仿生與實驗室晶片導論- 2020

Introduction to Biomimetics

仿生科技之探索

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Biomimetics . . . *Learning from the Nature!*

The examination of nature, its models, systems, processes, and elements to emulate or take inspiration from in order to solve human problems. The term *biomimetics* comes from bios, meaning life, and mimesis, meaning to imitate.

… *from Wikipedia*

Observation, Learning, Imitation, Inspiration → Creation

Science News, 2011,
News & Views, Nature Physics, 2011
Yang *et al.*, NTU

Example:

Fluid Mechanics →

Biophysics & Biomechanics

→ MAV

Research Motive for Biomimetics

All living creatures on earth have experienced tremendous **evolution** for a very long period. To fit for survival and to extend existence, creatures have evolved their special gifts, such as self-cleaning structures on the leaves of plants near the water area and the high energy conversion efficiency and skillful maneuverability for swimming or flying species.

The research on these special biological features is one way to inspire us novel concepts of science and technology.

Research Motive

自然界的生物經過適者生存的自然淘汰法則以及千百萬年的演化過程之後，能夠存活下來的生物都擁有非凡的環境適應能力，不管是在外型上、動作上和繁衍方式…等各方面，無疑都是「最佳化」的設計。因此，對於自然界生物的研究以及模仿，可以啟發人類發展出新的工程理念，突破現有科技的瓶頸，對人類科學技術的進步有著極大的助益。

The Core Concept

「仿生」的核心概念及價值是：人類以獨特的思維功能，從大自然中擷取某些生物的運動方式，外觀、內部構造、習性、生存方式等，發展出新的工程理念，以突破現有科技的瓶頸；針對這種自然生物與工程之跨領域的新概念，學者創造出「**仿生學** **(biophysics/biomechanics/biomimetics)**」這個新名詞。簡單來說，就是以人為本，研究生物系統的結構和性質來創造工程技術的新設計思維及工作原理的科學。

Part 1: Lotus and Microchips

Part 2: Engineering & Fish, Butterfly, Bird

Gaudi's Natural Buildings

LOVE Casa Batlló

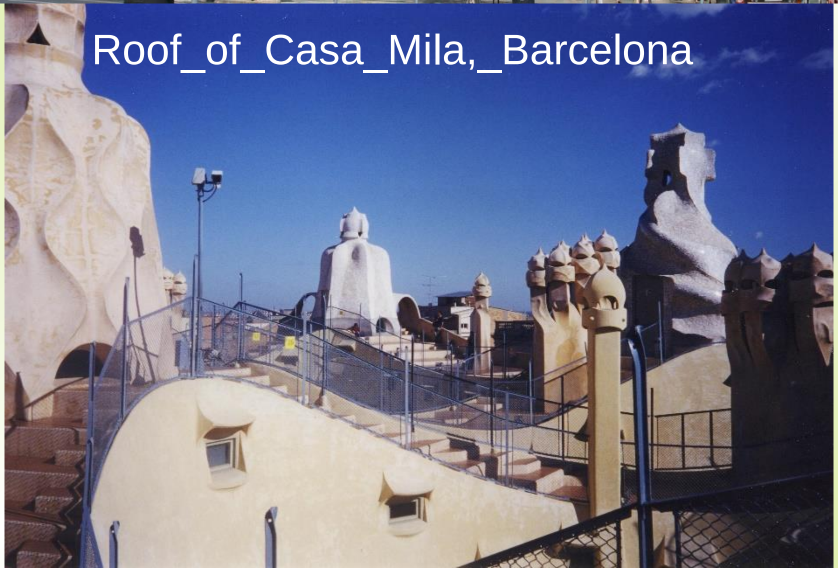
https://www.youtube.com/watch?v=G7pPXEG26zQ

https://www.youtube.com/watch?v=esMwj8W_jm0

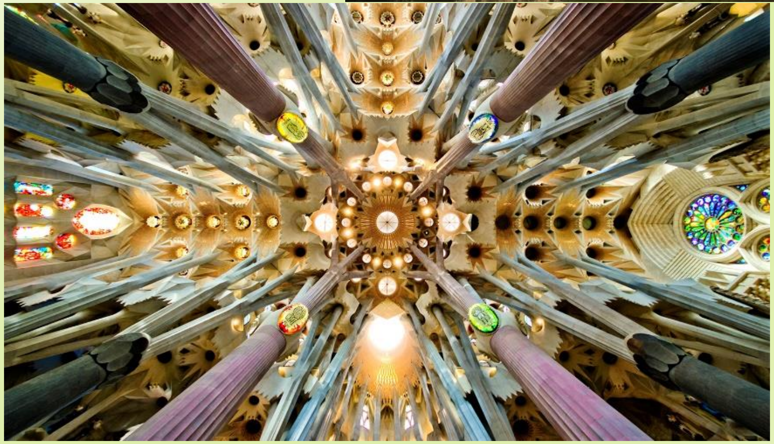
https://www.youtube.com/watch?v=xIZEsXEMnxA

https://www.youtube.com/watch?v=B2WV71dgrTs

SAGRADA FAMILIA, BARCELONA SPAIN



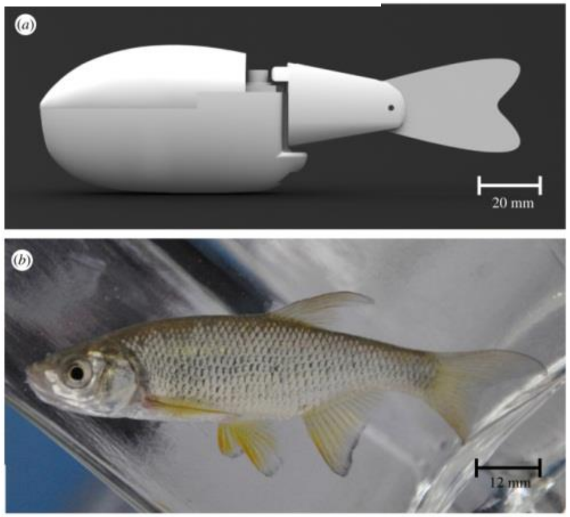
Roof_of_Casa_Mila,_Barcelona



芋葉之出淤泥而不染

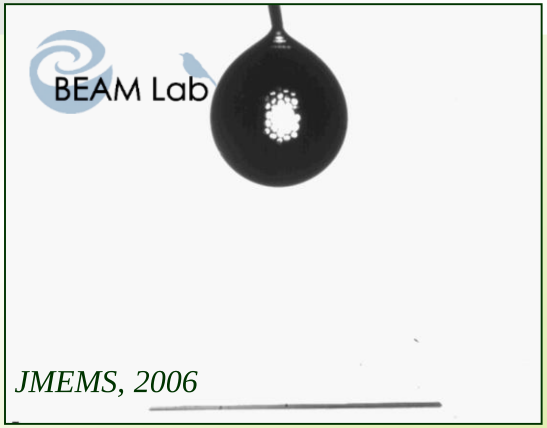
Biomimetic – Learning from the Nature

Biomimetic robots

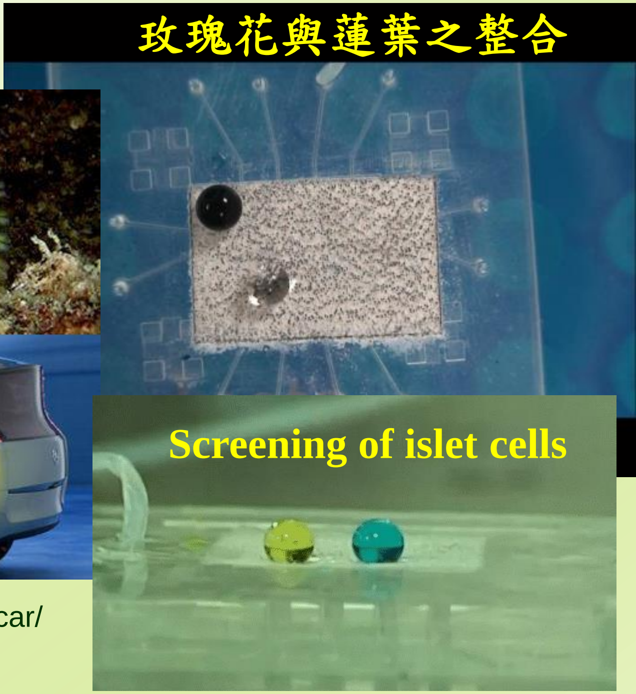


Marras *et al.*, *Interface*, 2012

Lotus Effect-- Lab on a Chip



http://www.beilstein-institut.de/en/spotlight/biomimetics; Yang's team, *JMEMS*, *JMM, MNF, SNB, Lab Chip*, 2004-2016



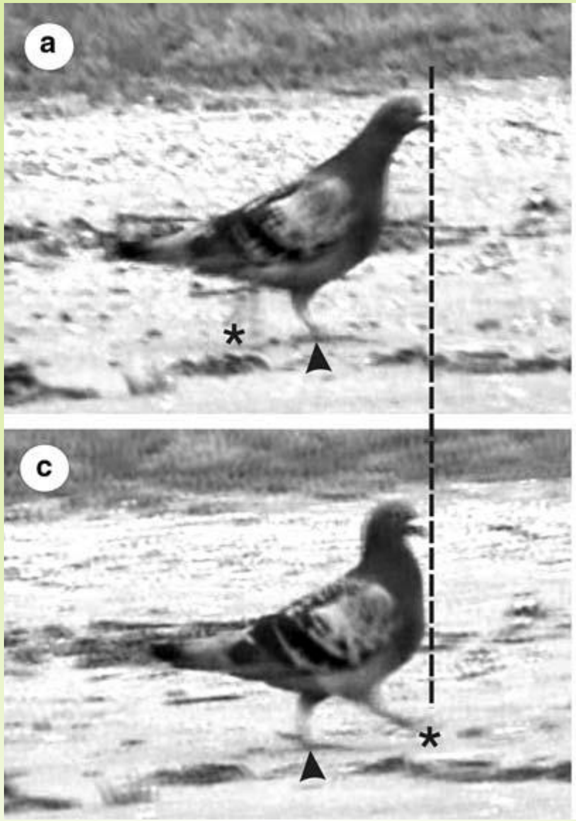
Mercedes-Benz bionic car

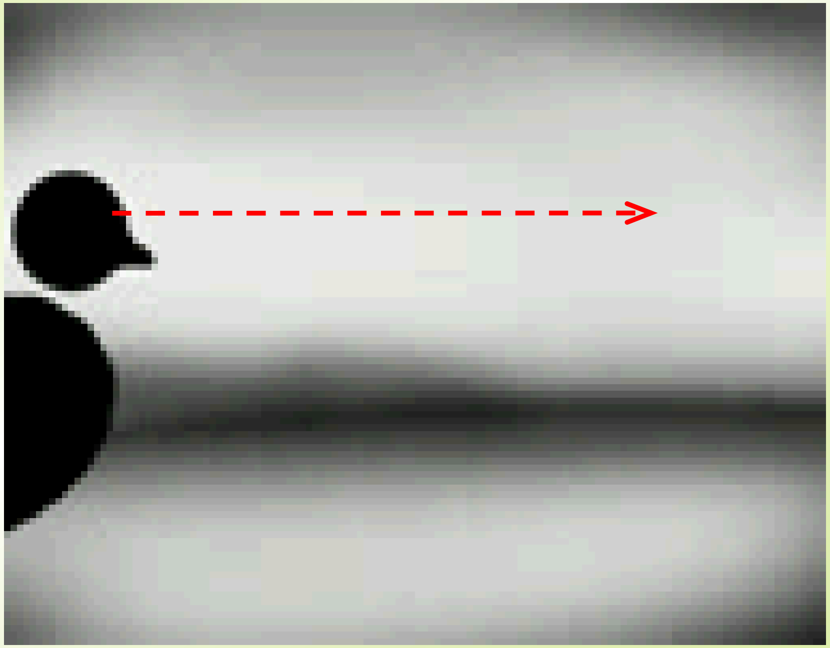
http://sites.psu.edu/khalid/blog2-the-bionic-car/

Bio-inspired material development

http://www.progettostima.it/?page_id=2&lang=en

鴿子行走時的頭部穩定





HEAD-BOBBING IN PIGEONS

“Head-bobbing” is characterized by a rapid forward movement (thrust phase) which is followed by a phase where the head keeps its position with regard to the environment but moves backward with regard to the body (hold phase).

R. Necker, 2007, J Comp Physiol A.

Chicken Head Steadicam

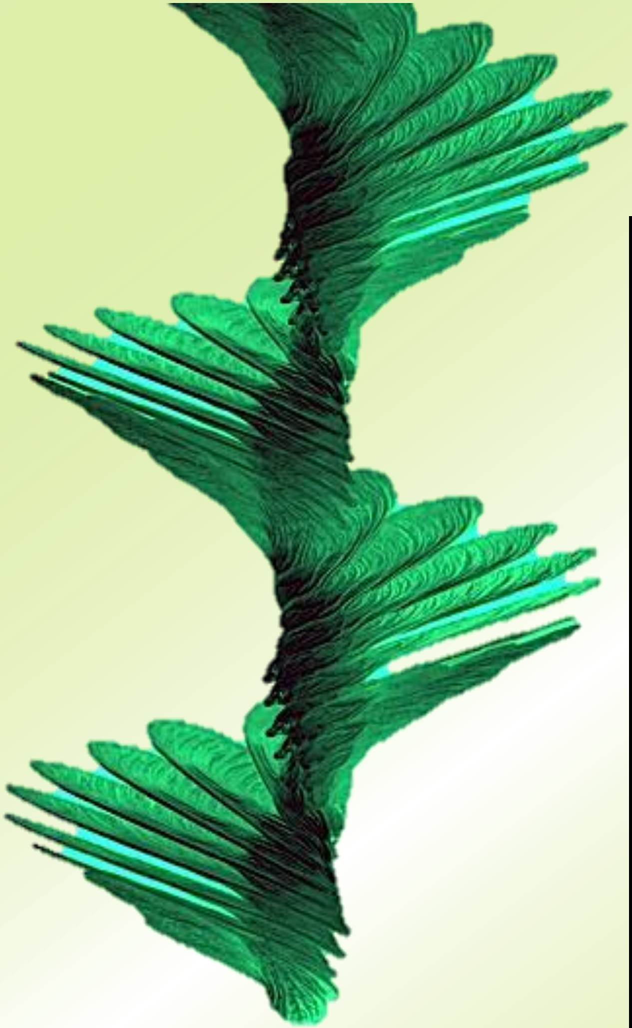
http://www.youtube.com/watch?v=m8sNHd0U7yw

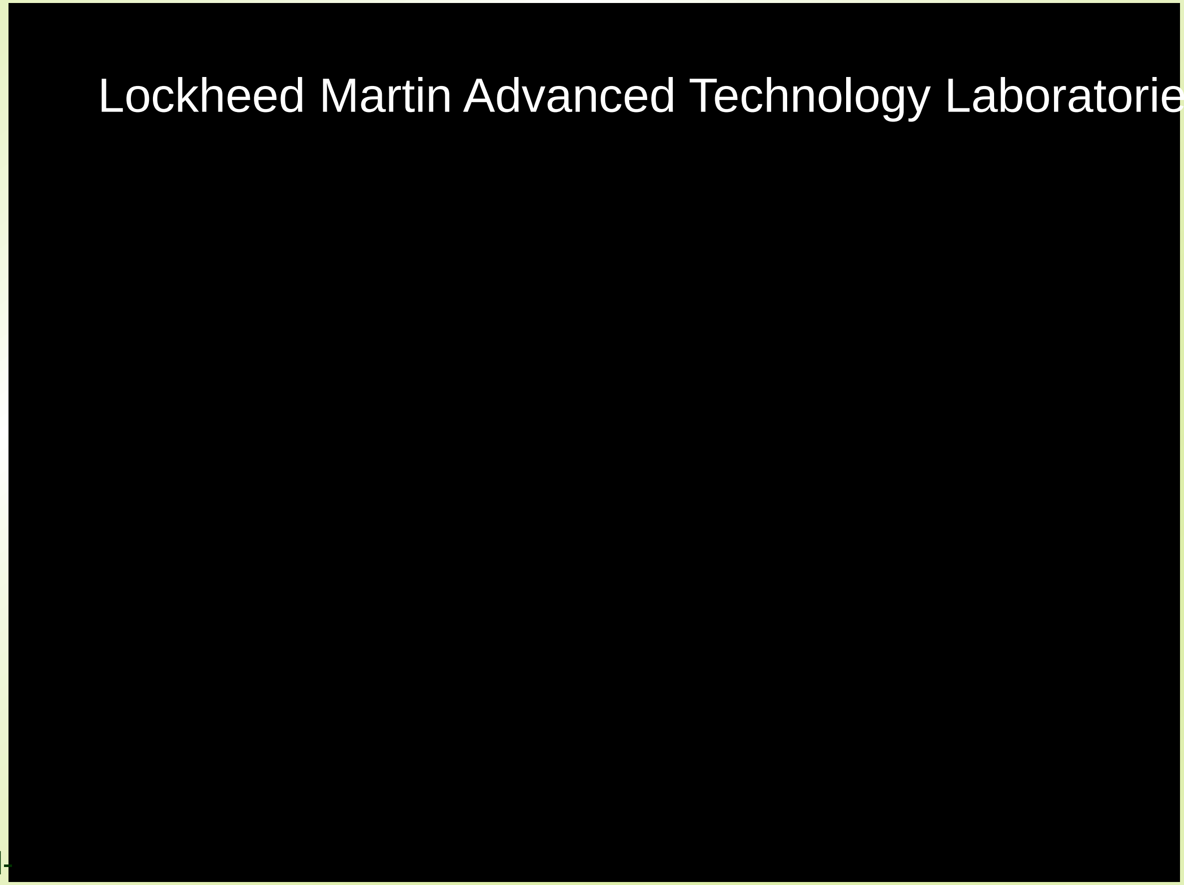
頭部包含許多重要器官，生物運動時會刻意穩定其頭部

頸 部 結 構 類 似 汽 車 之 懸 吊 系 統 ！

LG G2 chicken stabilizer

Maple Seed Flight Robot





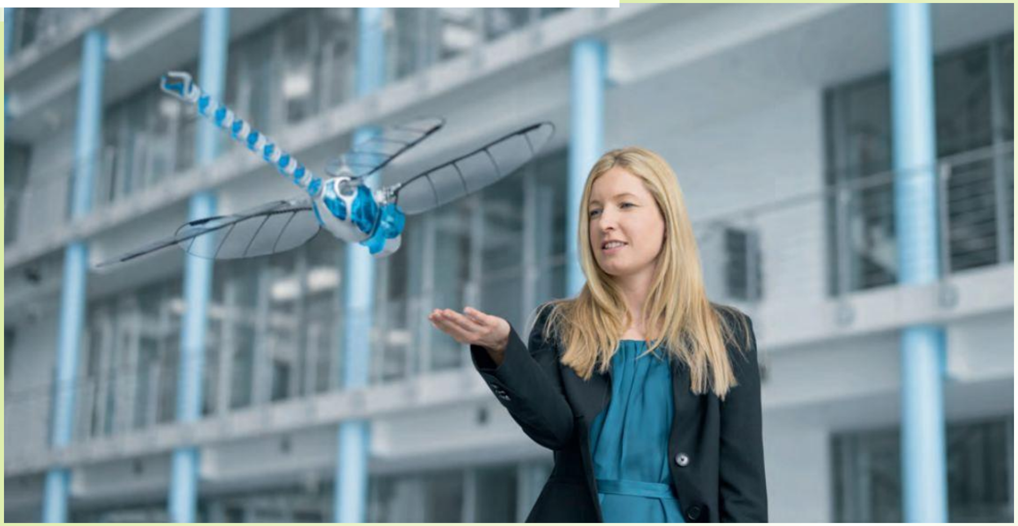
Lockheed Martin Advanced Technology Laboratories

https://www.caltech.edu/news/maple-seeds-and-animals-exploit-same-trick-fly-1540

https://www.youtube.com/watch?v=pUk6I2bL7j0

Future Flight Robots

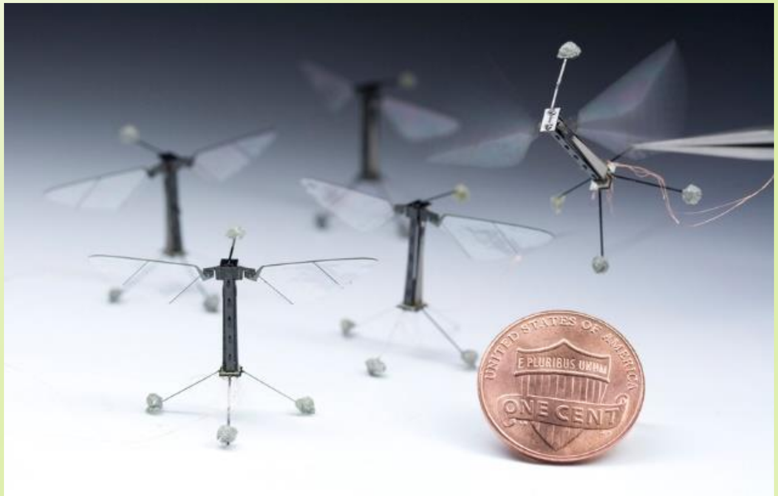
FESTO dragonfly robot



Humming bird robot (AeroVironment)

FESTO smart bird

Robotic insects (Harvard)



Biomimetic Robots

Cyber-Fish
英國埃塞克斯大學
(Essex University , London)
Japan, G8 Demonstration

機器鯛魚

日本北九州大學

Biomimetic Robotic Fish

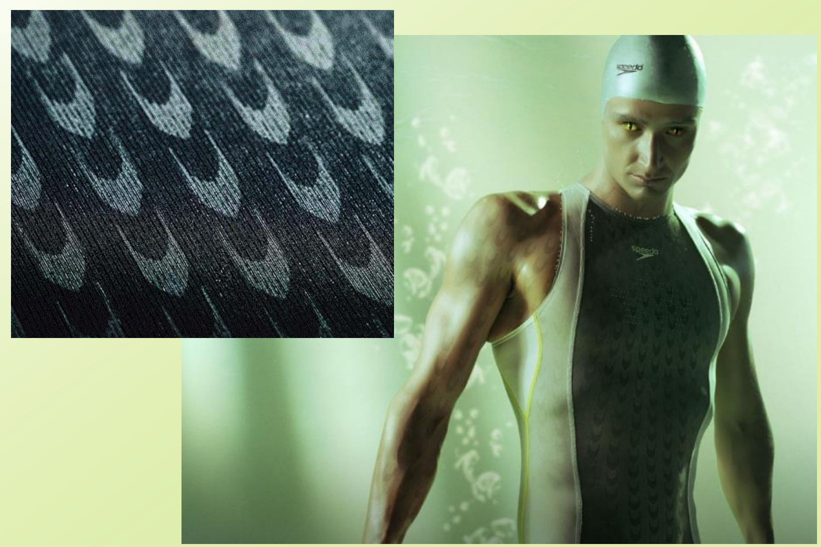
seabed exploration, detecting leaks in oil pipelines, mine countermeasures, underwater vehicles stabilization, underwater searching, escaping, military application, reconnaissance, disaster rescue, transportation, exploration, surveillance, guidance, inspection

J. T. Yang, 20081116

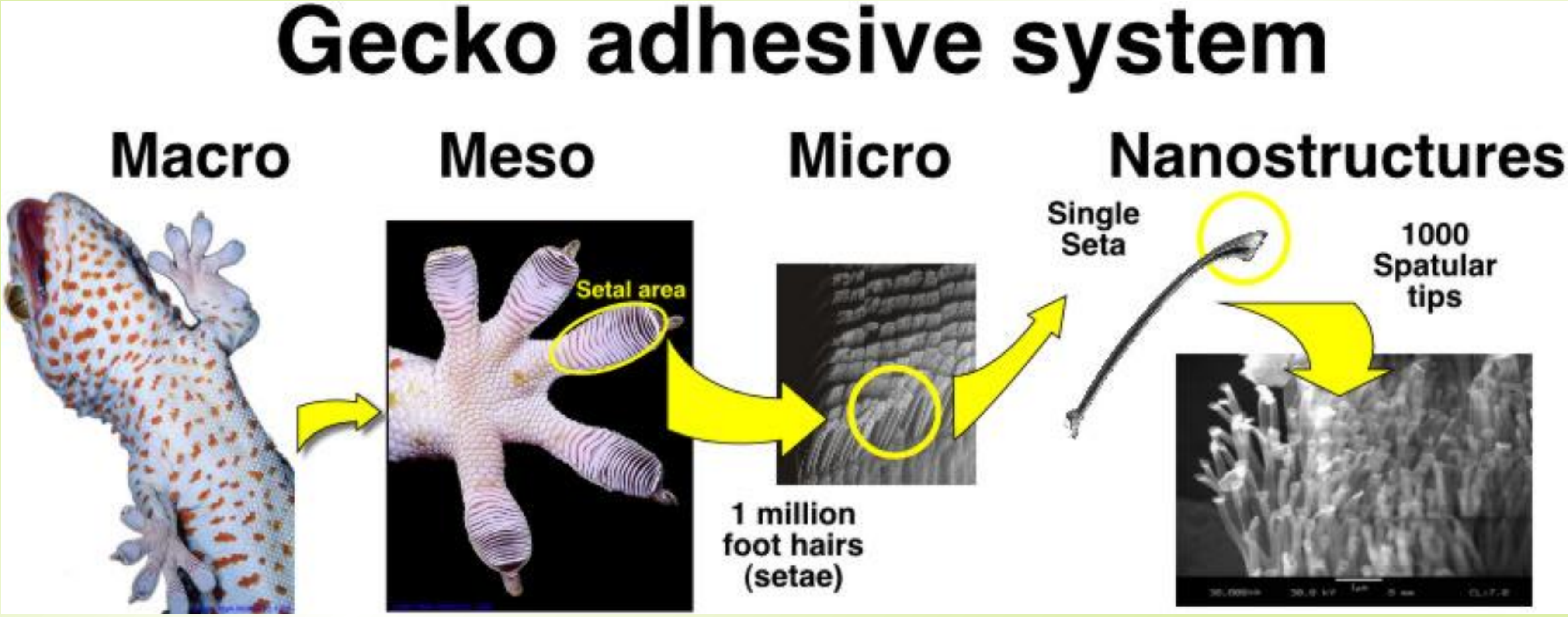
Interpretation of Several Engineering Applications

Biophysics Workshop II: Life among the Formulae of Physics

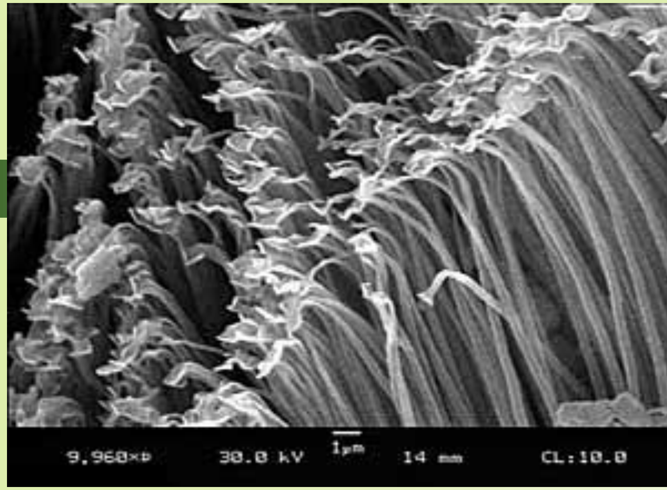
Gecko, Boxfish, Shark



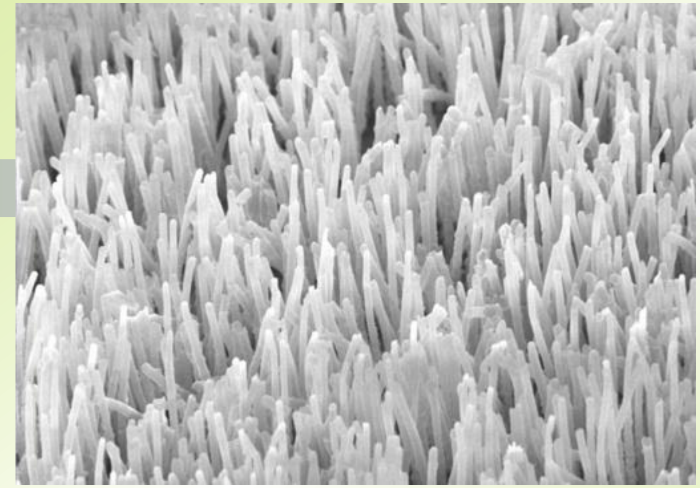
Why is a gecko capable of climbing walls easily?



Stanford University, Biomimetics dextrous manipulation laboratory

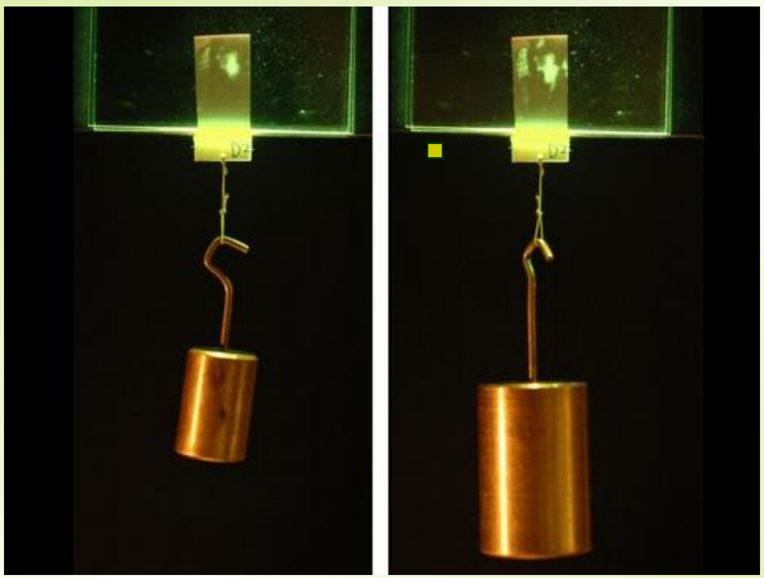


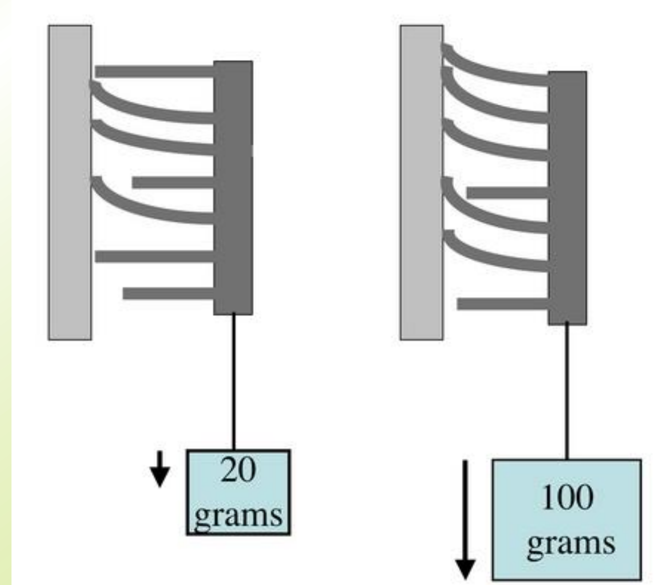
UC Berkeley researchers



Kellar Autumn, Lewis & Clark College

電子顯微鏡照片：左為壁虎腳掌的剛毛，右為人造聚合物微結構





利用聚合物纖維製造創新的易黏接易分離並具有方向性的仿壁虎貼。每平方公方佈滿了四千兩百萬個聚丙烯纖維，可承受的剪力為每平方公分九牛頓。當剪應力負載增加時，更多微纖毛會接觸玻璃表面。January, 2008。

J. T. Yang, 20081116

Films of an Artificial Gecko

壁虎機器人

http://bdml.stanford.edu/twiki/pub/Main/StickyBot/from_inside_sml.jpg

壁虎的訣竅

參與研究這種機器人的科學家Mark Cutkosky解釋這種神奇足部的原理，在每個足部上，都有數百萬根由人造橡膠製造的細毛，每根細毛的直徑大約有500奈米左右，比人類的毛髮還細很多，每根毛髮的長度則不到2微米，這使得 神奇足部能非常的接近玻璃壁的表面，這樣的結構還能夠使得人造橡膠毛髮中的分子和玻璃壁分子的距離異常接近。此時，兩者的分子們之間會產生一種奇異的自然現象“凡德瓦力” 。這種力大約可以幫助毛髮產生抓起一隻螞蟻的力量。雖然每一對力並不大，但是數百萬根毛髮產生的這種吸力卻能夠產生驚人的力量。根據分子物理學科學家們的研究，2平方毫米大小內的100萬根這樣的毛髮就能夠支持提起20公斤重量。所以要讓機器人能夠附著在直壁上，足部需要增大分子接觸面。

這項發明可不僅僅是為了樂趣，Mark Cutkosky表示，由於“壁虎” 機器人的爬牆能力並不像此以前利用真空吸盤靠大氣壓力吸附在垂直壁上的機器人那樣依賴大氣壓，所以這種新機器人在將來可以用在太空探索、空間衛星維修和特殊環境的救險中。

http://bdml.stanford.edu/twiki/pub/Main/StickyBot/from_inside_sml.jpg

A Product inspired by Sharks

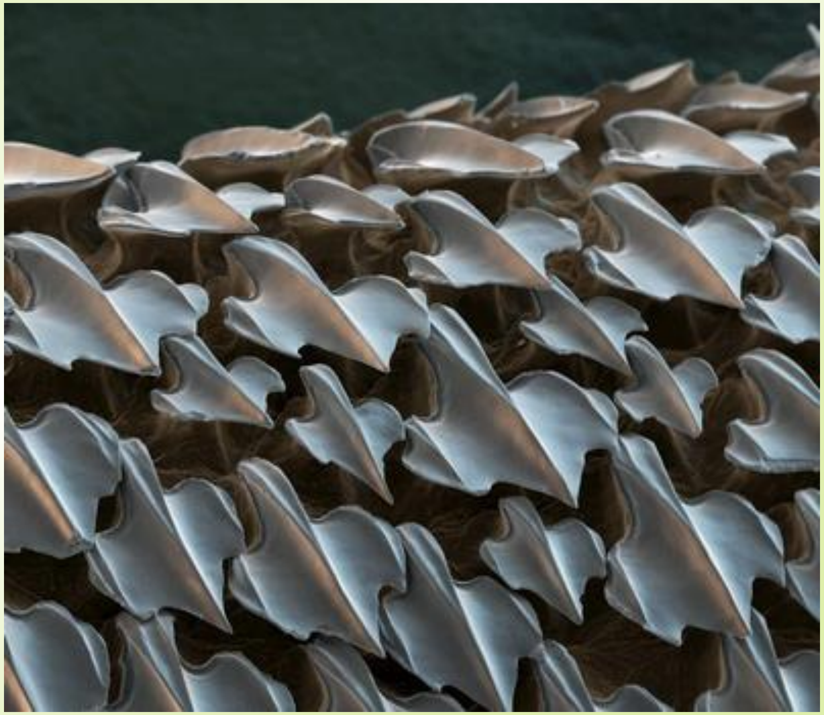
Speedo 第4代鯊魚泳衣LZR Racer

泳衣品牌Speedo研製歷時3年的第4代鯊魚泳衣LZR Racer，泳手穿在身上緊貼皮膚，感覺猶如脫光沒穿衣服，較去年推出的一款降低水中阻力5%，成為泳手最新武器。Speedo研發用超輕質防水纖維和去水快的物料來製造泳衣，這些物料都經過美國太空總署科學家測試。

J. T. Yang, 20081116

Textural Structure of Speedo & Shark's Skin

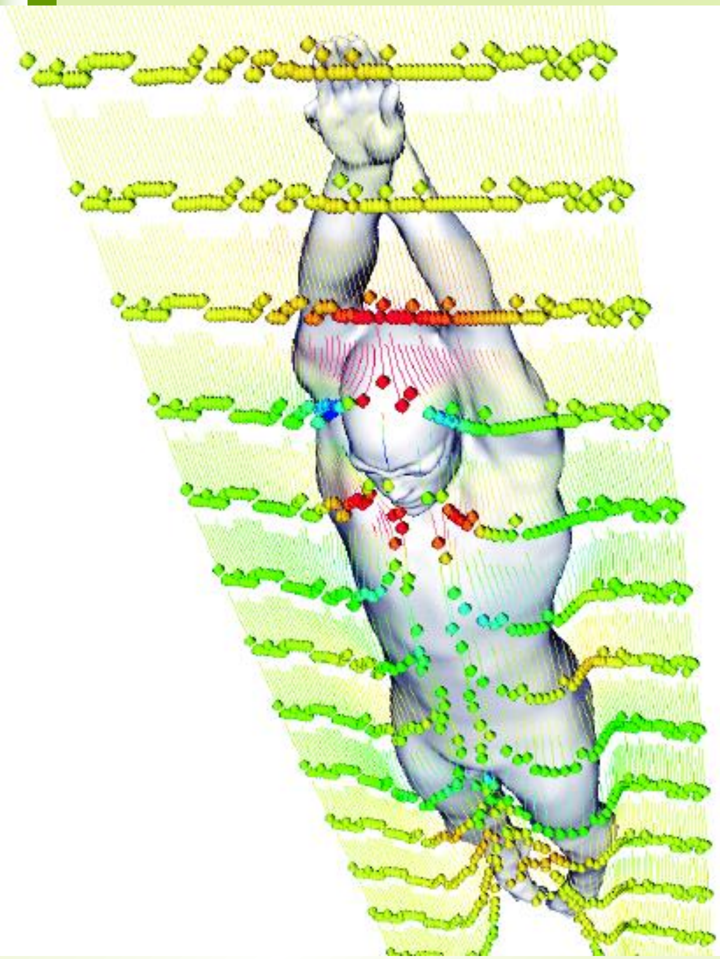
泳衣微結構



鯊魚盾鱗微結構

鯊魚裝泳衣靈感來自鯊魚皮上的盾鱗，水從這些微小的溝槽之間快速流過，能減少阻力、增加速度。

CFD Simulation of Flow Field Generated by Speedo



實驗搭配計算流體力學，模擬游泳時的流場分佈情形，
降低形狀阻力係數，設計出鯊魚裝。

J. T. Yang, 20081116

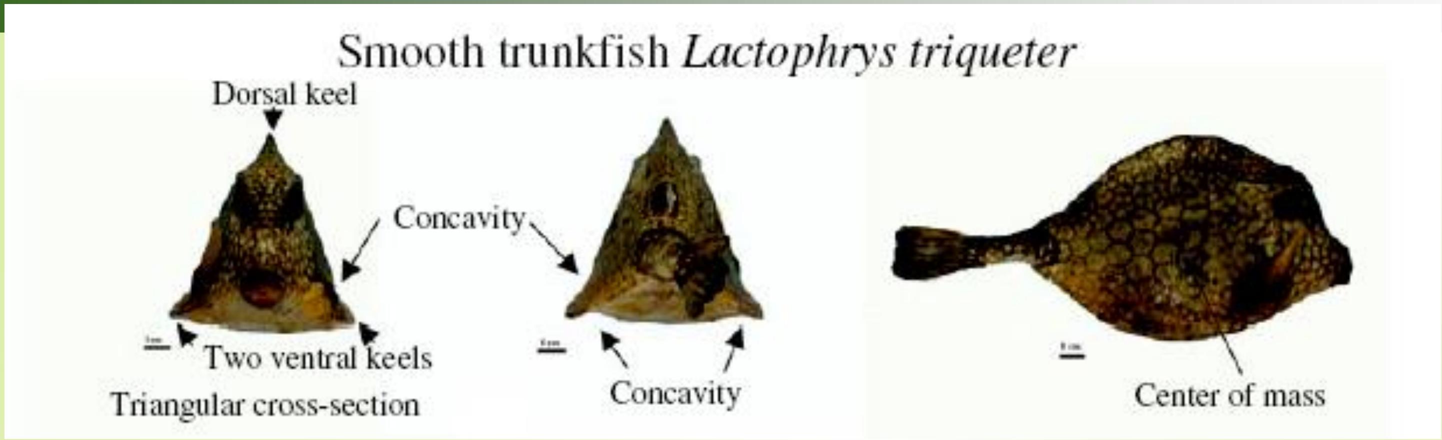
粒突箱魨 → 賓士仿生概念車

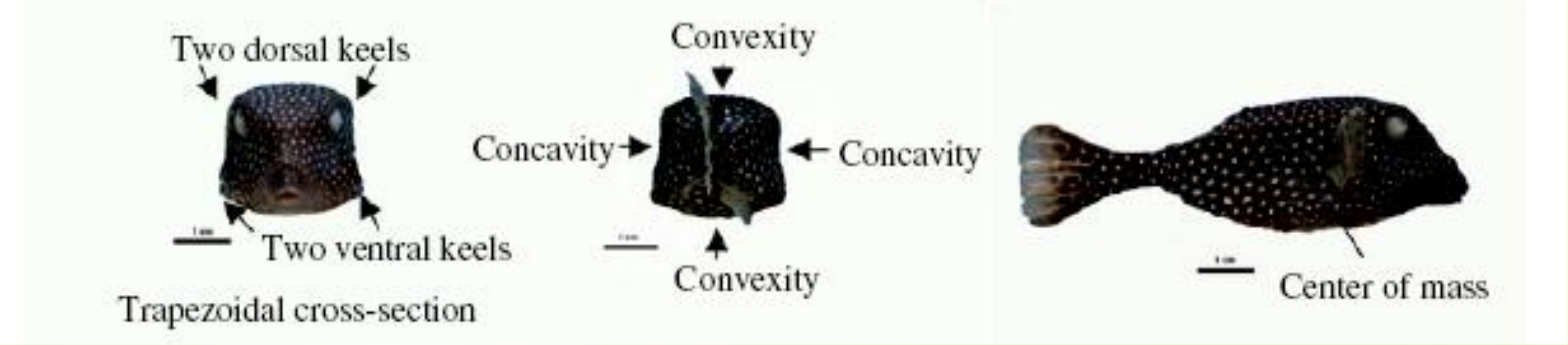
- 賓士仿生概念車的靈感得自於粒突箱魨令人驚奇的流線外型，車體經過風洞測試，這種汽車的空氣動力學，有助於將它的油耗降低至每公升30公里。
- 依照河魨魚外型所設計出來的賓士車阻力係數為0.19，此值低於先前具有最低阻力係數的HONDA車的阻力係數0.25.

http://bbs.yfsz.com/UploadFile/2008-1/200811610221541476.jpg

J. T. Yang, 20081116

兩種主要河魨魚外型特徵



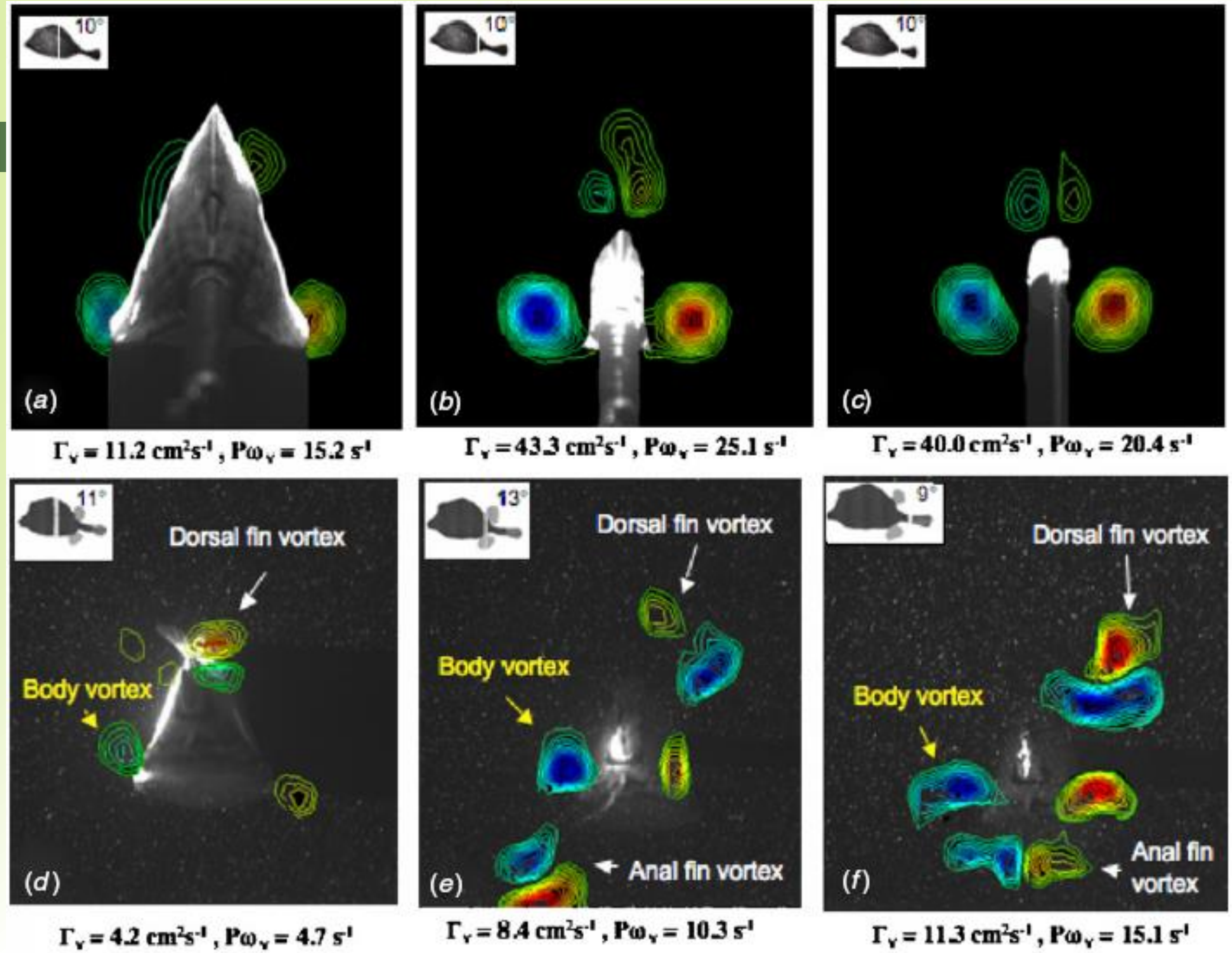


- 風洞及水洞實驗顯示: 阻力係數(C_d)為0.06，非常接近水珠的0.04
- 河豚的臉部小且尖，具有平順導流及減小紊流強度之作用，可大幅降低游動時所受到之流體阻力
- 河魨魚的身體外型特殊，能夠在身體中央背脊及兩側下方尖脊(keel)附近產生特殊渦漩結構，具有穩定平衡魚身及大幅減阻之功用

J. T. Yang, 20081116

模形PIV實驗

活魚PIV實驗



I. K. Bartol, M. S. Gordon, P. W. Webb, D. Weihs, and M. Gharib, 2008, " Evidence of self-correcting spiral flows in swimming boxfishes, " *Bioinsp. Biomim.* 3, 014001.

I. K. Bartol, M. Gharib, P. W. Webb, D. Weihs, and M. S. Gordon, 2008, "Body-induced vortical flows: a common mechanism for self-corrective trimming control in boxfishes, " *Journal of Experimental Biology*, 327-344.

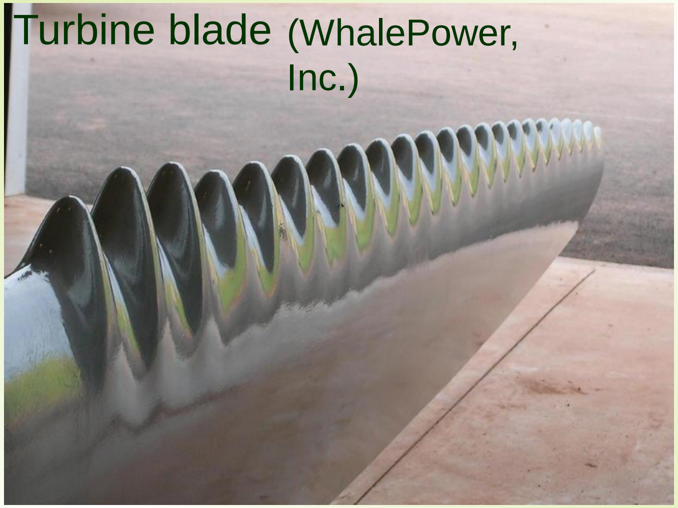
Whale-Inspired Wind Turbines --- 源自座頭鯨的靈感

楊鏡堂, 台大機械, 2010

http://www.guardian.co.uk/science/2008/jun/24/animalbehaviour.usa

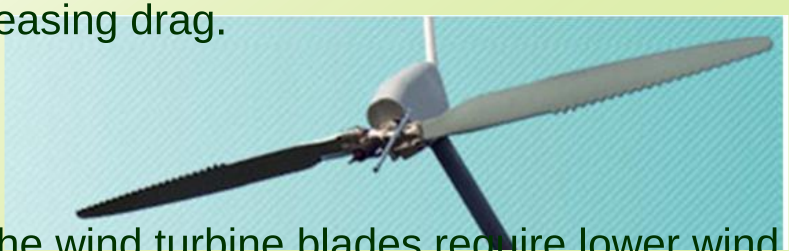
http://www.geotimes.org/

Turbine blade (WhalePower, Inc.)



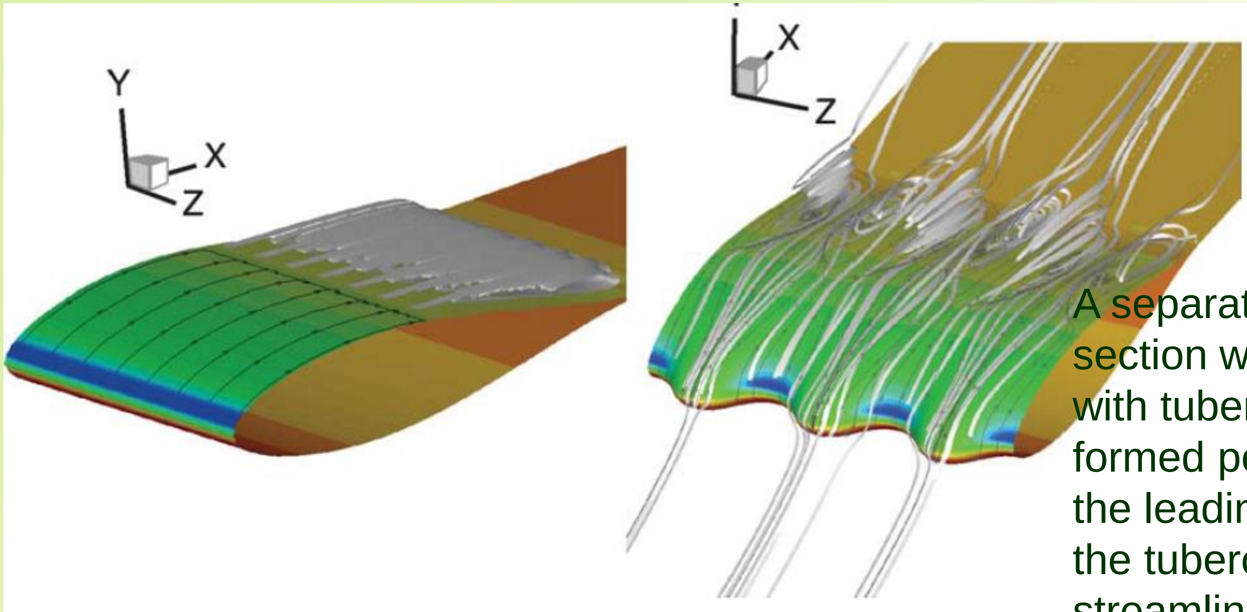
(Fish and Lauder, *Annu. Rev. Fluid. Mech.*, 2006)
(van Nierop *et al.*, *Physical Review Letters*, 2008)

WhalePower developed a new fan and wind turbine blade design using Tubercle Technology. This was inspired by the flippers of humpback whales, which have tubercles or bumps on the leading edges. Tubercles increase the operating angle from 11 degrees to 17 degrees, prior to stalling, a performance improvement of nearly 40%, increasing lift and decreasing drag.

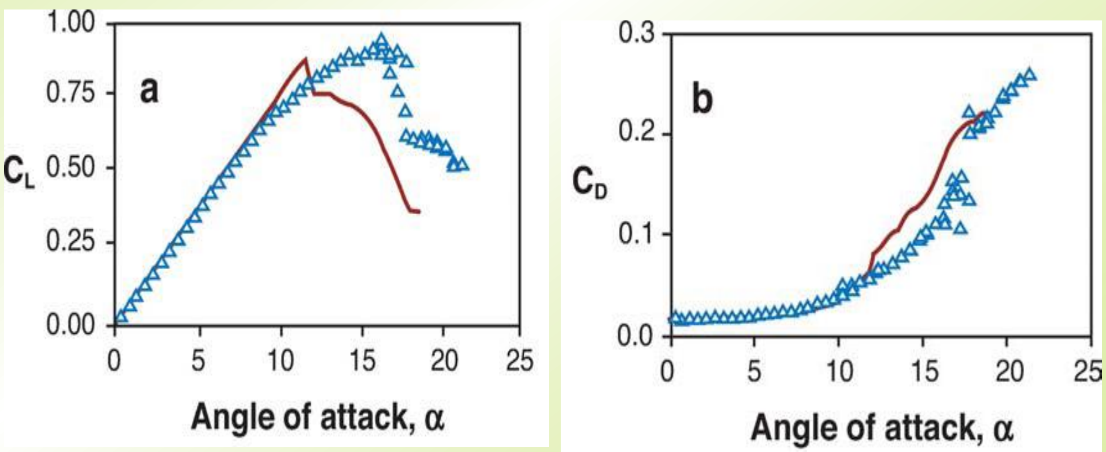


The wind turbine blades require lower wind speeds, increasing the amount of time and the number of locations where they can actively generate electricity.

Humpback whale's flipper with tubercles



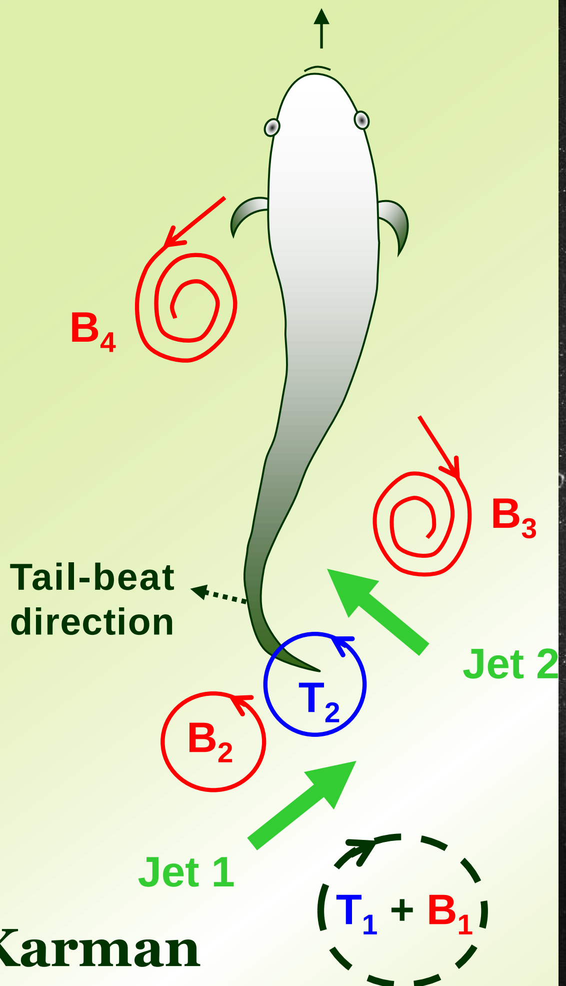
A separation line is shown on the wing section without tubercles. For the wing with tubercles, large vortices are formed posterior of the troughs along the leading edge and flow posterior of the tubercles is shown as straight streamlines without separation.



(Fish and Lauder, *Annu. Rev. Fluid. Mech.*, 2006)

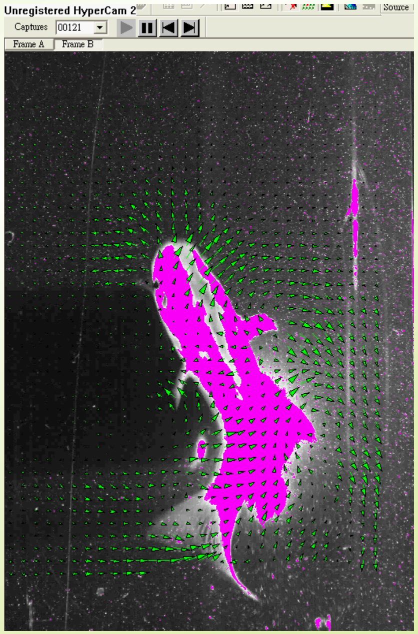
Hydrodynamic interactions between pectoral-fin vortices and body undulation in a swimming fish

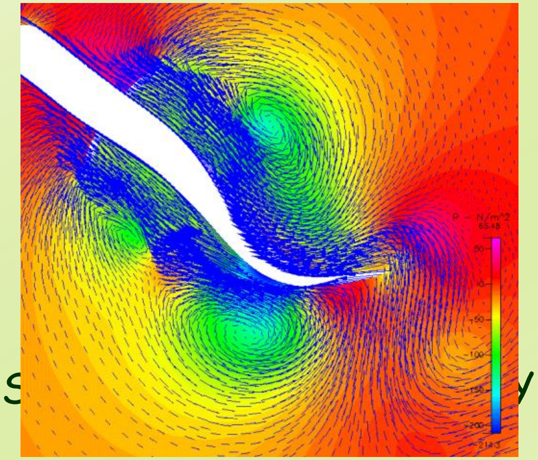
Ting and Yang,
J. Exp. Biology, 2008; 2008 *APS*, Texas



Karman Gait

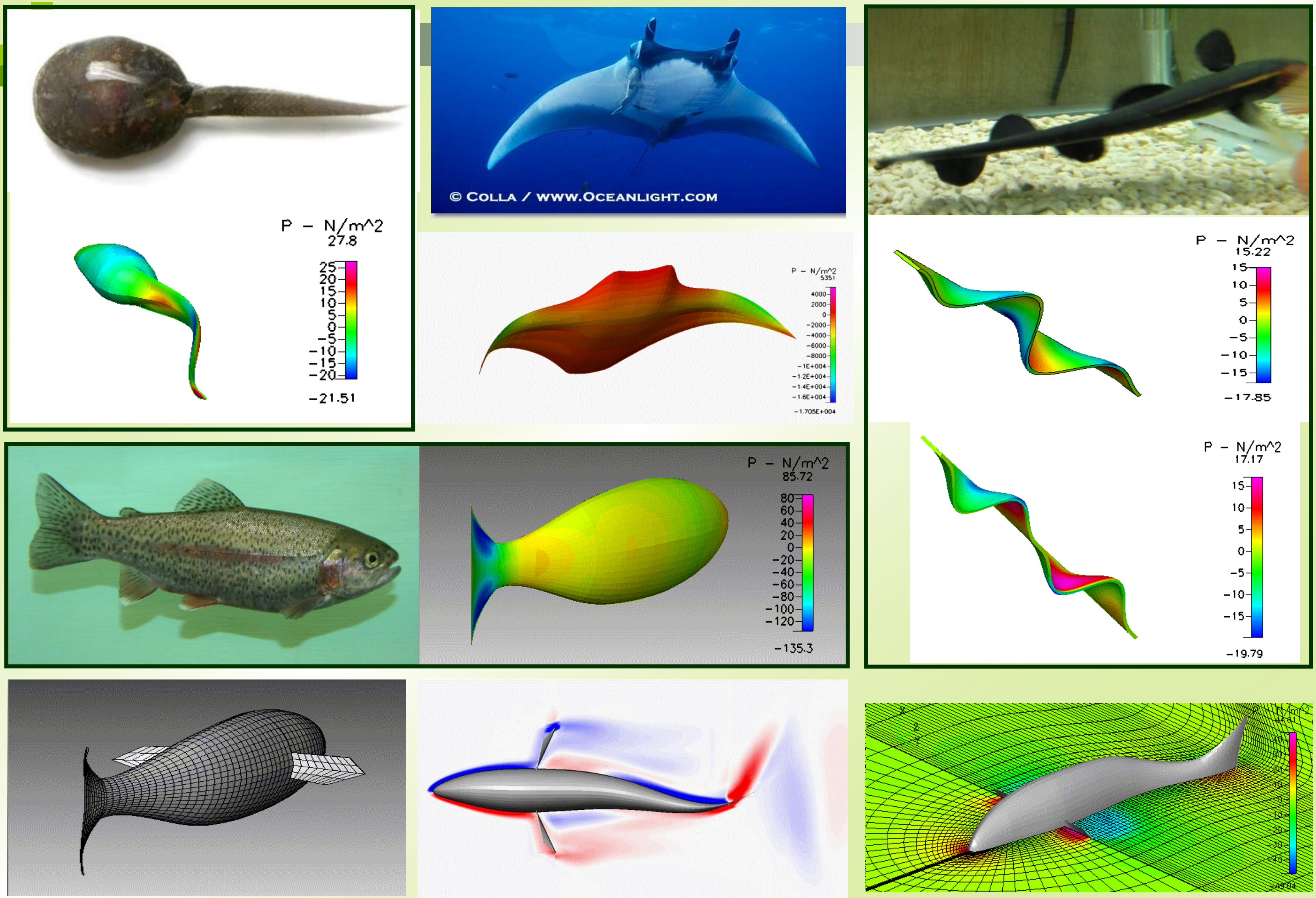
Yu *et al.*, *Physics of Fluids*, 2011





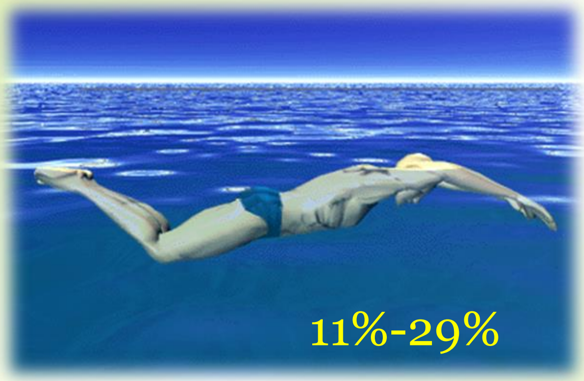
NS V3

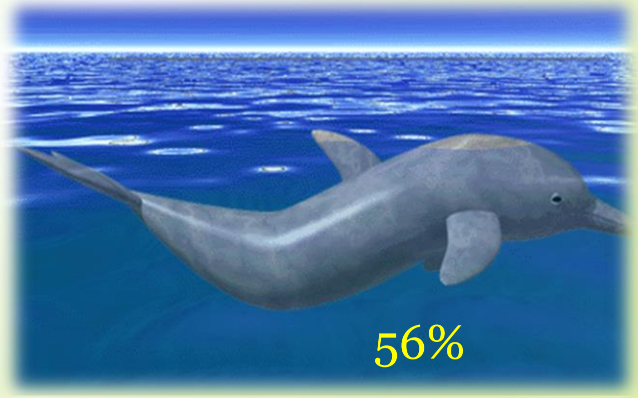
Fish Swimming … CFD Simulation



Propulsive Efficiency of the Underwater Dolphin Kick in Humans

- Fluid dynamic simulations of five olympic-level swimmers performing the underwater dolphin kick are used to estimate the swimmer's propulsive efficiencies.
- These estimates are compared with those of a cetacean performing the dolphin kick.





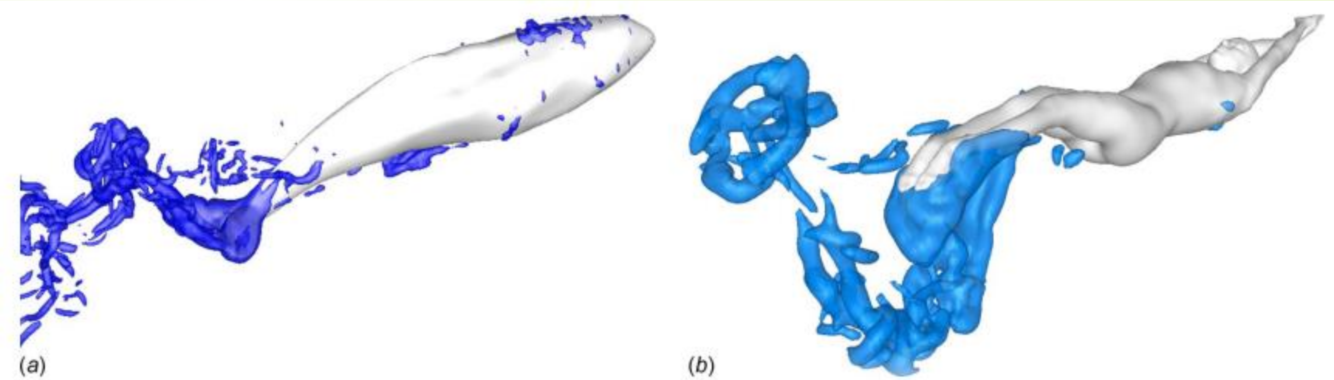


Fig. 1 Typical vortex structures seen in (*a*) the Cetacean stroke and (*b*) the human dolphin kick

新 型 仿 生 義 肢

-- 靈感源自於運動敏捷迅速的印度豹

This **Flex-Foot** prosthetic was inspired by the rear leg of a **cheetah** and gives the runner more altitude !

http://msande277.wordpress.com/

The Gift of Kingfisher

楊鏡堂, 台大機械, 2011

翠鳥、魚狗

Source: http://www.dailymail.co.uk/sciencetech/article-1190603/Totally-hooked-kingfishers-One-mans-love-affair-special-bird.html

The Kingfisher vs. Bullet Train

楊鏡堂, 台大機械, 2010

Imitating the kingfisher's shape, engineers equipped trains with a tapering nose nearly 50 feet long. As well as producing much less noise when exiting tunnels, the newly-designed train used 15% less electricity while travelling 10% faster. Shinkansen train technology is cutting-edge, and the Japan Railways Group prides itself on the speed, reliability and smooth ride the trains offer.

http://www.designboom.com/contemporary/biomimicry.html

Kingfisher's streamlined beak

Kingfishers experience a comparable change in pressure when they dive from the air into water to catch fish. The birds create very little splash when they enter the water due to the aerodynamic shape of their head and large beak.

Tiny robot flies like a fly

- A robot as small as a housefly has managed the delicate task of flying and hovering the way the actual insects do.
- Its wings flap 120 times a second, which is on a par with a housefly's flapping rate and weighs in at just 80 milligrams.

Constraints:

- The tiny drone cannot carry its own power source. It also relies on a computer to monitor its motion and adjust its attitude.
- The biggest technical obstacle to independent flight is building a battery that is small enough to be carried by the robotic fly.

Ron Cowen/02 May 2013/*Nature*

魔 鬼 氈 (VELCRO) *--- hook and loop fasteners*

Cockleburr

蒼耳屬植物, 芒刺類雜草

http://www.velcro.co.uk/

http://www.velcro.co.uk/

http://audubonmagazine.org/features0909/greenDesign-InspiredByNature.html

The story of the discovery of hook and loop fasteners begins with George de Mestral taking a walk through the countryside. The Swiss engineer enjoyed hunting. One morning in 1941, while returning from the fields with his dog, he noticed how difficult it was to detach the flowers of the mountain thistle from his trousers and his dog's fur. He discovered that the flowers were covered in hundreds of tiny but strong hooks and where thus able to attach themselves to animal fur and fabric.

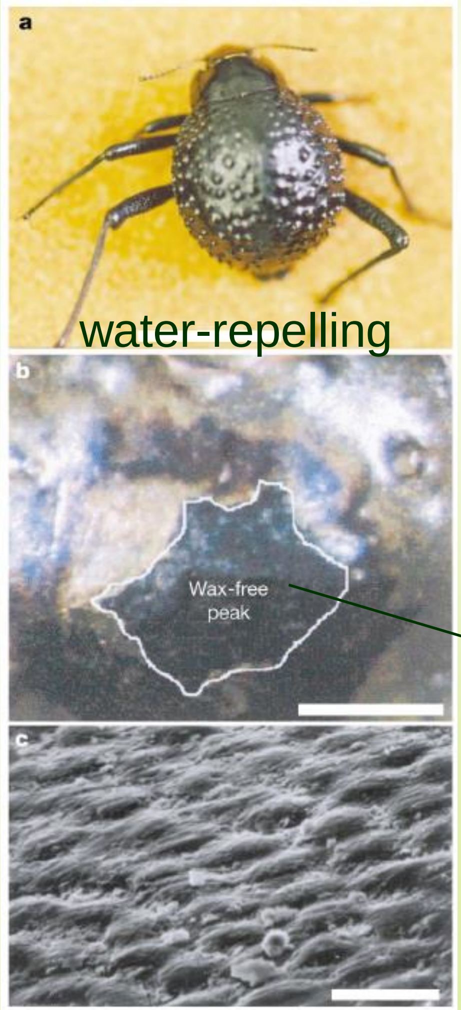
Water capture by a desert beetle

This insect collects water from early-morning fog

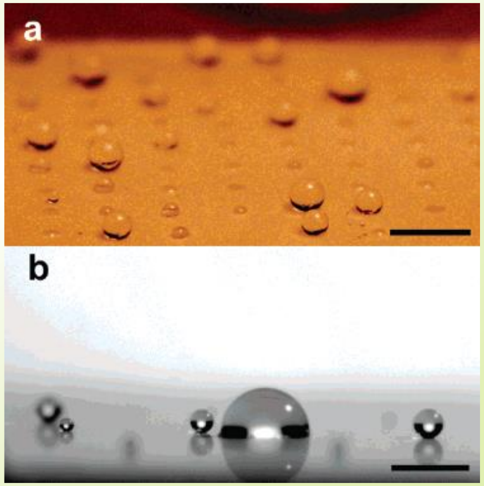
The Namib Desert beetle - photo by Andrew Parker

http://www.engineeringservicesoutsourcing.com

antibacterial coatings, tent covering, roof tiles (in arid area for drinking-water collection)



Parker and Lawrence, *Nature*, 2001

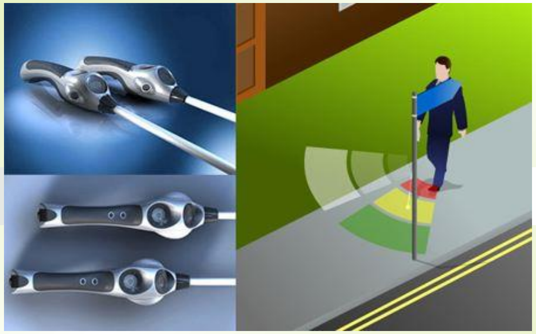


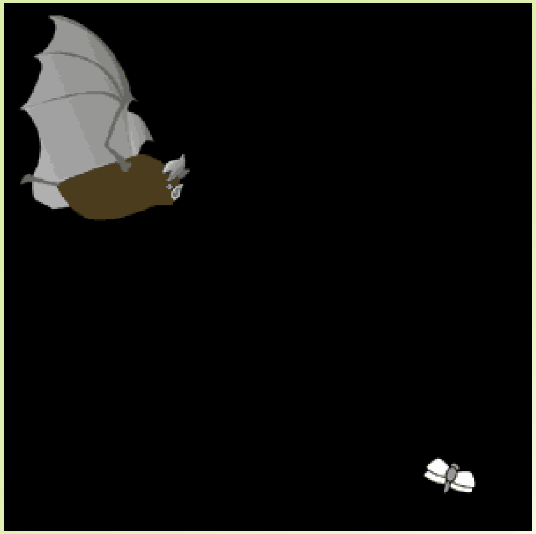
(Zhai et al., *NANO LETTERS*, 2006)

Potential applications of such surfaces include water harvesting surfaces, controlled drug release coatings, open-air microchannel devices, and lab-on-chip devices.

源自於蝙蝠的靈感 ！

楊鏡堂, 台大機械, 2011





Sound Foresight, a small company in England, created the UltraCane. The high-tech device for the vision-impaired uses a sonar-like technology—similar to the way bats navigate in the dark—to prevent collisions. The cane sends out sound waves ahead of the person holding it. These sense upcoming objects, such as street signs or other people, and provide a tactile warning of an oncoming obstacle's location through the cane's handle.

A **bat** is an echolocating animal, because it emits calls out to the environment and listens to the returning echos so that it can identify an object and determine how far away it is. The **Ultracane** uses technology that allows visually impaired humans to use echolocation in the same way.

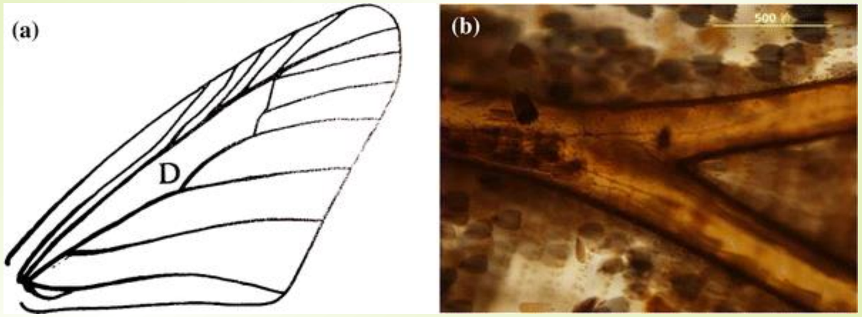
http://images.businessweek.com/

http://msande277.wordpress.com/

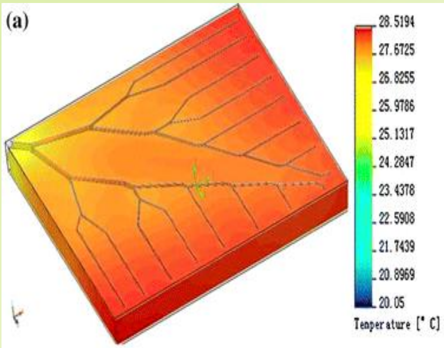
The design of an asymmetric bionic branching channel for electronic chips cooling

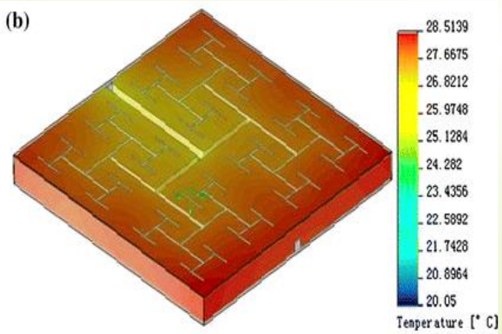
Introduction

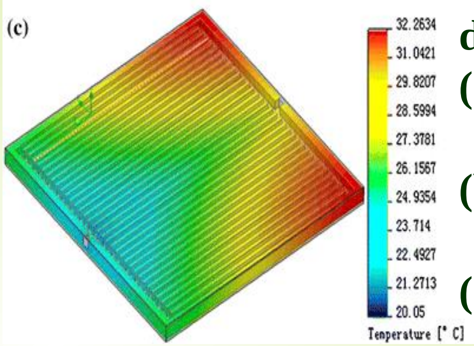
- **Inspired by the wing vein of Lepidoptera, design of asymmetric bionic branching channel for electronic chips cooling is developed**



Simulation results







The temperature distributions in
(a) asymmetric bionic branching channel,
(b) fractal-like branching channel
(c) parallel channels

Conclusion

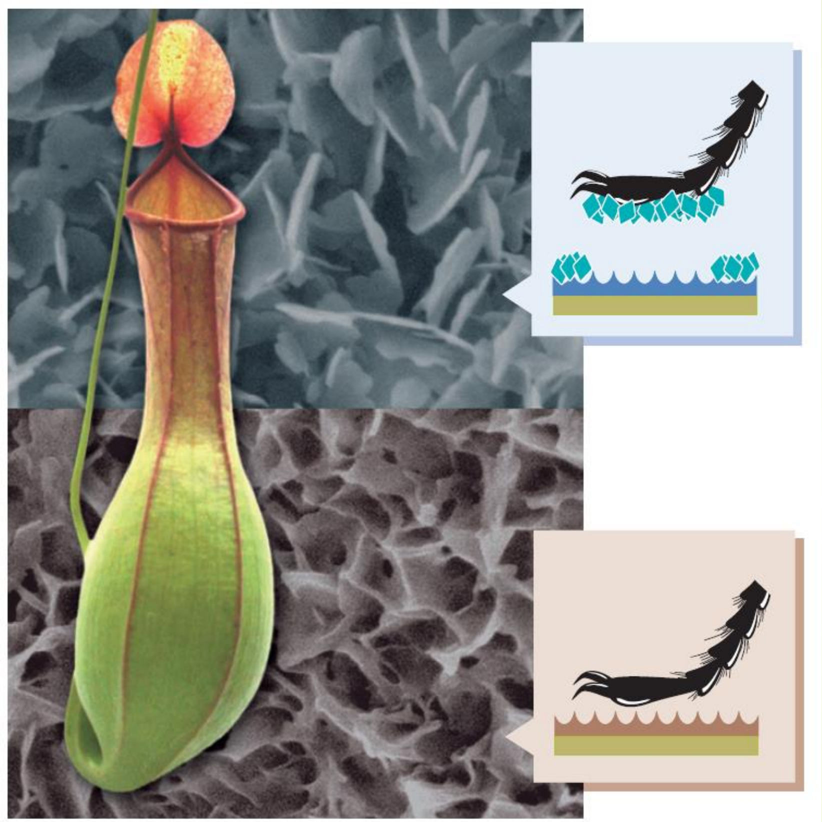
Through **computer simulation** and **experimental verification**, the asymmetric bionic branching channel provided a **stronger heat transfer capability**, **lower pressure drop** and **lower flow resistance** than the fractal-like branching channel.

From:
Shanglong Xu , Jie Qin, Wei Guo and Kuang Fang
Department of Mechatronics Engineering, University of Electronic Science and Technology of China, Chengdu, China

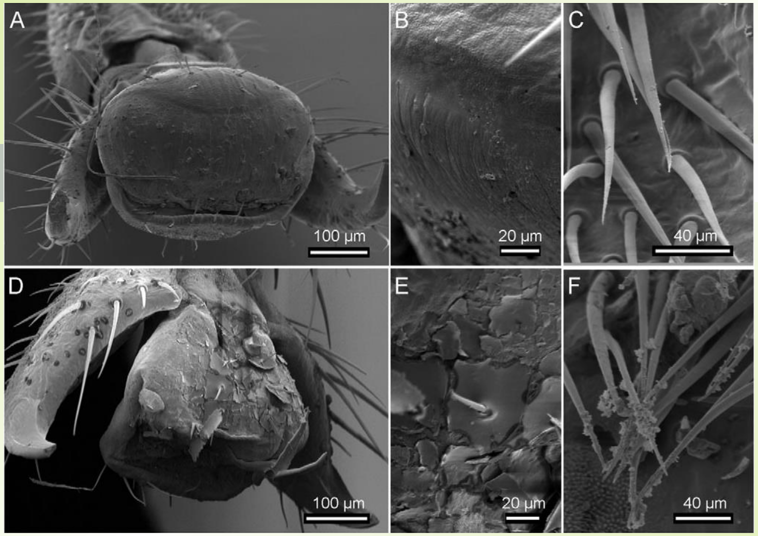
Received: 15 February 2011
Accepted: 25 February 2013
Published online: 6 March 2013

豬籠草的捕蟲秘技

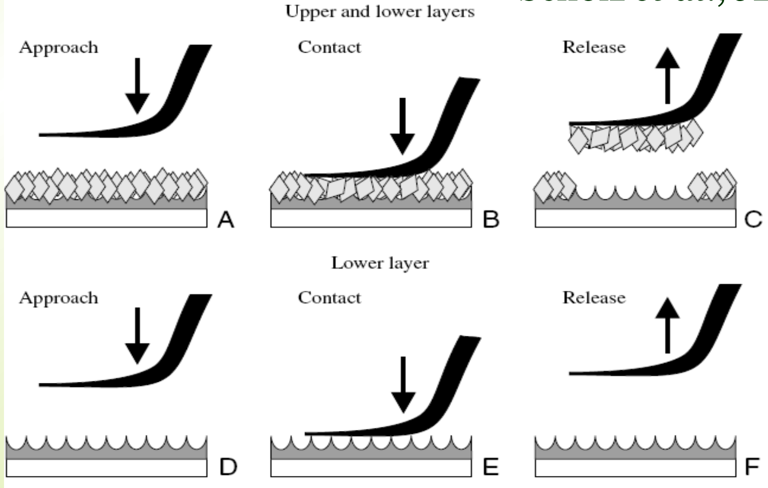
楊鏡堂, 台大機械, 2011



EMBO Reports, Vol. 8, No. 11, 2007



Scholz *et al.*, *JEB*, 2010



Gorb *et al.*, *JEB*, 2005

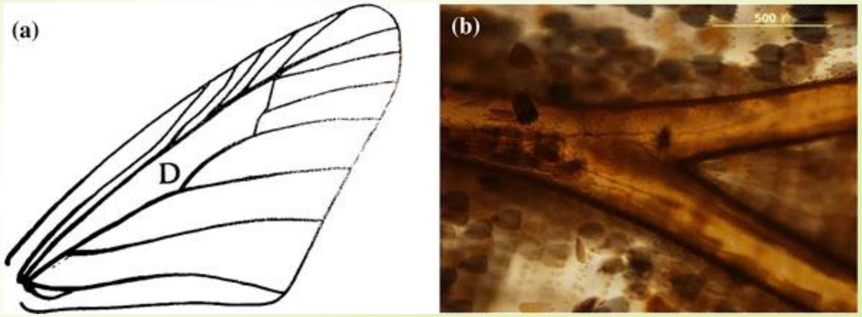
A Germany scientist, Gorb, has shown how these surfaces influence insect adhesion. The secret lies in a double layer of crystalline wax, the upper layer of which has crystals that contaminate the insect's adhesive appendages, while the lower layer reduces the contact area between the insect's feet and the plant surface.

These results provide ideas for further developments of technological non-adhesive surfaces. The principle is recently patented and will be applied in anti-insect foils, anti-adhesive materials and soft-touch surfaces.

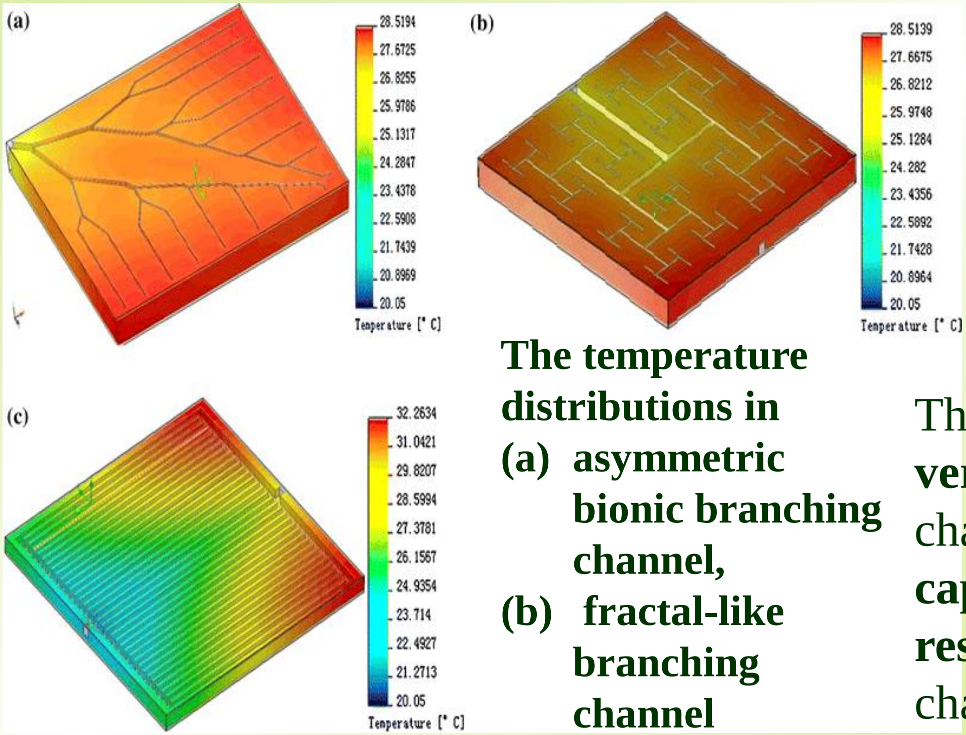
The design of an asymmetric bionic branching channel for electronic chips cooling

楊鏡堂, 台大機械, 2013

- **Inspired by the wing vein of Lepidoptera, design of asymmetric bionic branching channel for electronic chips cooling is developed.**



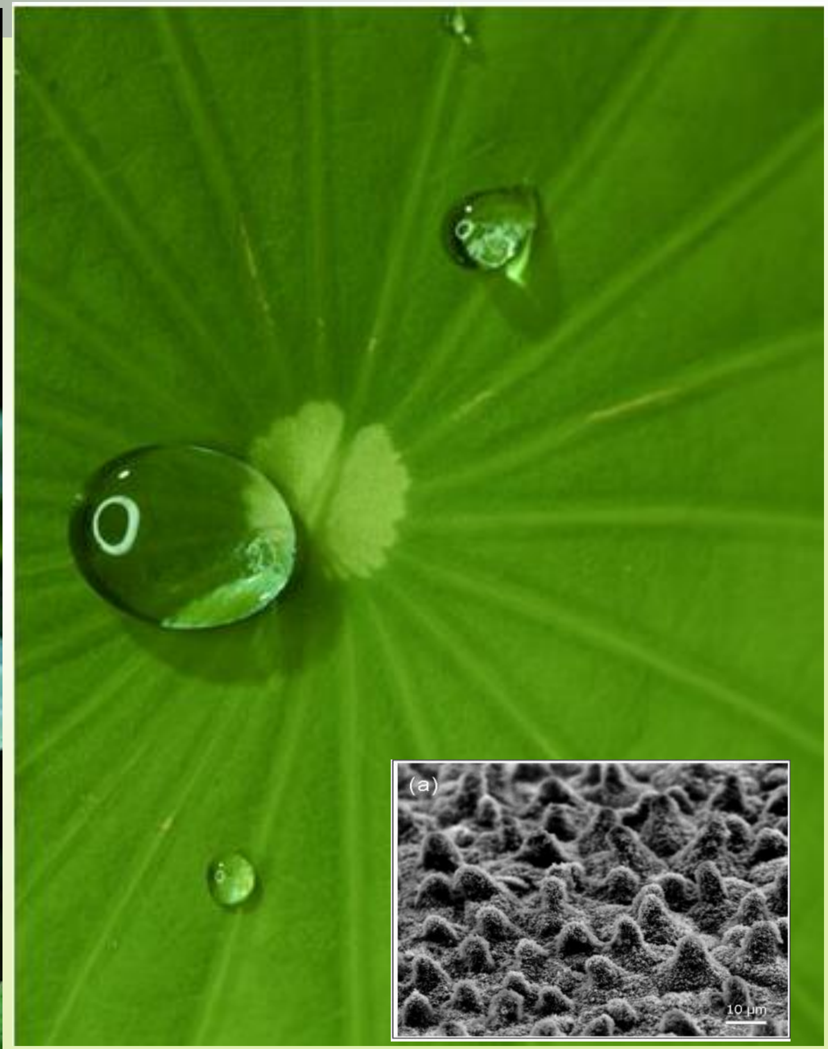
Simulation results



The temperature distributions in
(a) asymmetric bionic branching channel,
(b) fractal-like branching channel
(c) parallel channels

Through **computer simulation** and **experimental verification**，the asymmetric bionic branching channel provided a **stronger heat transfer capability**, **lower pressure drop** and **lower flow resistance** than the fractal-like branching channel.

Lotus Effect



Source: SPIE Newsroom, DOI:10.1117/2.1200901.1441
Source: National Geographic, Photograph by Robert Clark
Source: zhiwu.xooob.com/zwyj/20091/368967_1022039.html

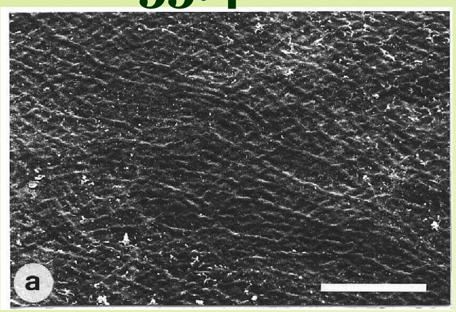
生物晶片設計

Hydrophilic and Hydrophobic Features of Leaves

楊鏡堂, 台大機械, 2010

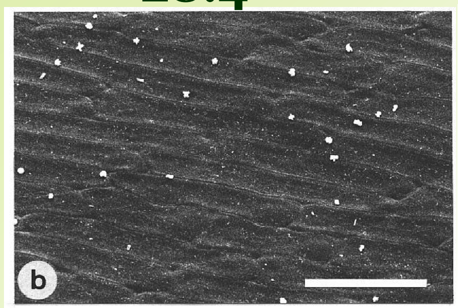
wetted plant leaf

55.4 °



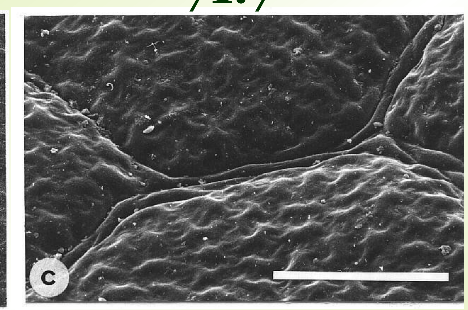
Gnetum gnemon

28.4 °



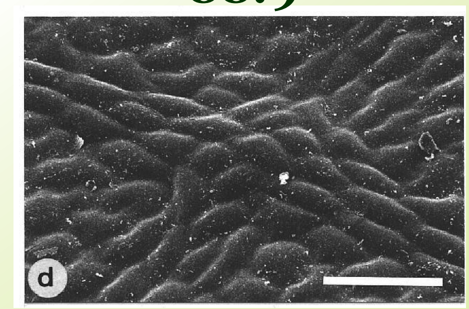
Heliconia densiflora

71.7 °



Fagus sylvatica

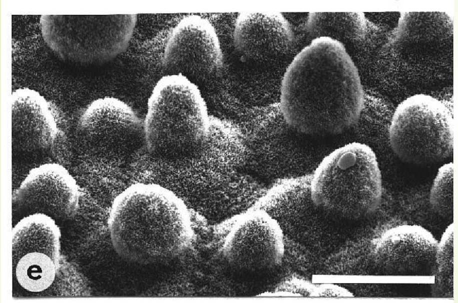
88.9 °



Magnolia denudata

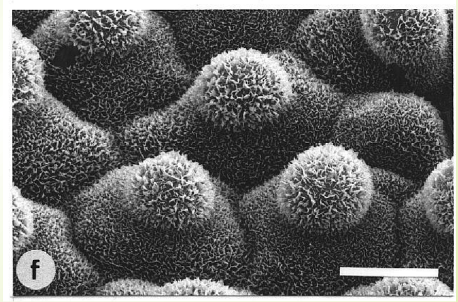
non-wetted plant leaf

160.4 °



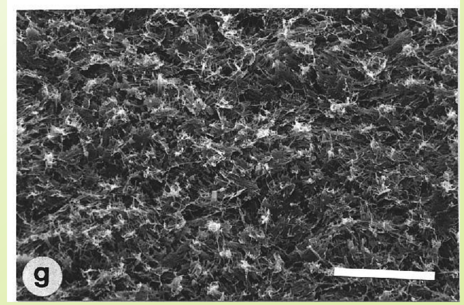
Nelumbo nucifera

159.7 °



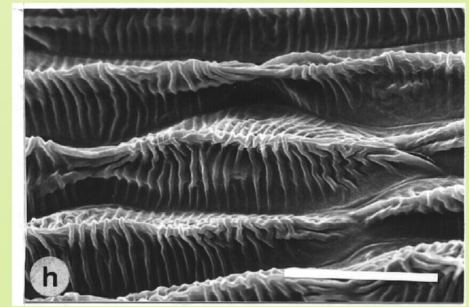
Colocasia esculenta

160.3 °



Brassica oleracea

128.4 °



Mutisia decurrens

(Barthlott *et al.*, 1997)

玫瑰的“花瓣效應” --- Rose's 'Petal Effect'

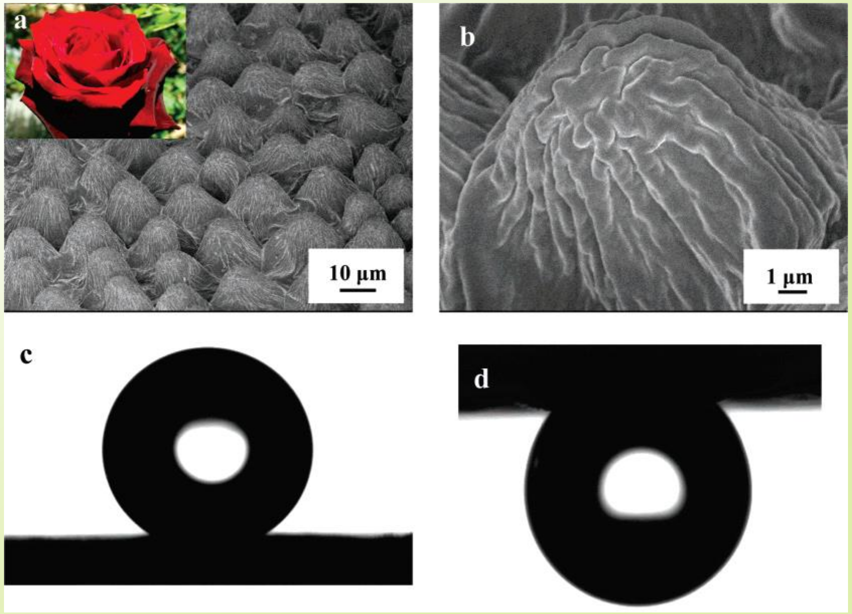
ScienceDaily (Apr. 25, 2008)

This fascinating "petal effect" could lead to unique new adhesive materials, coatings and fabrics

Petal Effect:

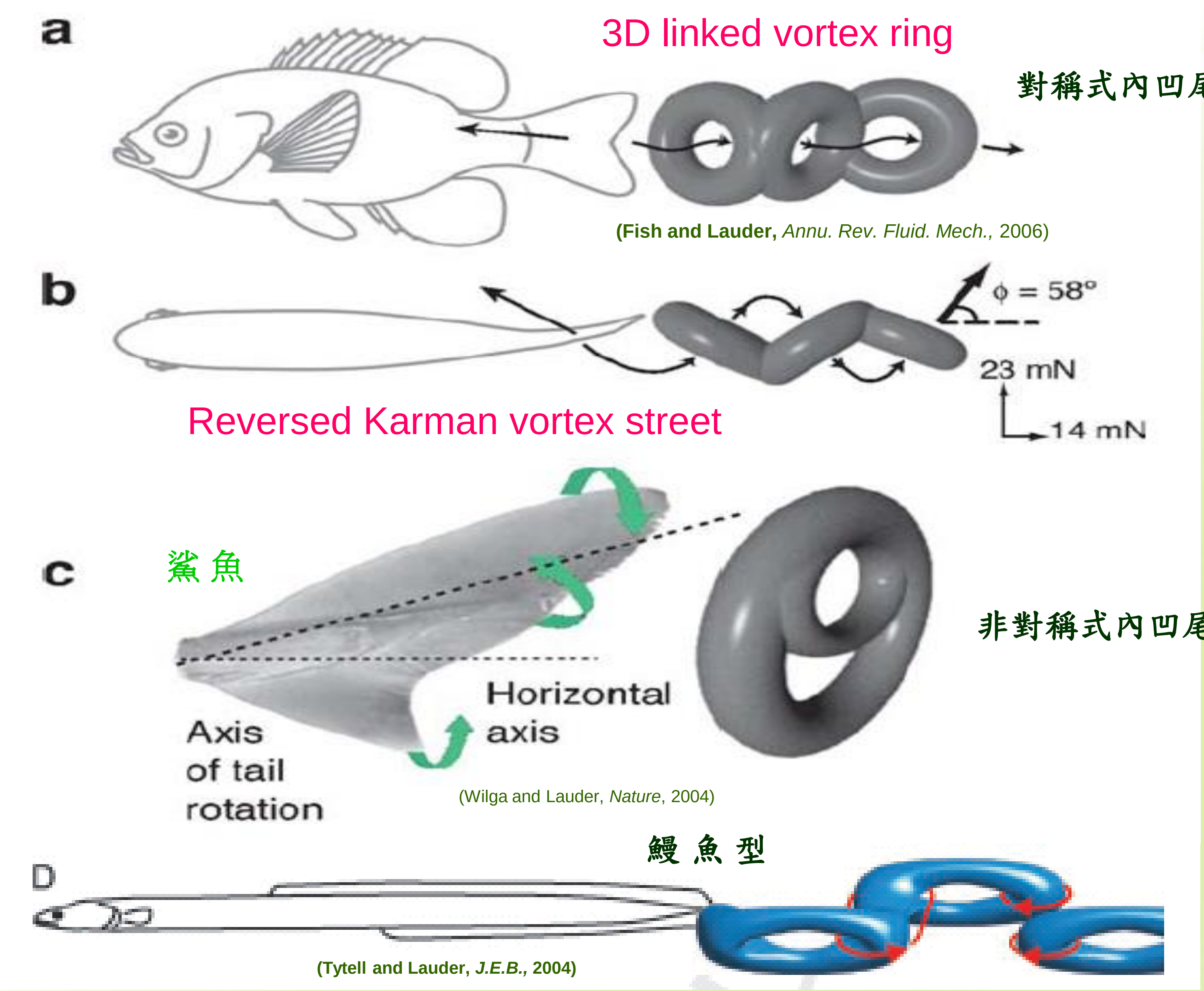
A Superhydrophobic State with High Adhesive Force

The rose's ability to grip water droplets in place, even when the flower is upside down.



L. Feng et al., Langmuir, 2008.

魚類推進3D立體渦流環尾流結構



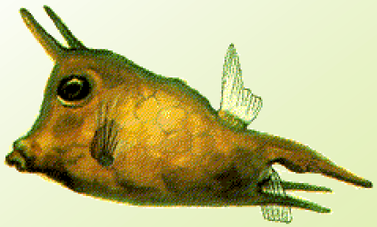
squid_robot

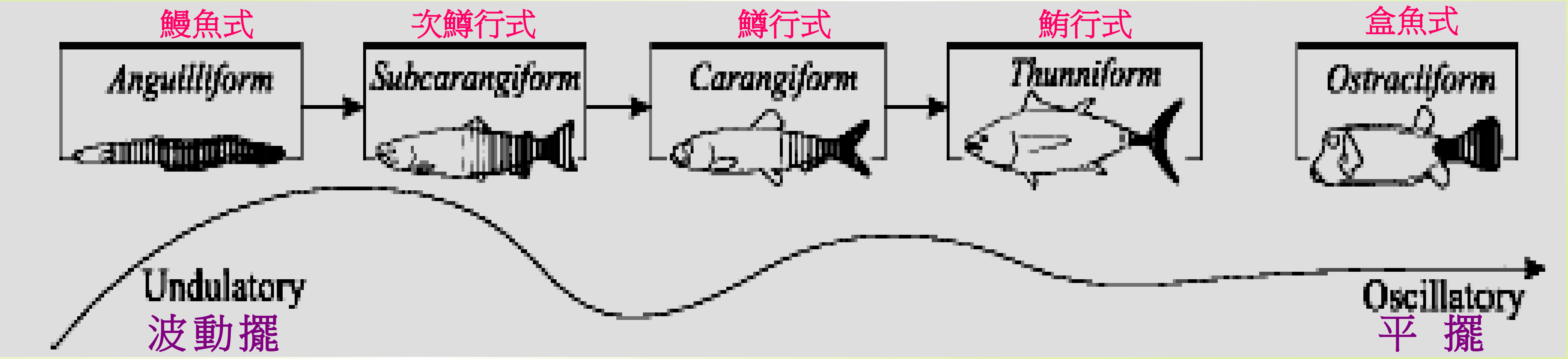
單純左右擺動，渦流環為尾流之主要結構單元

Propulsion Modes of Fish (1)

Sfakiotakis, 1999; http://www.ece.eps.hw.ac.uk

一般魚類大都藉由尾鰭及身軀之擺動以獲得推進力



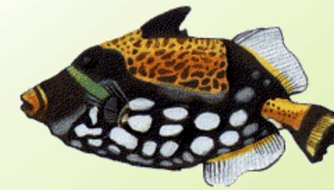


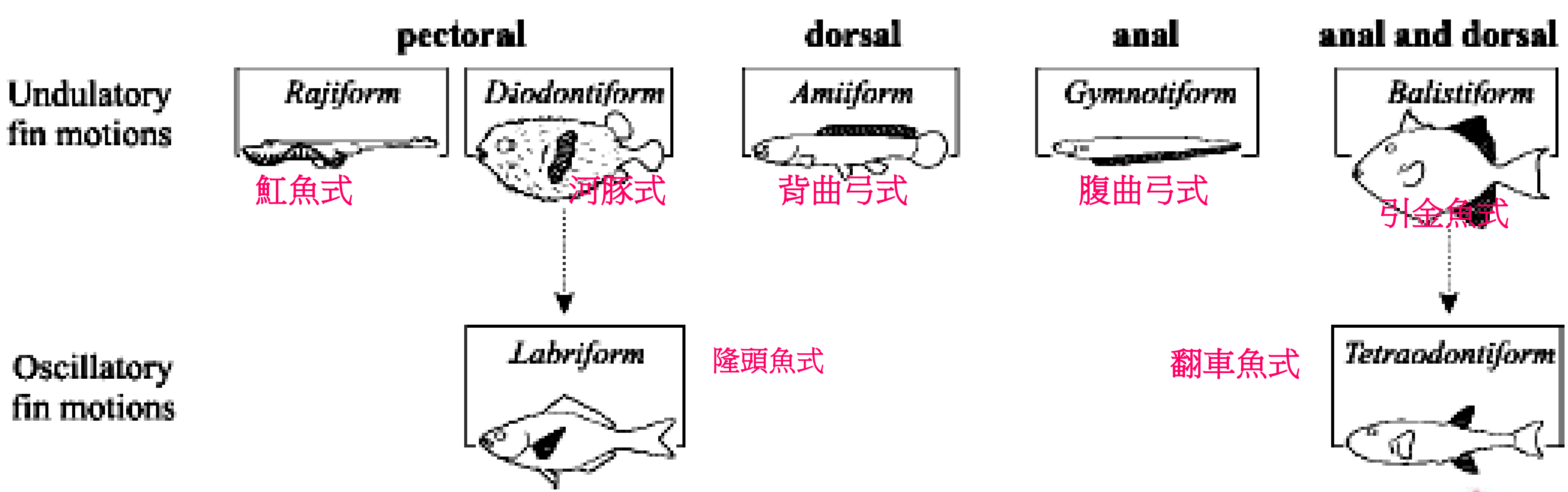
魚類之推進模式(2) 胸鰭、背鰭、臀鰭、腹鰭推進類型

Sfakiotakis, 1999; http://www.ece.eps.hw.ac.uk









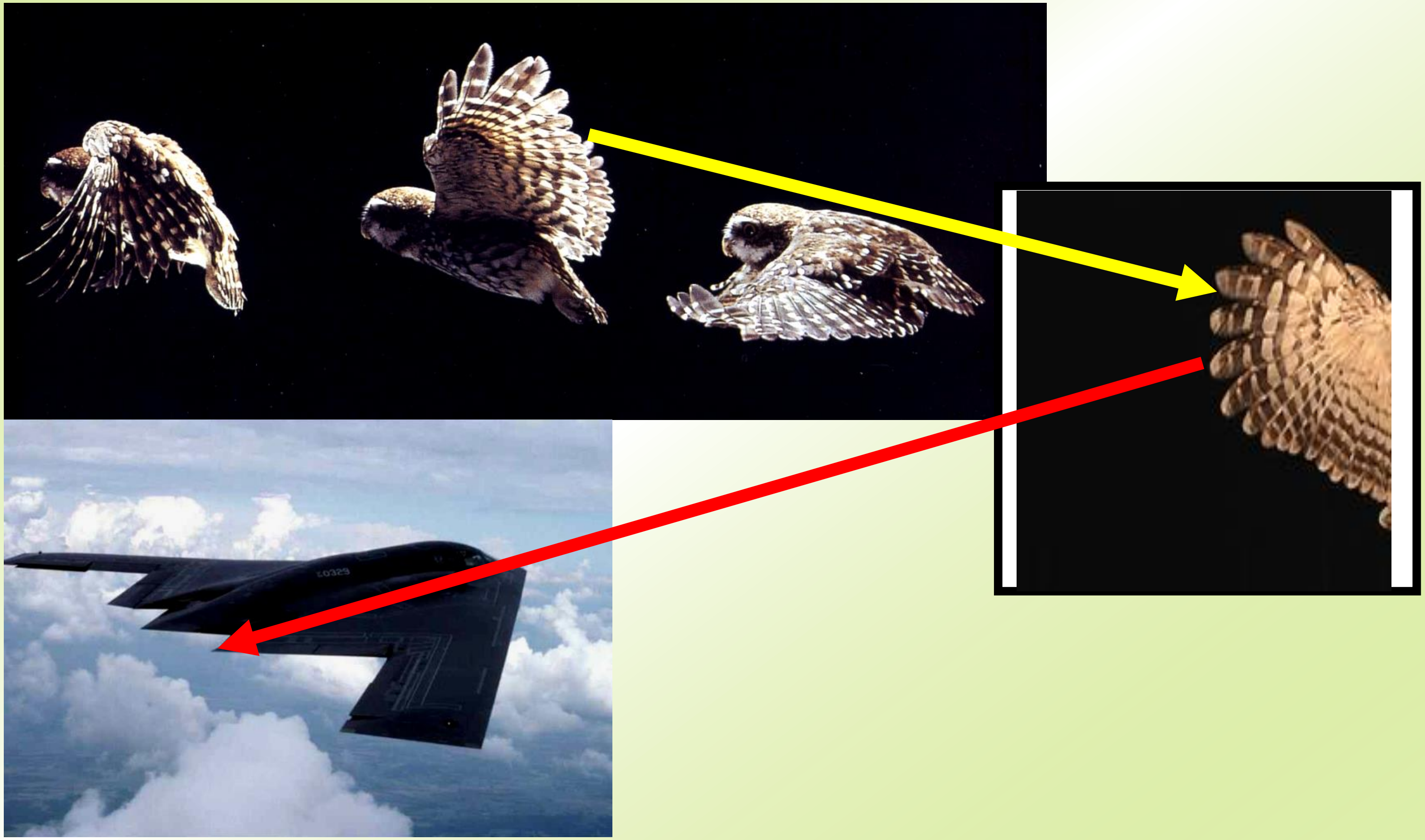

Birds

Biophysics Workshop II: Life among the Formulae of Physics

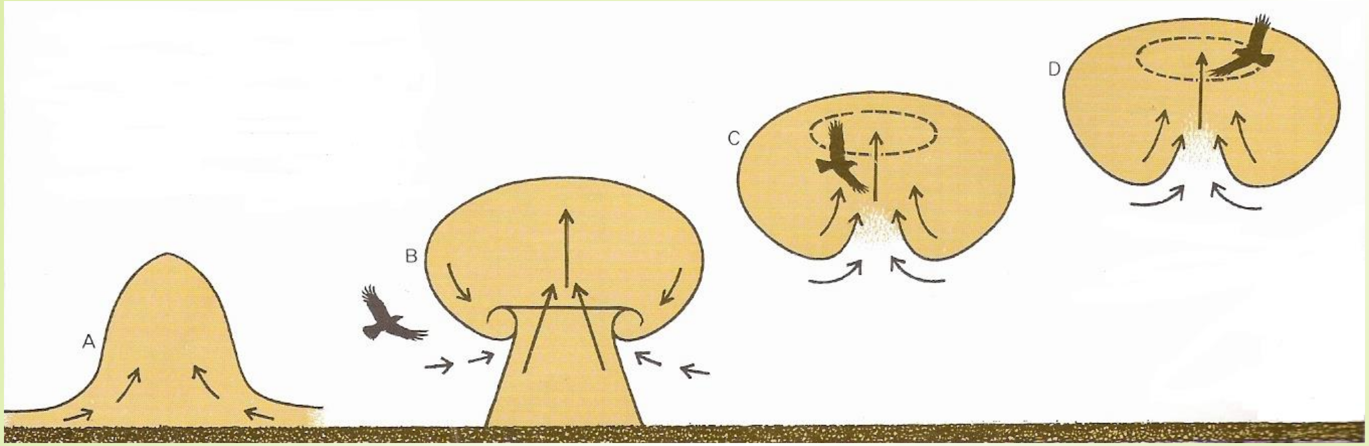
J. T. Yang, 20081116

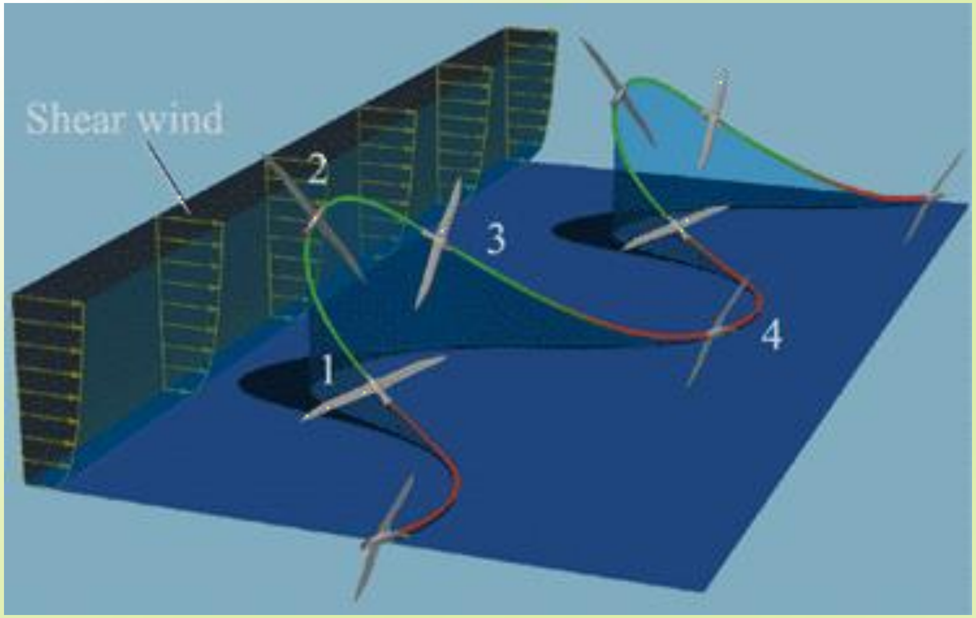
Wings Design Concepts of B2 Bomber & an Owl

http://www.edwards.af.mil/archive/2003/images/b2.jpg



Balloon

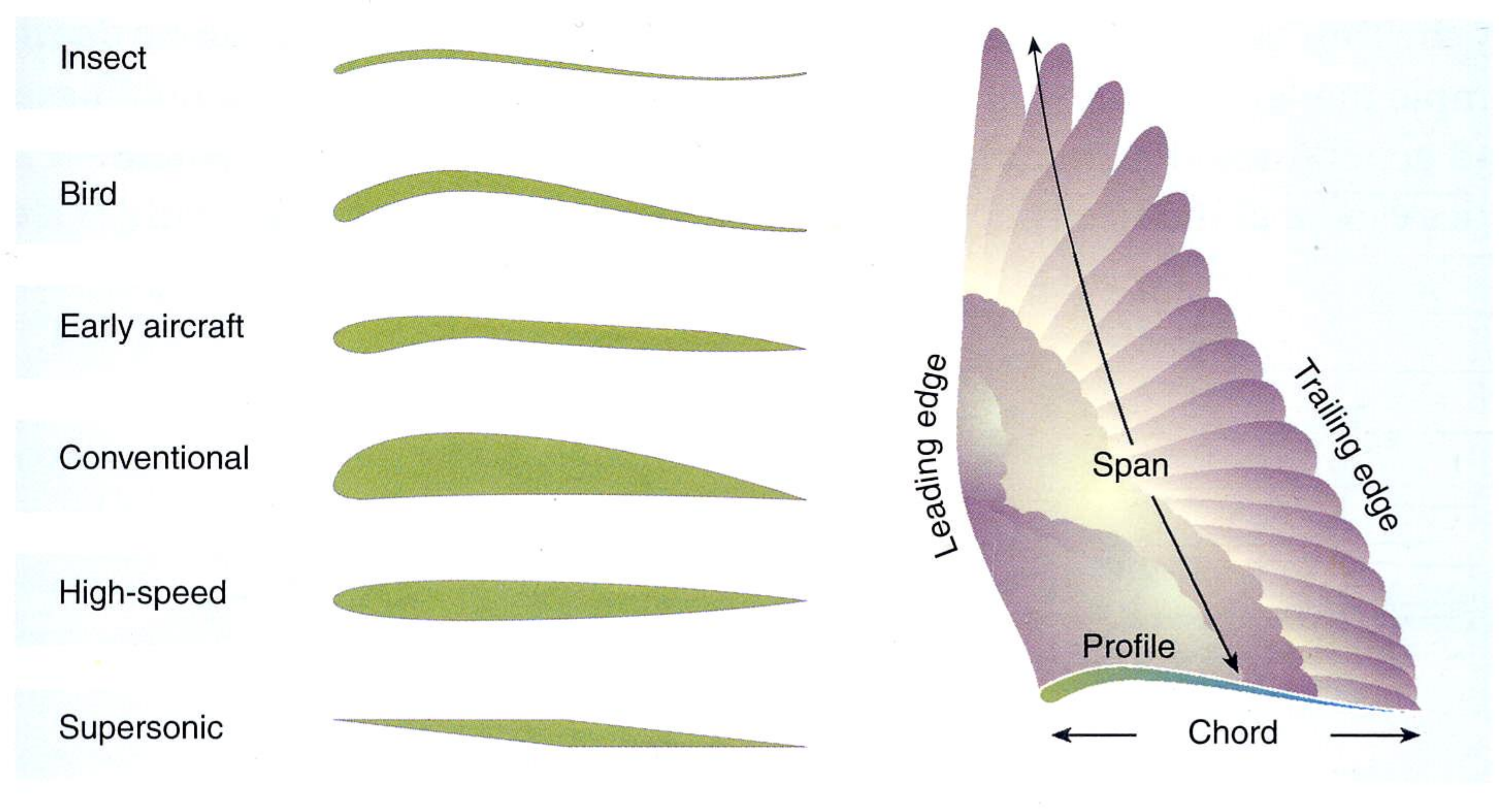




信天翁如此不斷向下滑翔和向上升騰，毫不費力地在海面上迴旋飛翔，可以連續幾十個小時都不用拍動翅膀。海洋風越強它越是飛行的自在，可稱得上世界上最有效率的滑翔機。

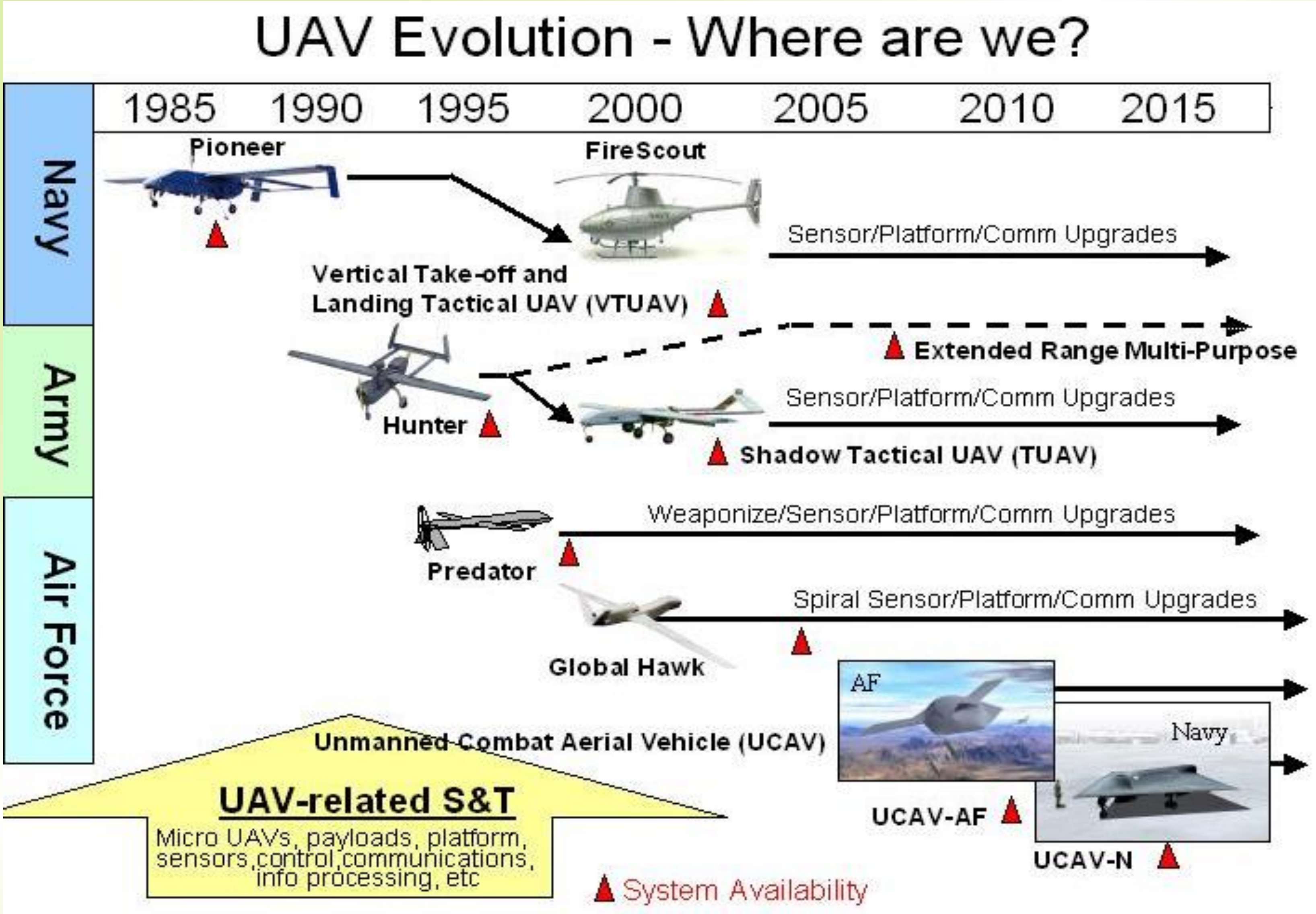
各種飛行物種翅膀截面圖

Burton, R., 1990, Bird Flight, England, ISBN 0-8160 2410-3



UAV發展圖

(United States Department of Defense, 2002)



Insects

Biophysics Workshop II: Life among the Formulae of Physics

J. T. Yang, 20081116

新型遙控蜻蜓↑

傳統遙控飛機 →

仿生應用 - 機器人及載具

Cyber-Fish
Essex University , London
(http://news.bbc.co.uk.stm)

Robotic Pets
Japanese manufacturer Takara
(http://news.bbc.co.uk.stm)

Microbat
(Caltech/UCLA/ Aerovironment)

Entomopter
MARS exploration
(NASA/Georgia Tech)

Biomimetic Robots

- **Robot fish :**

seabed exploration, detecting leaks in oil pipelines, mine countermeasures, underwater vehicles stabilization, underwater searching, escaping, ……

- **Robot flapping flyer (Ornithopter) :**

indoor manipulation, military, application, reconnaissance, disaster rescue, ….. transportation, exploration, surveillance, guidance, inspection

昆蟲飛行時速比較 (朱耀沂, 2004)

蒼蠅 7~8 km/h

金龜子 8~13 km/h

飛蝗 16~20 km/h

蜜蜂 20~22 km/h

天蛾 18~40 km/h

蜻蜓 25~40 km/h

單帶弄蝶 16~30 km/h

小灰蝶 19~26 km/h

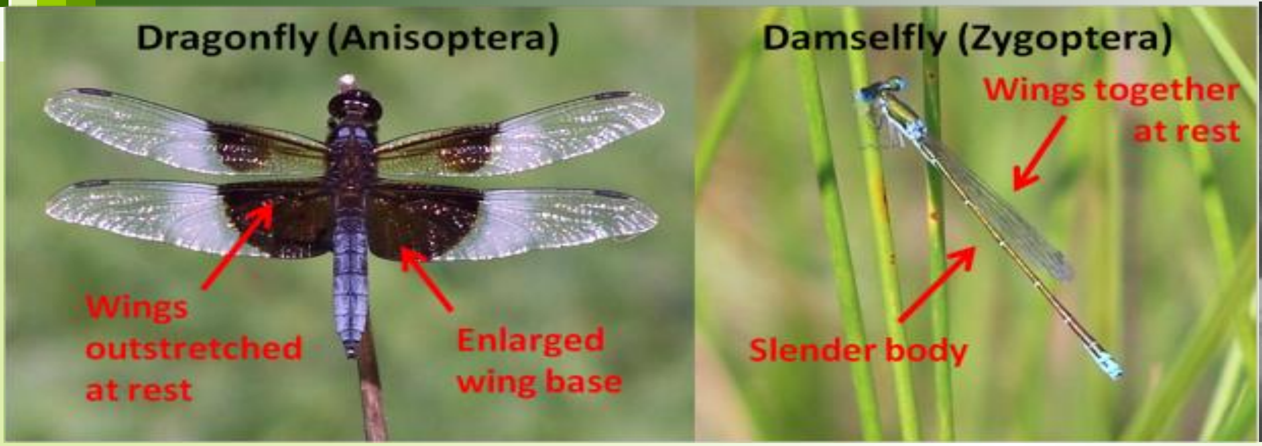
大黃蝶 20 km/h

非洲粉蝶 10~13 km/h

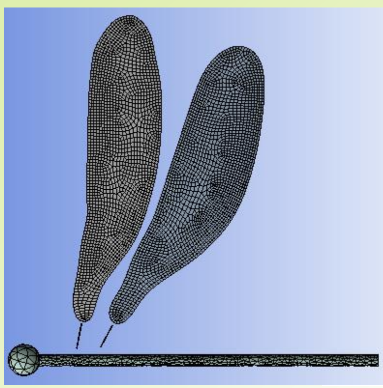
Butterfly Kingdom- Taiwan

http://www.xuexuecolors.com/column.php?xue=4&id=226

How do we study damselfly?



http://katatrepsis.com/2011/08/14/dragonflies-vs-damselflies/



CFD + Experiment

Damselflies have several advantages over dragonflies

(1) higher velocity, acceleration and lift coefficient per stroke. (Wakelin & Ellington, *J. Exp. Biol.*, 1996)

(2) higher degree of freedom in wing motion, including clap-and-fling mechanism. (Rudolph, 1976)

Strategy and Approaches

Biophysics → Biomechanics → Biomimetics

Life among the Formulae of Physics

(Lotus leaf & new concepts; fish, butterfly, dragonfly, bird)

2003-2006 2005~

Biomimic Technology and Novel Design Concepts

(textured-gradient surface & biochips; flow with flapping wings)

2007-2010 2008~

Innovative Products

(**Lab on a Chip** for biology and medical; **MAV/ flapping machine**)

2011-2024 2009~2024

研究策略與大綱

章聿珩碩士論文, 台大機械, 2011

操控性飛行模式
Maneuvering Flight

- 懸停
- 爬升

生物模型建立

運動學參數
- 拍翅頻率
- 轉翅頻率
- 翼肘關節變化角
- 翼展弦比

生物流場分析
- DPIV
- 渦漩環理論
- 估算升力

仿生拍撲機構

- 雙軸運動控制
- 拍撲飛行機構設計
- 重現生物動作
- 拍撲機構實驗

基於生物模型與生物智慧，建立仿生拍撲機構，找尋鳥類飛行時造成主要升力變化的拍翅模式，以及流場特徵

Flapping Flight of Flyers

Yang, Li, Liu, Lee, and Yu, 2008