

Animal Locomotion

Introduction to Biomechanics

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MOVEMENT: MOLECULAR TO ROBOTIC
REVIEW

How Animals Move: An Integrative View

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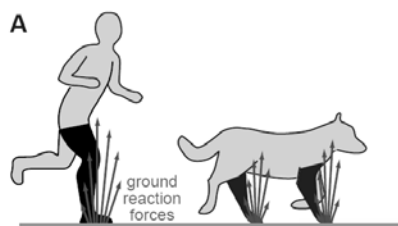
Recent advances in integrative studies of locomotion have revealed several general principles. Energy storage and exchange mechanisms discovered in walking and running bipeds apply to multilegged locomotion and even to flying and swimming. Nonpropulsive lateral forces can be sizable, but they may benefit stability, maneuverability, or other criteria that become apparent in natural environments. Locomotor control systems combine rapid mechanical reflexes with multimodal sensory feedback and feedforward commands. Muscles have a surprising variety of functions in locomotion, serving as motors, brakes, springs, and struts. Integrative approaches reveal not only how each component within a locomotor system operates but how they function as a collective whole.

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I. Forcing the Issue— Forces during locomotion vary in space & time

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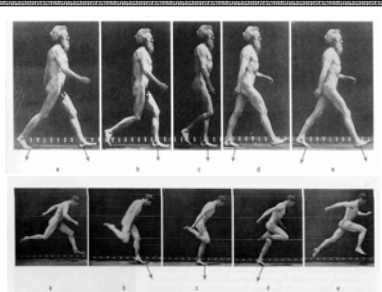
Ground reaction forces



- GRF vectors— equal time interval
- Braking → propulsion
- @ each instance, resultant vector points to the hip (shoulder) of each leg → ↓ torque at each joint

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Walking vs. Running



Photographed by Eadweard Muybridge in 1880's
Alexander, *Exploring Biomechanics: Animal in Motion*

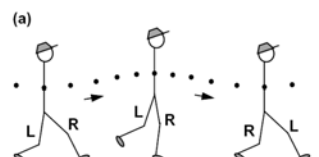
What are the difference?

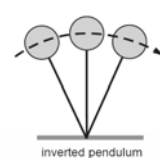
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Models

Walking

(a)

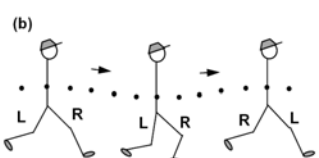


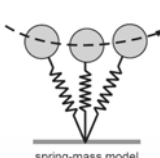


inverted pendulum
= walking

Running

(b)





spring-mass model
= running

Vogel, *Comparative Biomechanics: Life's Physical World*

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Walking

Models

inverted pendulum
= walking

Energy transformation

Potential energy
↔ Kinetic energy

Running

spring-mass model
= running

Potential + kinetic energy
↔ Elastic energy

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O2 consumption in walking vs. running

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The "spring" in a running step

Major player: tendon

93% energy returned Collagen fibers in a tendon

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50 kg person → 3500 N
70 kg person → 5000 N

→ 56 MPa stress
(~ 1/2 that could break the tendon)

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Another player— arch of the human feet

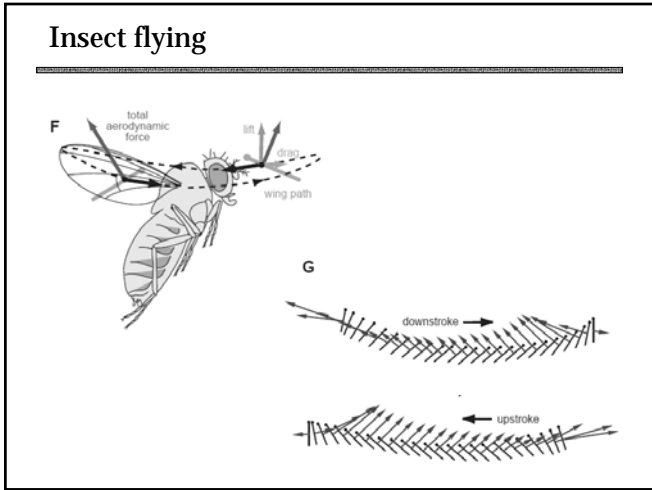
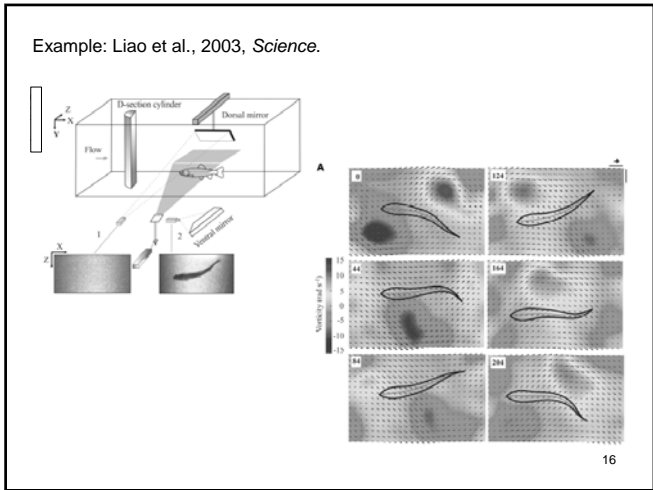
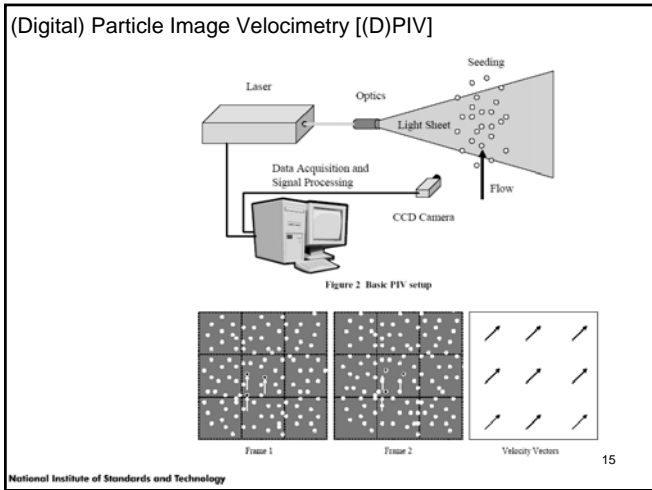
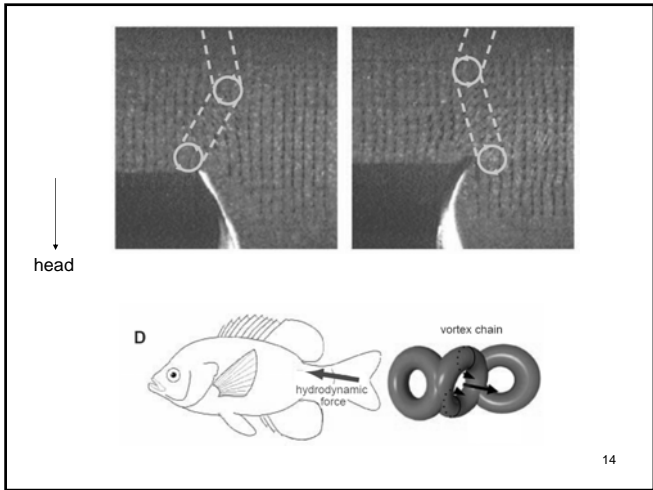
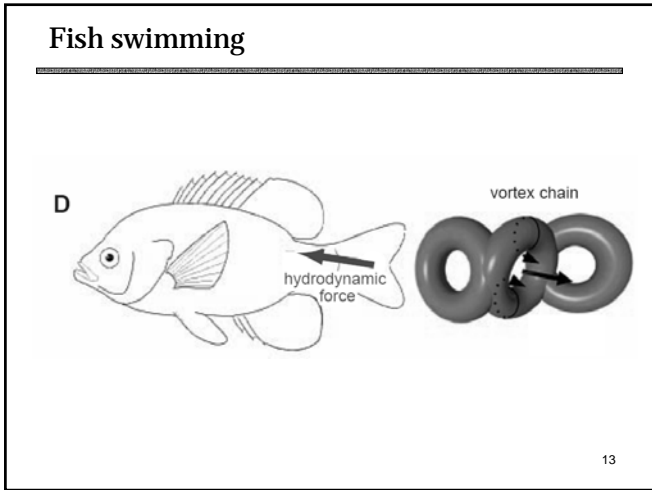
78% energy returned

Total: 1/2 Energy Saved by two kinds of springs

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How about lateral forces?

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II. Leaving the Straight and Narrow— Moving in a natural context

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Trade-offs b/w locomotion & other functions

Example:
Swimming jellyfish

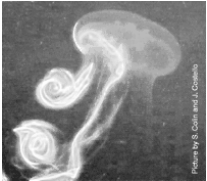
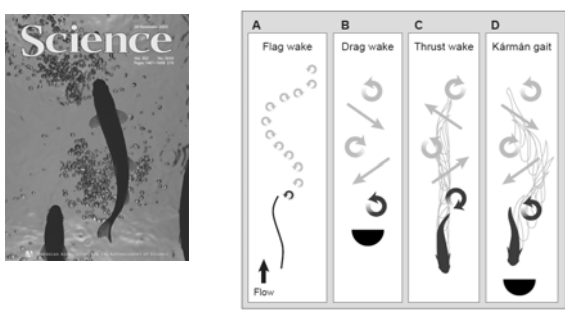


Photo by R. Goffard, J. Combe

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Effects of mechanics of environment



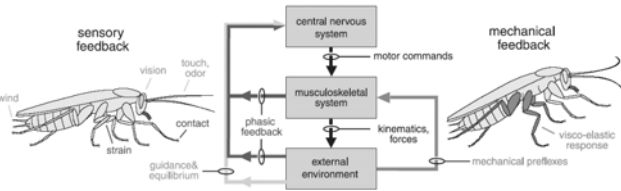
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III. Control Systems Are Closely Coupled

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Neural & mechanical feedback of locomotion control

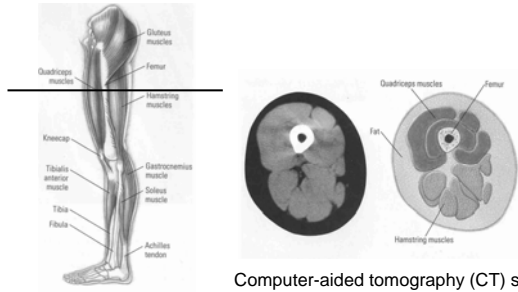


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IV. Muscles Are More Than Motors

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The Anatomy: Muscles in human Leg



Computer-aided tomography (CT) scan

Alexander, *Exploring Biomechanics: Animal in Motion*

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Some important facts about muscles

- Force \propto cross-sectional area
- Can only **contract** actively

Figure 23.5. (a) The arrangement of fibers in ordinary and pennate muscles; (b) the human gastrocnemius, a bipennate muscle, in situ.

Figure 23.6. How pennate muscle works as a constant volume system: contraction leaves width and length—and hence area and (in three dimensions) volume—unchanged.

Vogel, *Comparative Biomechanics*

Work loop: Muscle as a engine (work output)

Spider silk—Energy lost

Figure 23.7. (a) Work loops for spider silk. (b) Motor and strut work loops for a bird's wing.

Vogel, *Comparative Biomechanics*

Muscle also serves as a break (absorb energy)

Figure 23.8. (a) Two extensor muscles in the hind leg of a cockroach. (b) The work loops for these muscles. One turns out to be a flexion-resistor rather than a functional extender.

Vogel, *Comparative Biomechanics*

Figure 23.9. (D) Spring mechanism with compliant and stiff phases. (E) Fish showing strut and motor. (F) Bird showing motor and strut work loops for uphill and level flight.

*** About Three of the Authors**

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Dickinson Lab

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... is dedicated to integrated, interdisciplinary, multi-levelled approaches to the study of animal physiology and behavior.

Current research focuses on the neurobiology and biomechanics of locomotion in flies.

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