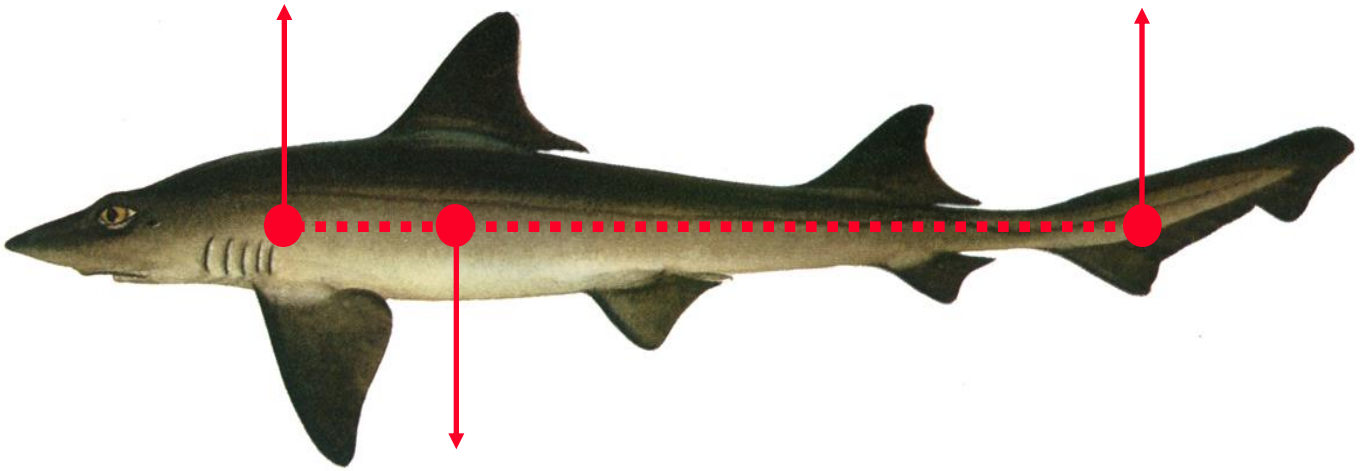
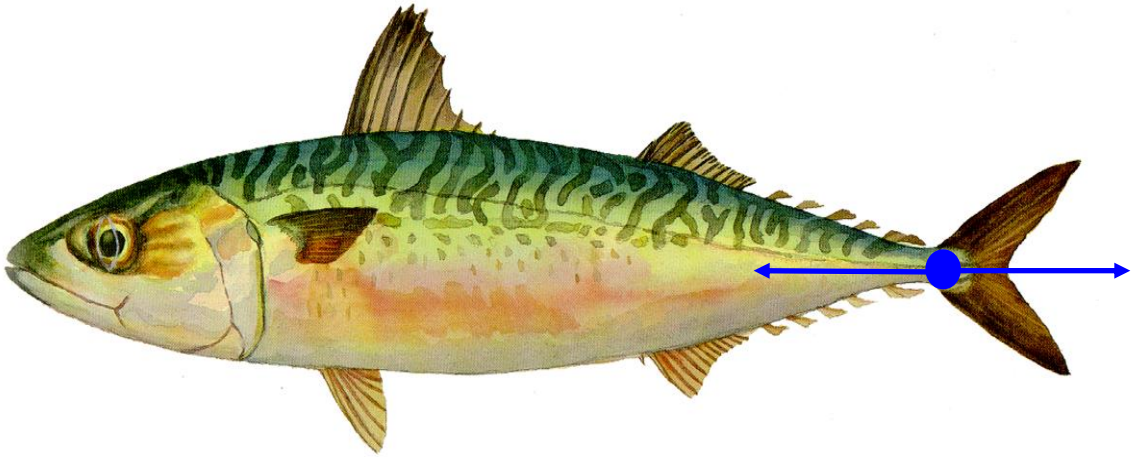
OEB 130: BIOLOGY OF FISHES

Lecture 11: Locomotion Part 2





Outline

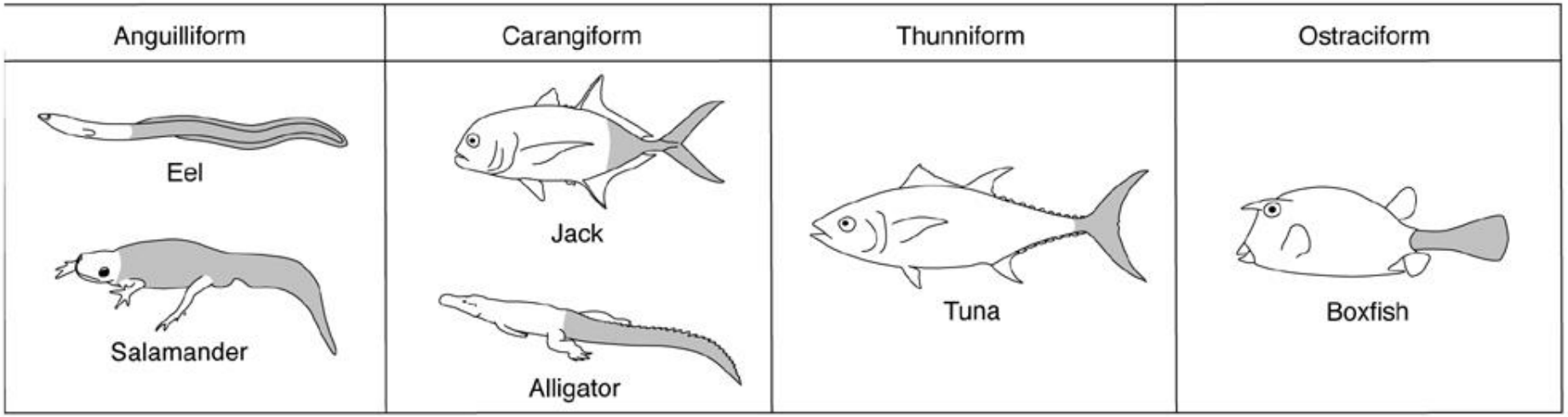
Lecture outline:

- Review of body muscles; how these muscles produce a wave of body bending
- Undulatory locomotion: how force is produced
  - Part 1: airplane wings, lift and drag
  - Part 2: fish bodies and tails: producing thrust with a bending body
- Function of the tail in sharks and teleosts
  - Heterocercal vs. homocercal tail function
  - force balance on a swimming shark

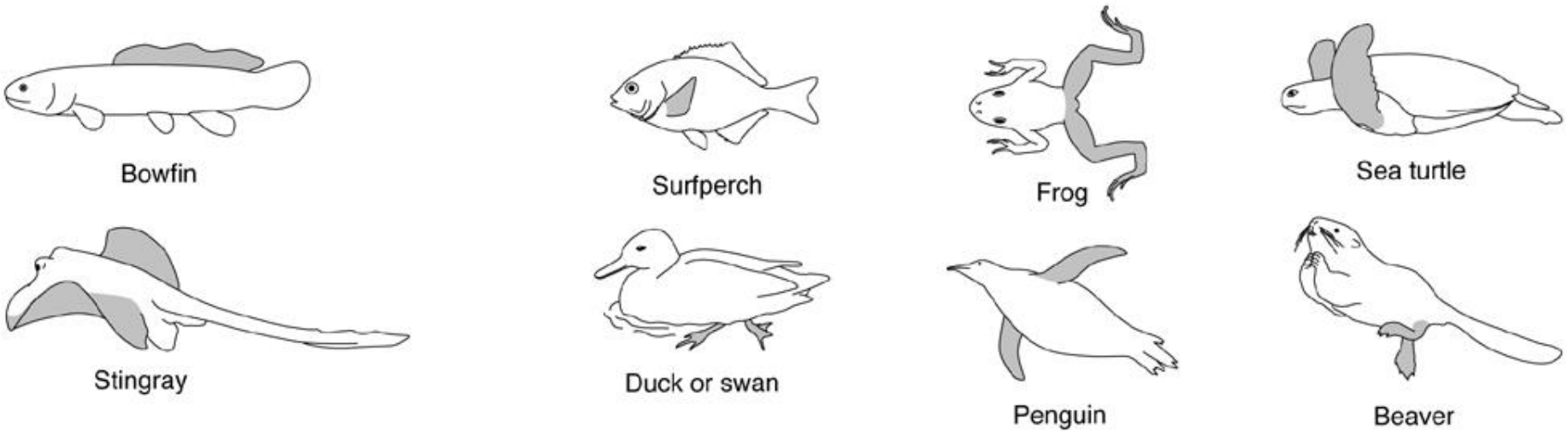
I <u>will</u> have office hours this Friday as usual.
No lecture Wed. – have a good break!
After spring break: Locomotion part 3; tuna dissection

Review: modes of locomotion

(Slightly different version of this topic from last lecture)



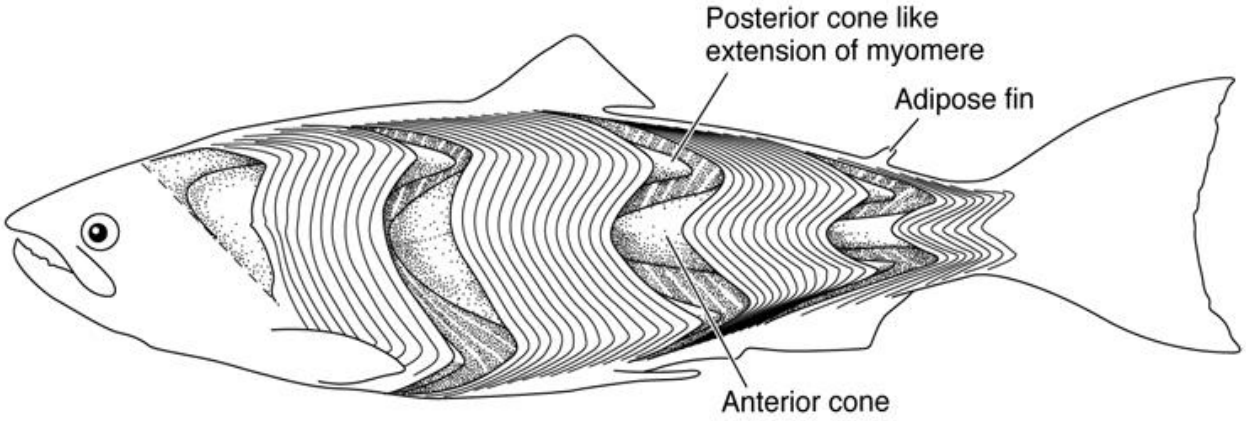
A. Undulatory swimmers using trunk and tail



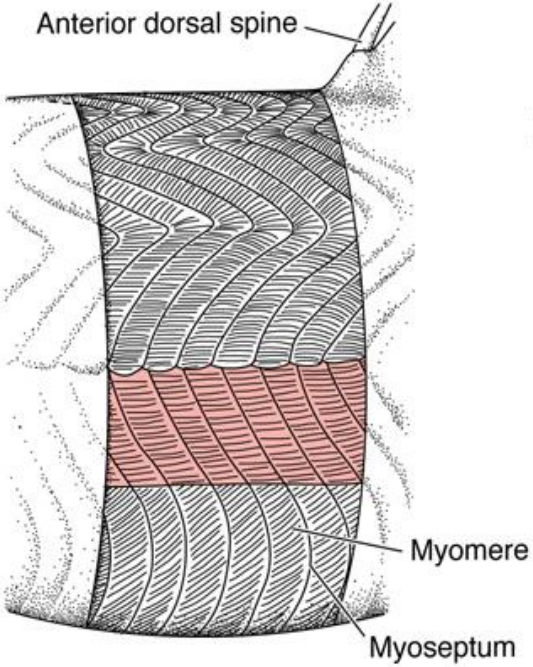
B. Undulatory swimmers using fins

C. Oscillatory swimmers using fins or limbs

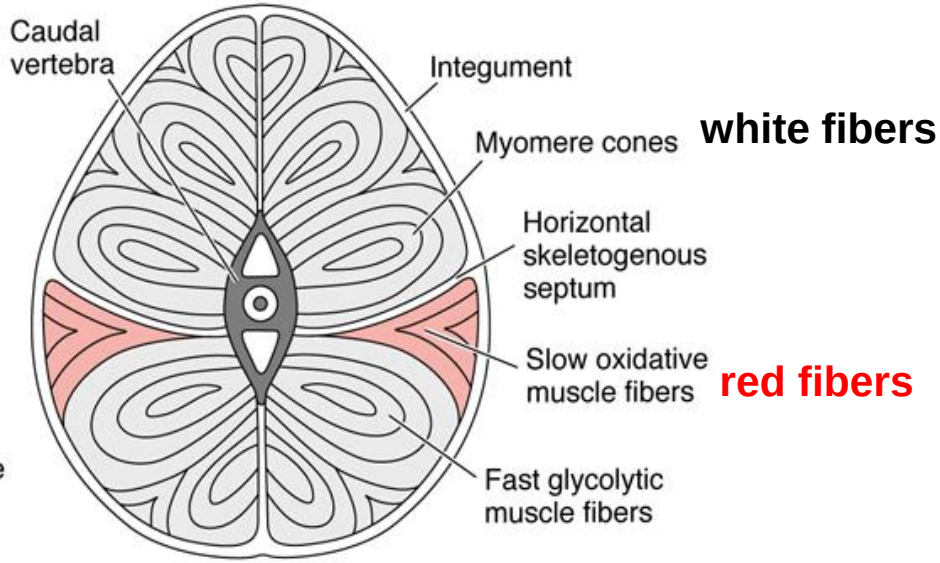
Axial muscles in a “typical” fish



A. Dissection of trunk muscles of a salmonid



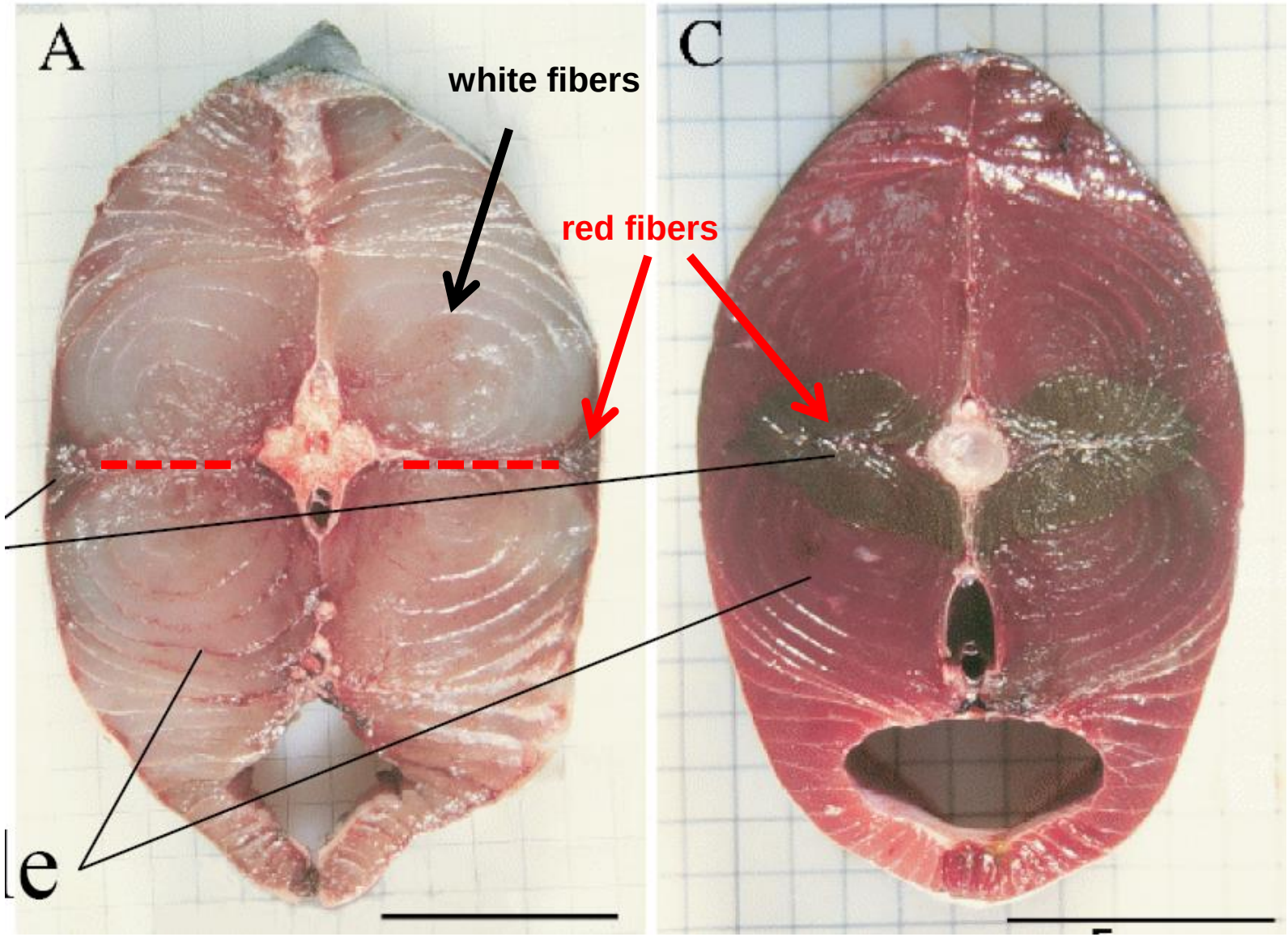
B. Distribution of muscle fiber types



C. Distribution of muscle fiber types in cross section

Review: body musculature

In many tuna and relatives, the red fibers are "internalized"



"normal" fish **tuna-like fish**

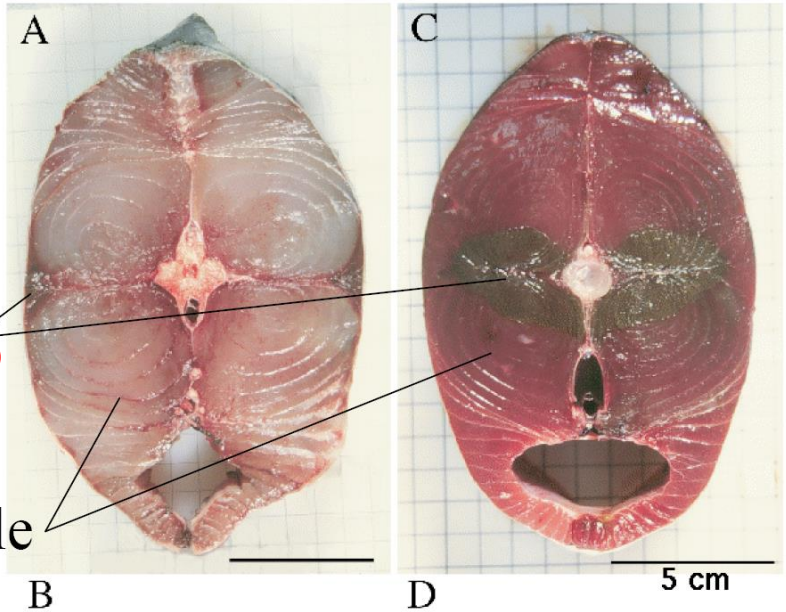
Cross-sections to see the myotomal fiber types: “white” and “red”

Fish muscle has been a model system for studying muscle recruitment patterns due to the spatial segregation of muscle fiber types.

mackerel **tuna**

SO red (SO) muscle

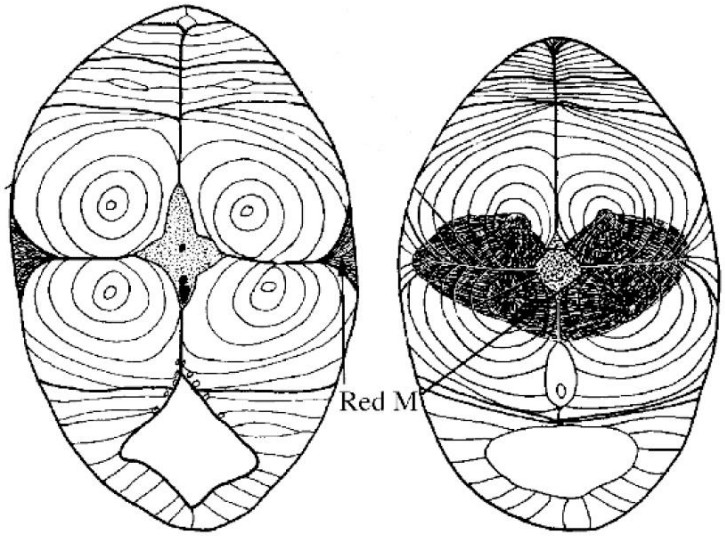
FG white (FG) muscle



Fish muscle recruitment:

Red for slow steady swimming

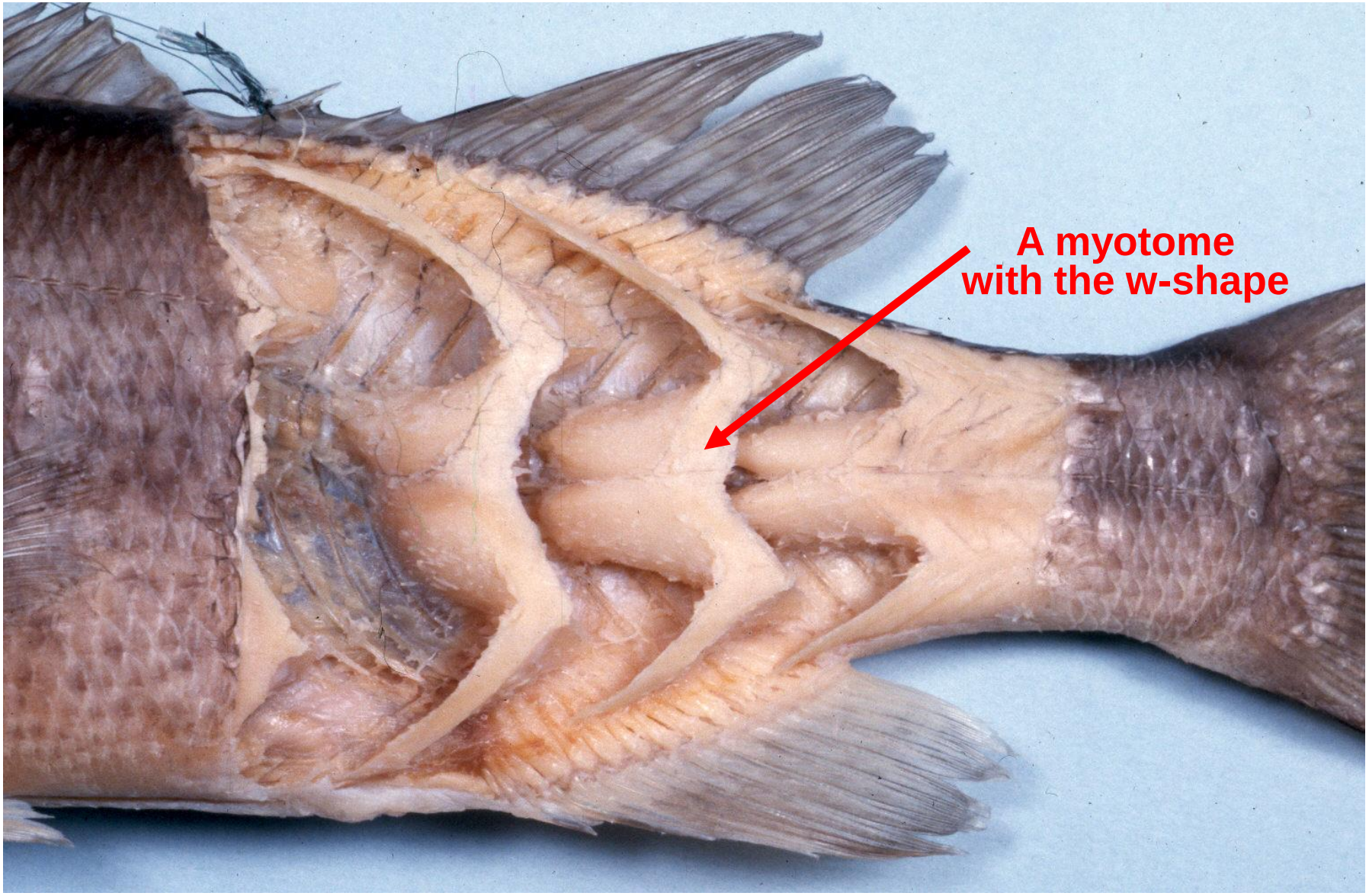
White for burst fast swimming



Differential muscle fiber use for swimming

Axial muscles: white fibers; segmental muscles are actually very complex

The strange shape may function to allow equal strains in superficial and deep fibers as the body bends (red fibers removed)



Posterior propagation of a wave of electrical activity in sequential myotomes bends the body in an undulatory wave

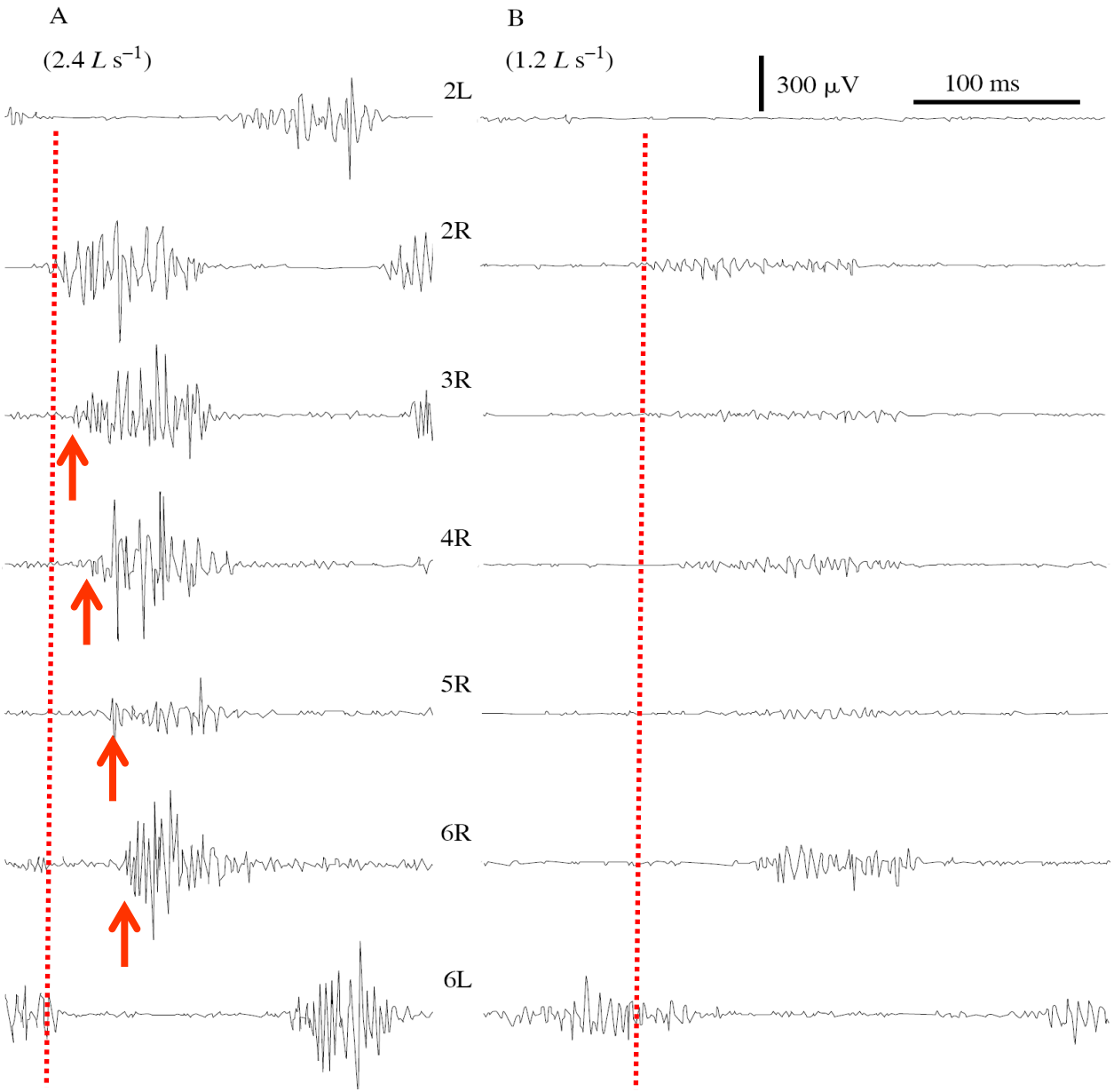
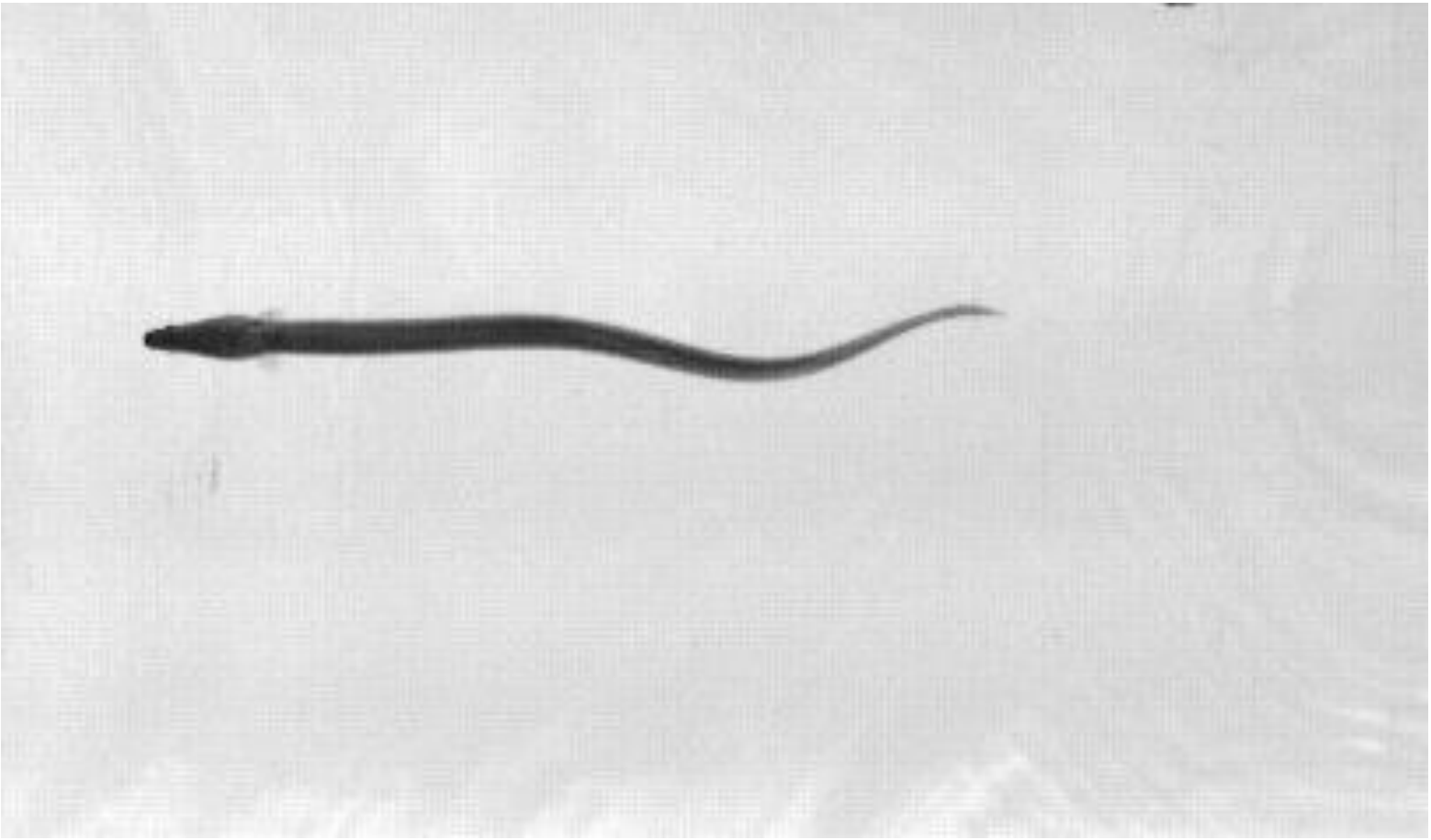


Fig. 4. EMGs from the superficial red muscle of a single *Micropterus salmoides* swimming at speeds of 2.4 (A) and 1.2 $L\,s^{-1}$ (B). The time and voltage scales are identical for all channels. For each channel, numbers indicate the longitudinal location of the recording site, with 1 being most anterior (Fig. 1), and R and L indicate right and left sides, respectively.

Undulatory locomotion: how force is produced

Undulatory body motion in the eel

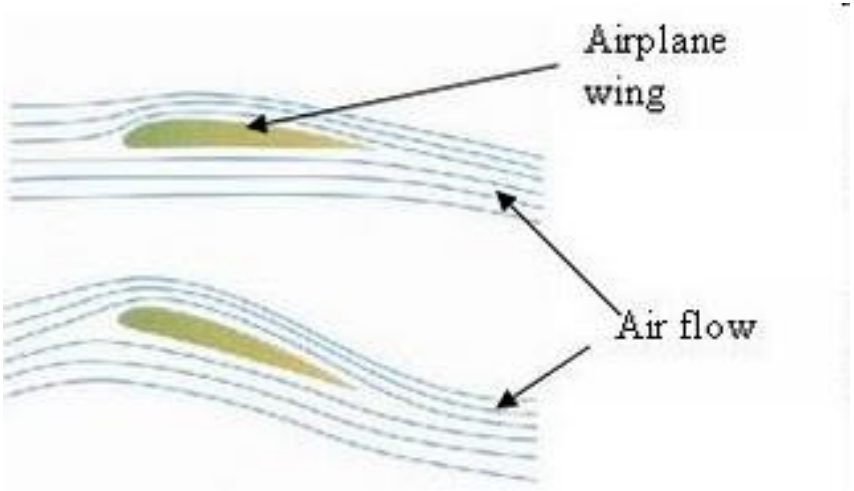


Applying the concepts of Lift and Drag to fish swimming

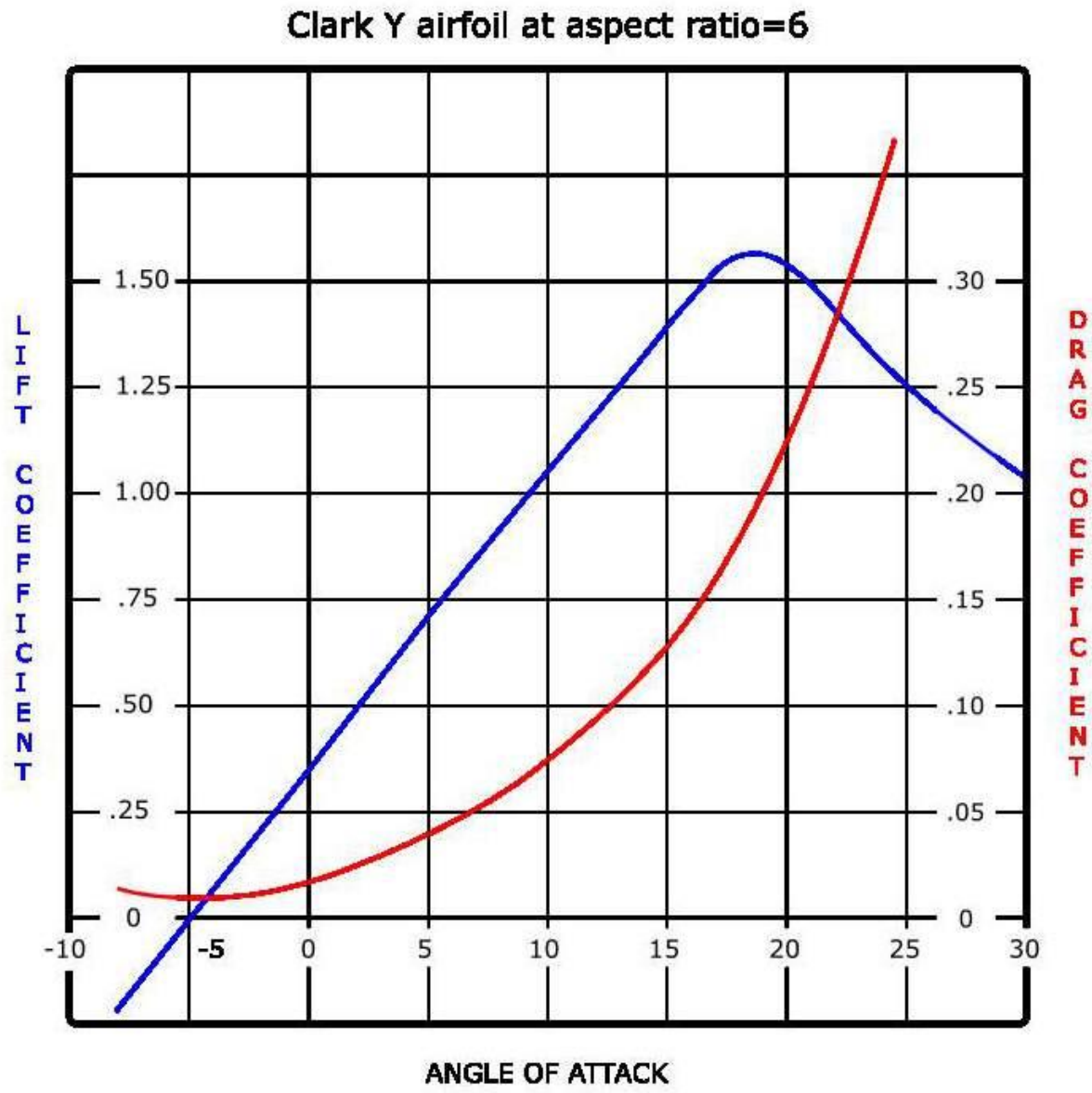
How does body undulation result in locomotor forces that move the fish forward?

Start with an airplane: consider the forces that can act on the wing

Wing cross-section

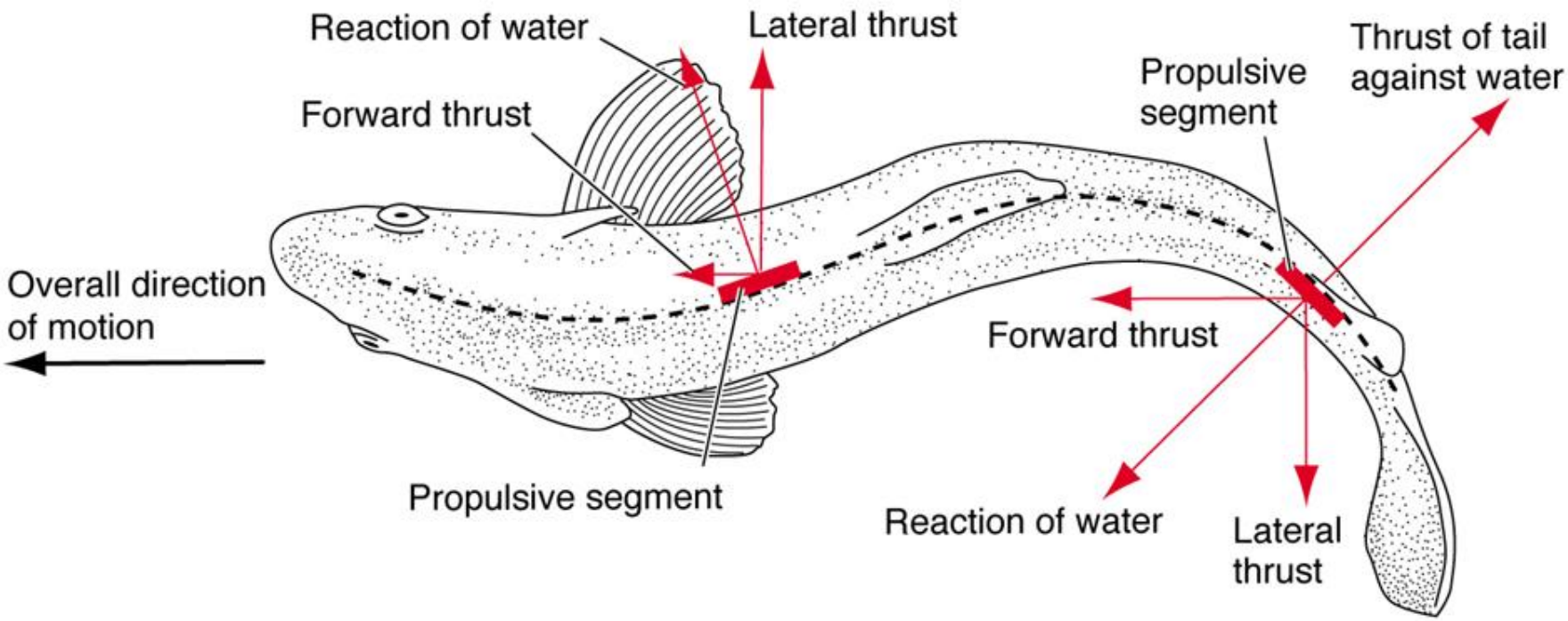


How does body undulation result in locomotor forces that move the fish forward?



Coefficients of lift and drag versus the angle of attack

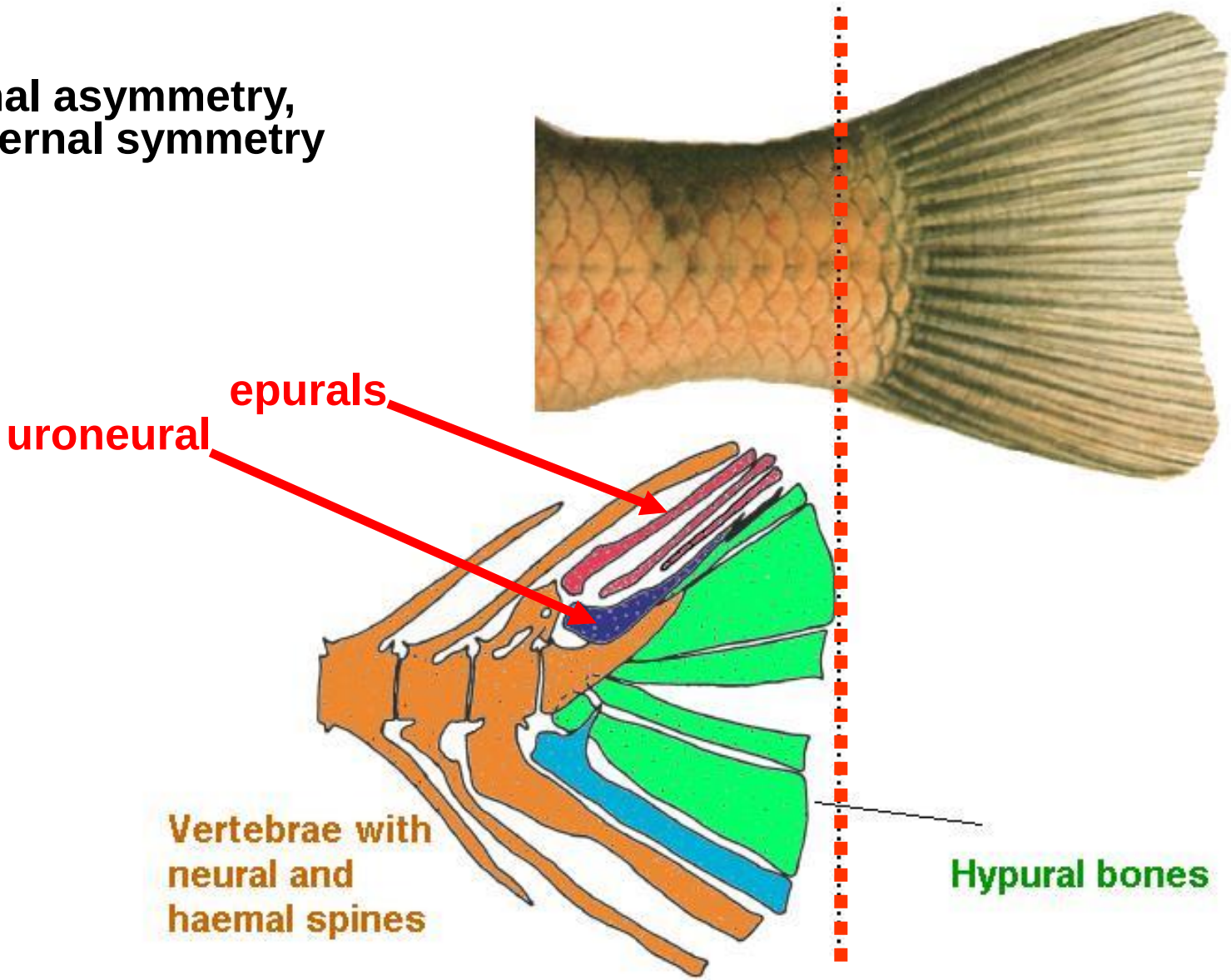
How are locomotor forces produced?



Common textbook illustration
(not that great)

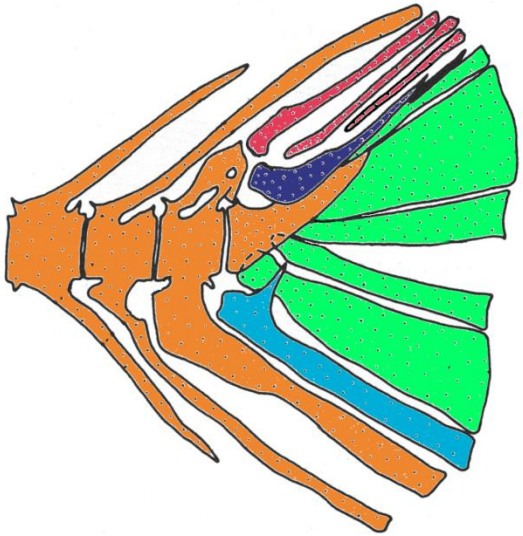
Function of the tail in sharks and teleosts

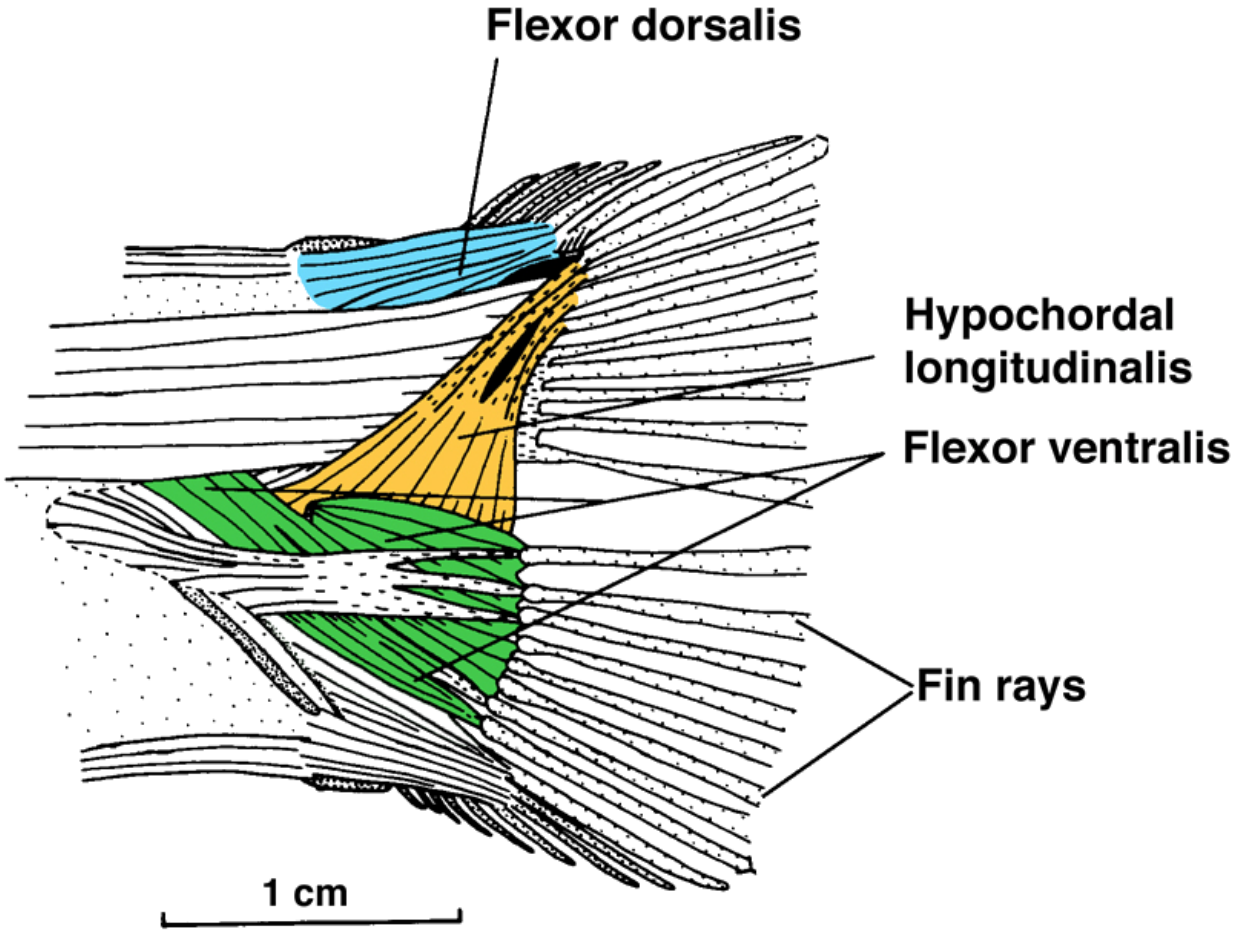
**Internal asymmetry,
but external symmetry**



Function of the tail in sharks and teleosts

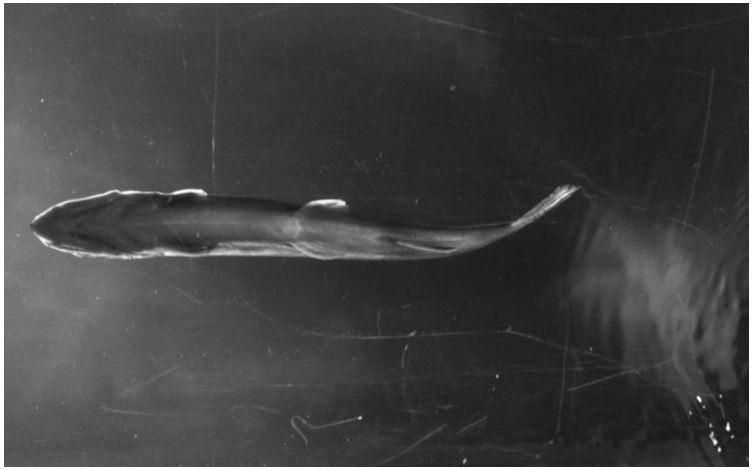
Intrinsic tail muscles (these are not myotomal muscles) allow fine control of tail motion.

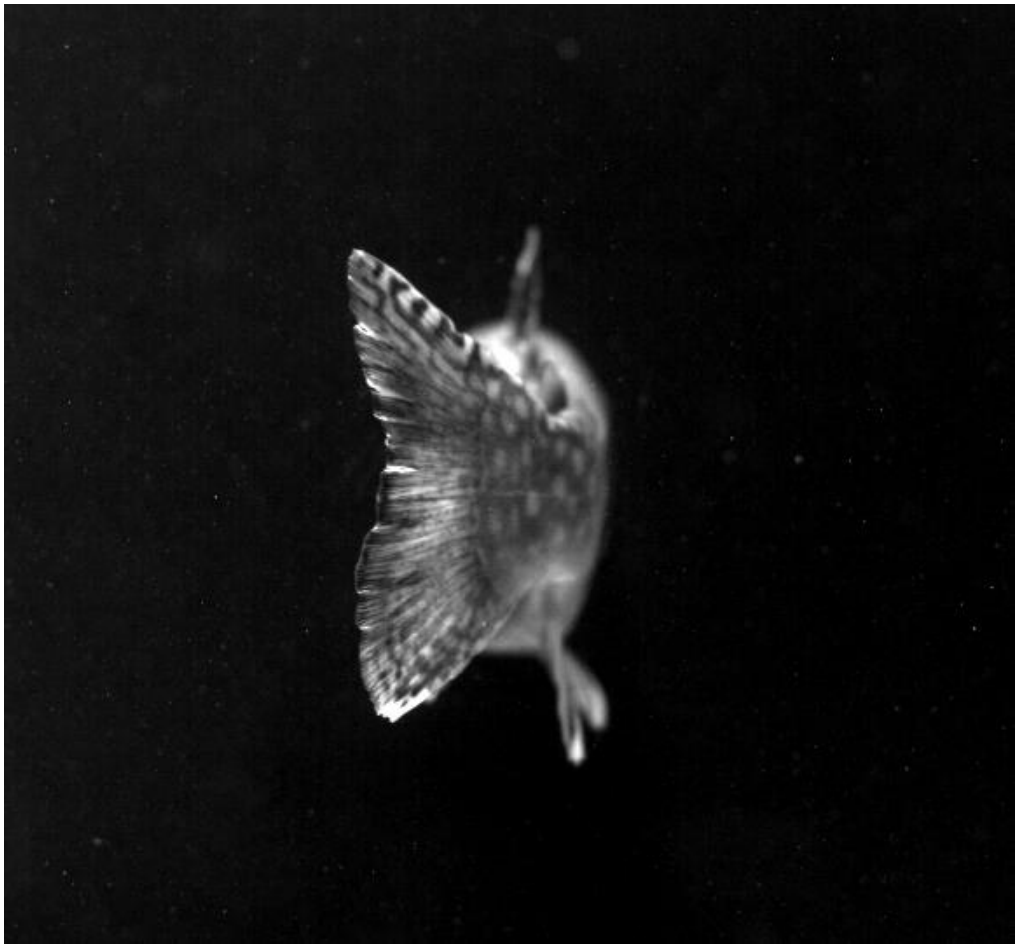




Function of the tail in sharks and teleosts

3D motion of the tail in a teleost fish: a trout

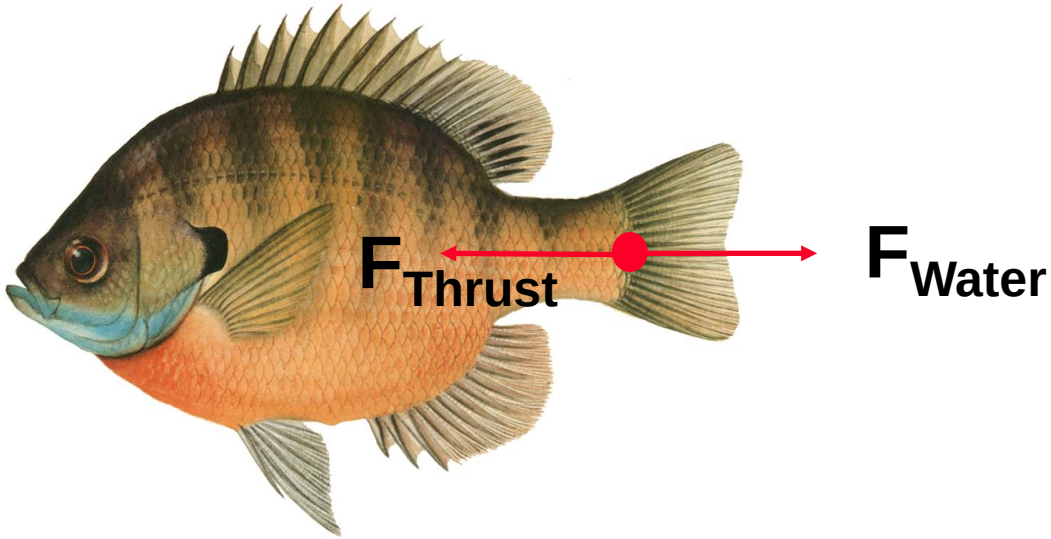




Function of the homocercal teleost tail

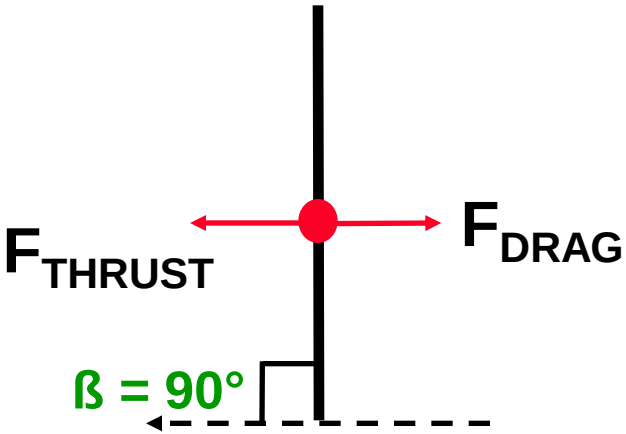
Symmetrical (but adjustable) function of the homocercal tail

Lateral view

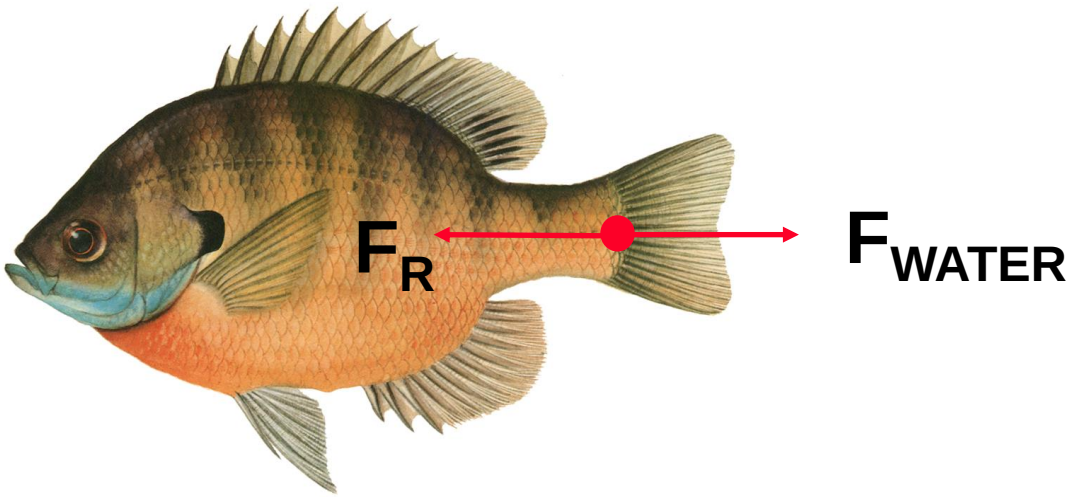


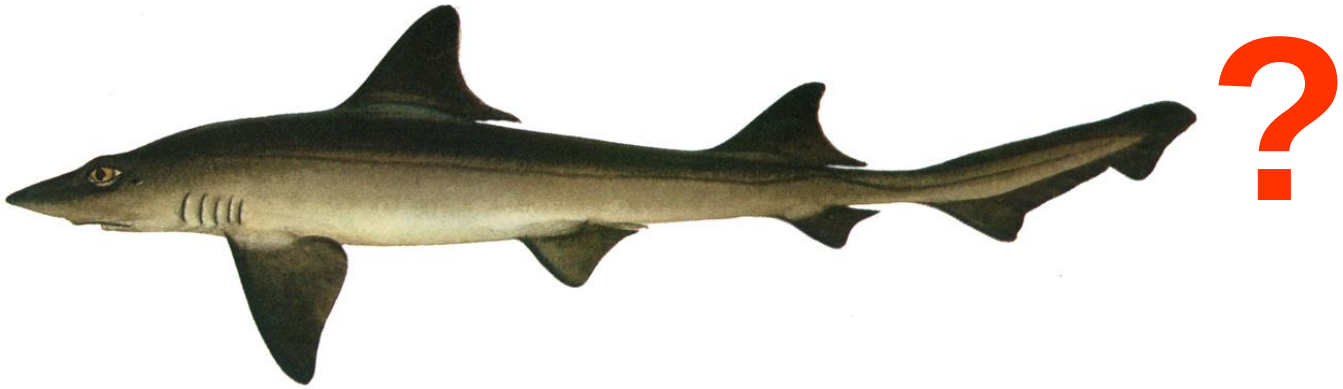
Thrust goes through the center of mass

Schematic
View from behind



Tail function: heterocercal vs. homocercal

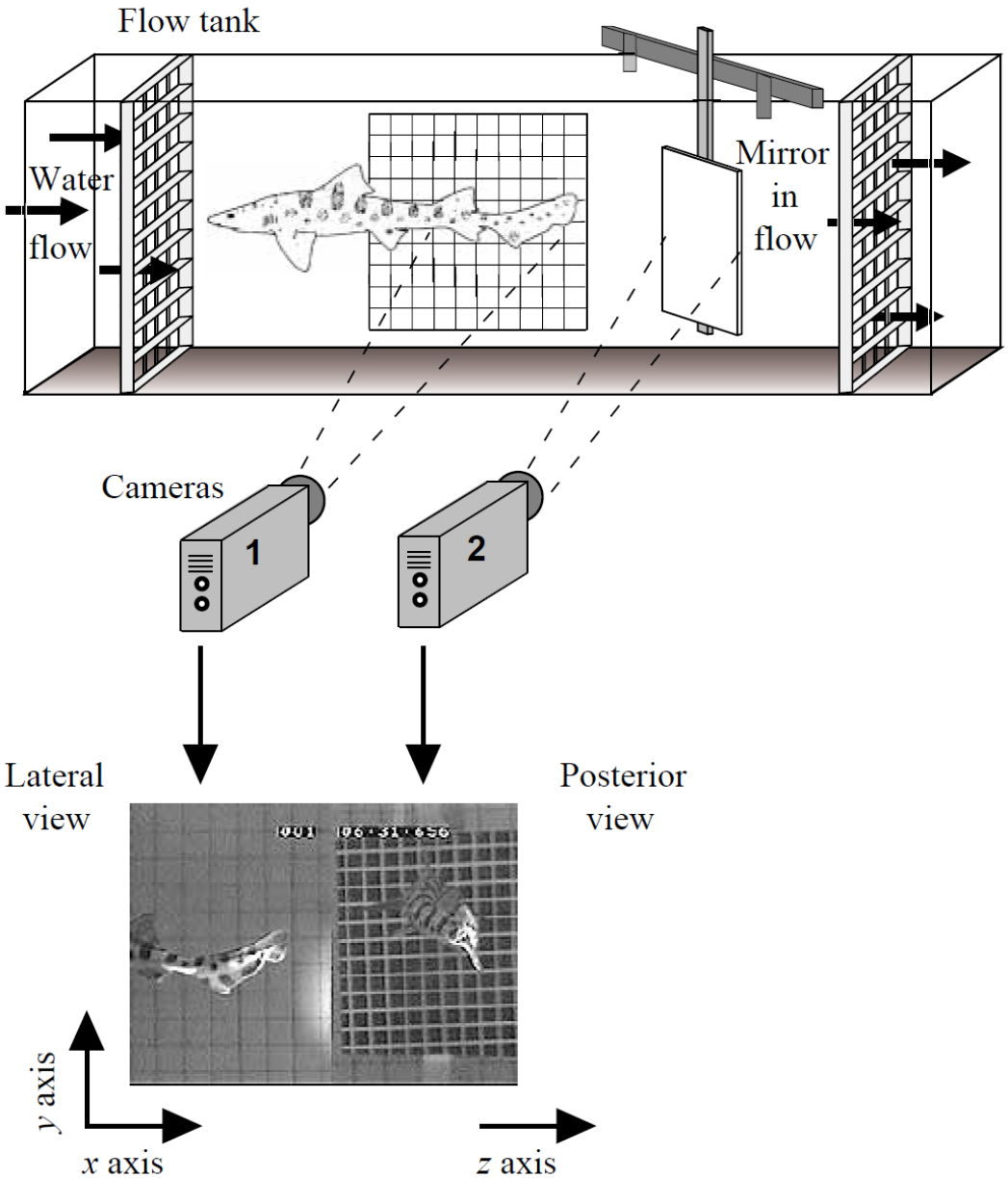




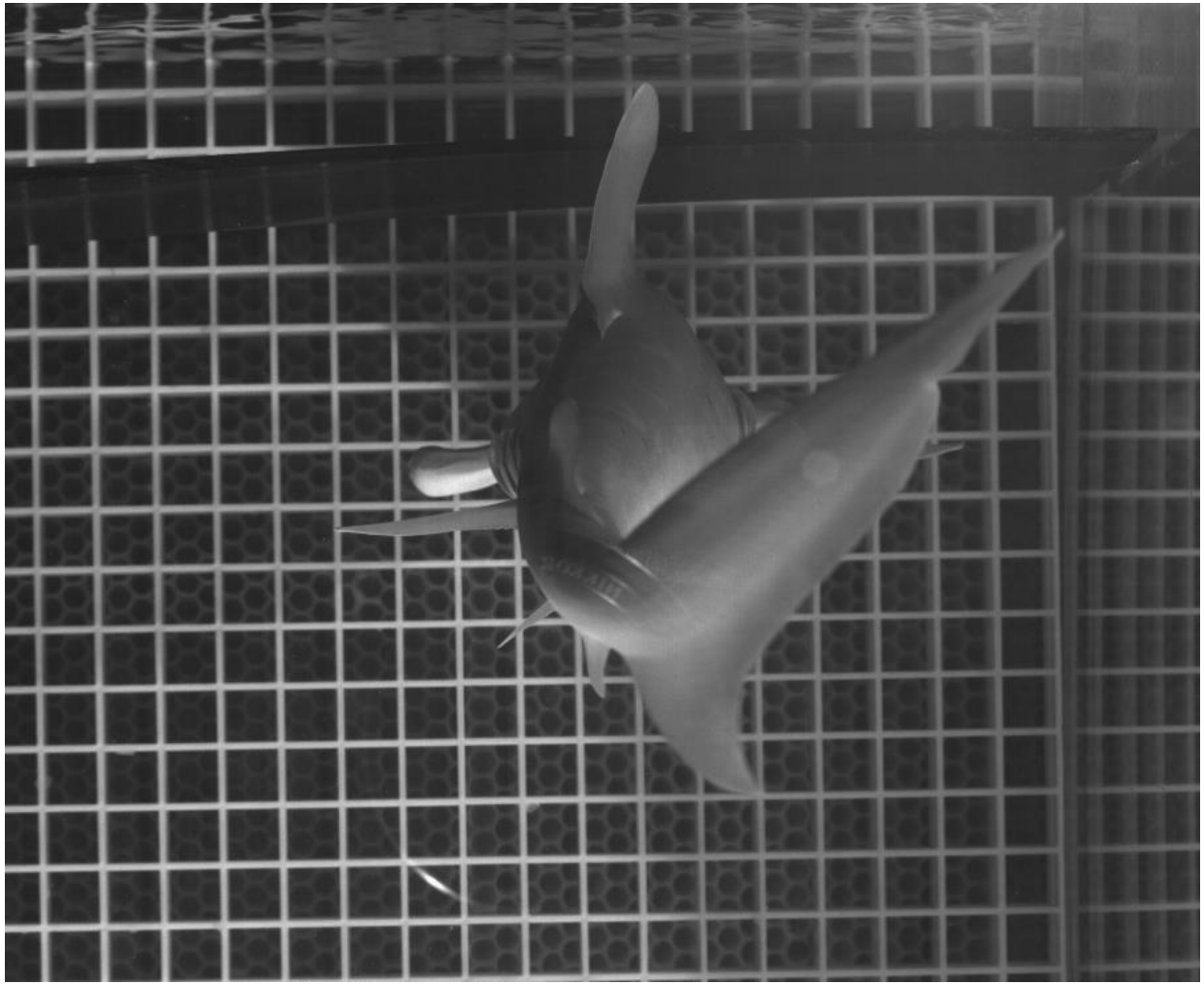
What about the function of the asymmetrical heterocercal tail in fish like (many) sharks

How does the heterocercal tail function?

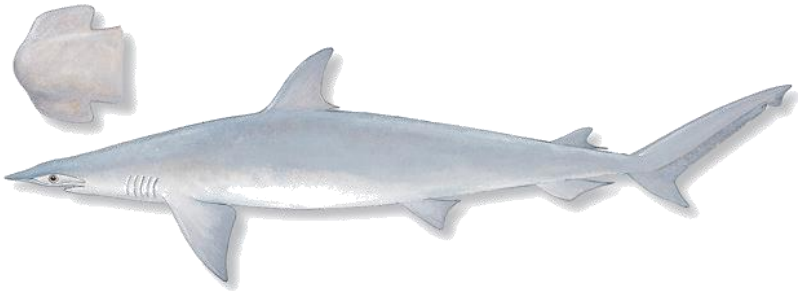
Quantify the 3D motion of the tail



How does the heterocercal tail function?



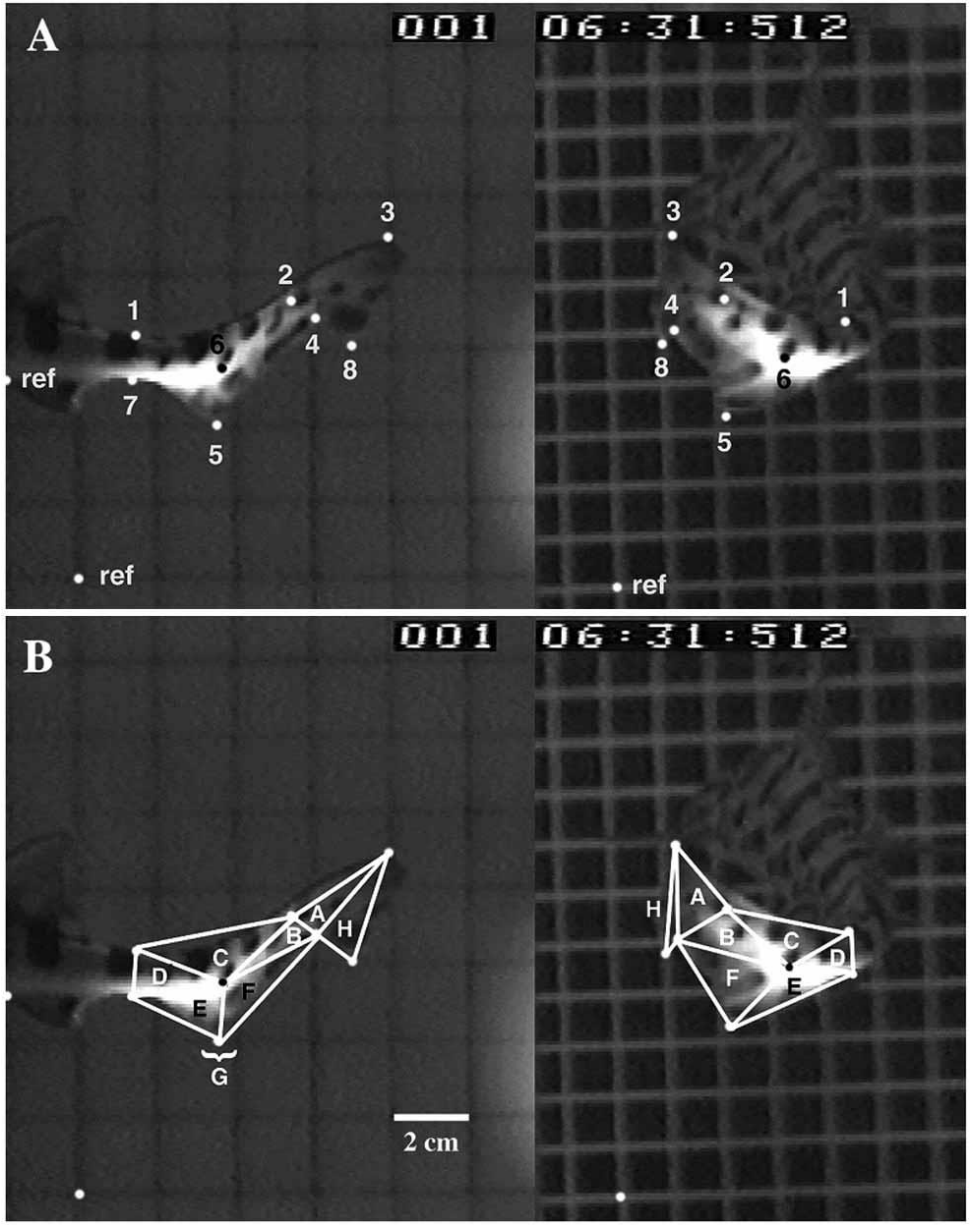
Movie of shark tail function from behind (bonnethead shark)



How does the heterocercal tail function?

Quantify the 3D motion of the tail

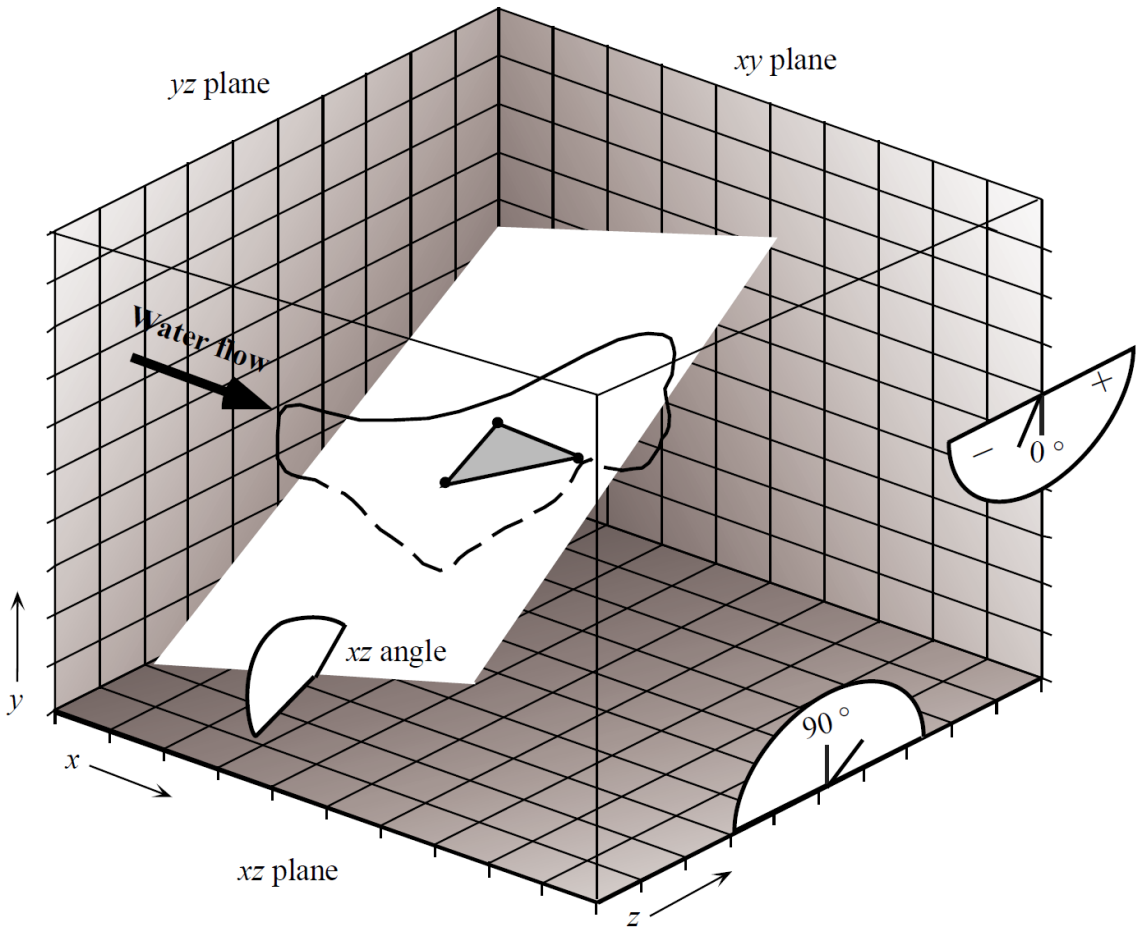
- Take movies from 2/3 views
- Digitize points
- Make triangular surfaces
- Measure orientation of these surfaces



How does the heterocercal tail function?

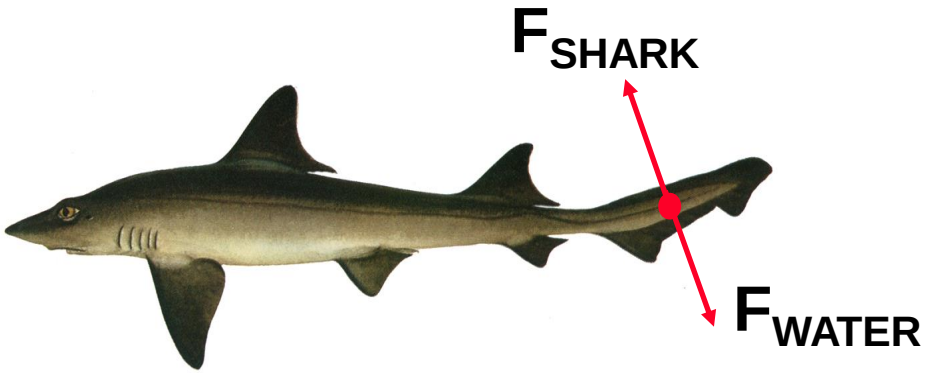
Quantify the 3D motion of the tail

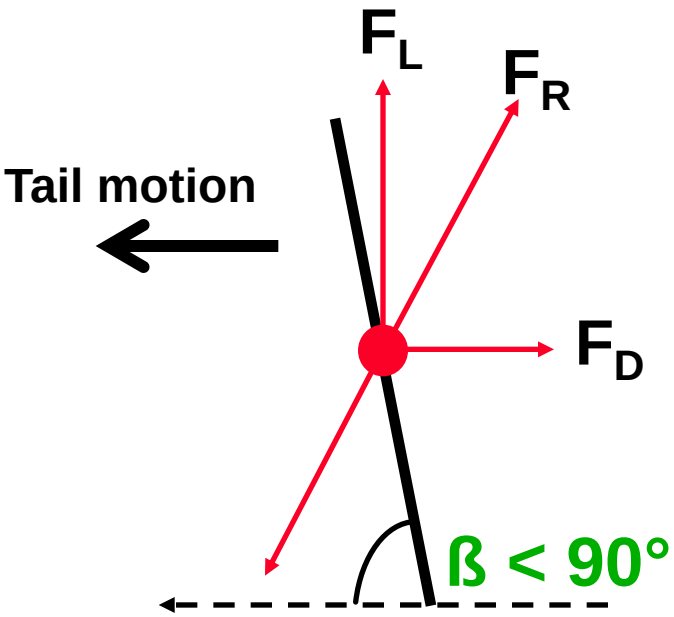
3D analysis shows that the tail triangles are angled with respect to the horizontal



How does the heterocercal tail function?

3D analysis shows that the tail triangles are angled with respect to the horizontal





What does this angled orientation imply about the forces generated by the tail?

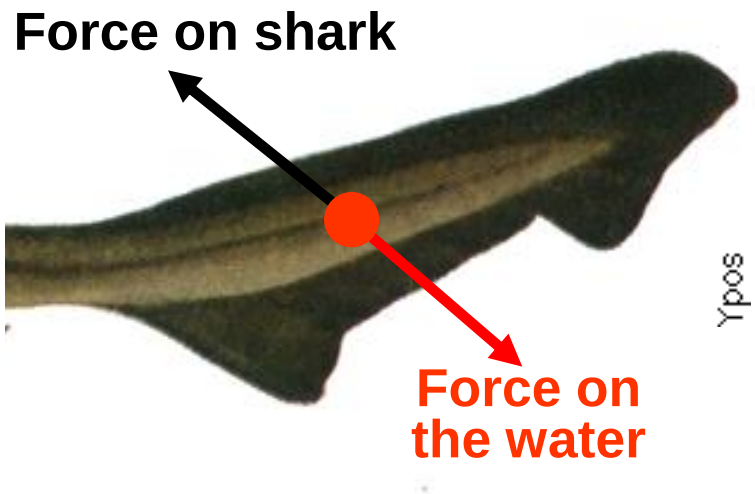
How does the heterocercal tail function?

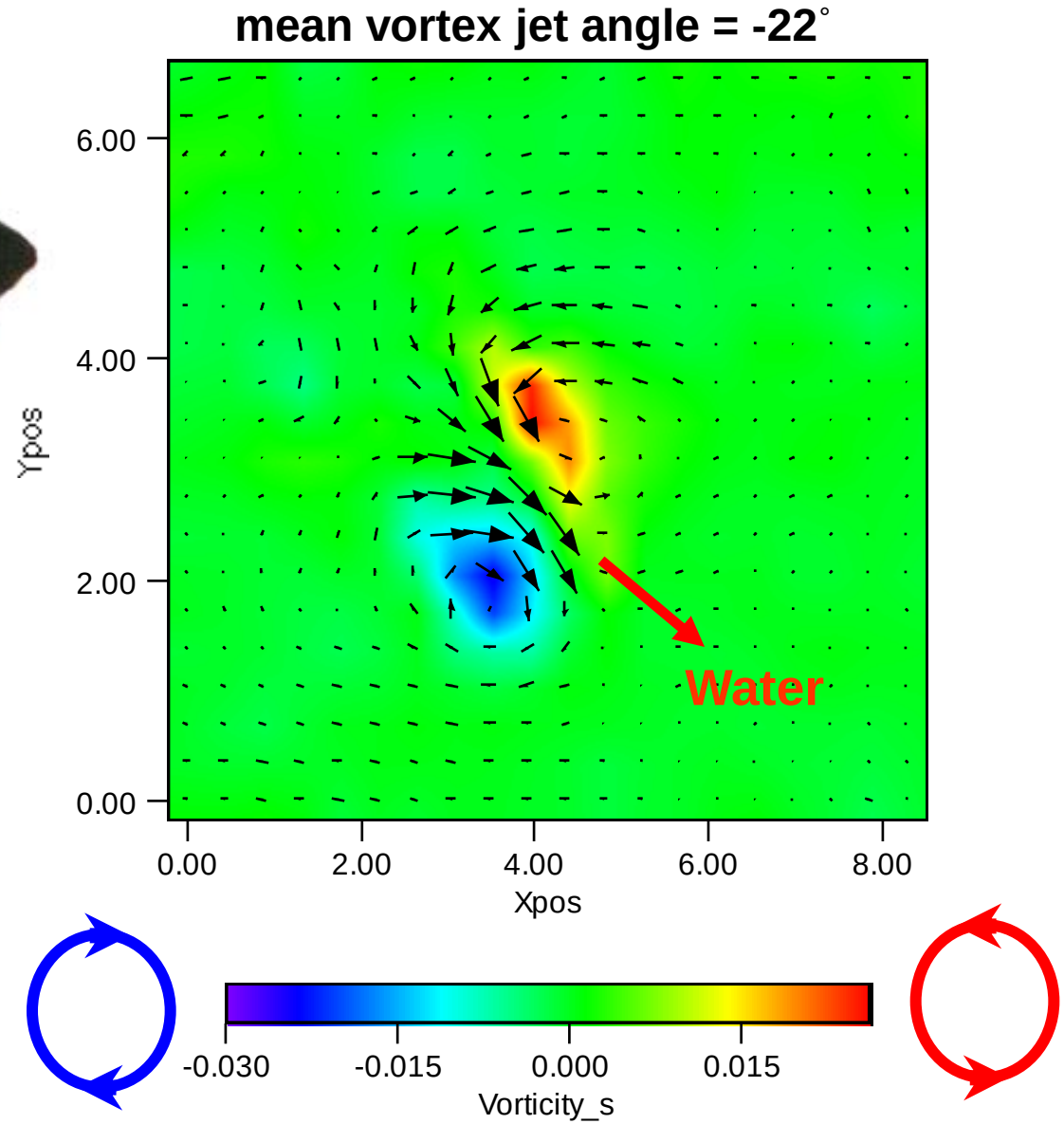
Apply an experimental hydrodynamic approach: Digital Particle Image Velocimetry

CAMERA 1
View of shark body angle

CAMERA 2
Particles in light sheet

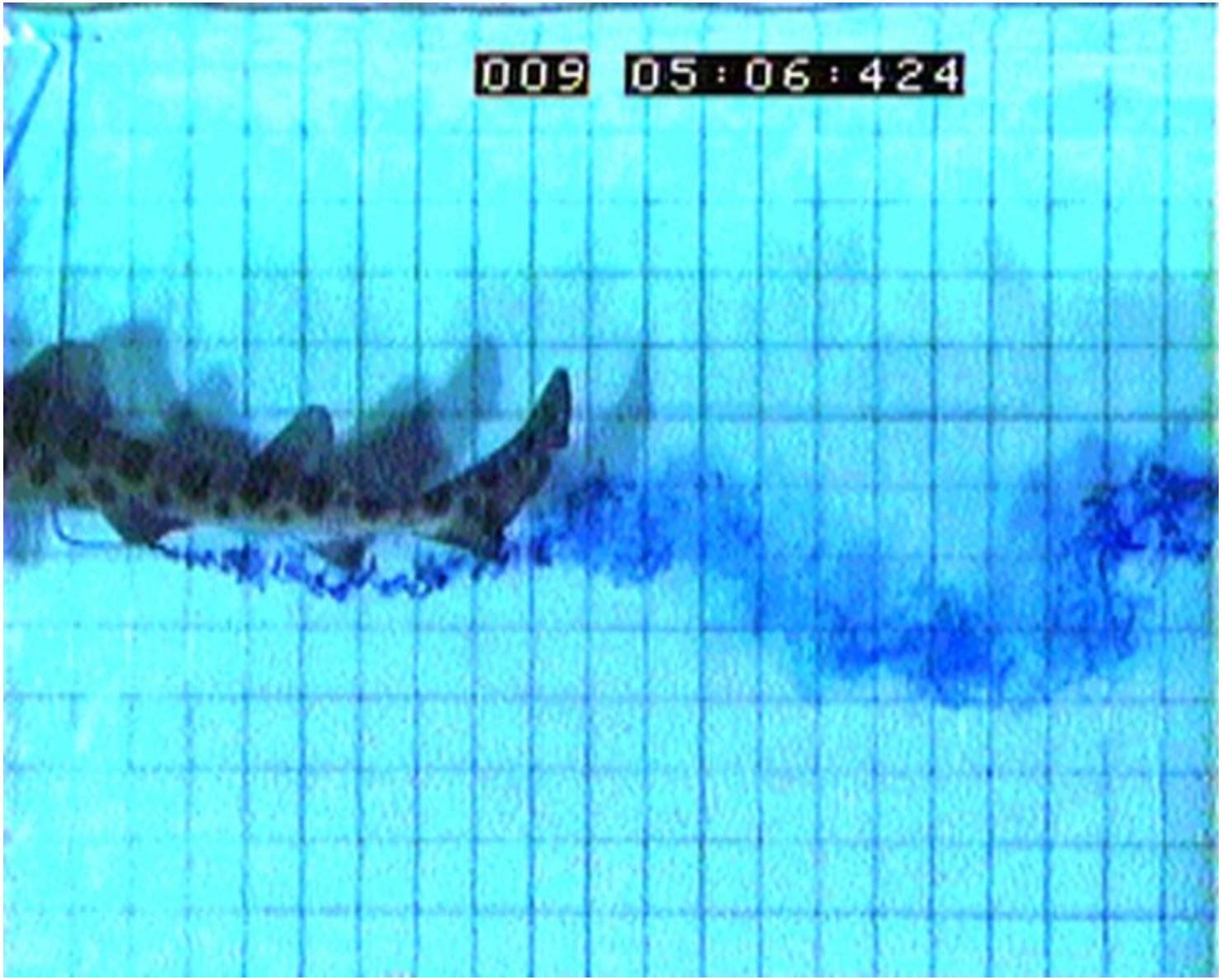
Water flow behind the shark tail



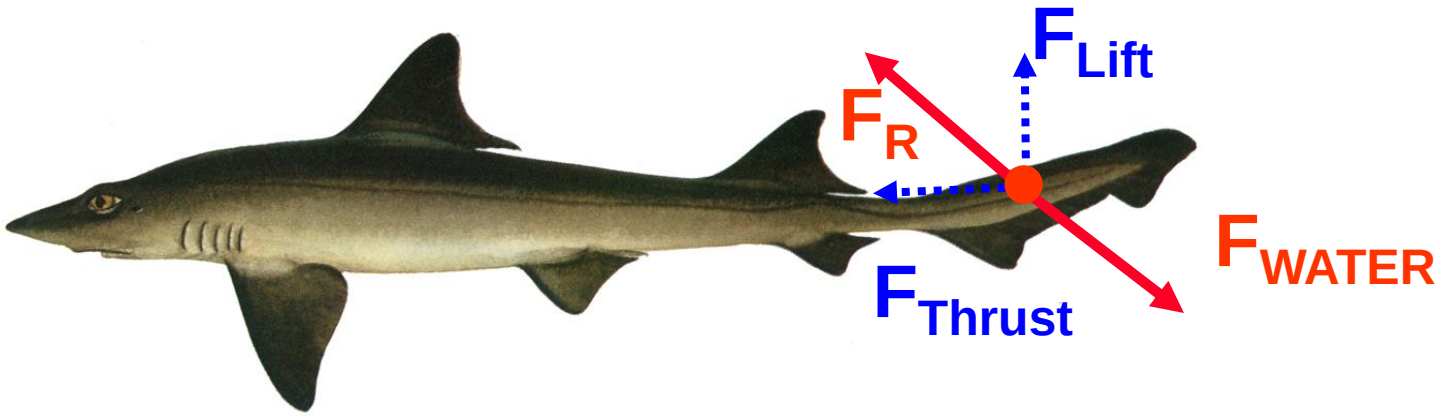


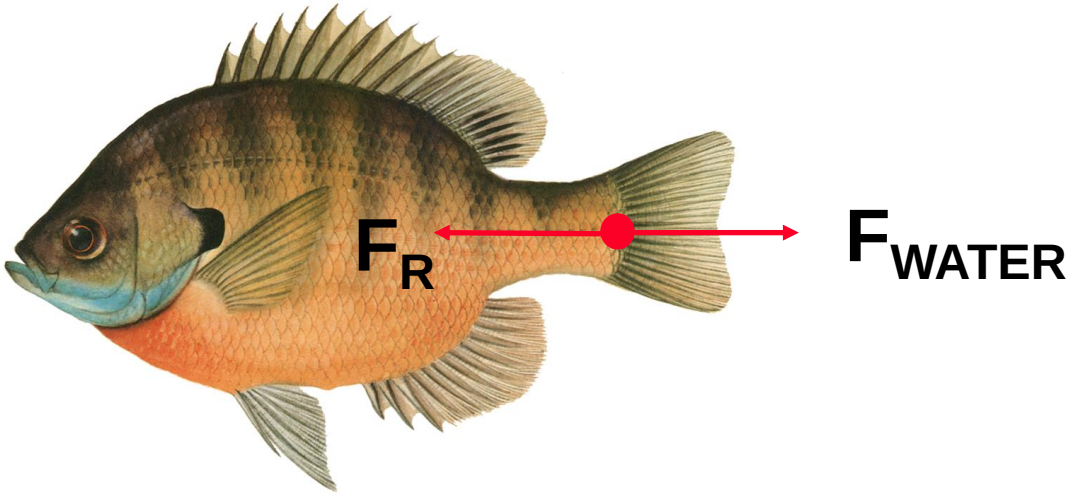
Water flow behind the shark tail

Inject blue dye next to the shark body



Tail function: heterocercal vs. homocercal

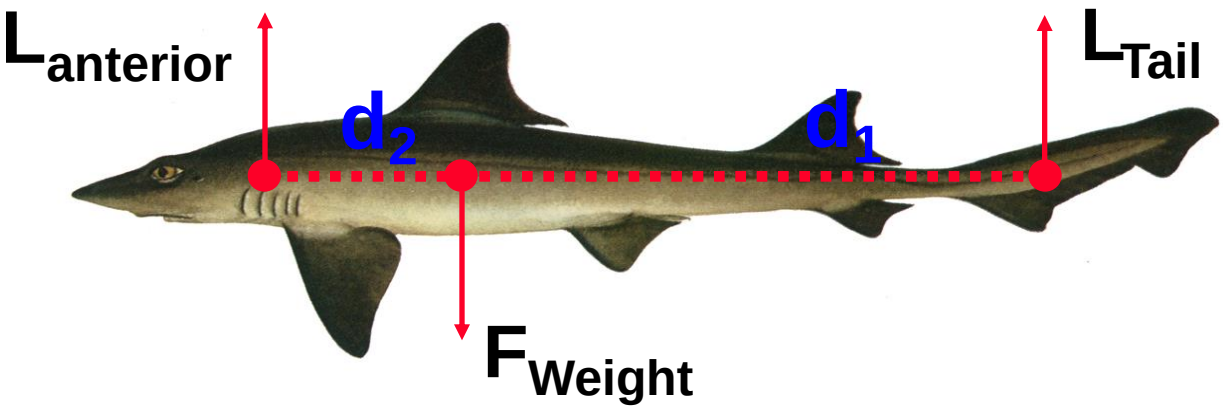




Note the lift force generated by the shark tail!
What does this mean for swimming?

Tail function: balancing forces

Both vertical forces and moments must balance.



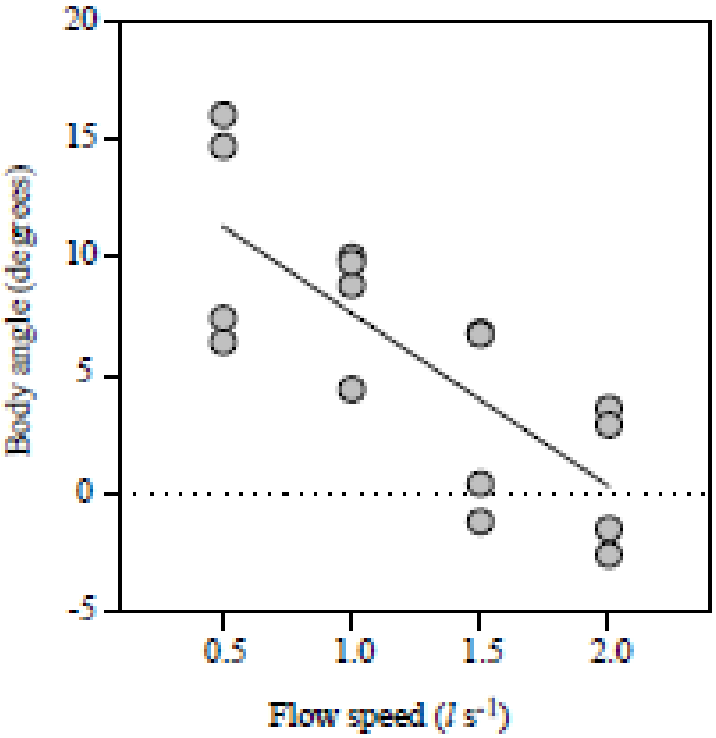
Lift force balance: $L_T + L_P = F_W$

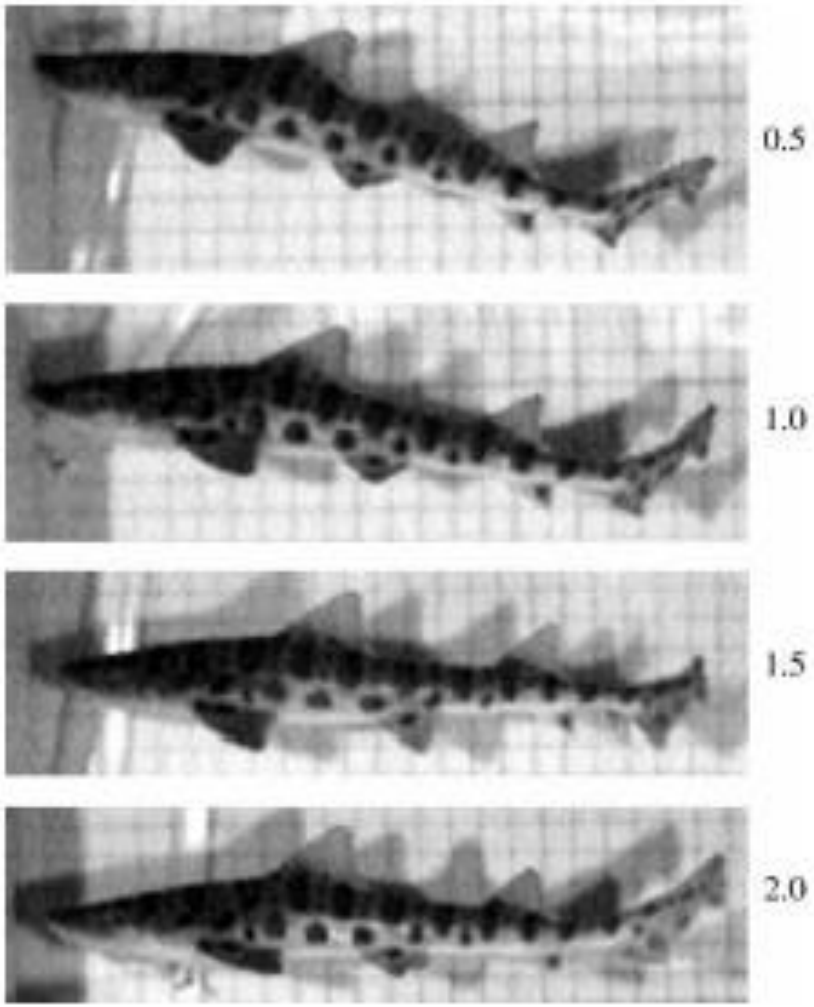
Moment balance: $L_T * d_1 = L_P * d_2$

Note the lift force generated by the shark tail.
What does this mean for swimming?

Tail function: balancing forces

Sharks often swim slightly tilted, at an angle to the horizontal

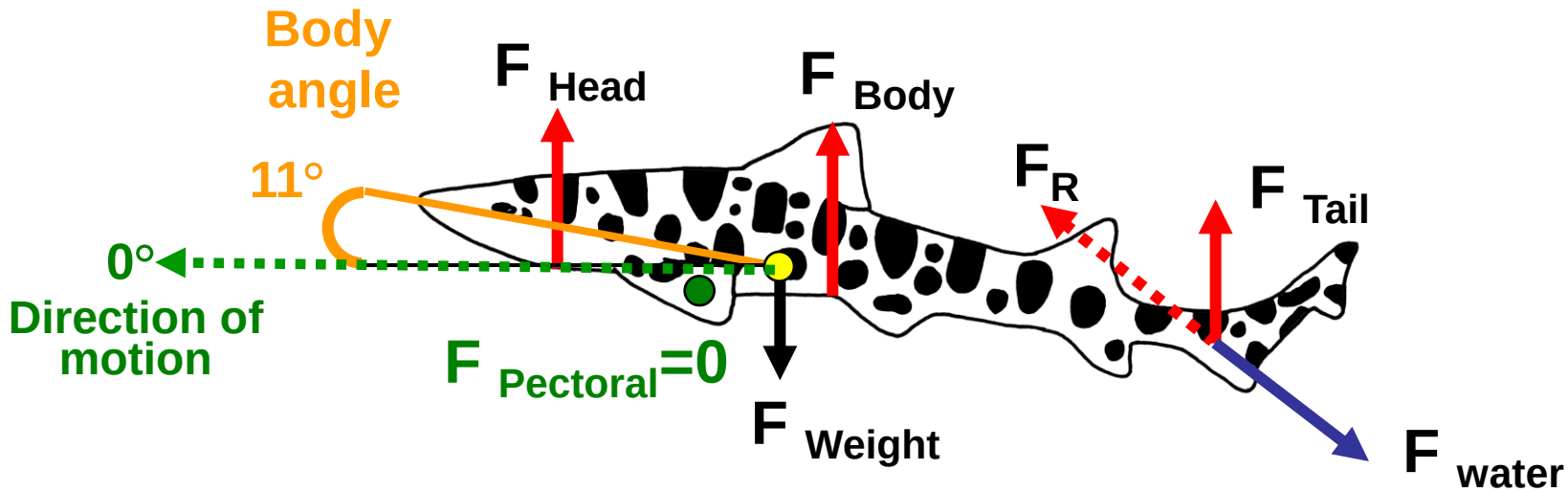




Body angle decreases as swimming speed increases

Overall force balance on a swimming shark

Sharks often swim slightly tilted, at an angle to the horizontal



- **Pectoral fins generate no significant lift during steady forward locomotion. (But they do during maneuvering.)**
- **The body is at a positive angle of attack and generates lift anteriorly to balance the moments and lift from the tail.**