生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	蜂鳥手腕關節旋轉以保持懸停 (Hummingbird Wrist Joints Rotate to Maintain Hover)
生物系統 LIVING SYSTEM	蜂鳥 (Apodiformes)
功能類別 FUNCTIONS	#修改物理狀態 #移動或保持原地 #Modify Physical State #Move or Stay Put
作用機制標題	蜂鳥的腕關節可以透過前後旋轉來懸停。 (The wrist joints of the hummingbird enable hovering by rotating back and forth.)
生物系統/作用機制示意圖 (確認版權、註明出處；畫質)	

作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)

鳥類透過上下拍打翅膀來飛行，從而達到‘提升’。原因是以翅膀的形狀在上方會產生較低的壓力，下方產生較高的壓力，將鳥抬高，除此之外，當鳥類拍動翅膀，下擊產生升力，上擊為下次下擊做準備。
昆蟲的飛行方式使他們能夠透過他們的上風和下風產生升力，原因是能夠使關節處扭曲翅膀，使之靈活運動，從而提高空氣動力學效率，而鳥類因為肌肉和骨骼關節配置為允許重複的來回運動而無法做到這點。然而，蜂鳥能夠在腕關節處將翅膀向後旋轉，在向上和向下的過程中產生升力，由於恆定的升力使蜂鳥能夠保持懸停。
為了知道蜂鳥如何在惡烈環境中移動，把蜂鳥至於風洞並提供強風使蜂鳥必須在風中逆風飛行才能吸食糖水，當風導致蜂鳥的身體產生晃動，利用翅膀來調節身體平衡是其策略之一，除了翅膀，尾翼的展開以及方向改變都同時使蜂鳥能成功在強風中進食。即使是下雨也無法阻止蜂鳥進行，蜂鳥淋濕之後會像狗一樣甩掉誰上詹到的水滴。

(Birds are able to fly by flapping their wings up and down, which creates ‘lift.’ This is because the shape of the wing creates a lower pressure above and a higher pressure below, lifting the bird upwards. Besides, when birds flap their wings, the downstroke creates the lift, while the upstroke prepares the bird for the next downstroke. Insects, on the other hand, are able to use both their upstroke and downstroke to create lift because they are able to twist their wings at their flexible joints, which increases their aerodynamic efficiency. Most birds are unable to do this because their muscle and skeletal joints are configured to allow a repeatable back and forth motion. However, similar to the insect, the hummingbird is able to rotate its wings back to front at the wrist joint to create lift during both the downward and upward stroke. The hummingbird is able to maintain its hover due to the constant lift force created. To find out, the scientists moved hummingbird into a wind tunnel and began recording. The hummingbird must fly into the wind to get the sugar water. This high-speed footage shows how it turns and twists its body in the direction of the air flow, while using its wings for control and its tail like a rudder to stay steady.

Even rain cannot stop the hummingbird from feeding. The will shakes off drops of water from its body, like a wet dog.)
文獻引用 (REFERENCES)
蜂鳥和昆蟲已經從截然不同的祖先方向進化，以持續盤旋飛行，它們獨特的系統發育是其空氣動力學風格的差異。 在所有其他鳥類中——大概還有蜂鳥的祖先——下行在緩慢飛行和盤旋時提供 100%的重量支援[今天的蜂鳥在下行時產生 75%的重量支援，在上行時只產生 25%的重量支援]。(*自然* | 2005 年 6 月 23 日 | Warrick DR, Tobalske BW, Powers DR.) 為了理解區別，Hedrick 建議透過拍打手臂來模仿一隻鳥。 他說：“你正在做一些與海歐所做的事情沒有太大區別的事情。” 模仿蜂鳥，“將上臂靠近身體，肘部放在臀部，前臂來回拍打”。(*nature.com* | 2014 年 11 月 12 日 | Ed Yong) 在昆蟲中，主動翅膀反轉必須起源於翅膀底部，因為翅膀沒有遠端關節。 然而，飛行脊椎動物的翅膀上都有肌肉和骨骼關節，可以根據空氣動力學需求彎曲或旋轉不同的部分。 因此，蜂鳥飛行中風中翅膀反轉的來源仍然不確定，但假設發生在手腕上。(*皇家學會 B 的記錄：生物科學* | 2011 年 12 月 14 日 | Hedrick TL，Tobalske BW，Ros IG，Warrick DR，Biewener AA。) 模擬捕捉了行程迴圈中的升力和功率特性，以及流場的細節。 我們的結果證實並提供了之前根據機翼周圍迴圈測量建議的升力不對稱的具體資料。 此外，我們定量分析了升降不對稱的來源，並指出了導致不對稱的機制。 總結結果，下衝程產生的垂直力比上衝程高 150%。(*皇家學會期刊介面* | 2014 年 6 月 9 日 | Song J, Luo H, Hedrick TL) ‘‘Hummingbirds and insects have evolved for sustained hovering flight from vastly different ancestral directions, and their distinct phylogenies underlie the differences in their aerodynamic styles. In all other birds—and, presumably, hummingbird ancestors—the downstroke provides 100% of weight support during slow flight and hovering [hummingbirds today, produce 75% of their weight support during the downstroke and only 25% during the upstroke].’’ ‘‘To understand the difference, Hedrick recommends trying to mimic a bird by flapping your arms. “You’re doing something not too different to what a seagull’s doing,” he says. To mimic a hummingbird, “hold your upper arm close to your body with your elbow on your hip, and flap your forearms back and forth”. ‘‘In insects, active wing inversion must originate at the wing base because the wings have no distal joints. However, flying vertebrates have muscles and skeletal joints throughout their wings and may flex or rotate different segments according to aerodynamic demands. Thus, the source of wing inversion in the hummingbird flight stroke remains uncertain but is hypothesized to occur at the wrist.’’

‘‘The simulation captures the lift and power characteristics in a stroke cycle and also details of the flow field. Our result confirms and provides specific data for the lift asymmetry that was previously suggested based on the measurement of the circulation around the wing. Furthermore, we quantitatively analysed the sources of the lift asymmetry and pointed out the mechanisms that lead to the asymmetry. Summarizing the results, the downstroke produces 150% higher vertical force than the upstroke.’’
參考文獻清單與連結 (REFERENCE LIST) **Harvard 或 APA 格式**
Nature | 23/06/2005 | Warrick DR, Tobalske BW, Powers DR. (https://www.nature.com/articles/nature03647) *Nature* | 11/12/2014 | Ed Yong (https://www.nature.com/news/hummingbird-flight-has-a-clever-twist-1.9639#b2) *Proceedings of the Royal Society B: Biological Sciences* | 14/12/2011 | Hedrick TL, Tobalske BW, Ros IG, Warrick DR, Biewener AA. (https://royalsocietypublishing.org/doi/full/10.1098/rspb.2011.2238) *Journal of the Royal Society Interface* | 06/09/2014 | Song J, Luo H, Hedrick TL. (https://royalsocietypublishing.org/doi/full/10.1098/rsif.2014.0541)
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