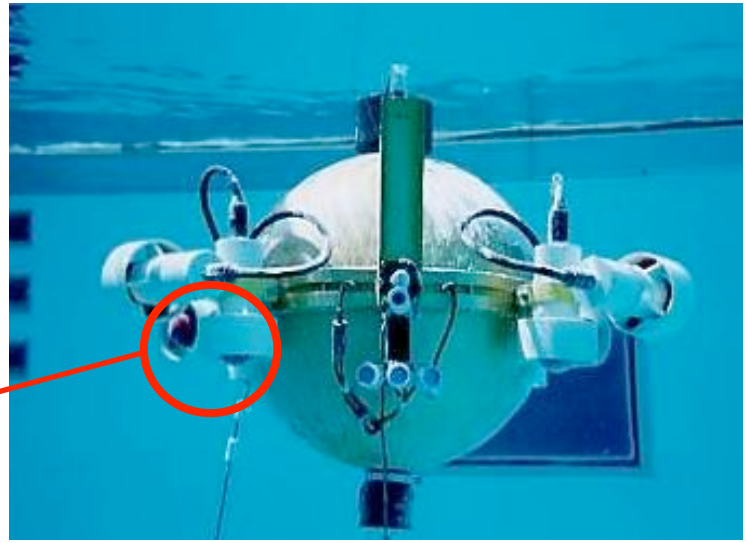
Outline

- Robot fishes in **1D**: propulsion
- Robot fishes in **2D**: turning in the horizontal plane
- Robot fishes in **3D**: Escape from flatland
- Our work (in progress...)

Underwater **robots**: propellers mainly used

- Problems of cavitation, noise, efficiency, dangerous, can get tangled with vegetation





Underwater **living** creatures: high performance movements, efficient

➡ A promising approach: taking inspiration from the mechanisms of fish locomotion

1D: propulsion

First specimens

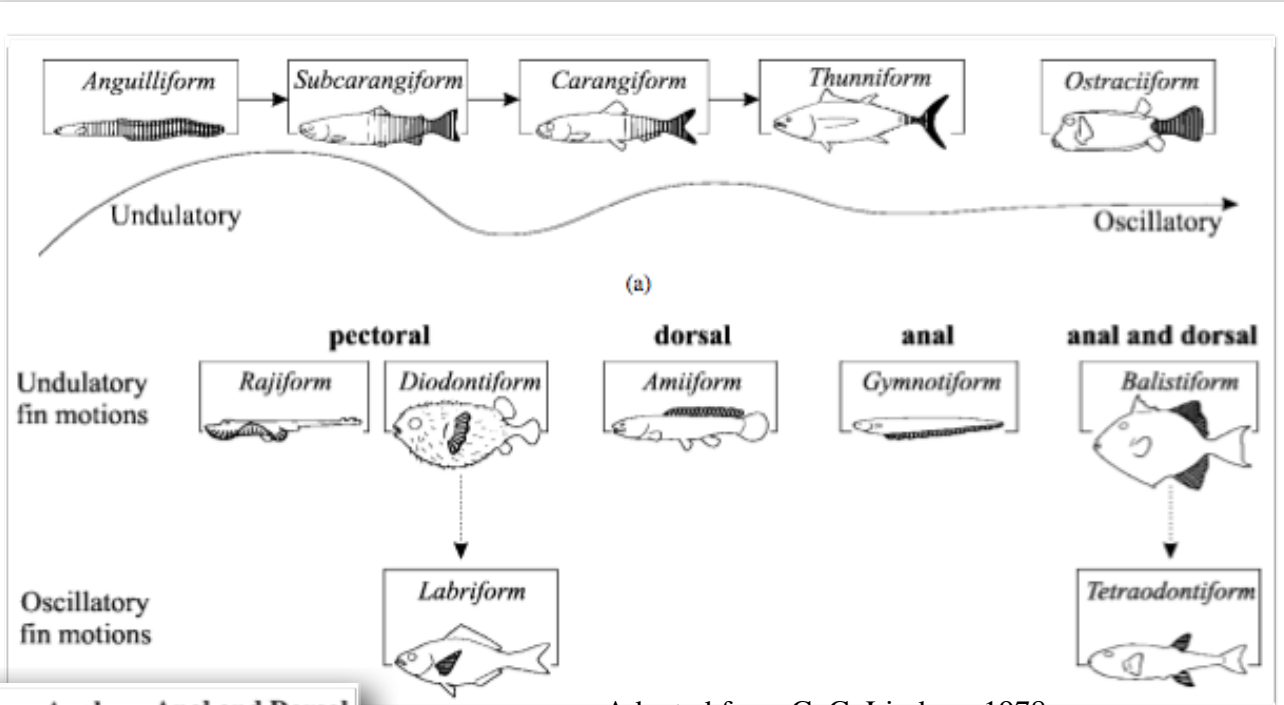
RoboTuna, MIT, 1993

Robo pike, "*the world's first free-swimming robot fish*", MIT, (year?)

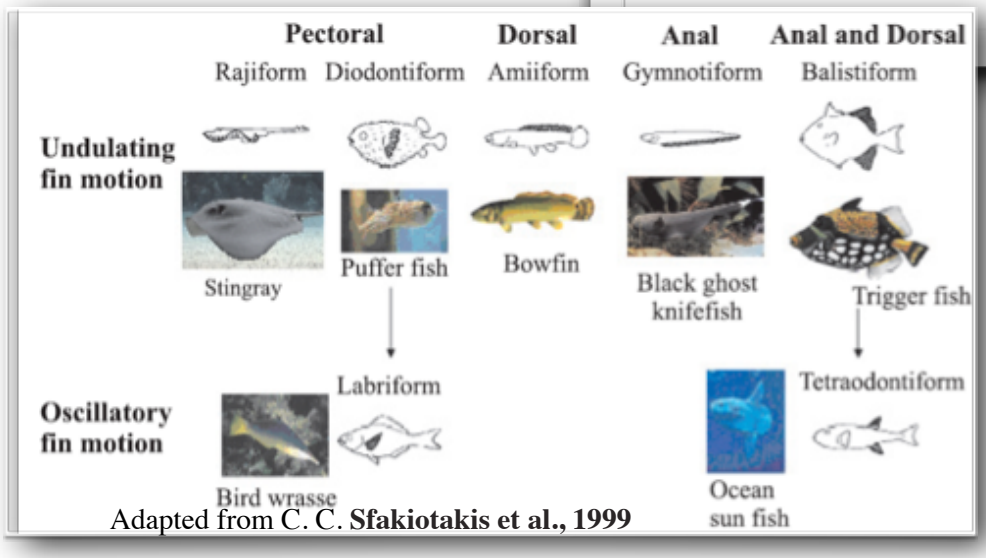
Many others since then ! → **Main focus on propulsion !**

Robot fishes: propulsion

Bio-inspiration is a hot topic in robotics



Adapted from C. C. Lindsey, 1978

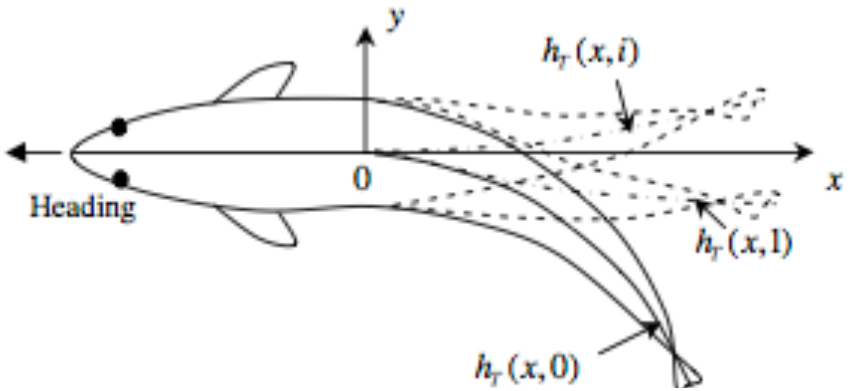


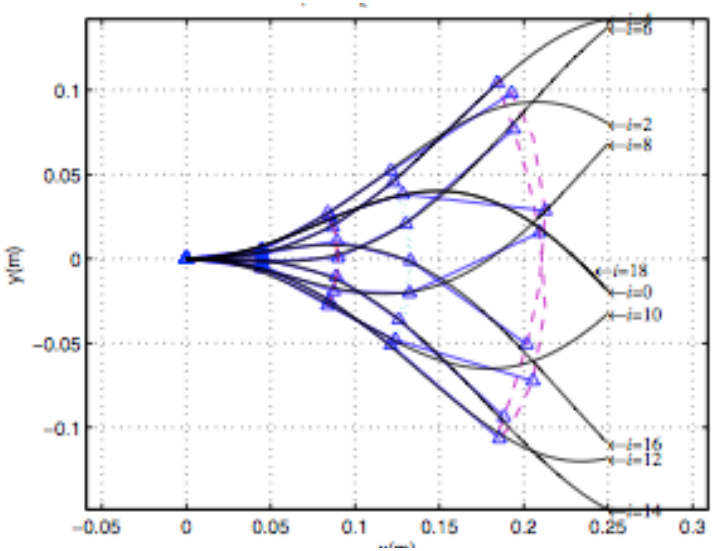
Adapted from C. C. **Sfakiotakis et al., 1999**

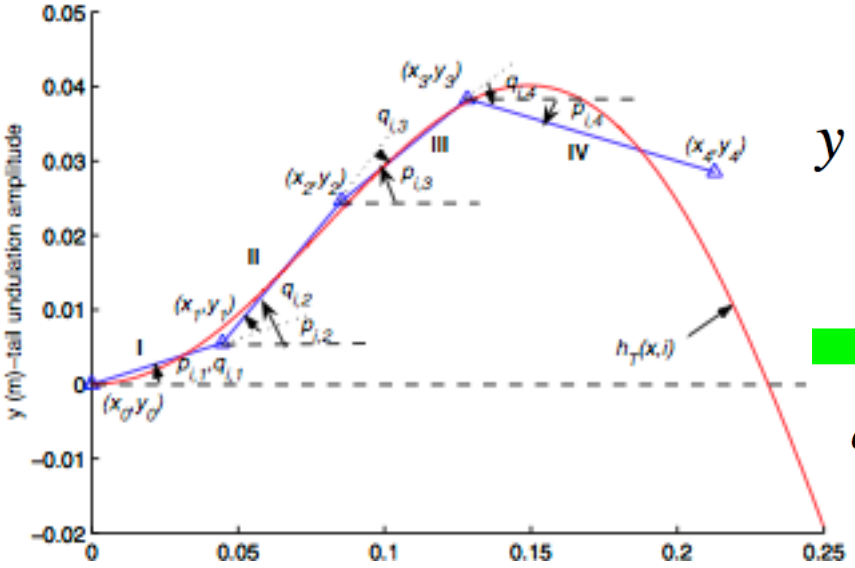
Diagrams ike these, and terms as "CARANGIFORM", "LABRIFORM", etc. are now quite common in robotics papers!

Robot fishes: undulatory propulsion

From: J. Liu and H. Hu, 2007



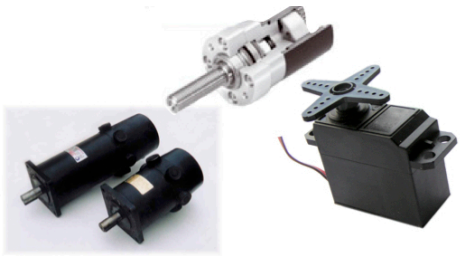


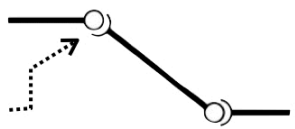


$$y = fs(x,t) = (c_1 x + c_2 x^2)\sin\left(\frac{2\pi}{\lambda}x + \omega t\right)$$

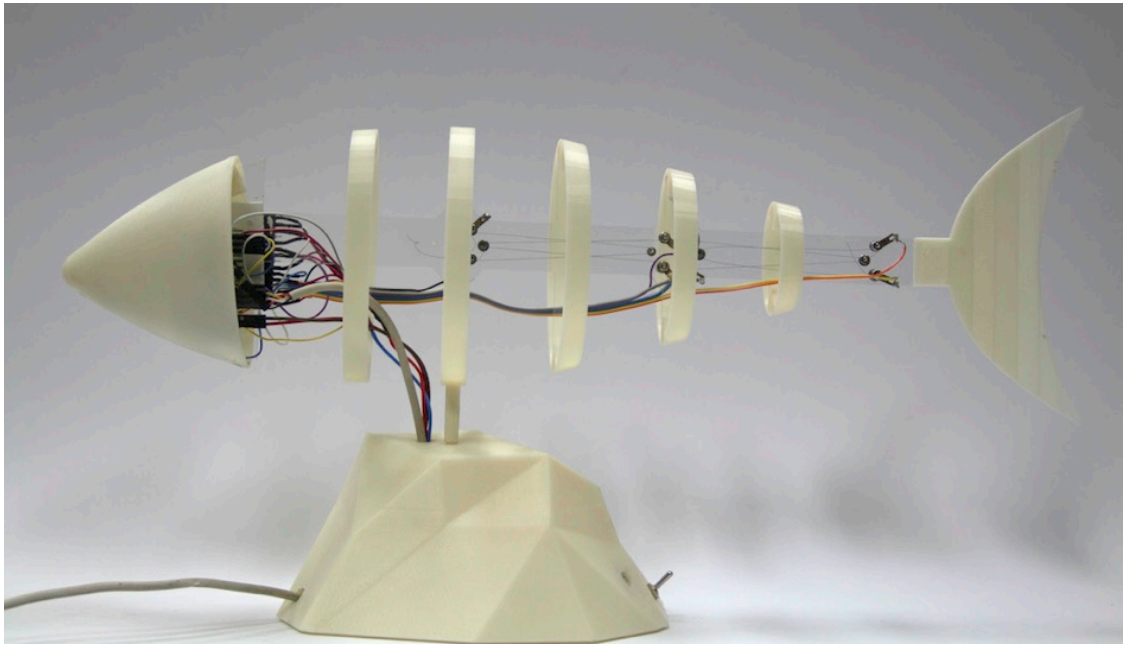
Approximation of ***fs*** with rigid segments (q_j=joint position):

$$q_j(t) = a_j \cdot \sin(\omega t + \phi_j), \quad j = 1..number\ of\ joints$$

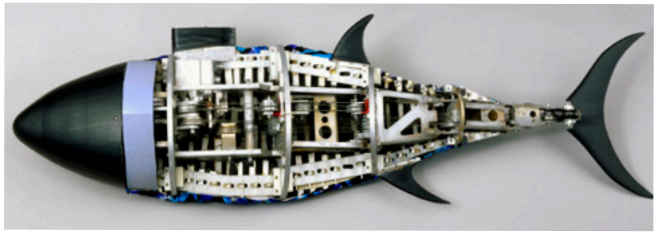




Robot fishes: the iTuna

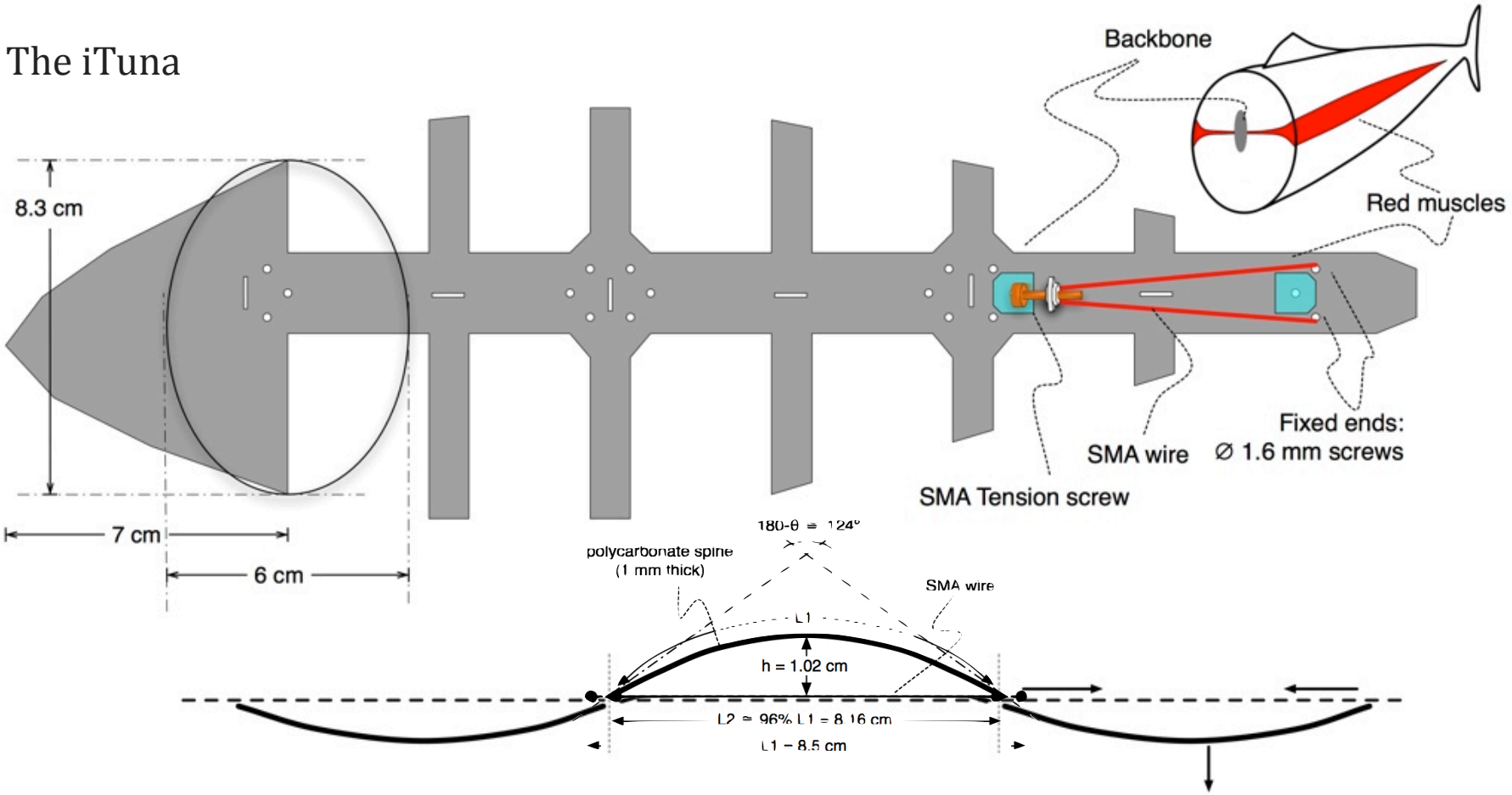


iTuna, UPM, 2010: **1** mechanical part, **0** rotating motors (6 Shape Memory Alloys -SMA- linear artificial muscles)



Robotuna, MIT, 1994: **2,843** parts controlled by **six** (rotating) motors

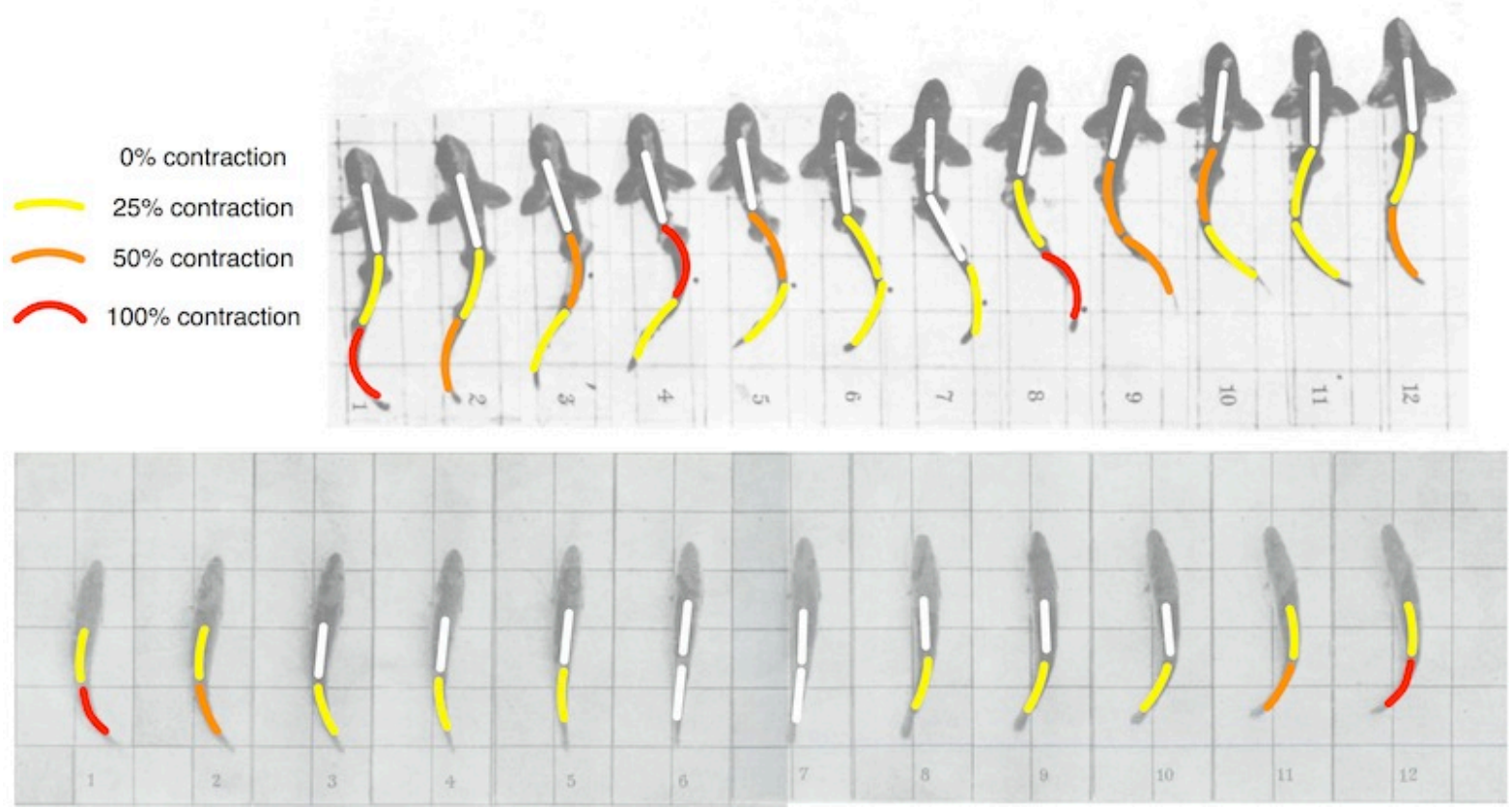
The iTuna



3 segments, length: 30 cm + caudal fin

Elastic polycarbonate notochord (1 mm thick)

The iTuna

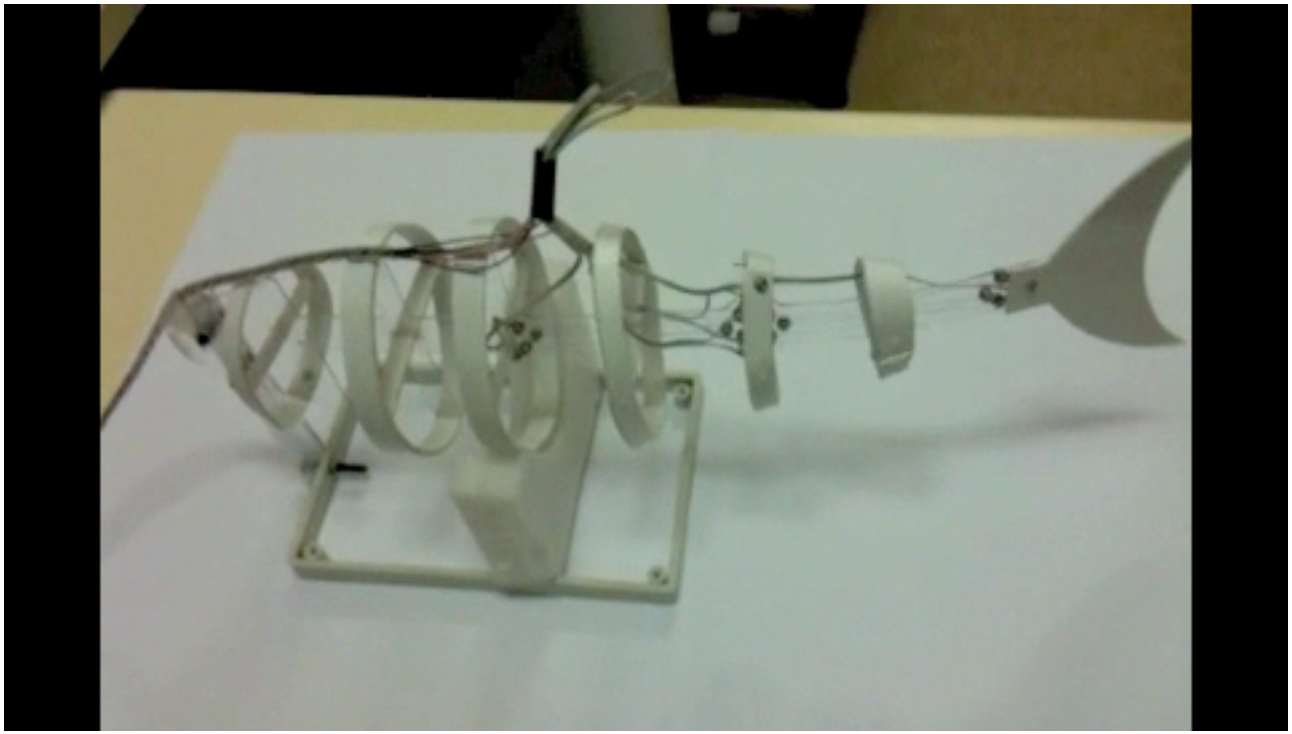


From Rossi et al., 2011 (adapted from Grey, 1933)

Main focus on propulsion !

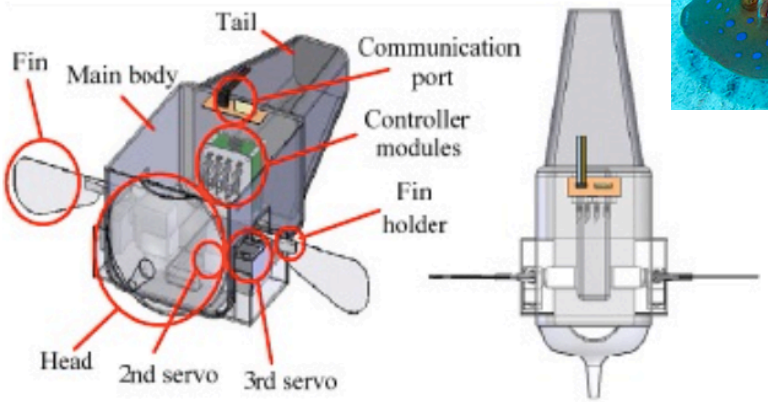
Robot fishes: undulatory propulsion

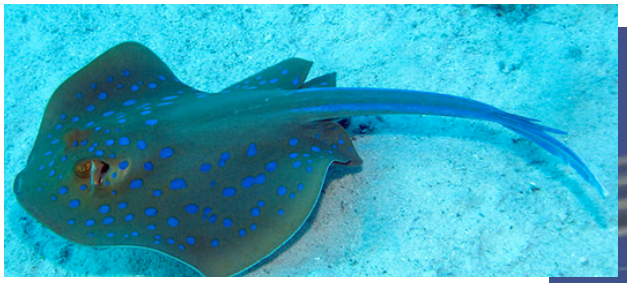
The iTuna



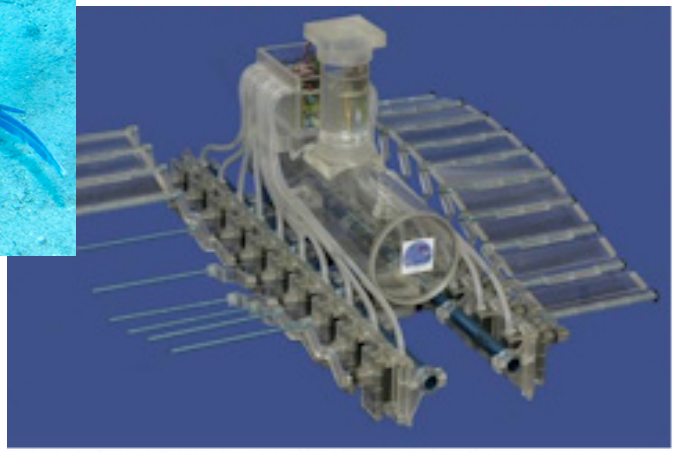
Robot fishes: fin-based propulsion

Budiyono, 2009



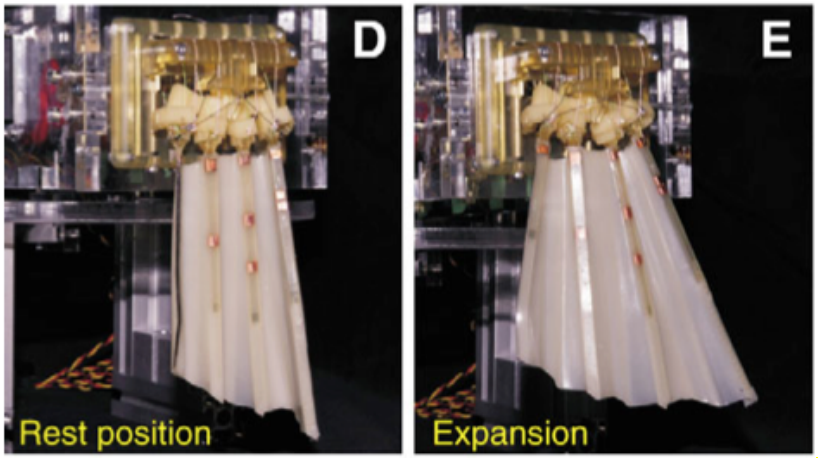


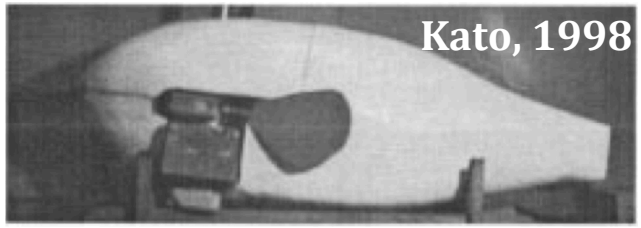
KH Low, 2006



Stingray NCF-I - Nanyang Technological Univ.

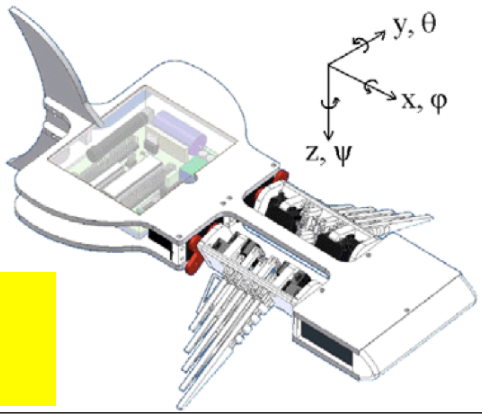
Lauder at al., 2007





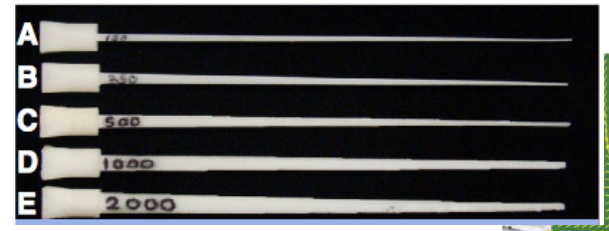
Geder et al., 2007

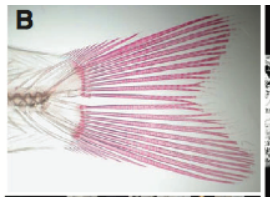
Dr. S. Zhang

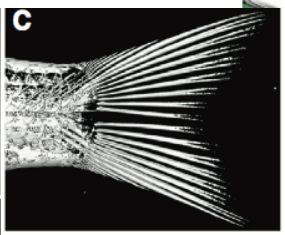


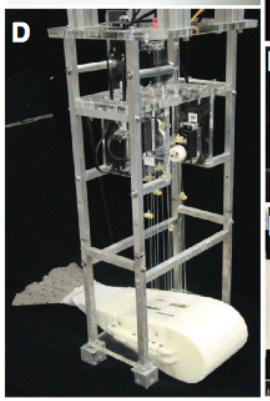
Many others ! (see, e.g., *Fish biorobotics: kinematics and hydrodynamics of self-propulsion*, George V. Lauder et al., 2007)

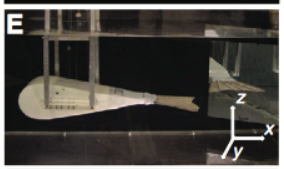
Robot fishes: effects of (caudal) fins on propulsion

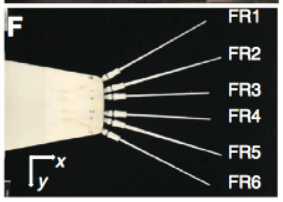


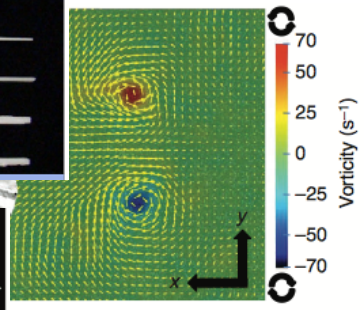


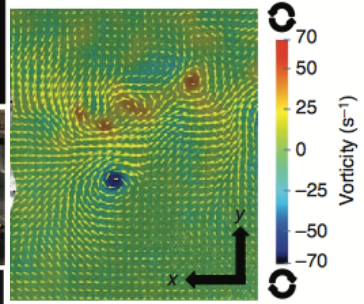




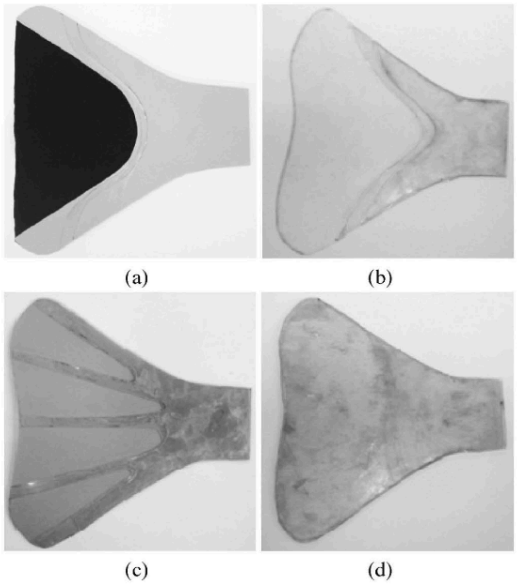


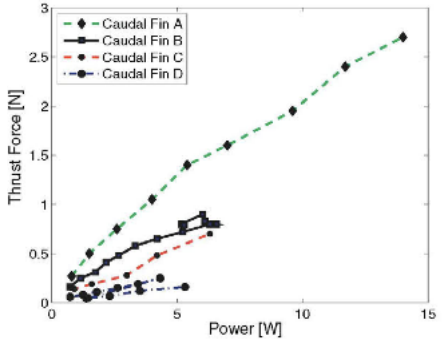


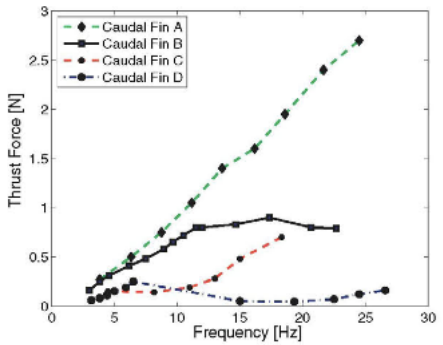




Esposito et al., A robotic fish caudal fin: effects of stiffness and motor program on locomotor performance, 2012

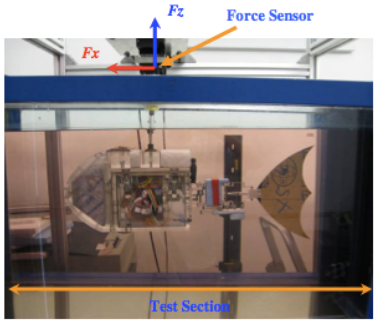


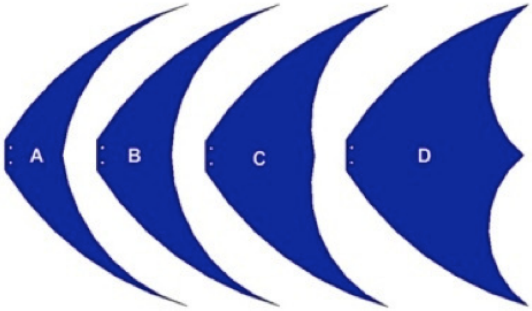




Apalkov et al., Mechanical actuator for biomimetic propulsion and the effect of the caudal fin elasticity on the swimming performance, 2012

K.H. Low, 2010



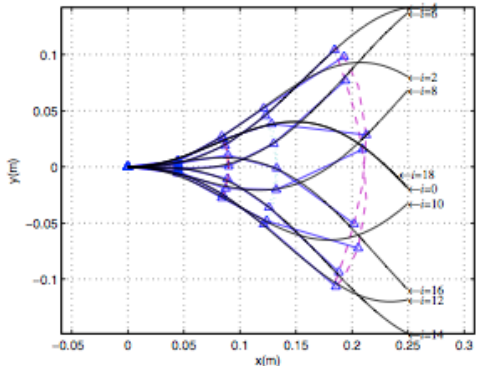


Similar research un other fins, (mainly pectoral fins)

2D: Turning

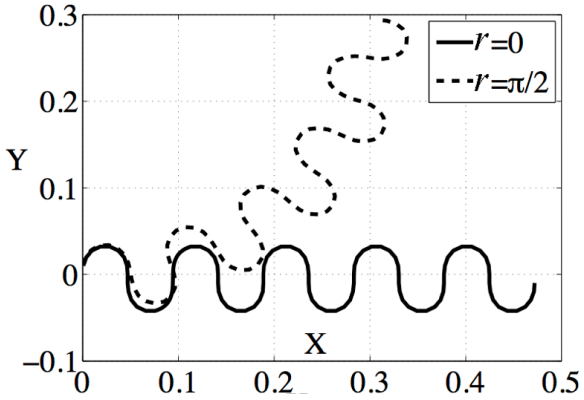
Robot fishes: turning

"In-cruise" turning (undulatory swimming)



$$y = f_S(x,t) = (c_1 x + c_2 x^2)\sin\left(\frac{2\pi}{\lambda}x + \omega t\right)$$

$$y = f_S(x,t) + d(x)$$



Approximation of ***fs*** with rigid segments (qj=joint position):

$$q_j(t) = a_j \cdot \sin(\omega t + \phi_j) + b_j$$

Robot fishes: turning

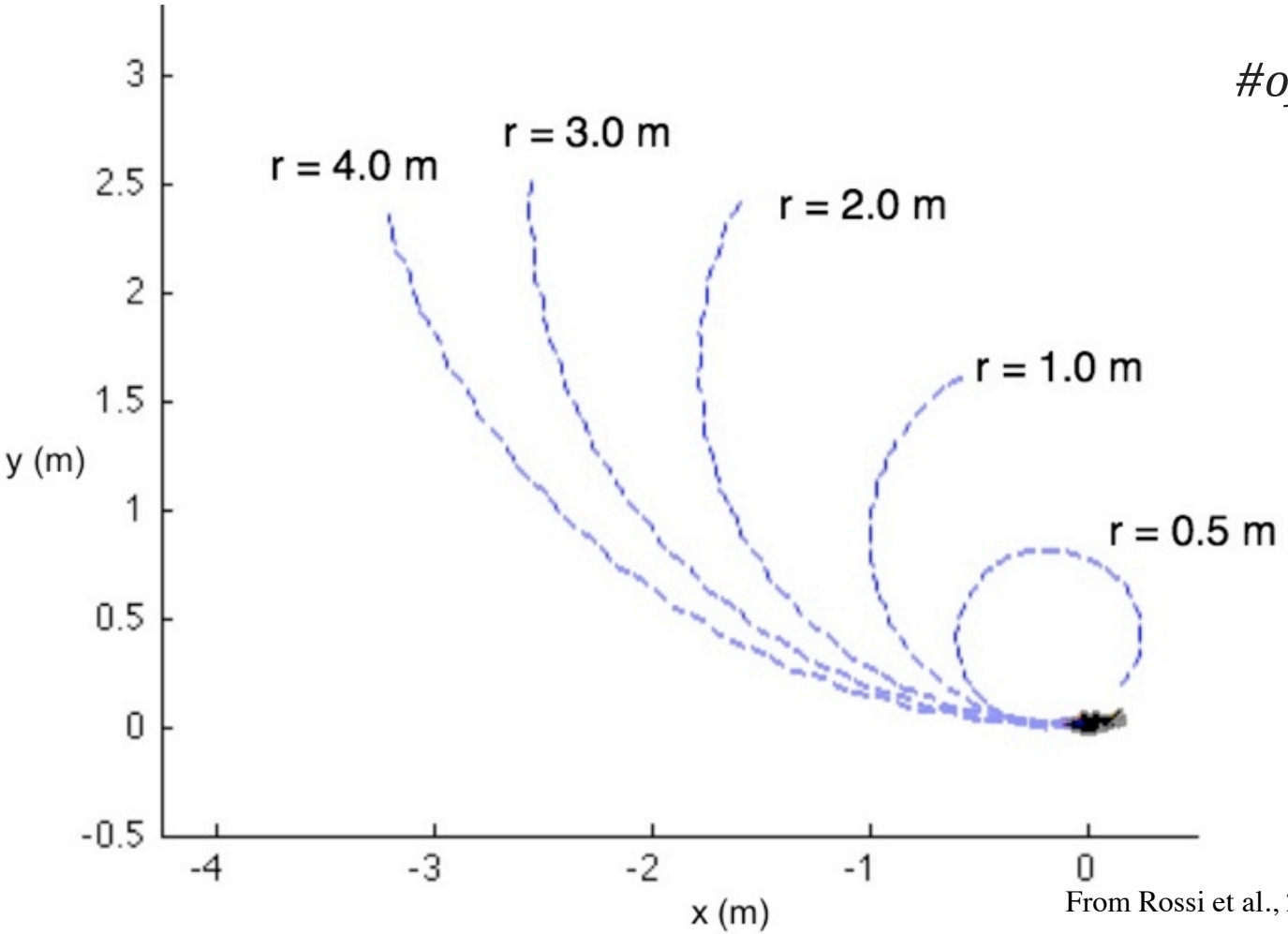
The iTuna

$$q_j(t) = a_j \cdot sin(\omega t + \phi_j) + b_j$$

Body length

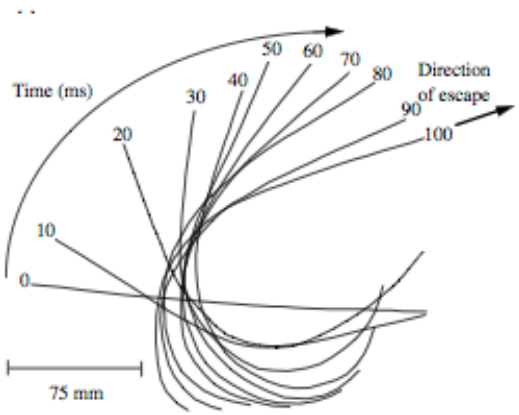
$$b_j = \frac{L}{n \cdot r}$$

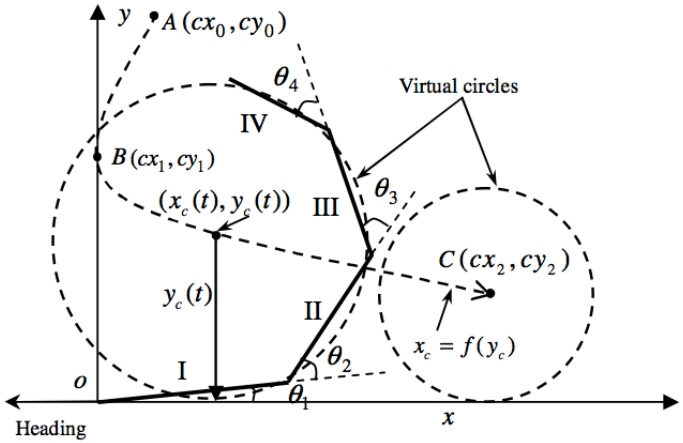
#of segments *curve radius*

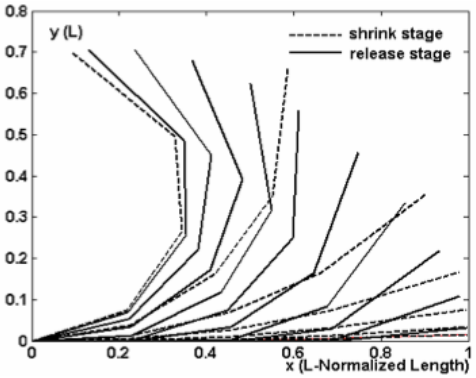


From Rossi et al., 2011

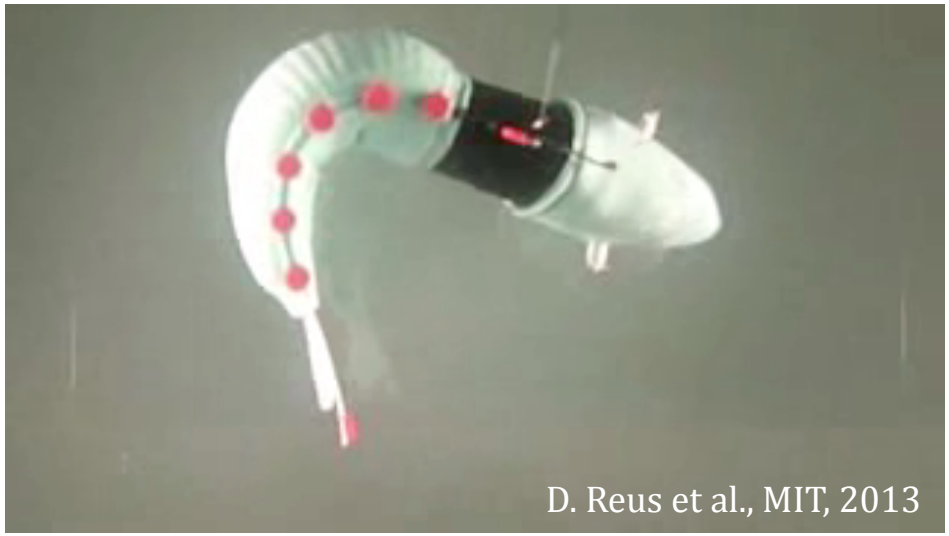
"Snap" turns or sharp turns/starts







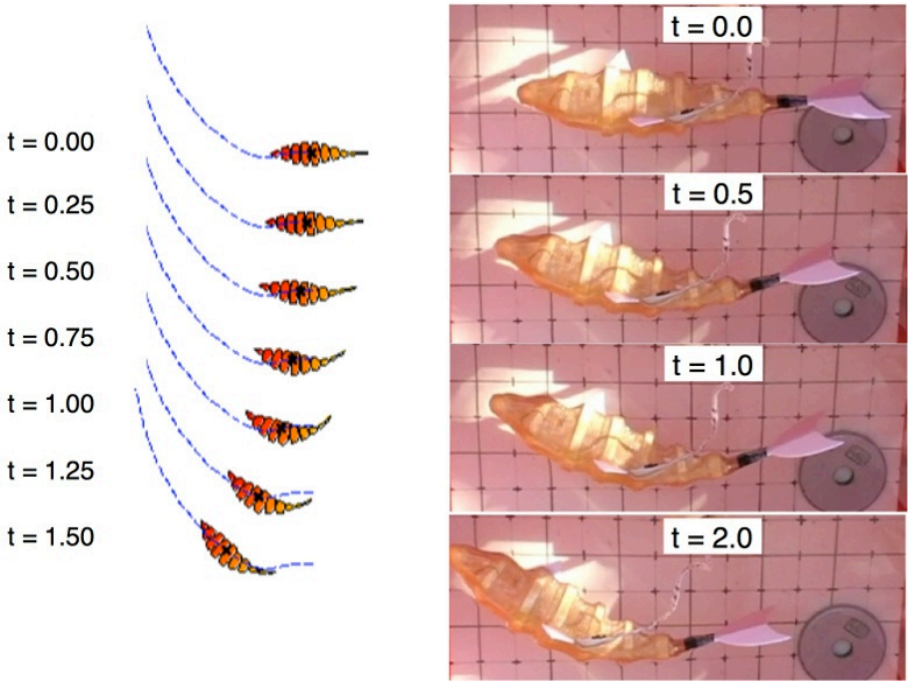
From: J. Liu and H. Hu, 2007



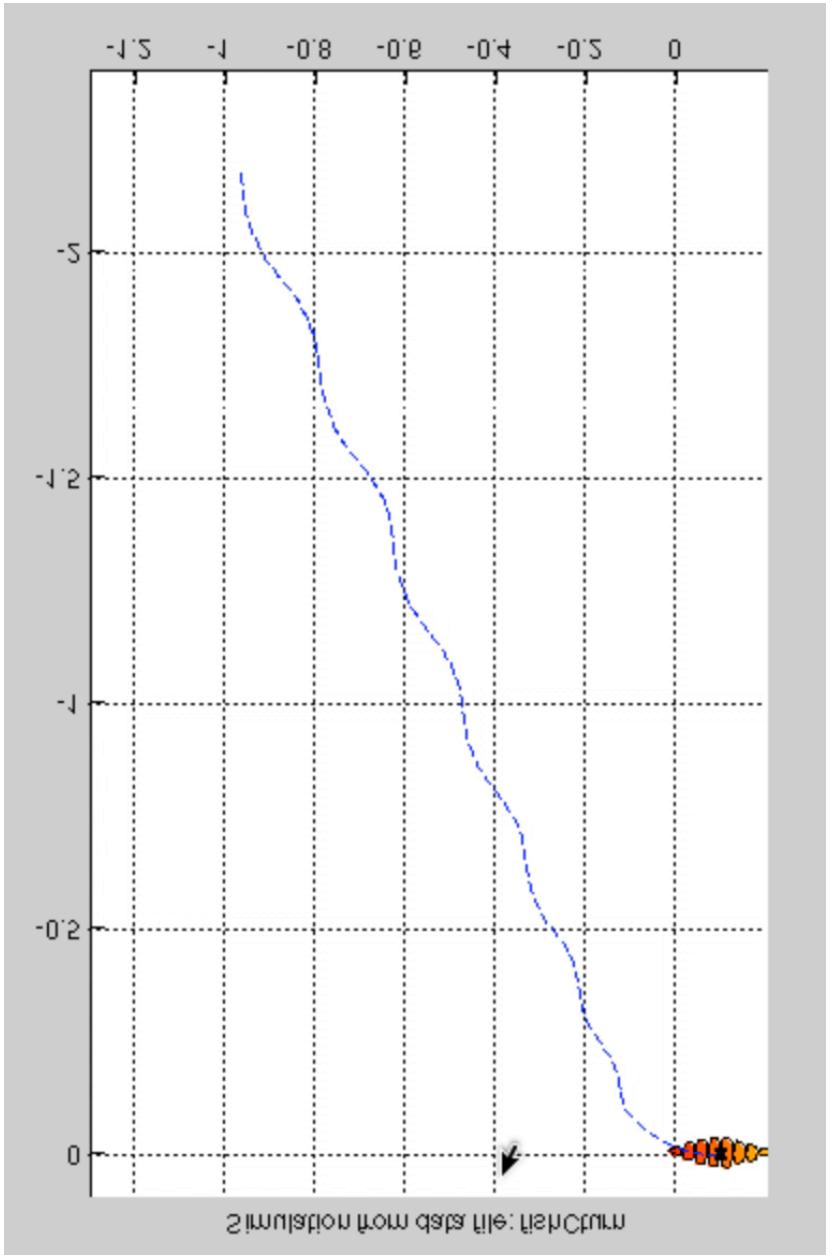
Robot fishes: turning

The iTuna

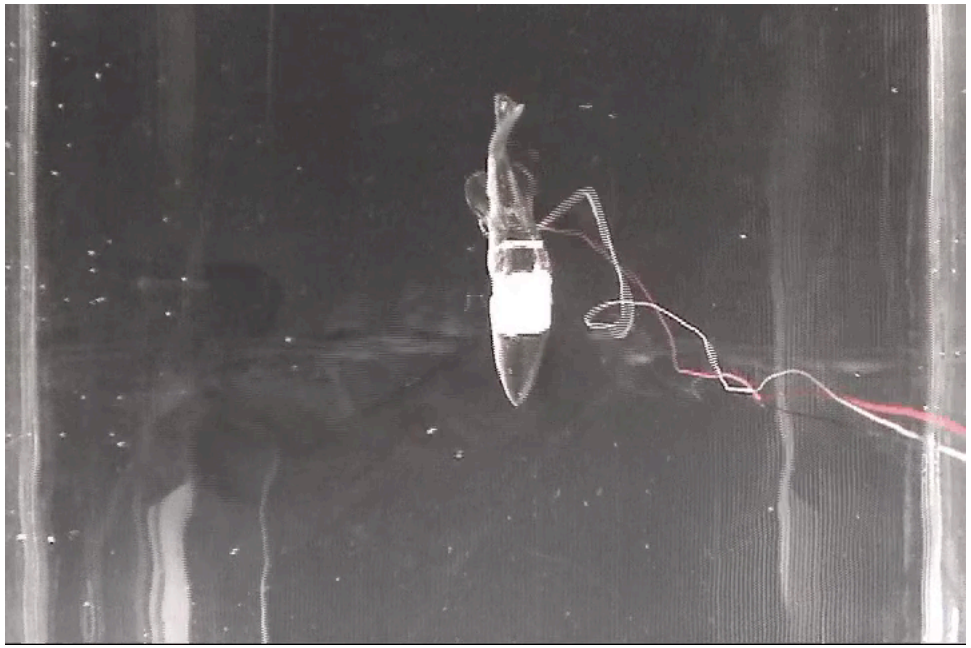
Simulations performed with the "Biohydrodynamics MATLAB Toolbox" by A. Munnier and B. Pinçon



From Rossi et al., 2011



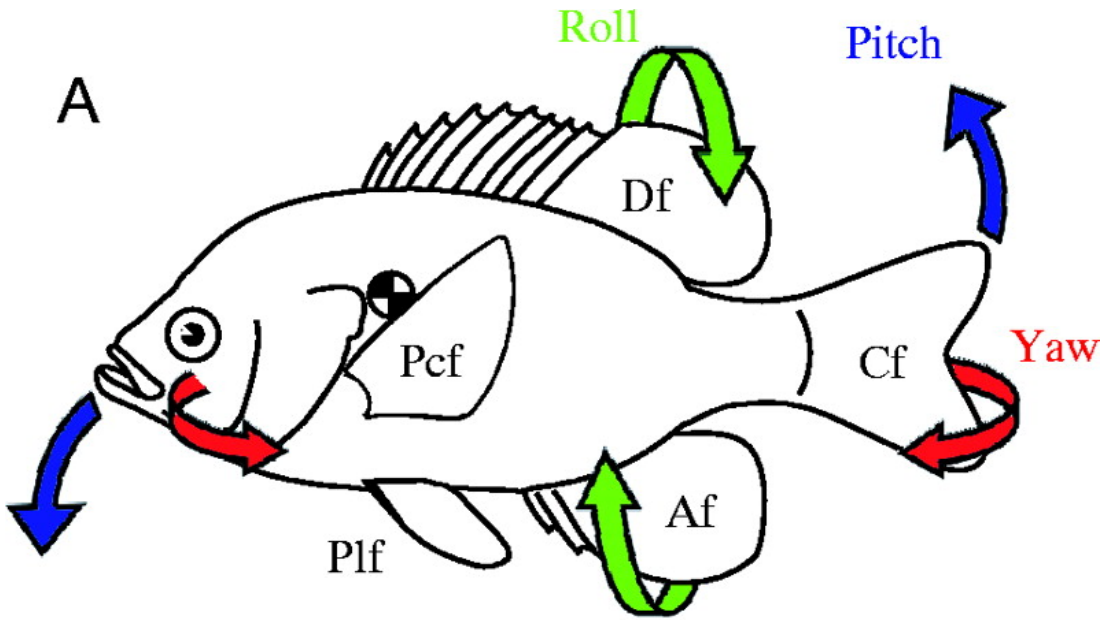
Robot fishes



Videos of robot fishes living in Flatland

3D: Escaping from flatland

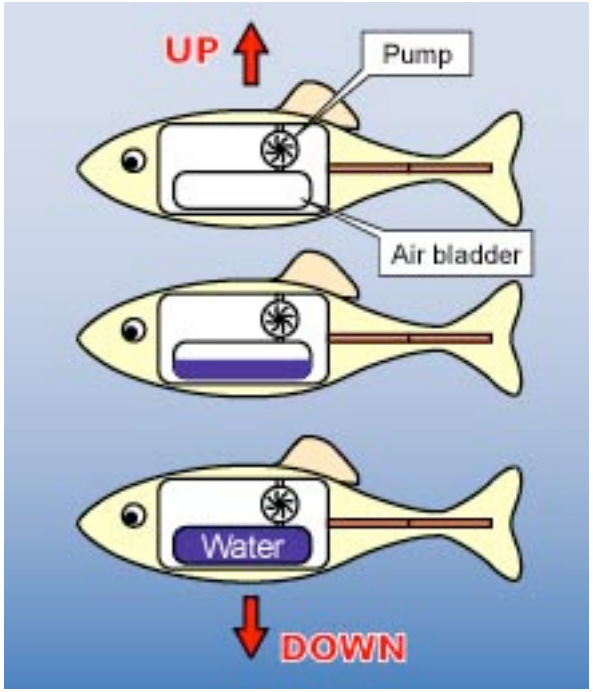
Terminology



Heave (buoyancy)

Image from Standen and Lauder, 2005

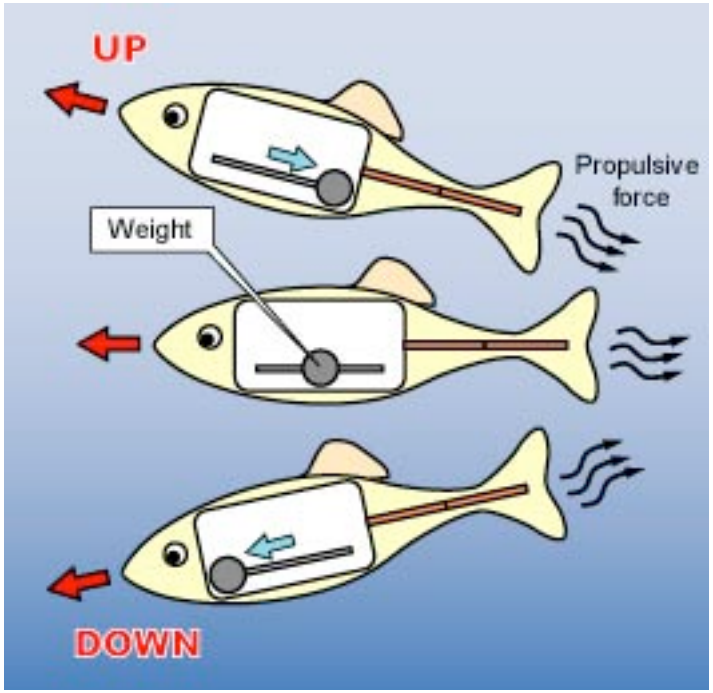
Heave (buoyancy): changing body's density



- Water pumping
- Compressed air tanks
- Changing density of a given material (e.g., oil) by heating/cooling

Drawings from: Up-down Motion for a Fish Robot, 2001, by Koichi Hirata, http://www.nmri.go.jp/eng/khirata/fish/

Moving ballast

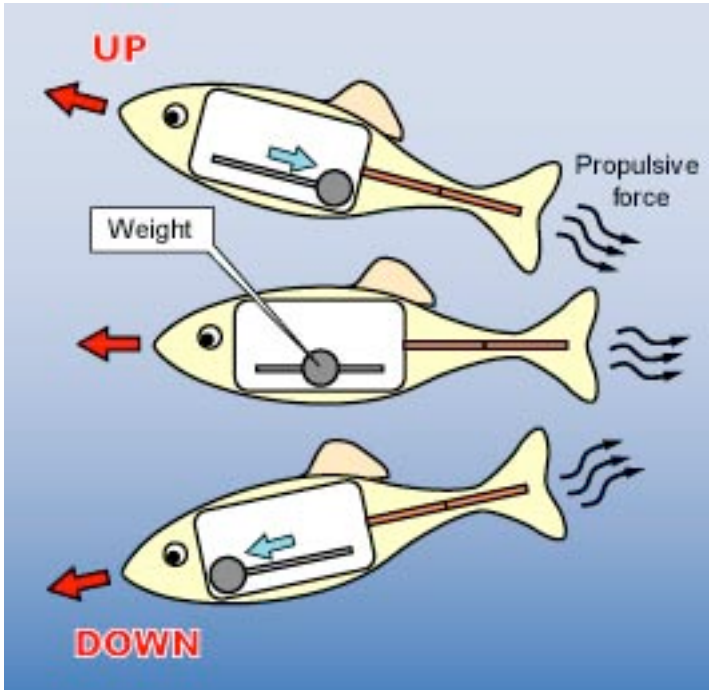


<<A weight block inside of the fish head can be moved forward and backward linearly by a DC motor so that the COG of the robotic fish is altered>>

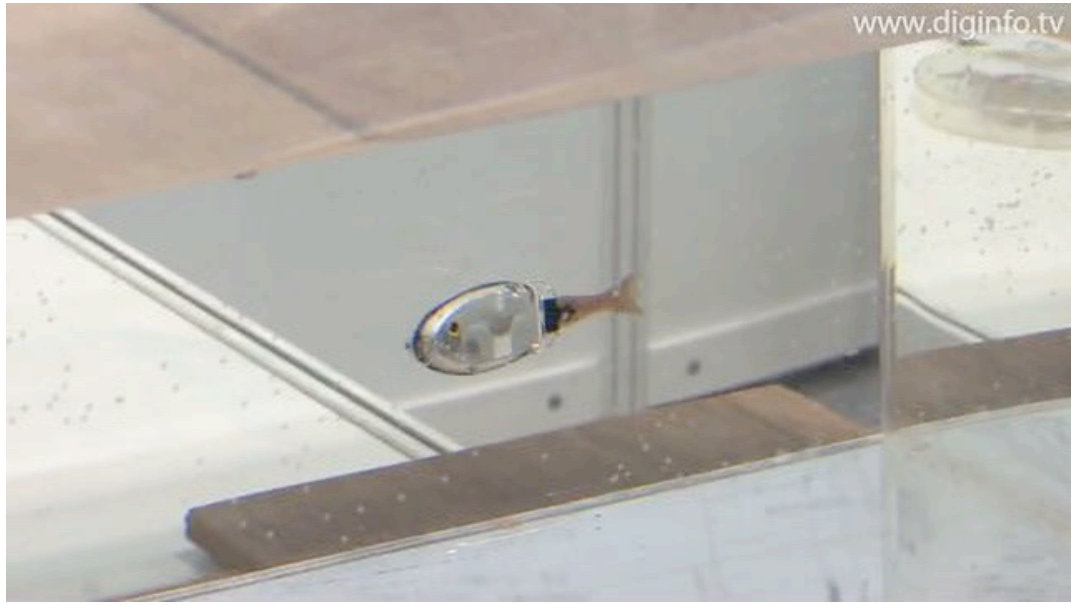
(*Design of 3D Swim Patterns for Autonomous Robotic Fish,* Huosheng Hu, 2006)

Escaping from flatland: pitch

Moving ballast



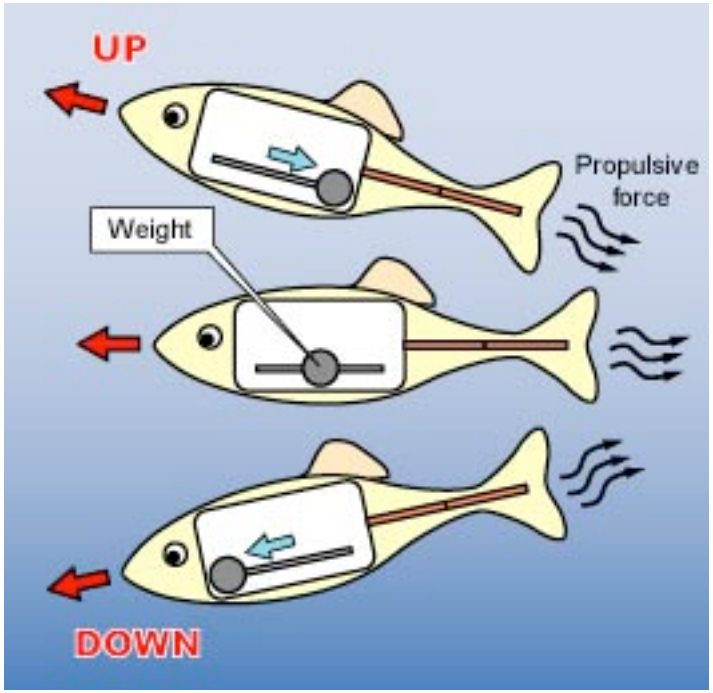
Hu, 2006

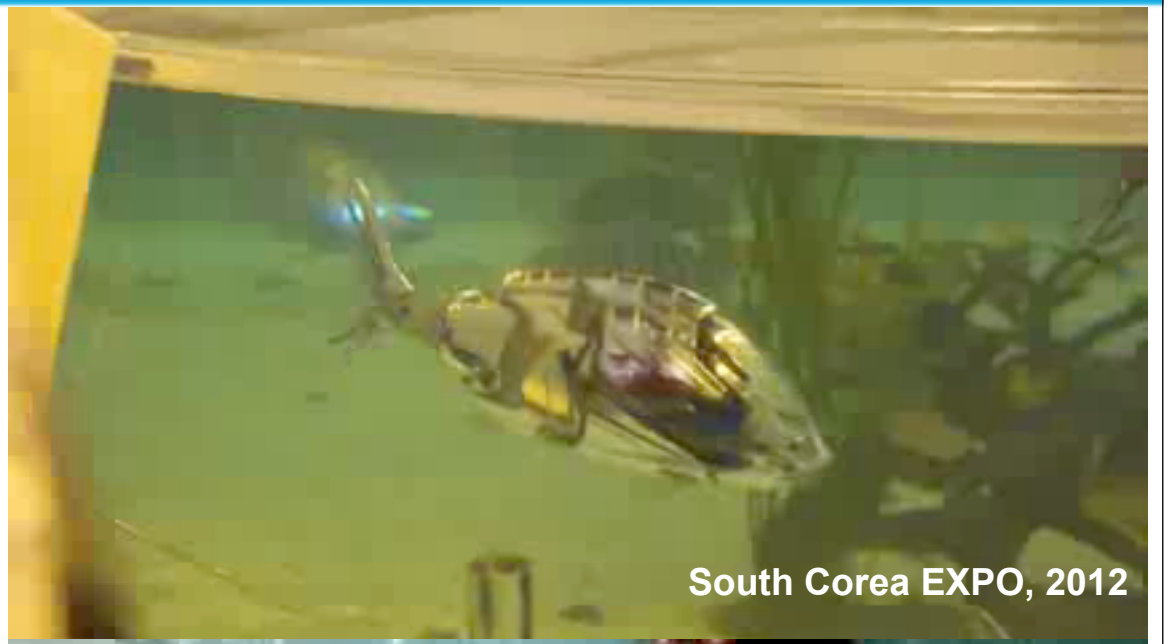


Magnetic fish, SH Kim,
Tohoku University, 2012

Escaping from flatland: pitch

Moving ballast

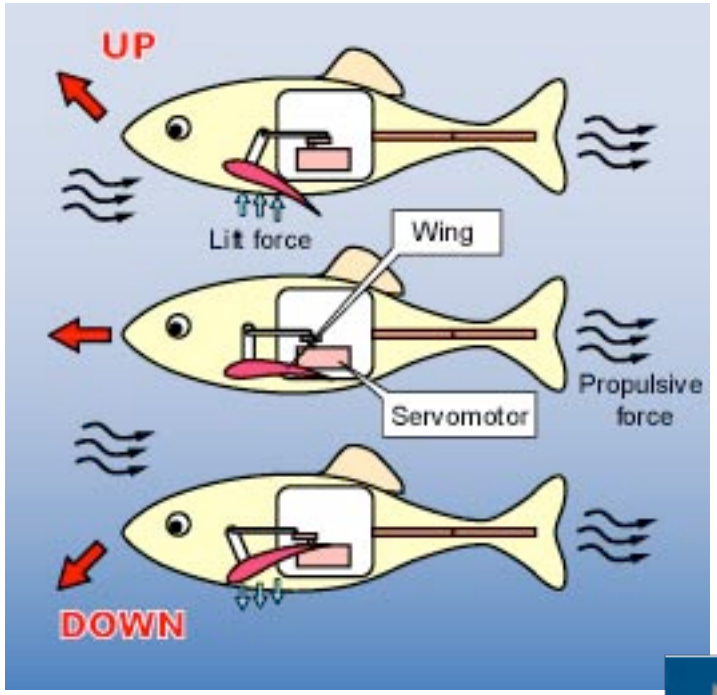




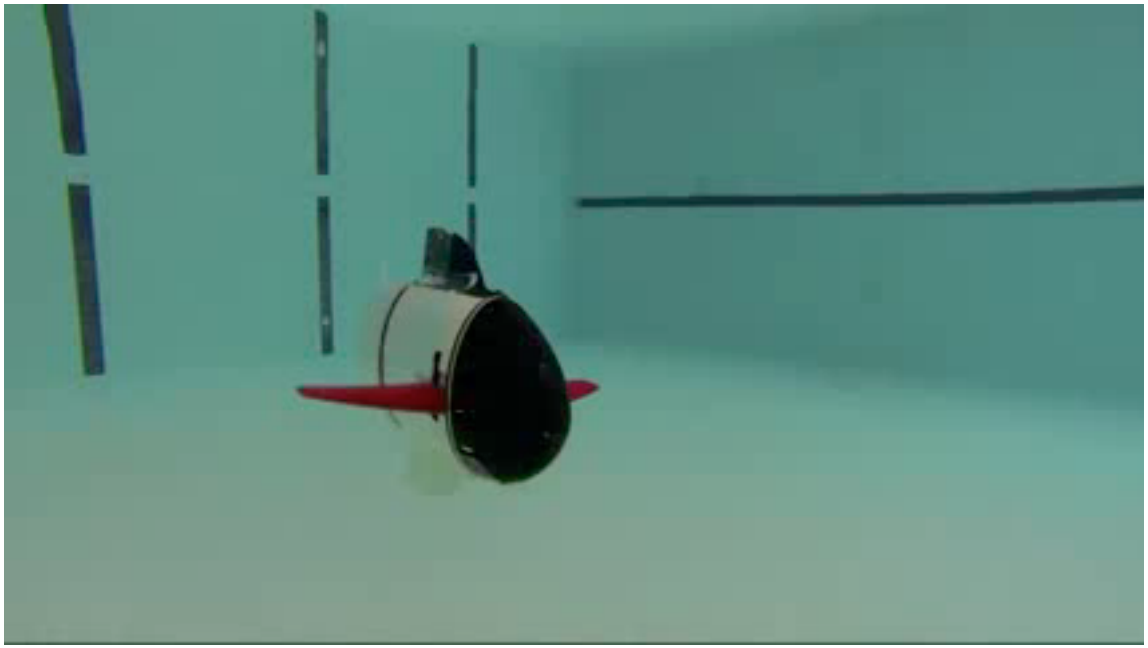
Jessiko robot fish,
by Robotswim

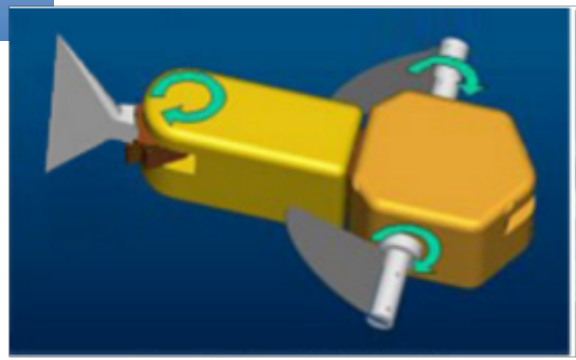
Escaping from flatland: pitch

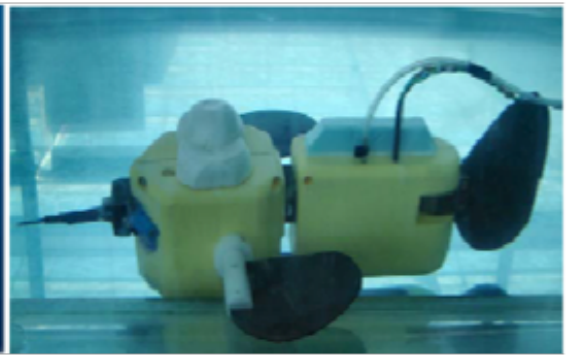
(Rigid) Rudders



MIT Distrib. Robotics Lab

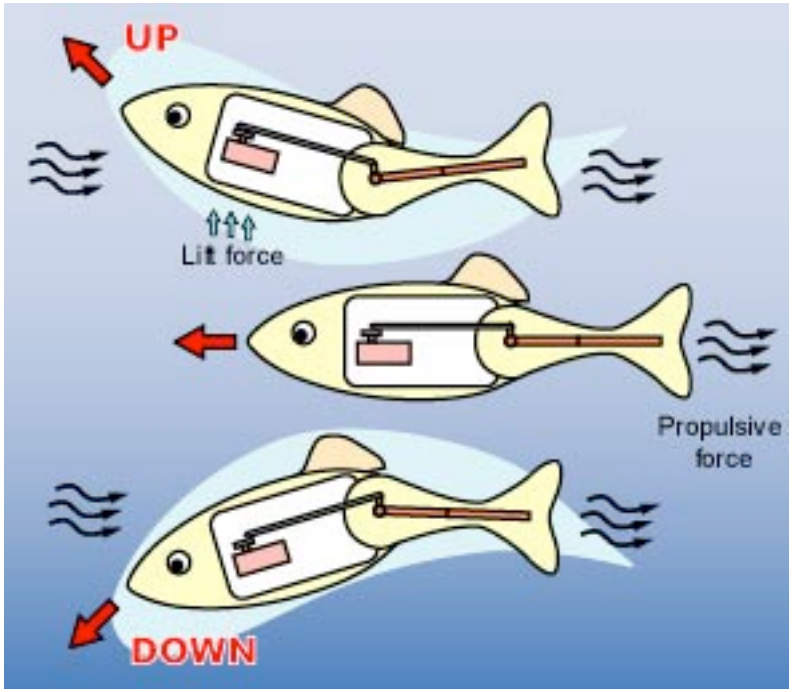






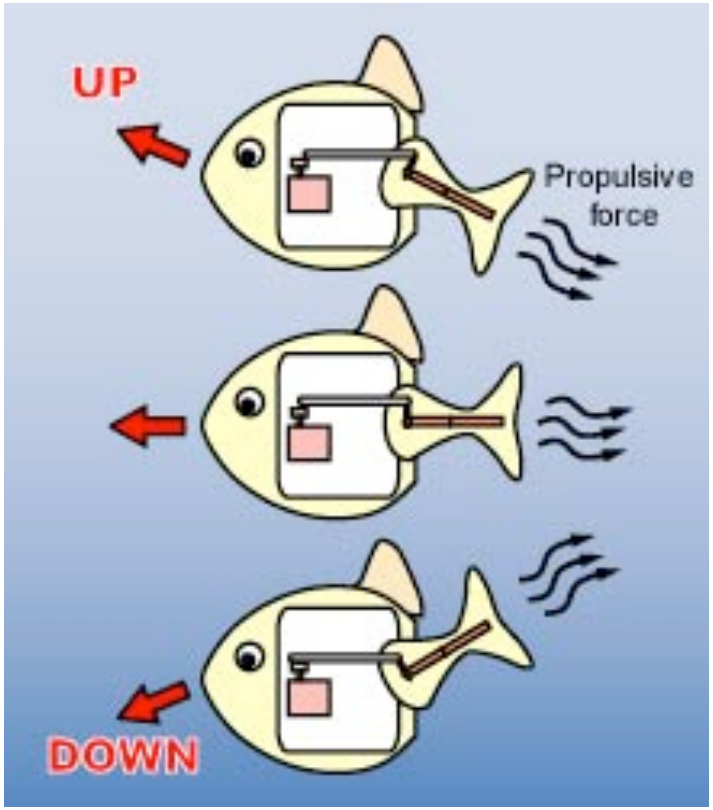
Boxybot (from boxfish), Daisy Lachat, BIRG – EPFL, Suiss

Twisting body



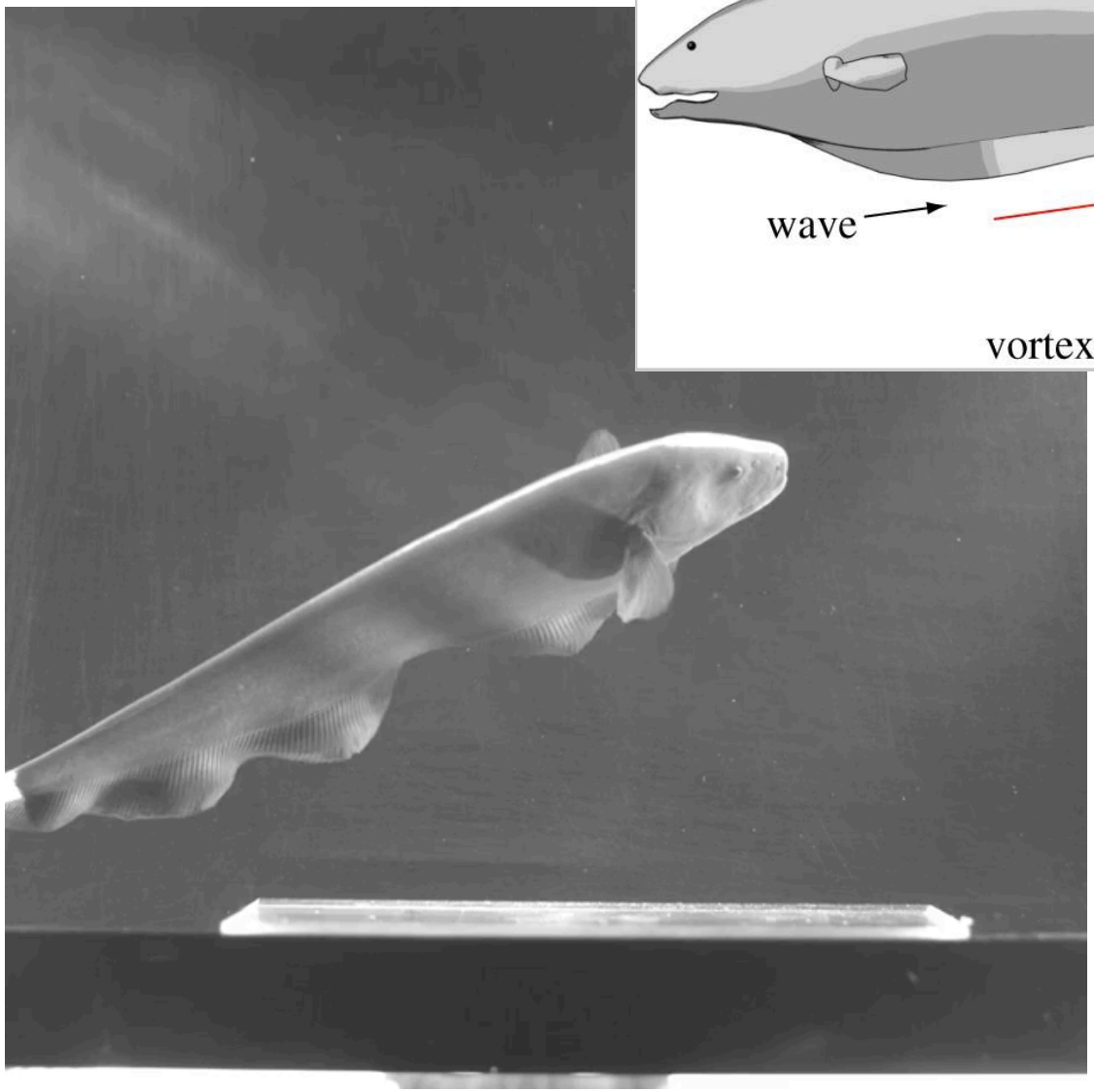
No prototype found

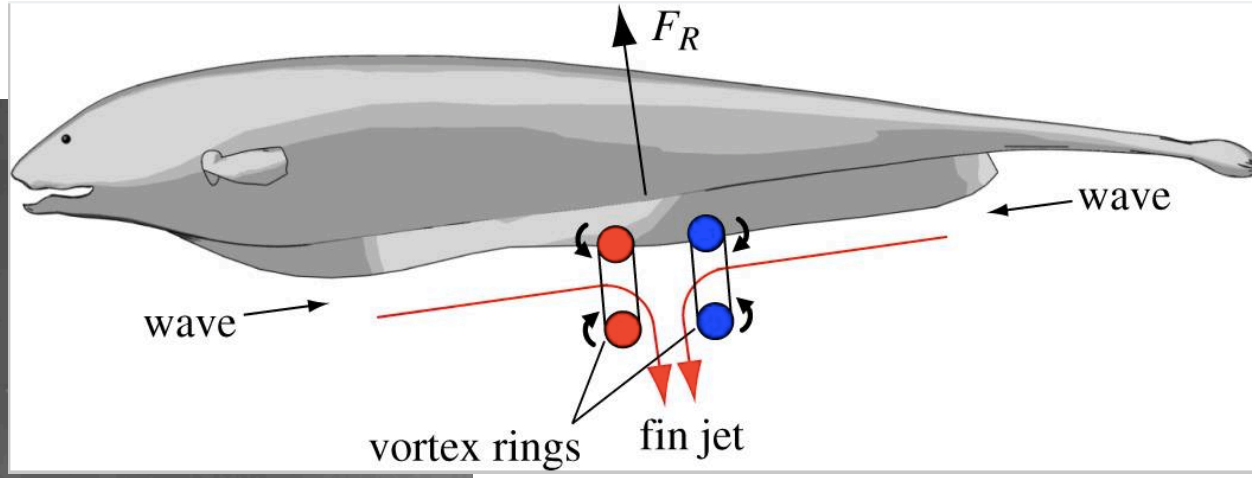
Bending caudal fin



No prototype found

Knifefish

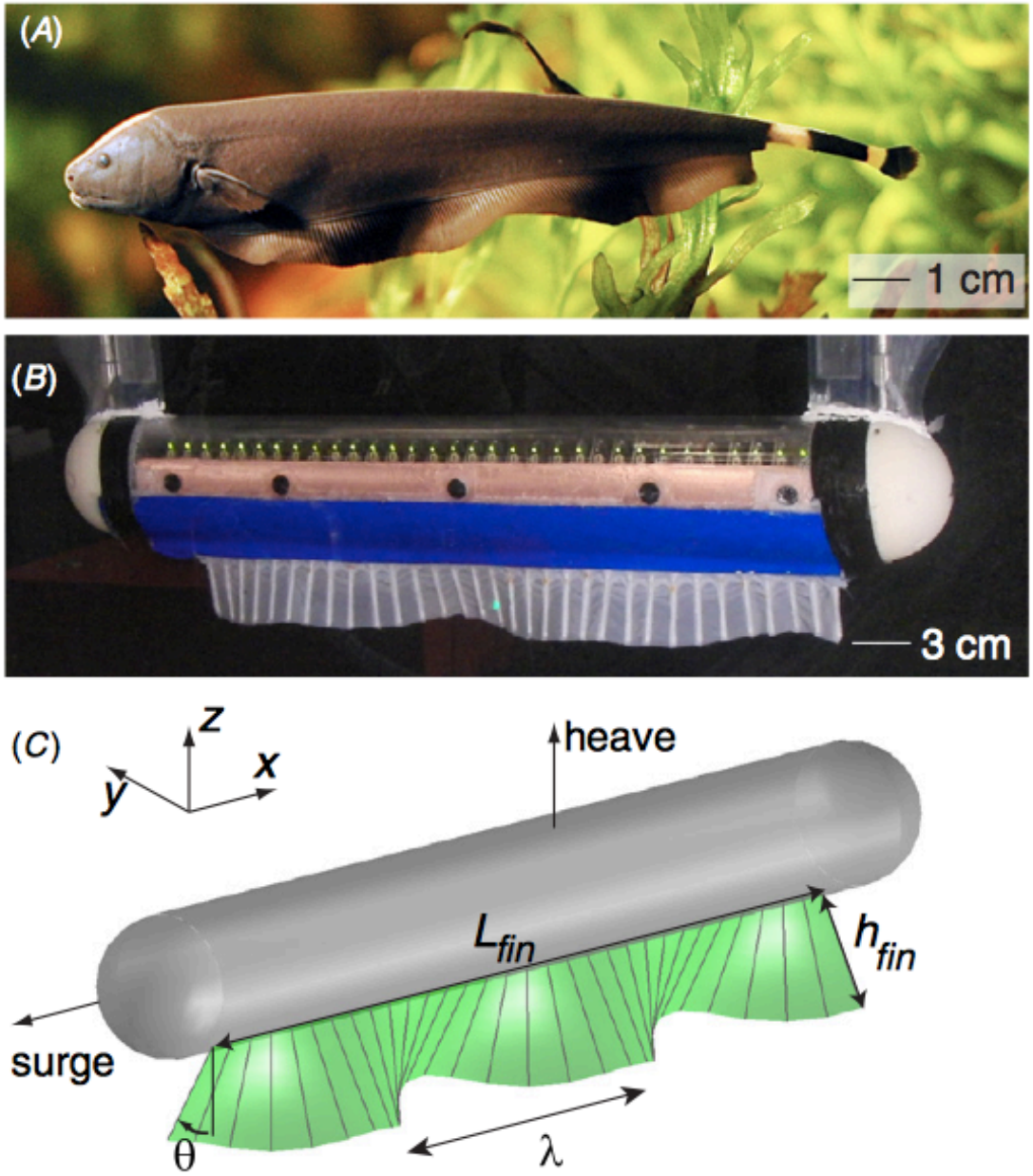




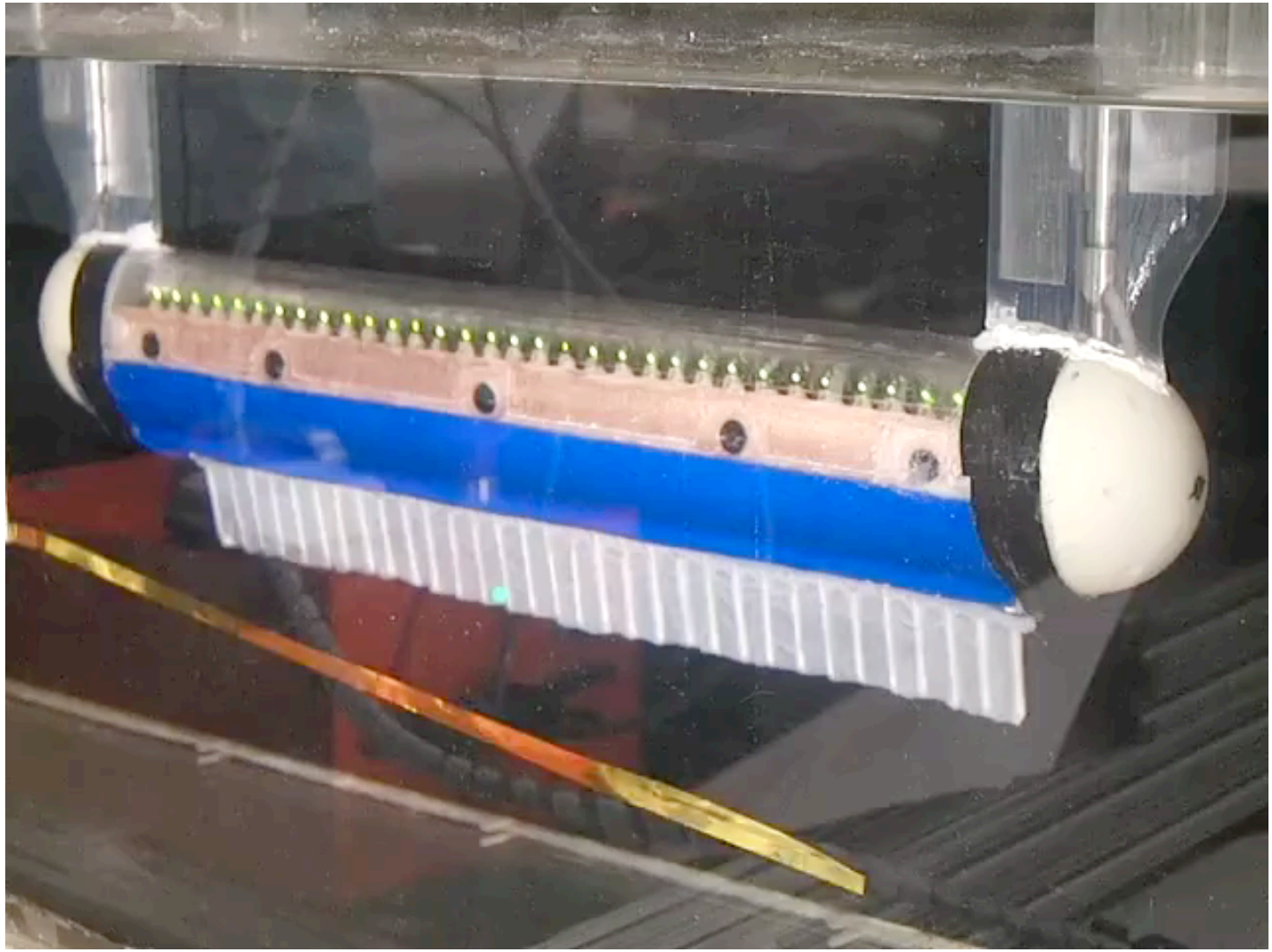
From:Aquatic manoeuvering with counter-propagating waves: a novel locomotive strategy, Oscar M. Curet et al., 2010

Escaping from flatland

From: Mechanical properties of a bio-inspired robotic knifefish with an undulatory propulsor, Curet et al., 2011



Escaping from flatland



From: Mechanical properties of a bio-inspired robotic knifefish with an undulatory propulsor, Curet et al., 2011

CENTRO DE AUTOMÁTICA Y ROBÓTICA

POLITÉCNICA

Our research line | bio-inspired systems lab

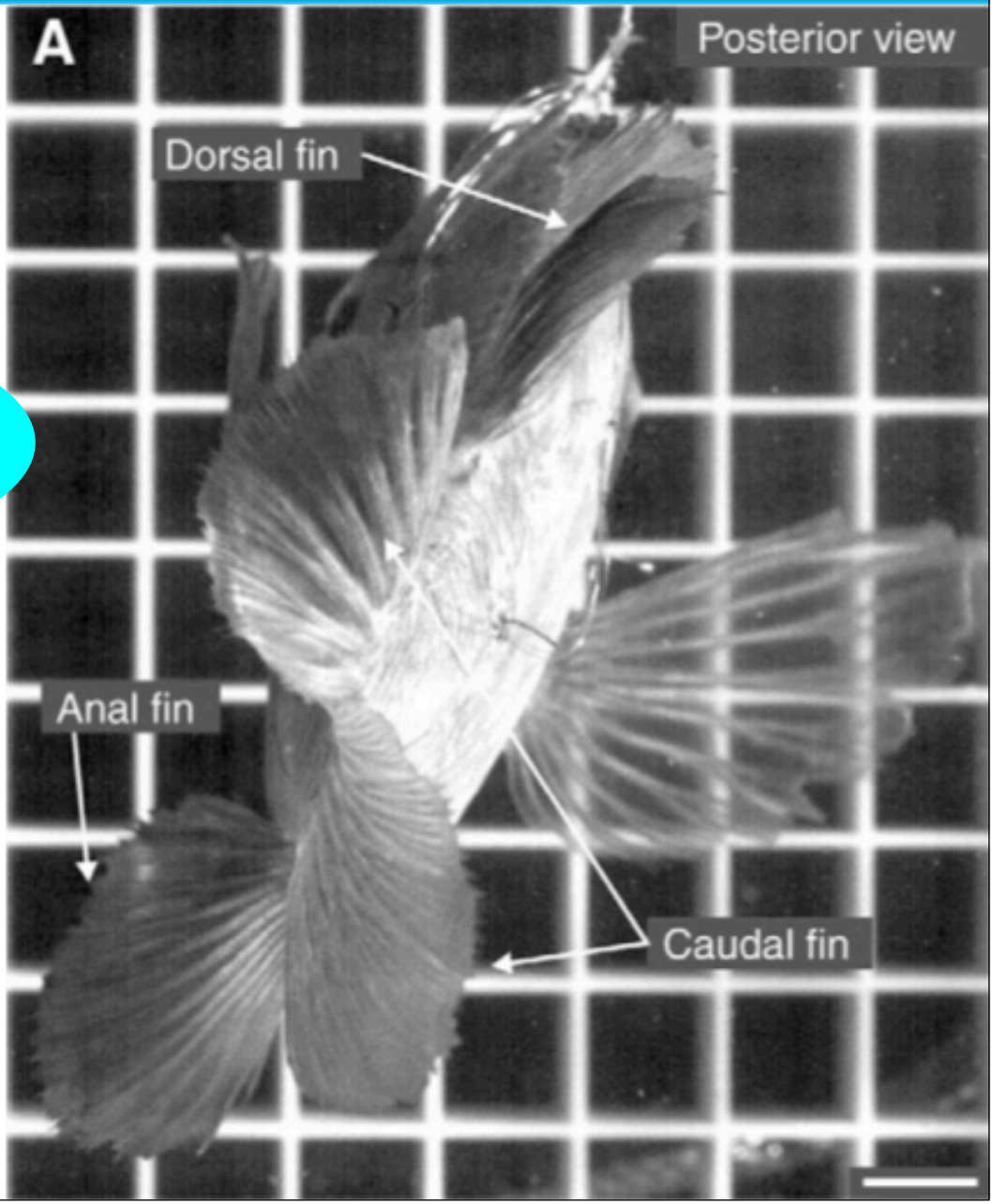
Fin-based maneuvering: a reductionist approach

Fin-based maneuvering: a reductionist approach

The title of this talk was subconsciously inspired by the title of this paper...

Image from "***Escaping Flatland**: three-dimensional kinematics and hydrodynamics of median fins in fishes"*, Eric D. Tytell, Emily M. Standen and George V. Lauder, 2008

(breaking configuration of a bluegill sunfish)



(1) Pitch control using pectoral fins

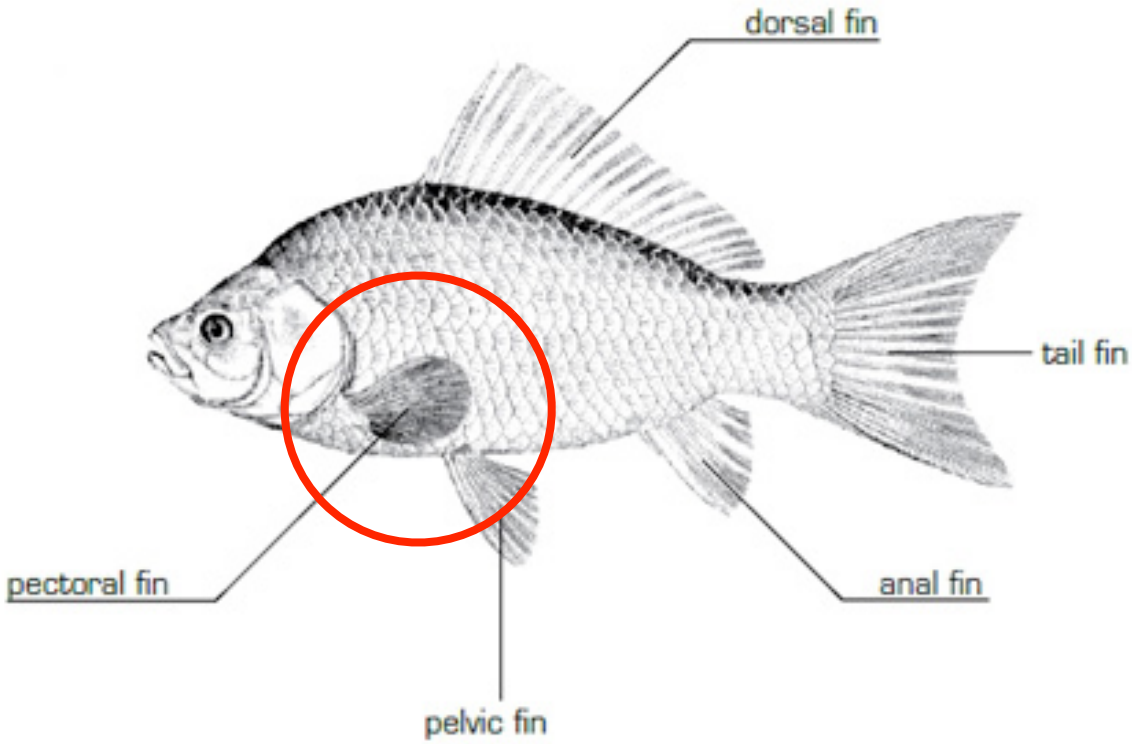


Image from ptbestaribiology.blogspot.com.es

Pitching: pectoral fins

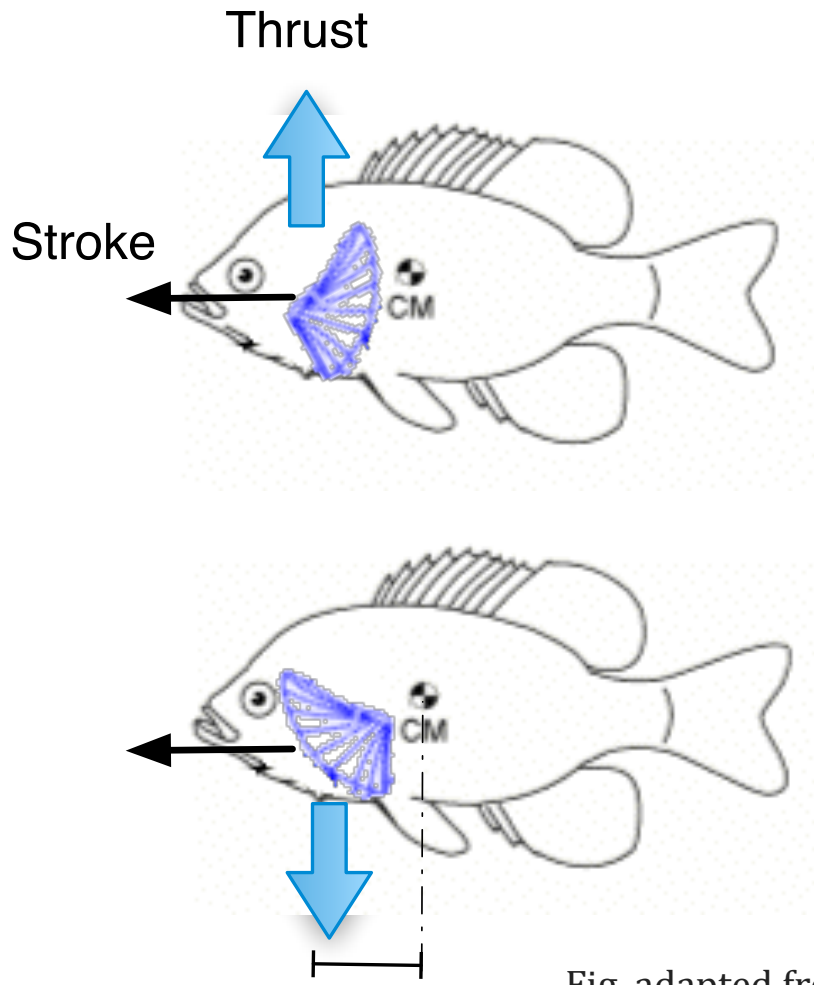


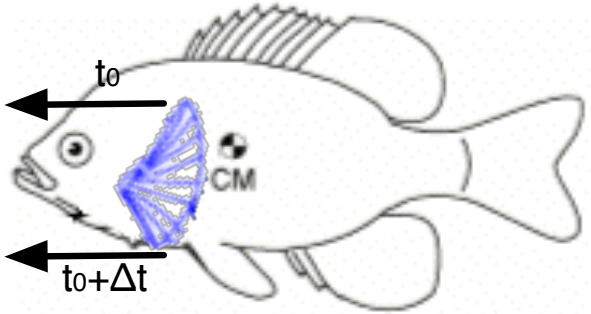
Fig. adapted from Drucker and Lauder, 2002

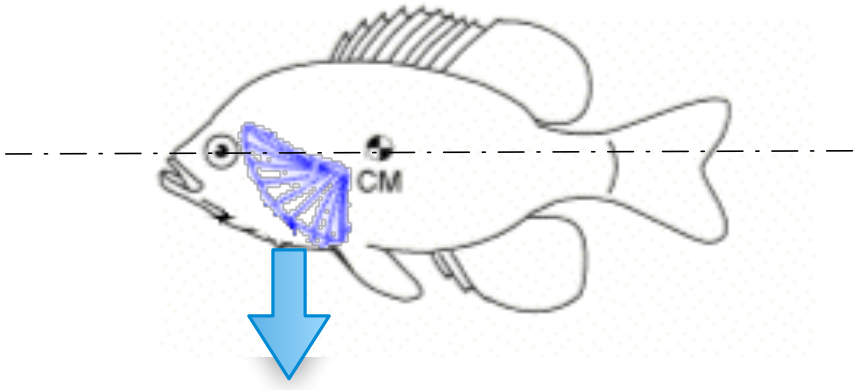
Pitching: pectoral fins

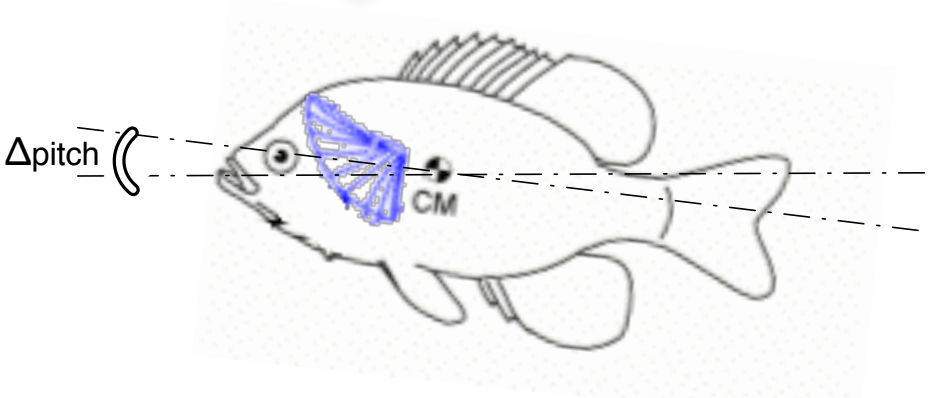
$\Delta pitch = f(\Delta t, v, \Delta x)$

$f = ?$ **(control)**

$\Delta pitch = p \Rightarrow \Delta t, v, \Delta x, n = ?$







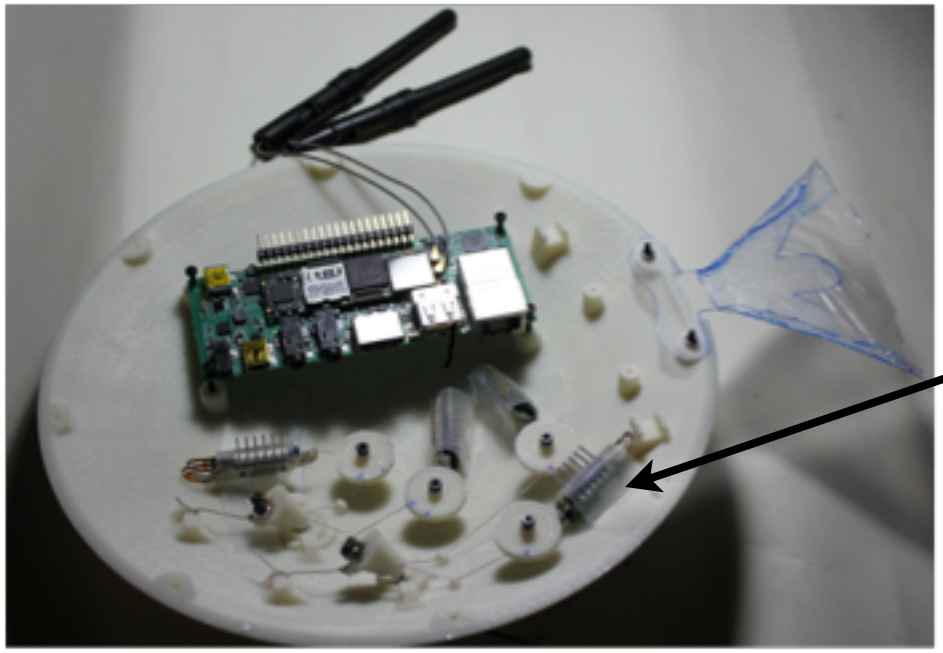
Heniochus acuminatus

AKA

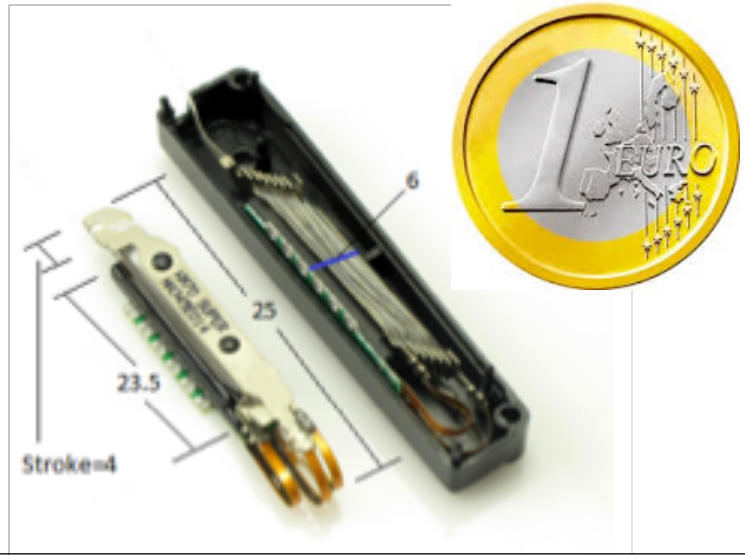
- Longfin bannerfish
- Butterflyfish
- Pennant corafish

http://www.fishbase.org

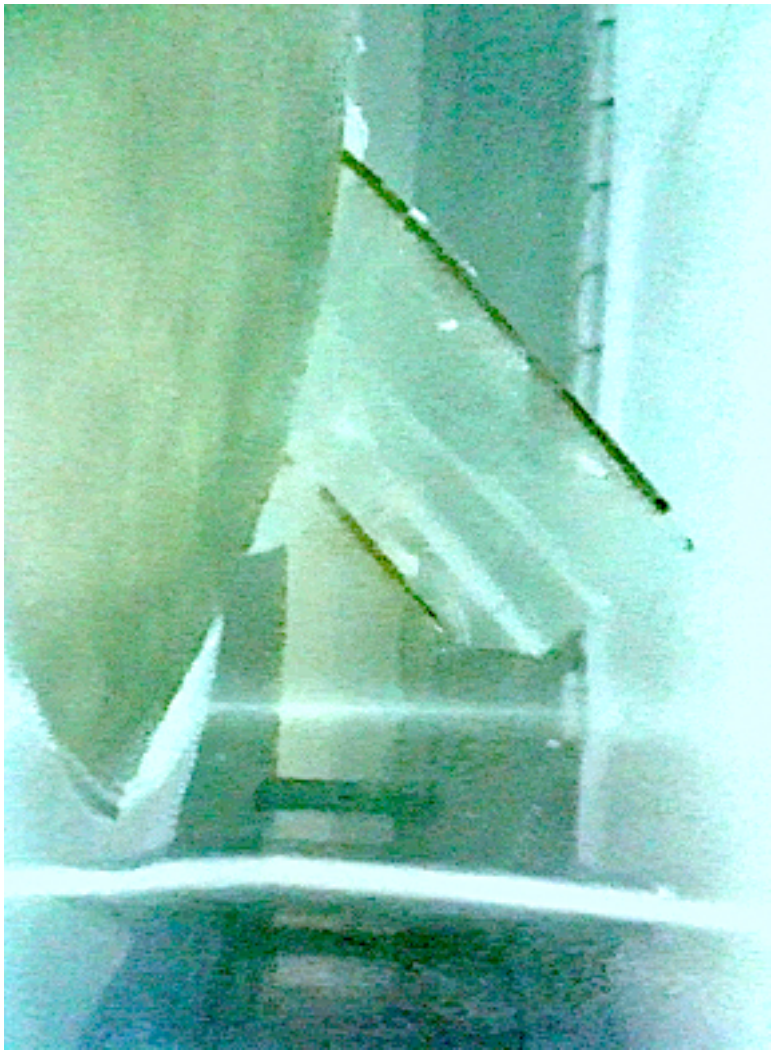
BSLab: fin-based maneuvering



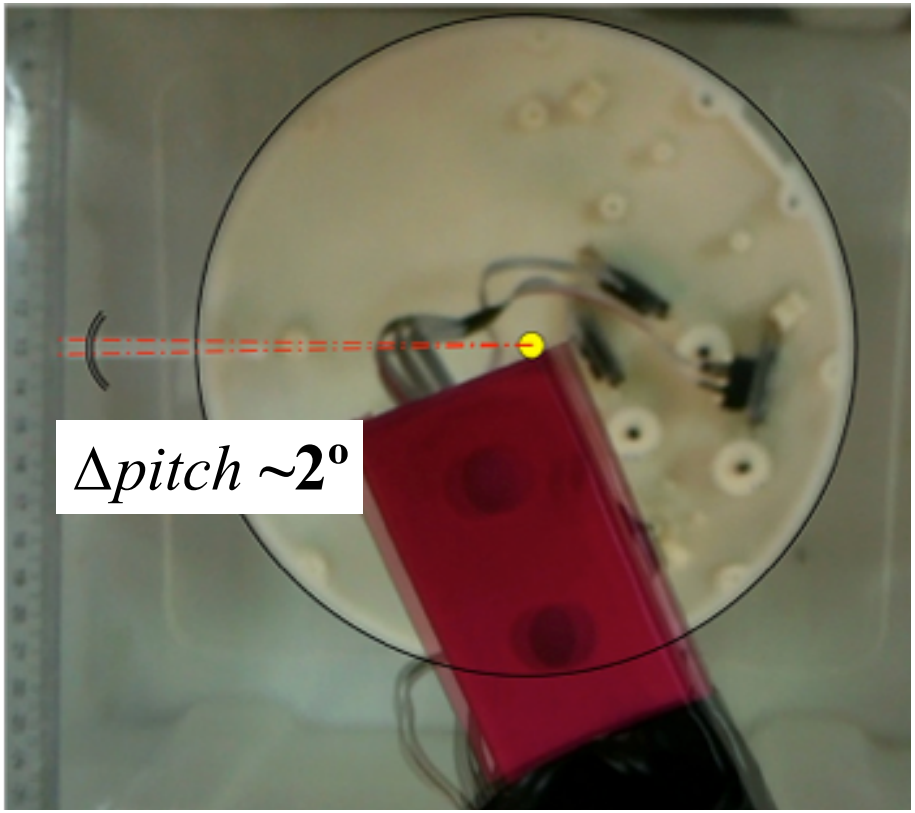
4 SMA-based artificial muscles (NM-706)

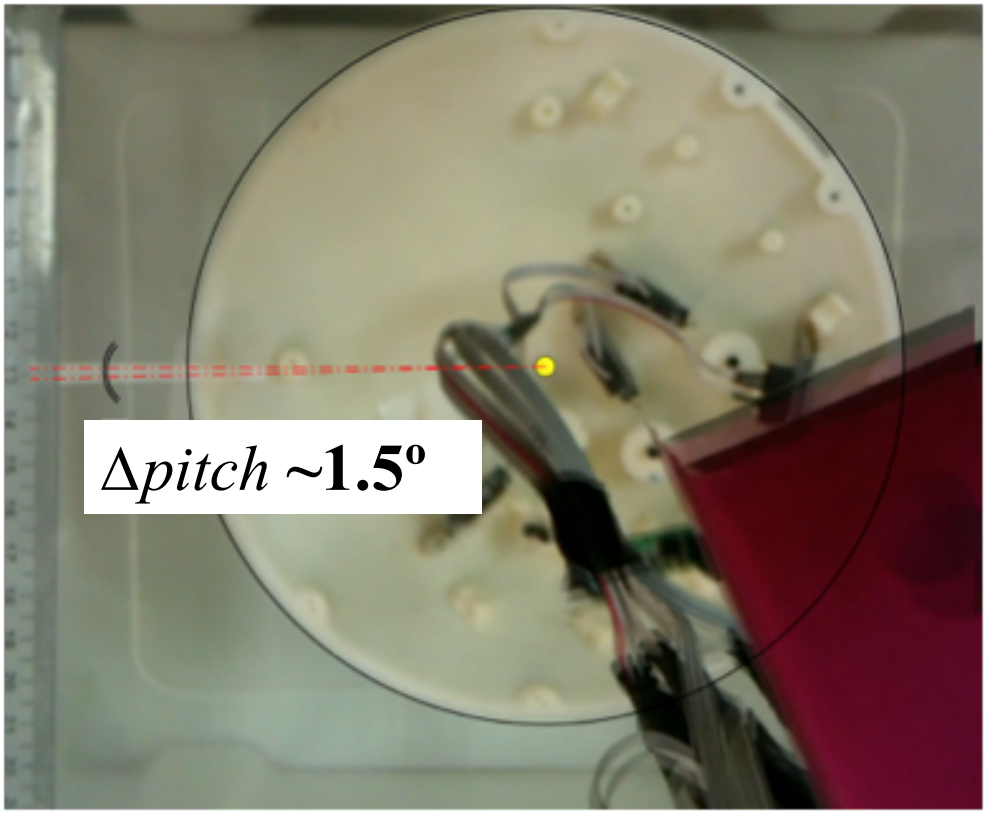


BSLab: fin-based maneuvering



BSLab: fin-based maneuvering

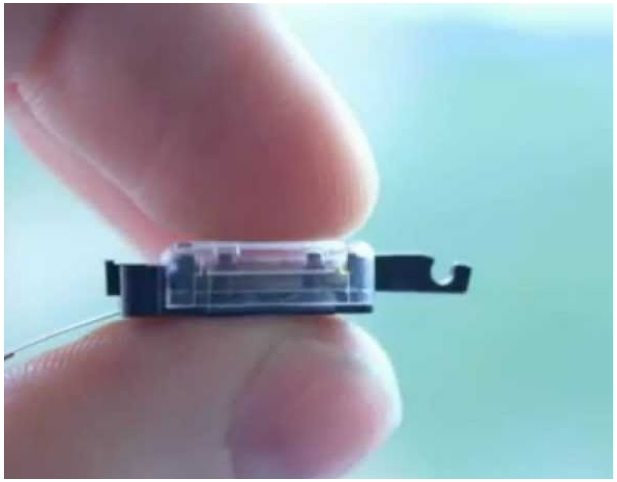




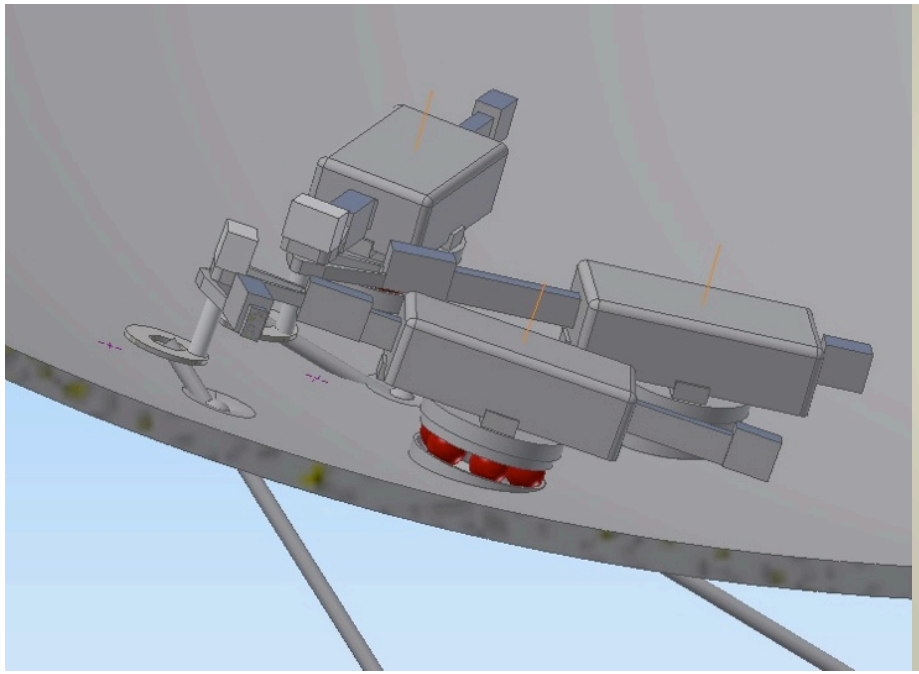
Δt_1

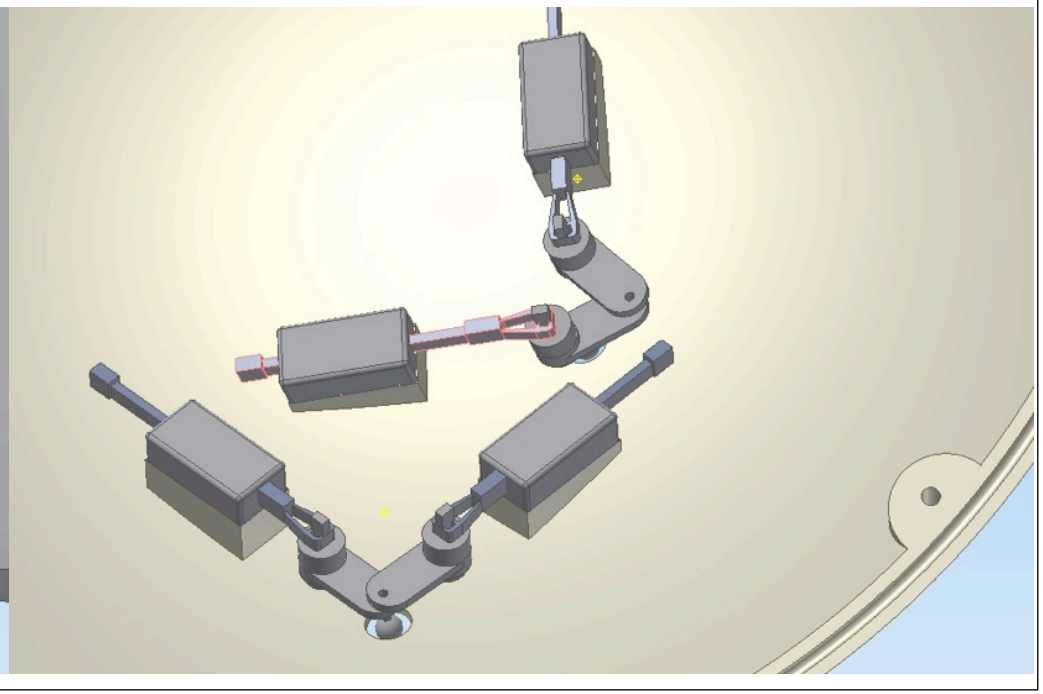
Δt_2

Current work

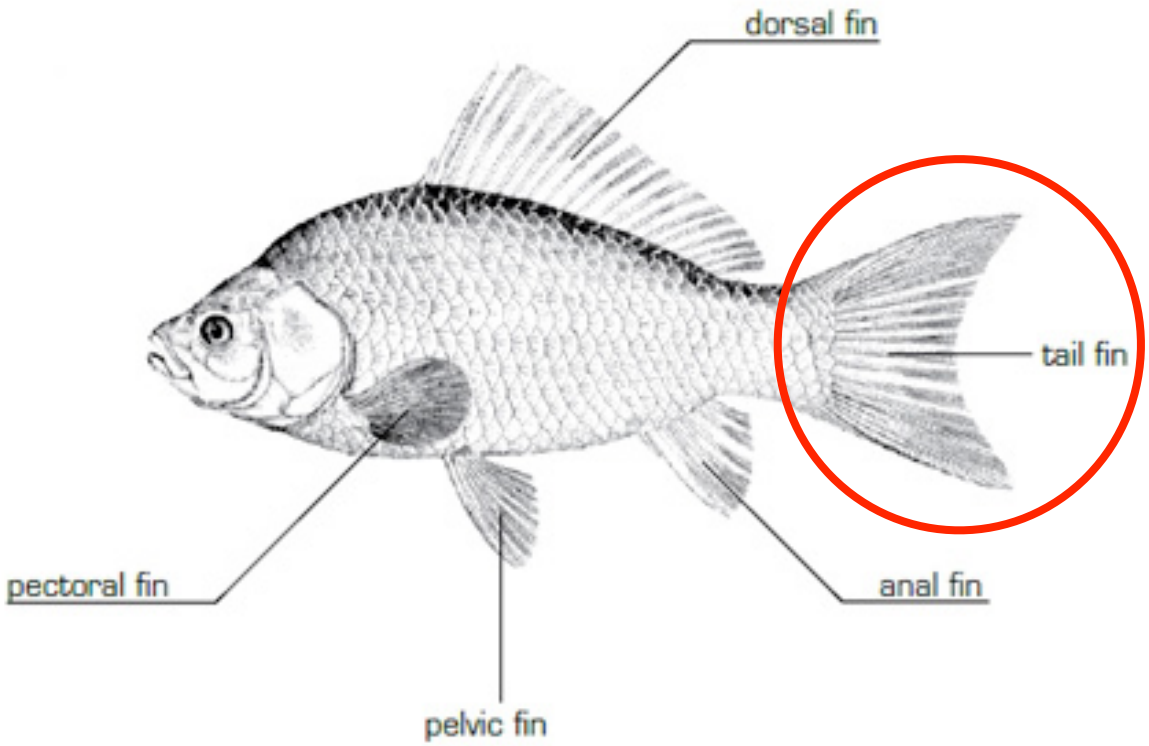


Piezowave, by PiezoMotors





Roll control: actuated caudal fin



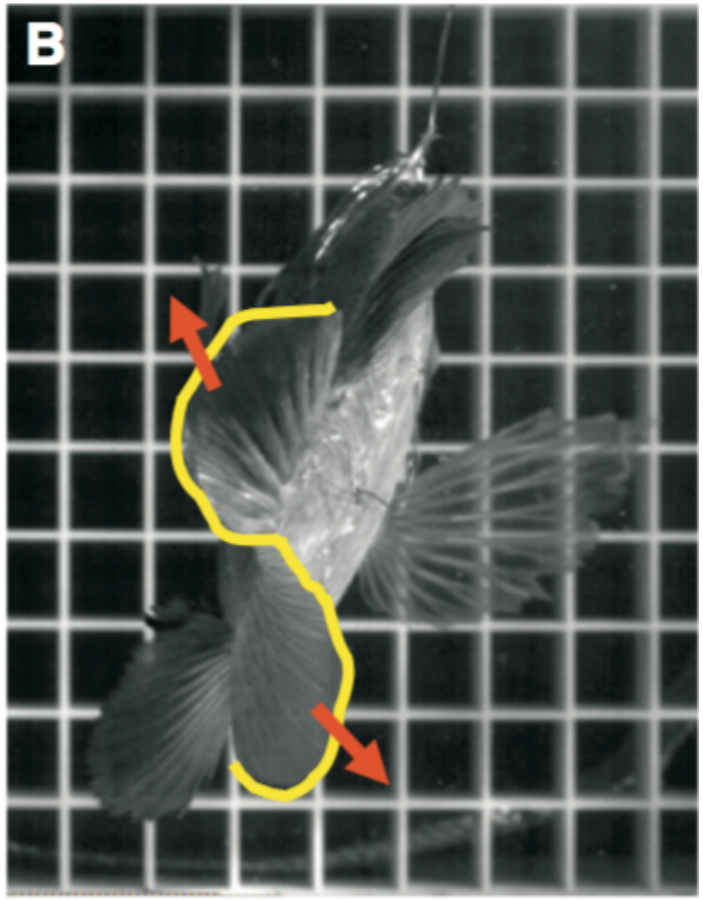
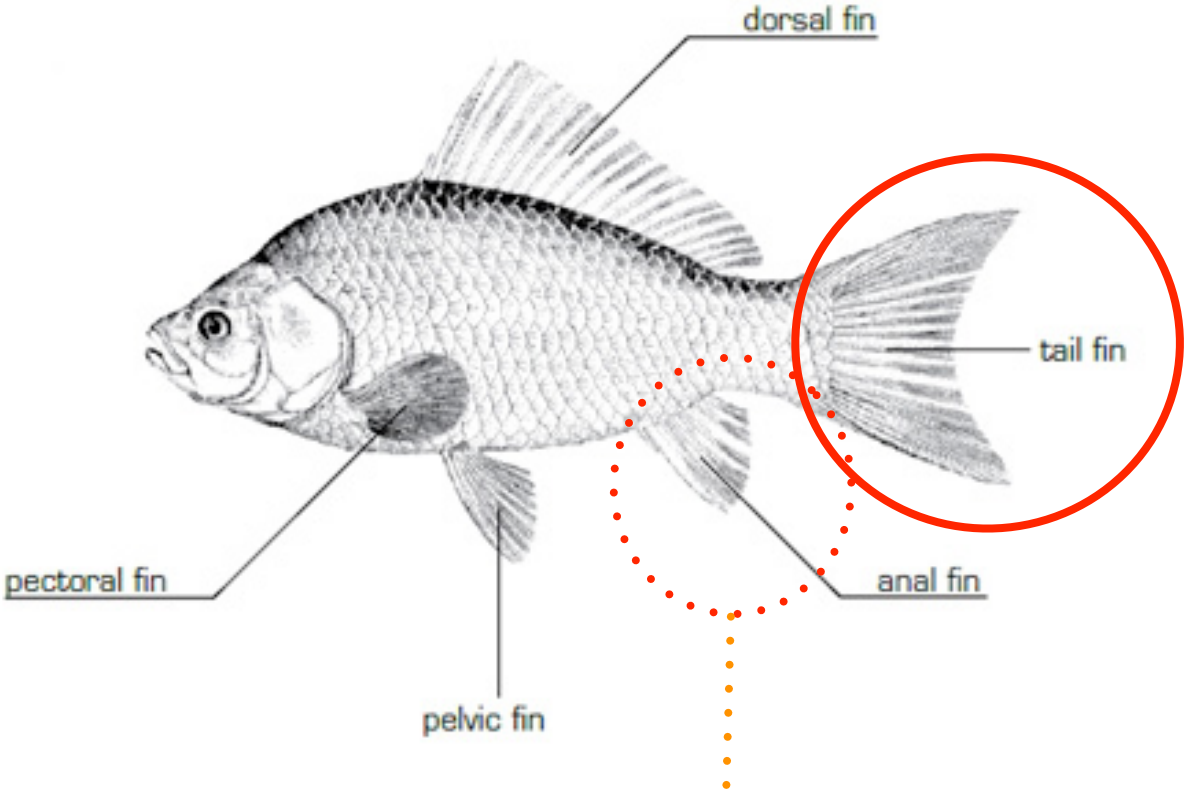


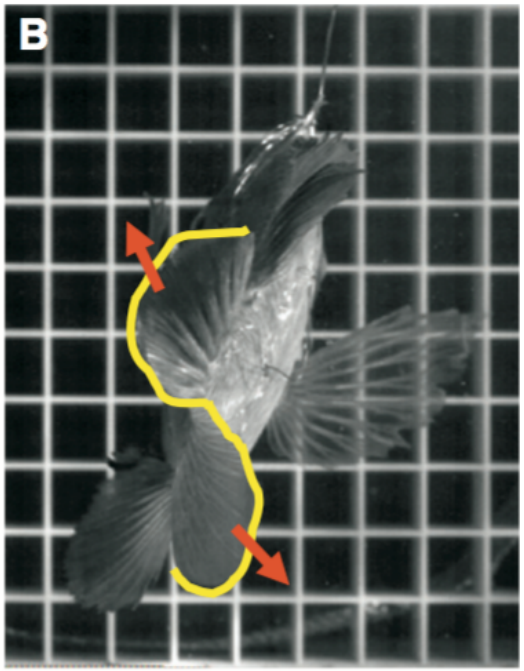
Image from Standen and Lauder, 2008

Roll control: actuated caudal fin

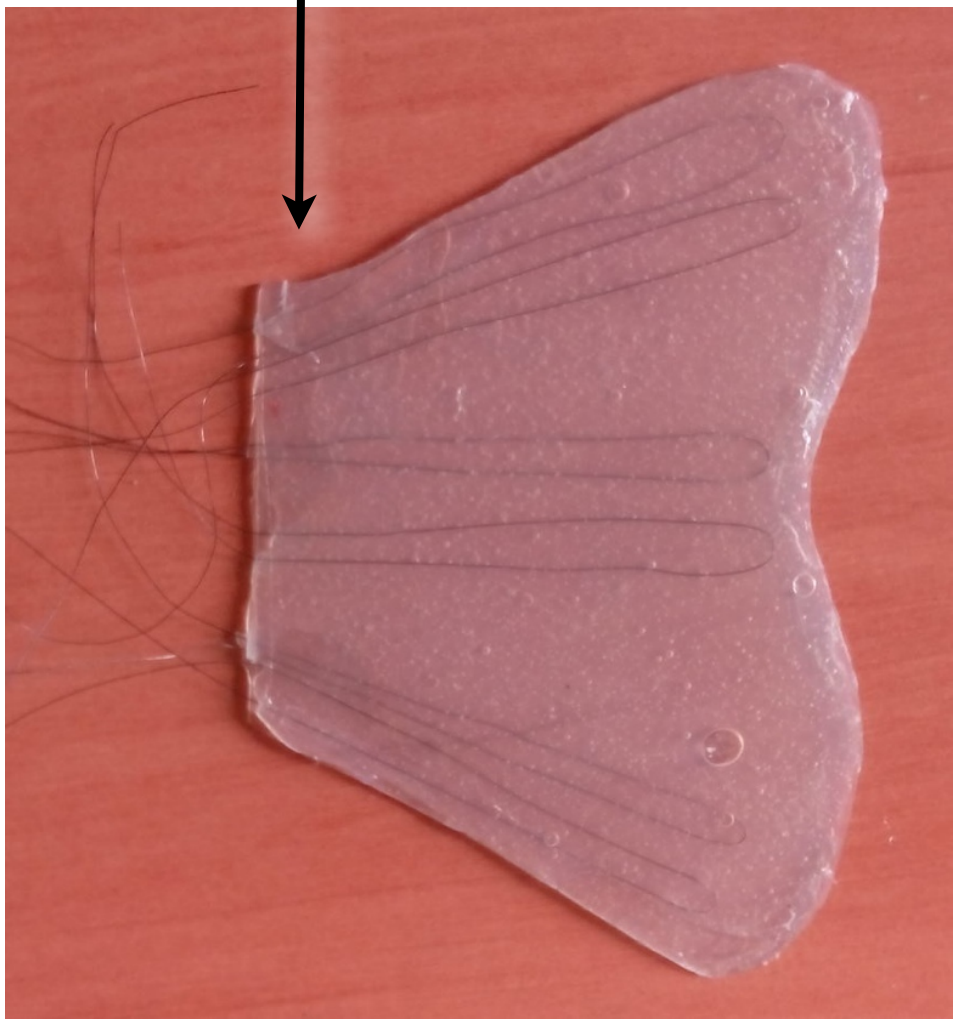


"(...) we hypothesize that the anal fin is also producing lateral fluid jets. Any jet produced lateral to the fish's longitudinal axis and above or below the COM will induce a rolling moment away from the direction of the jet". From Standen and Lauder, 2005

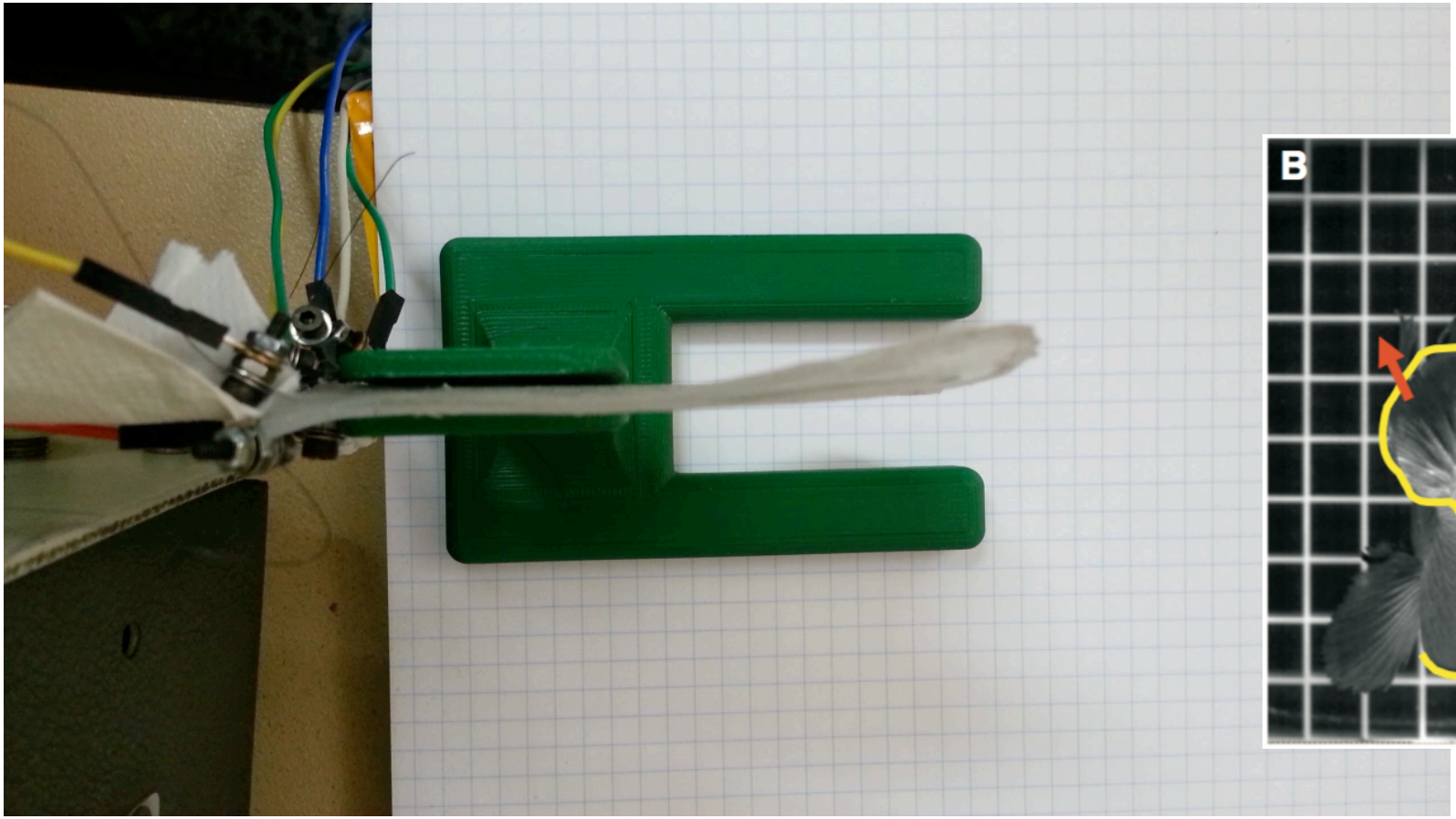
Roll control: actuated caudal fin

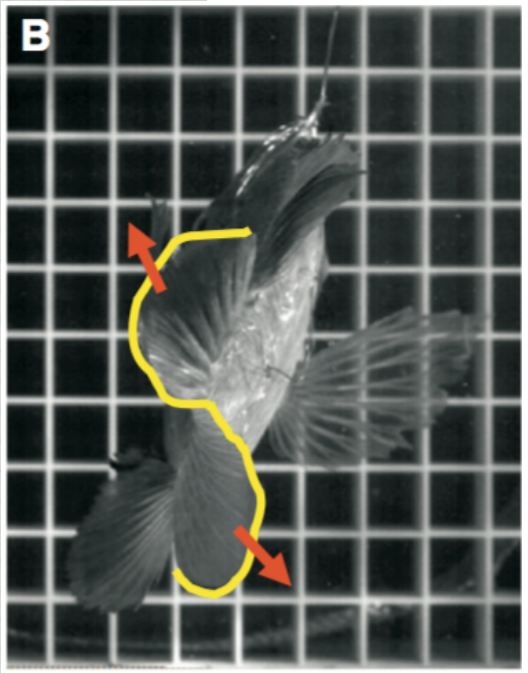


SMA wires embedded in silicon

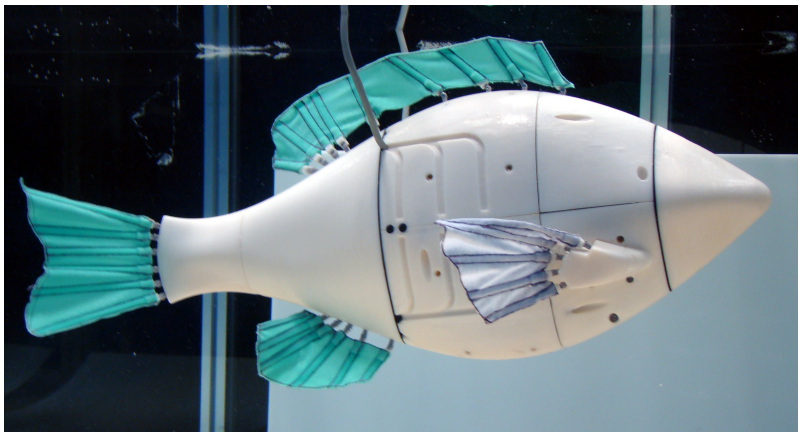


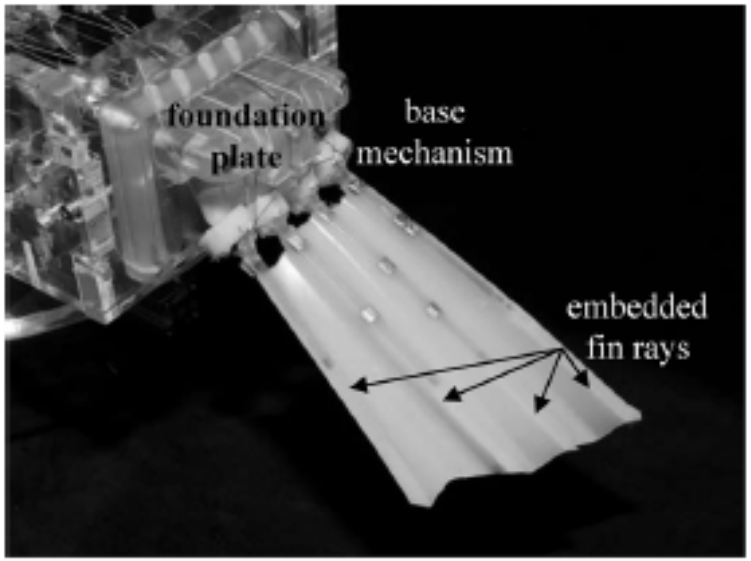
Roll control: actuated caudal fin



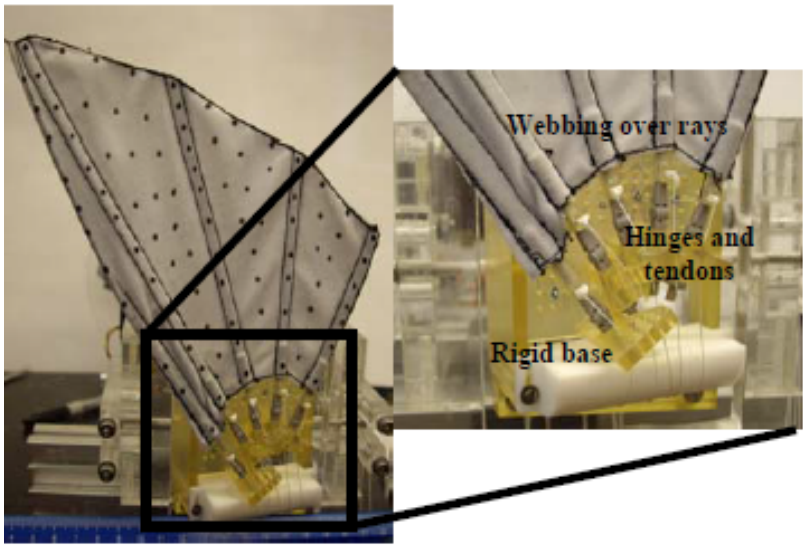


Fin-based maneuvering





Biorobotic Model for Investigations of Multi-fin Swimming, J. Tangorra, Lab for Biological Systems Analysis, Drexel Univ.



- Most of the work on robot fishes focuses on propulsion (1D)
- Some work on turning (2D)
- Few works on 3D maneuvering
  - Mostly non-biologically inspired
- We (and few others) are working on that !
  - Challenging issues in control, navigation, (bio-inspired) mechatronics design

CENTRO DE AUTOMÁTICA Y ROBÓTICA

Robot fishes' escape from flatland

2nd Fitfish workshop, Barcelona, October 2014

Claudio Rossi
- **Willam Coral**
- **Juan Antonio Jenaro**
- **Virginia Rodriguez**
- **Irene Perrino**

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http://www.disam.upm.es/~crossi/Bio_Inspired_Robots

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