Bio-fluid Mechanics

物理及生物物理學研究所
紀凱容

Roles of Physics in Biology?

What if Darwin had met Newton?

從生物力學(Biomechanics)談起

What’s in your mind?

Q: Difference b/w walking & running?
Physics

Walking

Running

Vogel, Comparative Biomechanics: Life’s Physical World

Q: Are fast moving elephants really running?

Hutchinson et al., 2003 Nature
(pictures from Summers, 2007, Natural History Magazine)

Physics

Model

Mechanical energy

Walking

Running

Potential energy ↔ Kinetic energy

Potential energy + Kinetic energy ↔ Elastic energy

Q: 貓為何總能安然降落？

［生物］
避震器：增長運動中的物體停止的時間

Δv
Δt

［物理］
刺蝟的刺也有同樣功能！
Q: Why can cats do, but we cannot?

I. Fluid Mechanics

Bernoulli’s Principle (Conservation of Energy)

\[ p + \rho g z + \frac{1}{2} \rho v^2 = \text{const}. \]
Applications of Bernoulli's Principle:

\[ p_2 - p_1 = -\frac{1}{2} \rho (v_2^2 - v_1^2) \]

Animals know Bernoulli’s, too!

- Ventilation in burrows of prairie dog (北美土撥鼠)

Q: Challenges of a tree?

- Spoonbill (琵鷺) feeding

Animals know Bernoulli’s, too!
Q: Can leaves reduce drag?

Test in wind tunnel
72.4 - 105 kph (8-11级风)

Measuring drag…

Steven Vogel, Duke University
II. Bio-Fluid Mechanics

Example: Shoes

Nature's Shoes—“Footpads” (腳掌墊)

Structural adipose tissue

Plantigrady ↔ Digitigrady

↑ Size
**Q: Function?**

- Protection
- Weight bearing
- Friction

<table>
<thead>
<tr>
<th>No pad</th>
<th>Elastic pad</th>
<th>Viscoelastic pad</th>
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![Image](image1.png)

Alexander et al. 1986

**Functions:**
- Transmit propulsive force
- Brake & Cushion impact
- Stabilize foot
- Return elastic energy

**Properties:**
- Stiff
- Compliant
- Damped
- Resilient

**Paradox**

Q: Can footpad perform multiple functions? How?

**During locomotion?**

**Breaking**

- Stabilize foot
  (Alexander et al., 1986)
- Brake & cushion impact
  (Valiant, 1984; Kinoshita et al. 1993)

**Propulsion**

- Transmit force
- Return elastic energy
  (Ker, 1996)

Pad properties to consider—
- Resists deformation (stiff or compliant)
- Loses energy (resilient or damped)

**Previous studies: constrained setup**

**Compressive tests**

- In vitro
- In vivo

![Image](image2.png)

(Ker, 1996)

(Kinoshita et al. 1993)
My study: Locomotion

Animal Locomotion Laboratory (Duke BAA)

- 6 human subjects
- Different gaits (walking, running, crouched walking)

Load:

Deformation:

Chi & Schmitt, 2005
J. Biomechanics

1. Mucus
2. Capillary force

3. Suction

4. Microinterlocking
5. Van der Waals force

e.g. Tokay Gecko

Bob Full, UC, Berkeley

Gecko feet

Lamellae

Setae

$2 \times 10^6$ setae/ gecko

$10^2$-$10^3$ spatulae/ seta

$\rightarrow 10^8$-$10^9$ spatulae/ gecko

IV. 應用

（模仿大自然的歷史紀錄）
E.g. Trout, Dolphins, and Streamlined Bodies

Cayley: drawing of dolphin & streamlined body (1809)

Bird Wings and Cambered Airfoils

Burrs and Velcro

Velcro (魔鬼氈)

Lesser burdock (Arctium minus)

Colored SEM
V. 未來:
效法大自然的仿生科技

E.g. “Gecko” tape

In theory, 1300N force/ gecko

Artificial gecko tape

Polyimide hairs
Carrying capacity of more than 200 g/cm²
Sticky & clear

How to self-clean?

2. 「壁貝」膠 (Geckel)
   =壁虎(gecko) + 贽貝(mussel)

A reversible wet/dry adhesive inspired by mussels and geckos
Harshin Lee¹, Bruce P. Lee² & Phillip B. Messersmith²,³,⁴

3. Spider silk

生物物理期刊俱樂部 (BJC)
(每週四中午, 系會議室)

本週活動:
環境中風的干擾對蜘蛛絲及蜘蛛網強度的影響