Multi-environment robotic transitions through adaptive morphogenesis

Nature： 2022-10-12

復旦大學
FUDAN UNIVERSITY

Contens

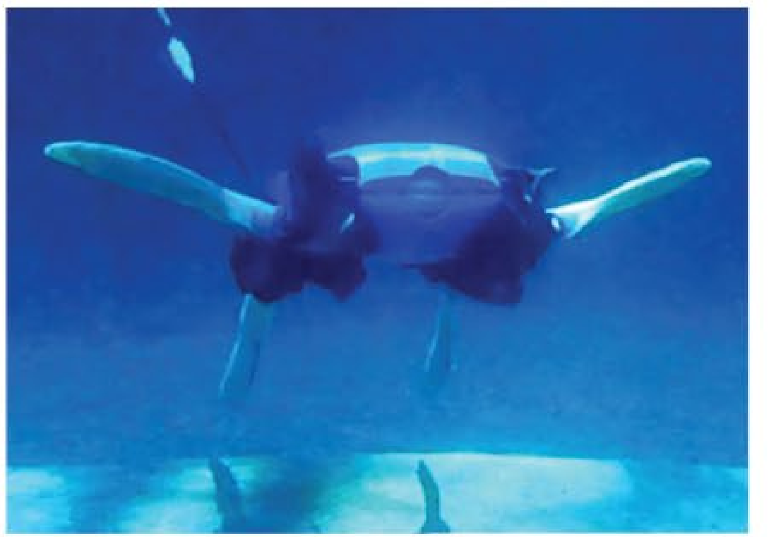
1 Background

- Expanding frontier of applications（广泛应用）
- Challenge： transit multiple environments（适应不同环境）
- Others' approaches and their disadvantages
  - biomimetic design： Lose the benefits of engineered materials
    （仿生设计）
  - Add a unique propulsive mechanism for each environment： energy-inefficient designs
    （为每种环境都加一个机制）（低效）

2 Introduction

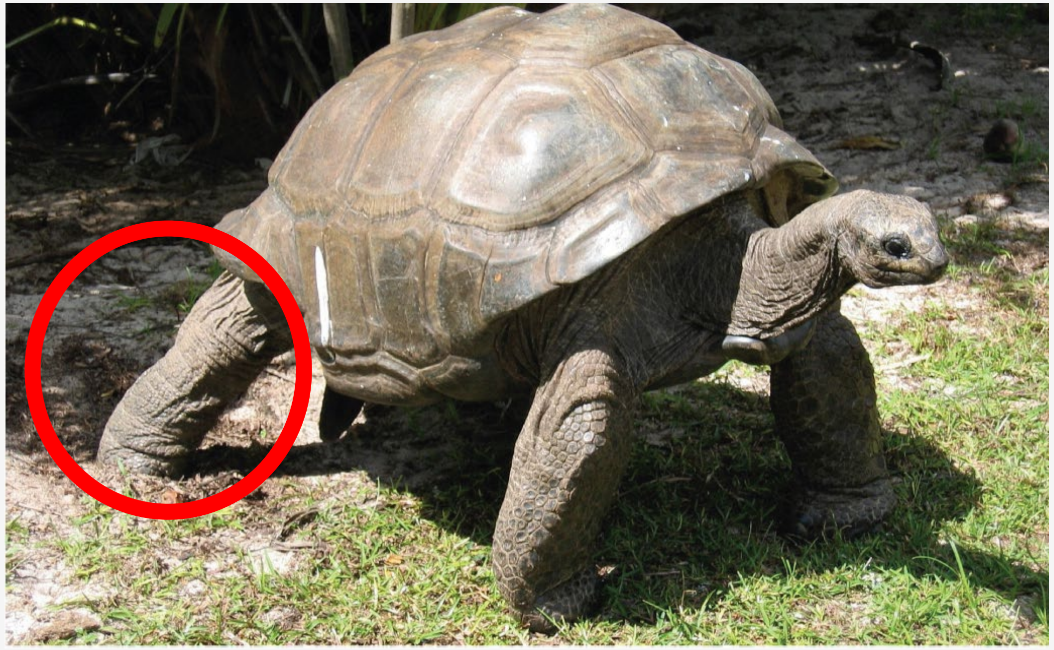
- The paper’s work——adaptive morphogenesis

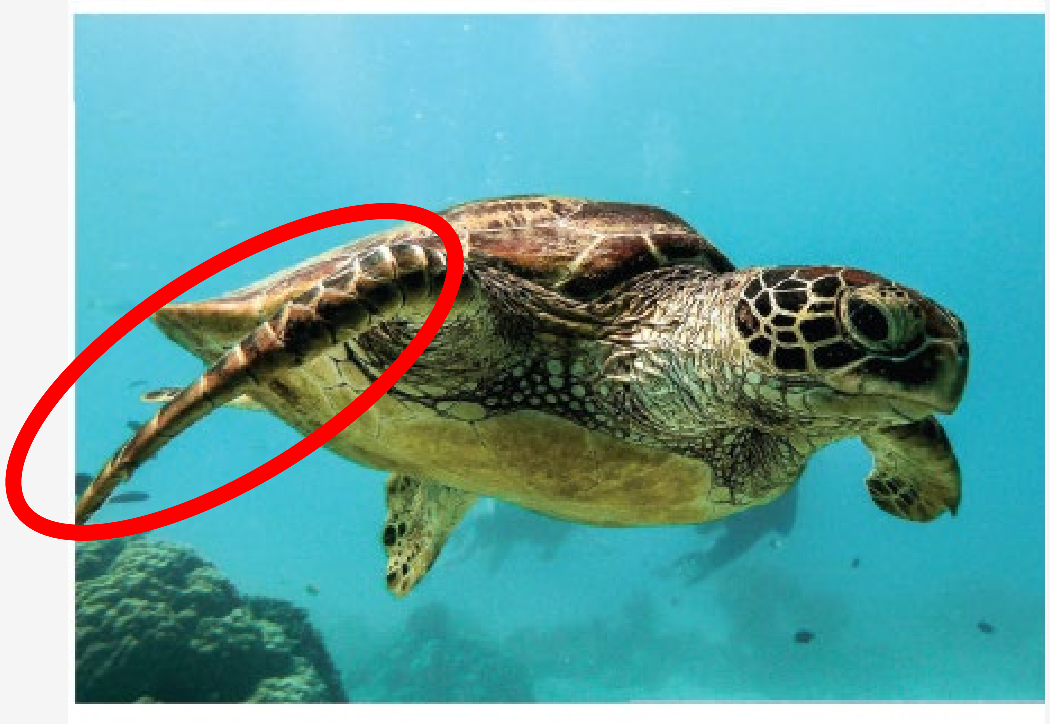
- Purpose： achieve specialized multi-environment locomotion（运动）
  - Terrestrial（陆） aquatic（水） and the in-between transition zones（过渡区）



2 Introduction

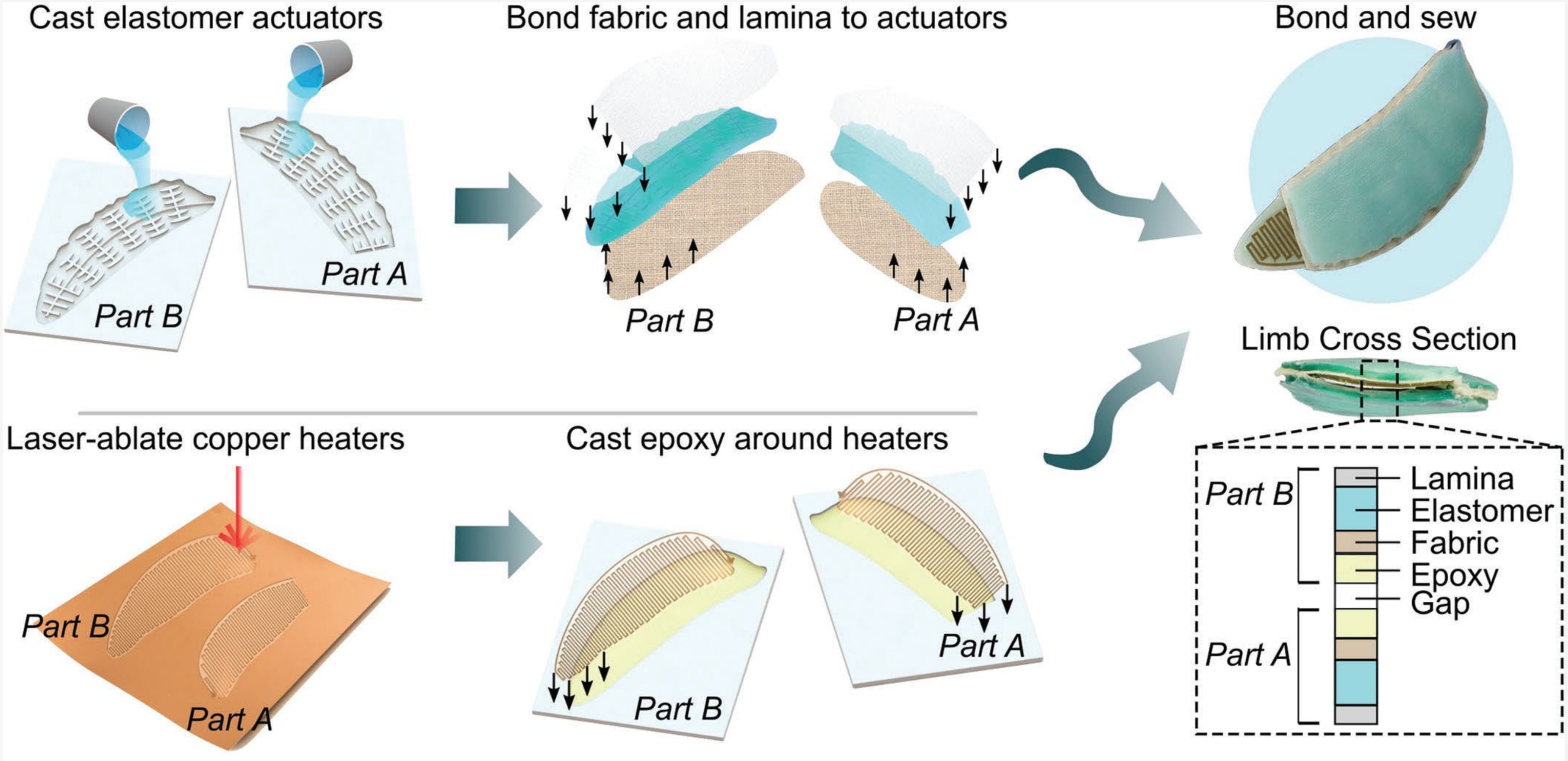
- Inspiration： terrestrial and aquatic turtles
  （陆龟） （水龟）
  - sea turtles： the streamlined flipper shape and gaits
    （平蹼）
  - land-faring tortoises： the columnar leg shape and gaits
    （柱形腿）





2 Introduction

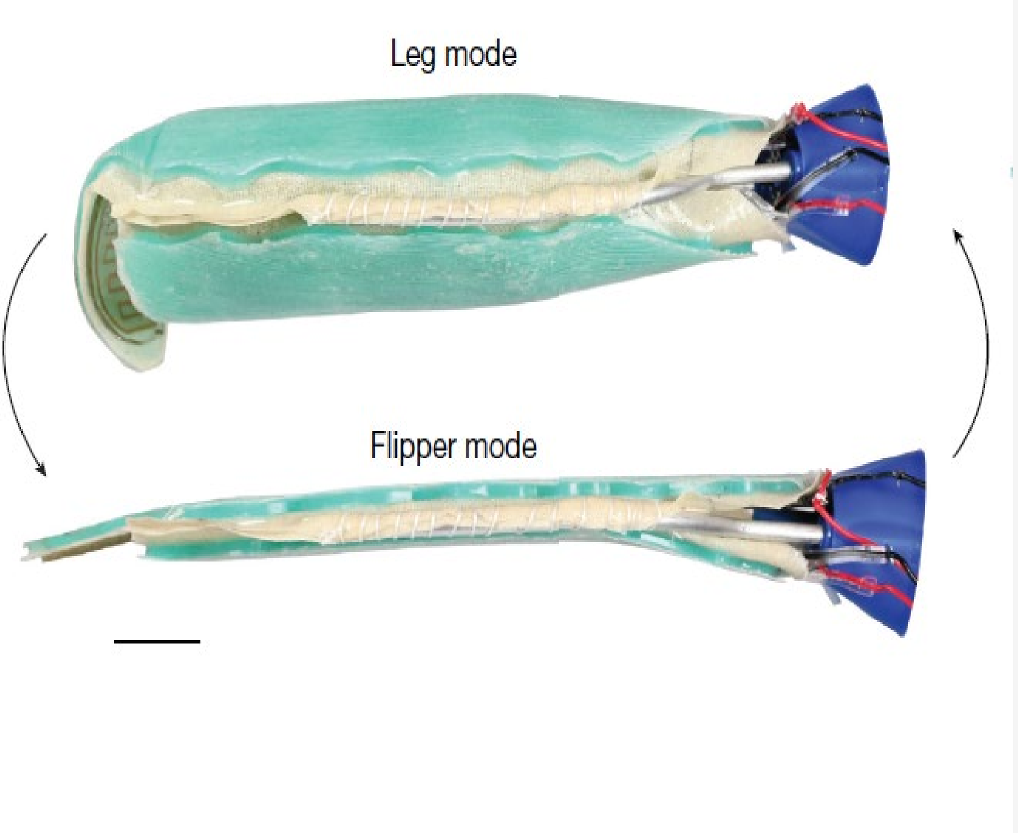
- How to achieve that in robot——ART（Amphibious Robotic Turtle）
  两栖机械龟
- Made of：
  - stimulus-responsive soft materials & traditional robotics components
    （刺激响应软材料）（传统机器人组件）

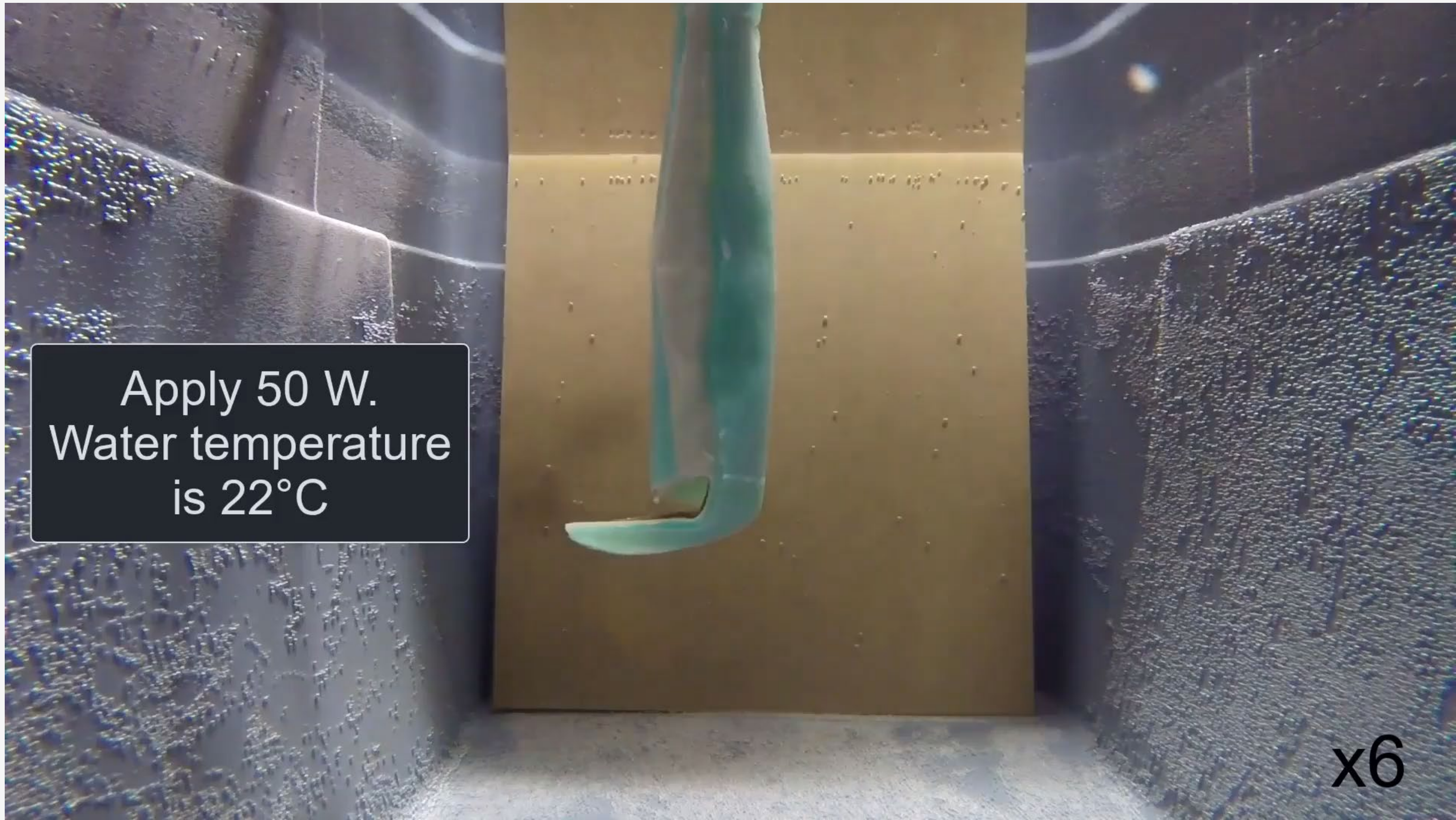


2 Introduction

- How to achieve that in robot——ART （Amphibious Robotic Turtle）

- Employ：
  - adaptive morphogenesis (Vary with the environment and change the shape)





2 Introduction

The meaning of adaptive morphogenesis

- adaptive：适应性的
- morphogenesis：指因适应环境而出现的形态及其产生的功能

- “adaptive morphogenesis”在生物学中描述的是细菌基于环境而改变形状和大小的现象。和该研究中机器人的改变有异曲同工之妙

2 Introduction

- Study the efficacy of adaptive morphogenesis：
  - Evaluating ART’s cost of transport (COT) against others in both environments
    （比较水、陆的运输成本）
  - combining favourable policies from both environments to derive transitional policies between terrestrial and aquatic habitats.
    （通过水、陆的有利策略，得出过渡区的有利策略）

Formula to calculate COT

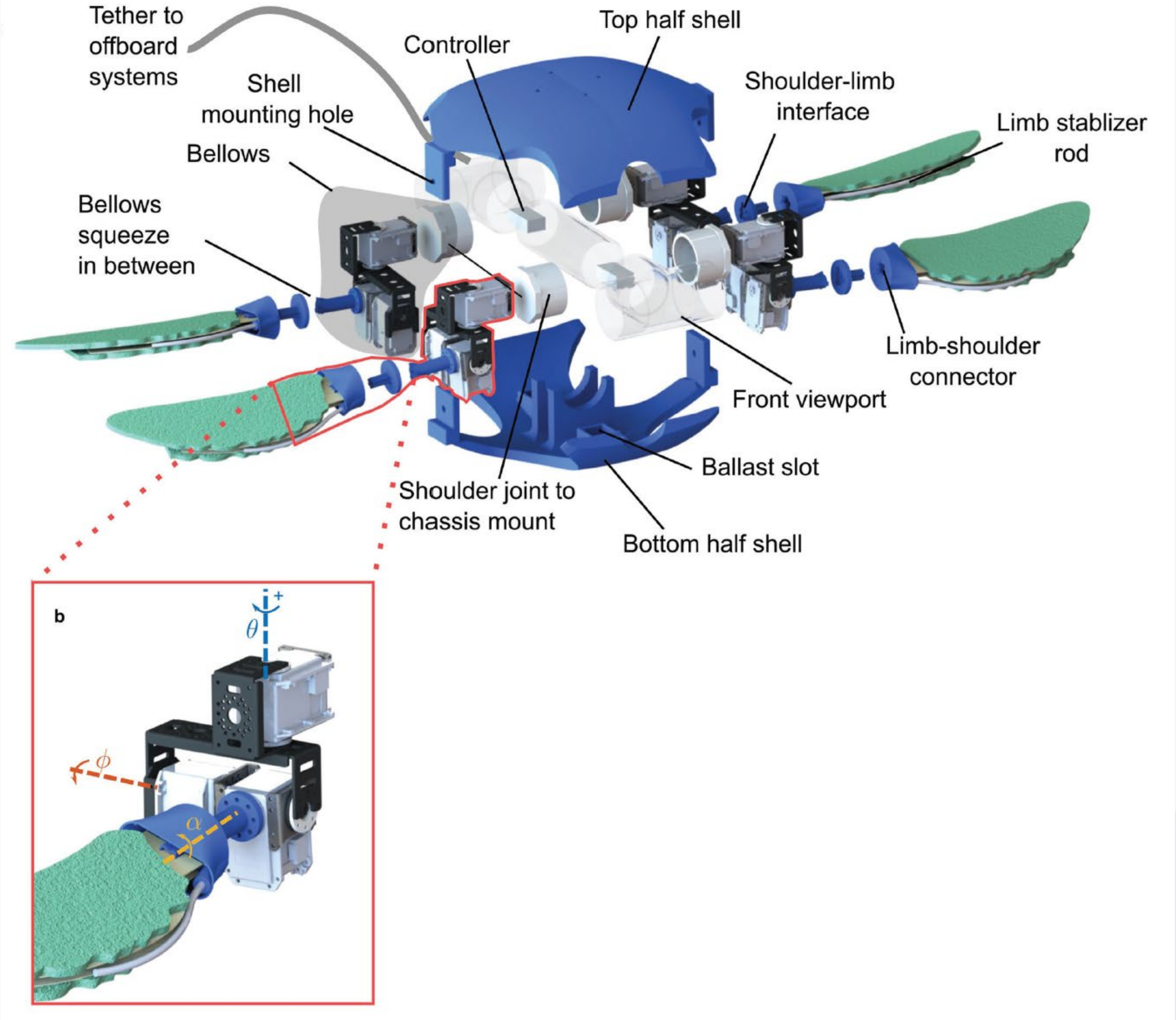
$$\mathrm{COT} = \frac{P_{\mathrm{in}}}{\mathrm{mgv}}$$

m：机器人的质量
g：重力加速度
v：机器人的速度
mgv：机器人的重力功率
P_{in}：电机的功率

COT表示的是电机与机器人重力功率的比值，无量纲（单位为1）
故可以在不同动物和机器人之间比较

2 Introduction

- ART's body
  - 4 subsystems:
    - Chassis（底盘）
    - Shell（外壳）
    - shoulder joints（肩关节）
    - morphing limbs（变形肢）



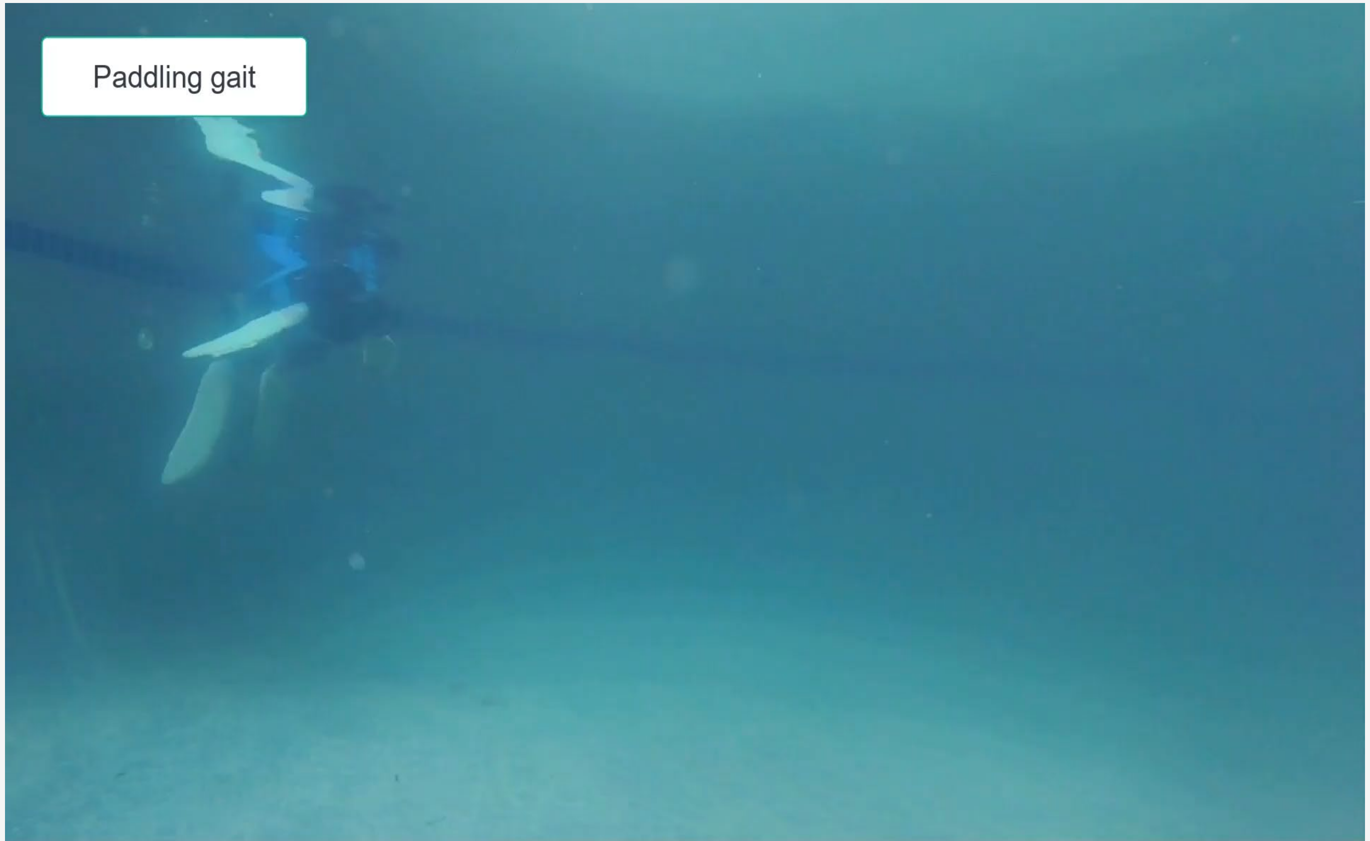
3 Test

- Swimming tests
  - ART's buoyancy was adjusted for surface and submerged swimming
    （浮力）（表面）（水中）

$F_{浮}=\rho_{液}gV_{排}$ （$V_{排}$不同）

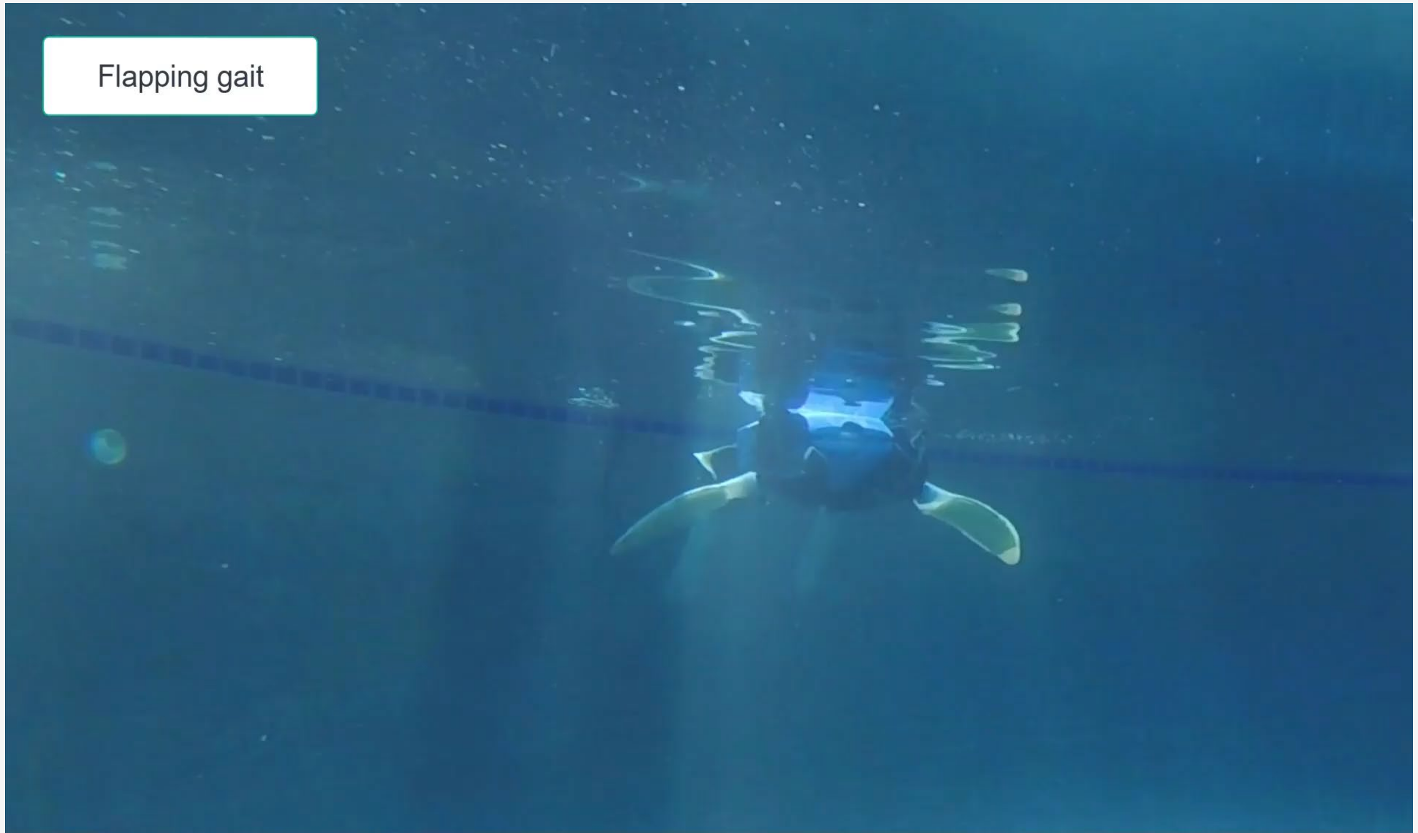
3 Test

- Swimming tests
  - Paddling： from freshwater turtles and semi-aquatic mammals
    （划水）　　　　　（淡水龟）　　　　　（半水生哺乳动物）
  - The paddling gait is a stroke directed ventrally rearwards relative to the robot’s body, followed by a feathering recovery stroke moving forwards and dorsally
    （先向后推，接着是向前和向背的恢复动作）



3 Test

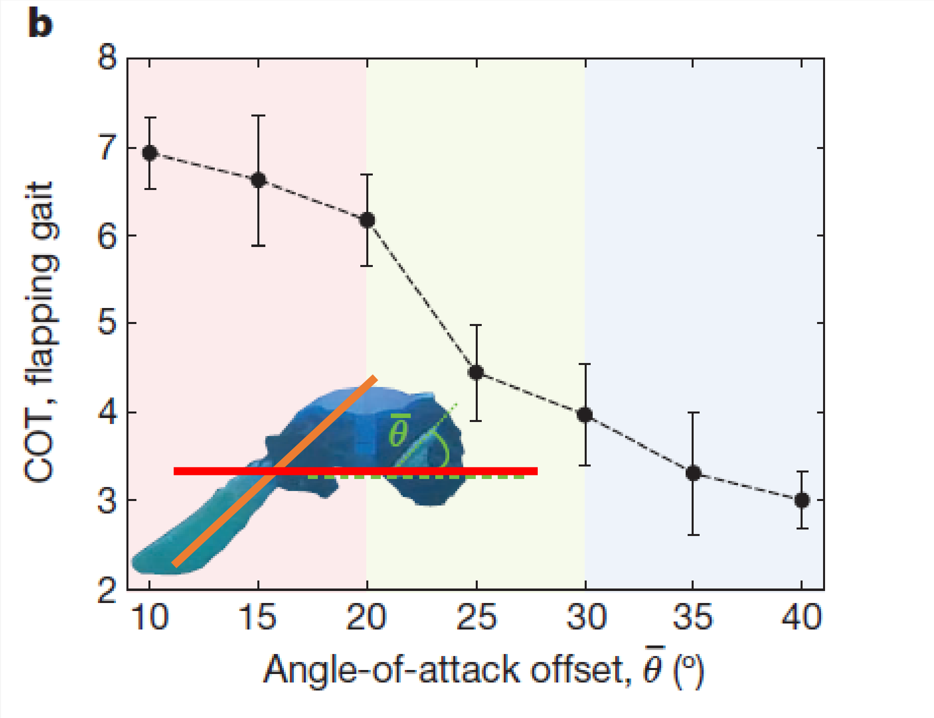
- Swimming tests
  - Flapping： from sea turtles and fully-aquatic mammals
    （拍打）
  - The flapping gait features a vertical movement profile of sequential upstrokes and downstrokes
    （由连续的上冲和下冲组成的垂直运动动作）



3 Test

- Swimming tests
  - Flapping gait's strong dependence on the angle-of-attack offset θ

（迎角）
飞机中的概念
对应到此处，指的是变形肢与水流方向的夹角



3 Test

- Swimming tests： Flapping

Three regions：

（区域）

1. flapping is less efficient than paddling

   so the COT of padding is about 6.2

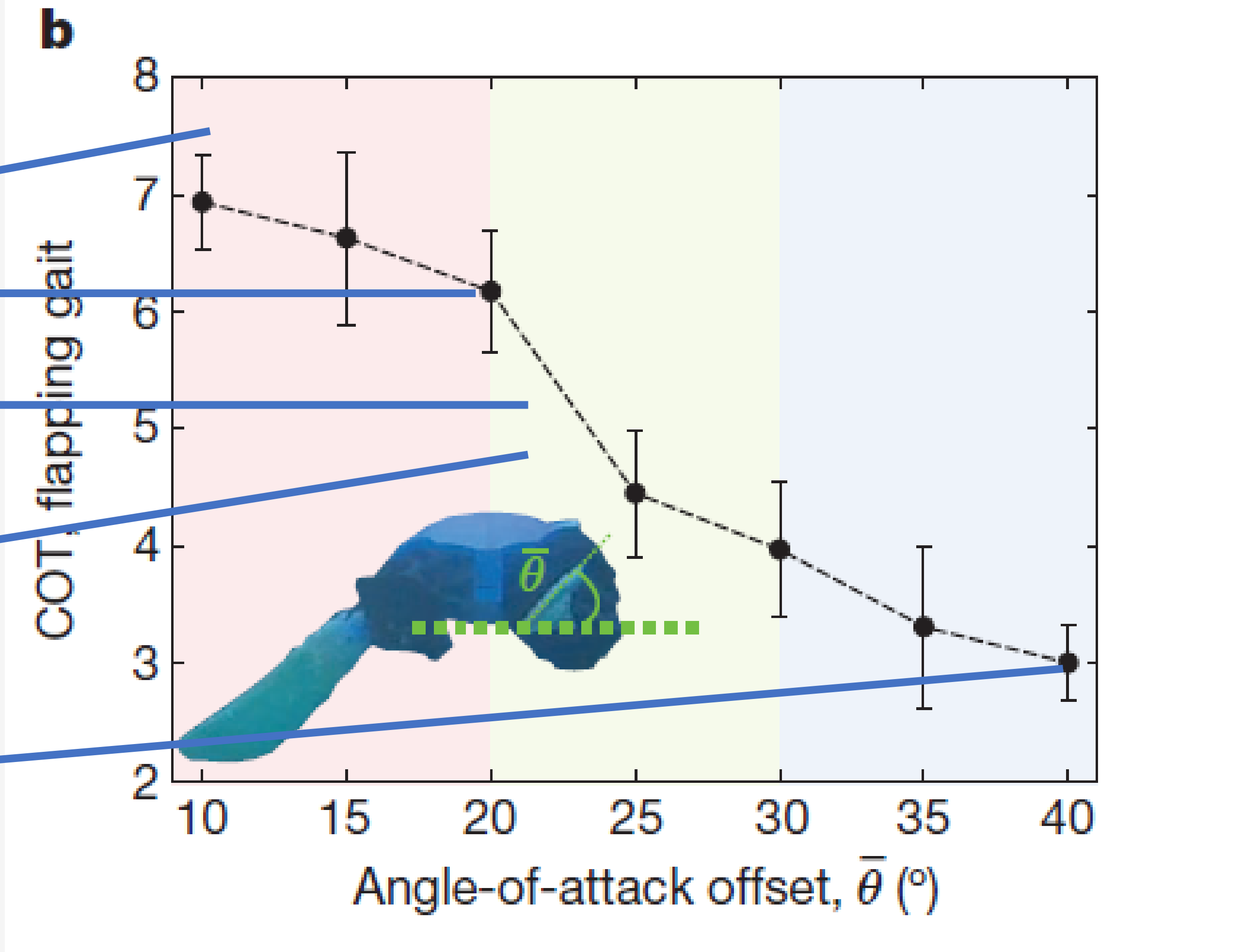
2. the COT drops

3. COT begins to plateau

   （平稳）

optimal $\vartheta = 40^0$

（最佳的）



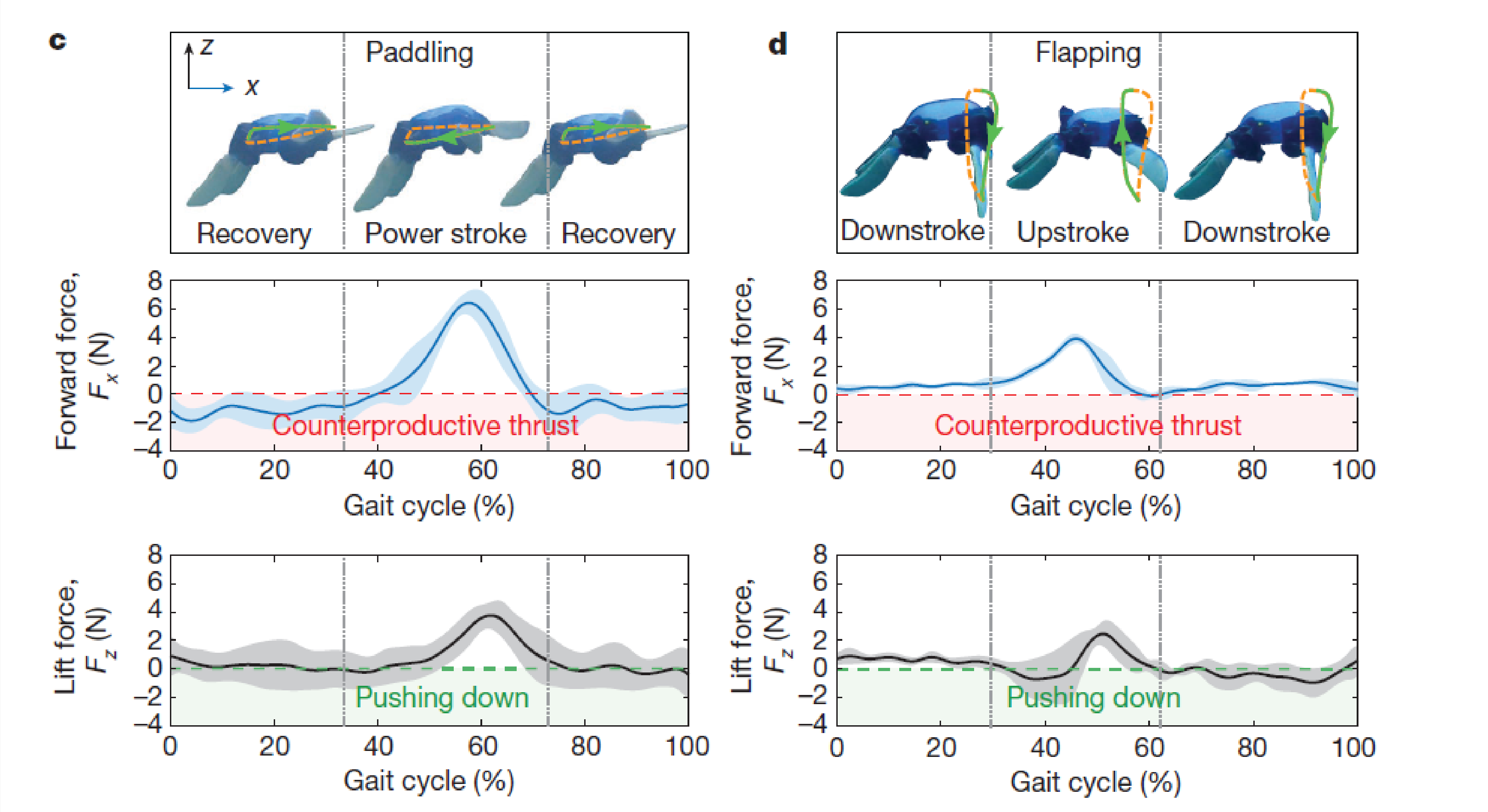
3 Test

- Swimming tests
  - elucidated the difference in the COT between paddling and the best flapping gait

（说明）　　　　　　　　　　　　　　　　　　（ $\vartheta = 40^0$ ）

Forward (Fx)
Padding:only 27% useful in giat cycle
Flapping:95% useful in giat cycle

Lift (Fz)
Padding:Fz max=3.4N
pitching （颠簸）
Flapping:Fz max=2.5N

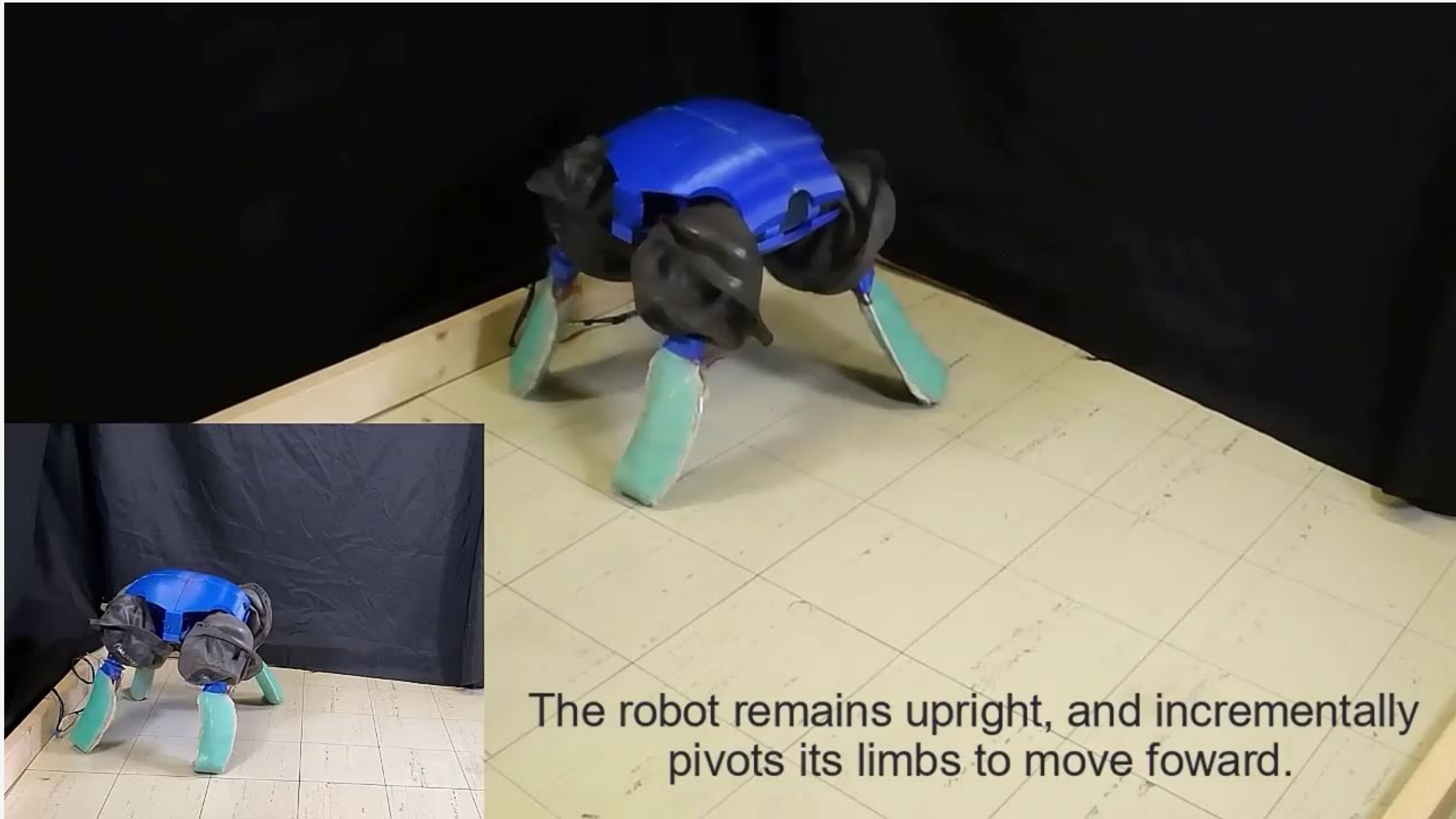


3 Test

- Terrestrial tests
  - representative substrates for outdoor urban environments:
    - ➢ porcelain tile（瓷砖）
    - ➢ concrete（水泥路）
    - ➢ granite（花岗岩）

A statically stable creeping gait（静态稳定的爬行步态）

- One limb off at a time（一肢离开地面）
- Pivoting its body to move forwards（转动身体前行）

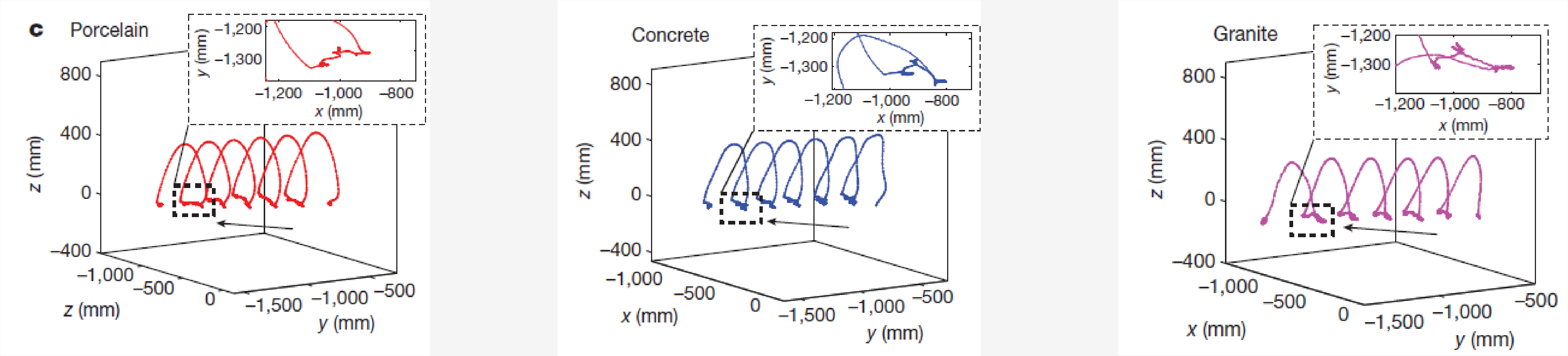


3 Test

- Terrestrial tests
  - 3D motion capture
    （动作捕捉）

verifying the efficacy：
（验证步态有效）

consistent swept trajectory and stride length on different substrates
（不同的基质，一致的轨迹和步长）



3 Test

- Terrestrial tests
  - 3D motion capture

  explain the COT differences：

  z-axis data projection (*z**)

  （z轴投影）

1. sharp increases when ART swings its leg for a step

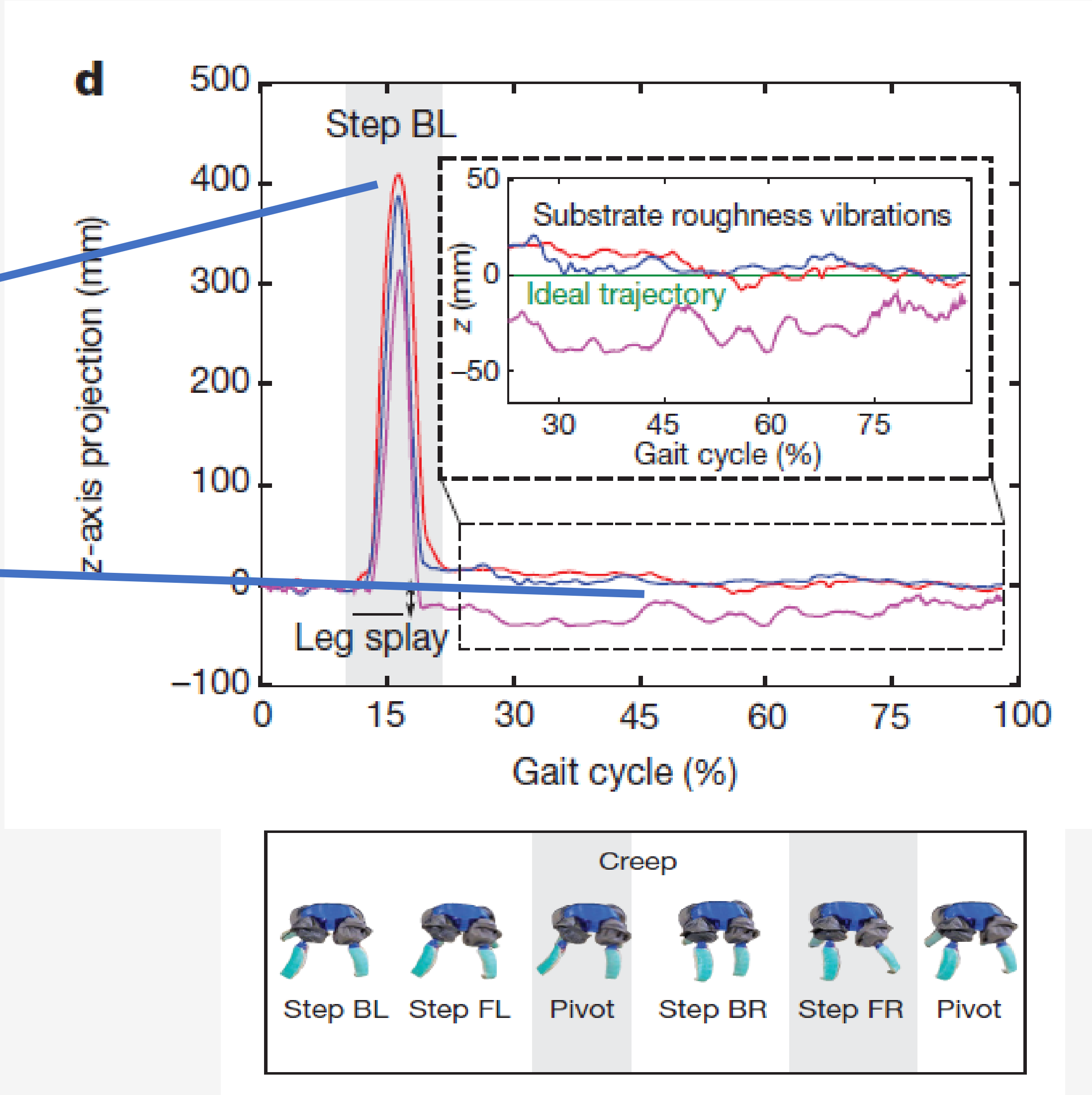
   （急剧增长）　　　　　（转动）

2. vibration signatures corresponding to interactions with the terrain

   （不同地形，表现出不同的图线振动特征）

gradual splay or tucking of the legs as ART walks

（行走时腿部伸展和收拢的过程）



3 Test

- Terrestrial tests
  - 3D motion capture

explain the COT differences：

z-axis data projection (z^*)

（z轴投影）

the stability metric （稳定度）

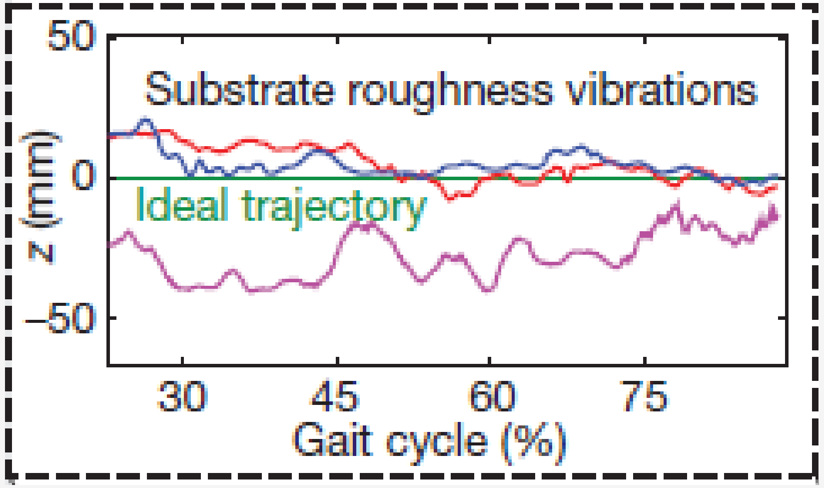
$$S=\sqrt{\frac{\sum_{i=1}^{n}(z_i - z_{ideal})^2}{N}}$$

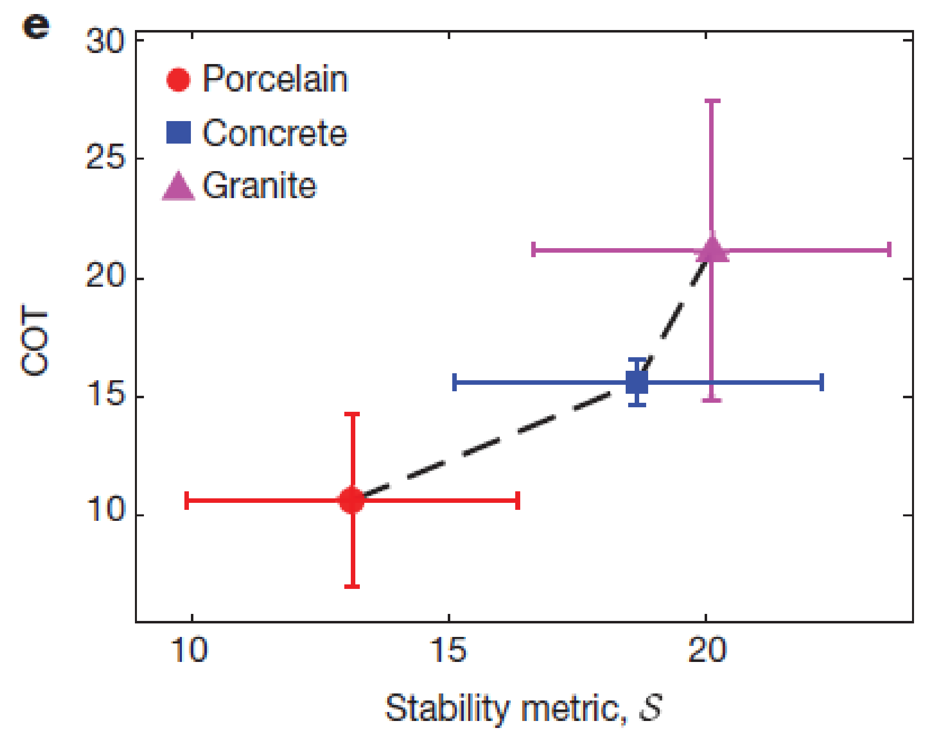
positive correlation between COT and S

(正相关)

Reason: friction and topographical features

（摩擦） （地形特征）





3 Test

- Q:
  - ✓ What limb morphology–gait pairing will allow transitioning between land and water?
    (什么样的肢体和步态适合过渡地带)

3 Test

- Transition-substrate tests
  - feature： fluidized sediment （流化沉积物）
    exert drag forces and impact stability
    （产生阻力） （影响稳定）
  - Locomotor efficiency governed by： critical yield stress
    （运动效率取决于） （屈服应力，流体力学概念）
    substrate penetration depth, percent water content, and granule size and dispersity
    （基质深度） （水占比，湿度） （颗粒大小和硬度）

3 Test

- Transition-substrate tests
  - locomotion strategies：

（运动策略）

upright locomotion （直立行走）

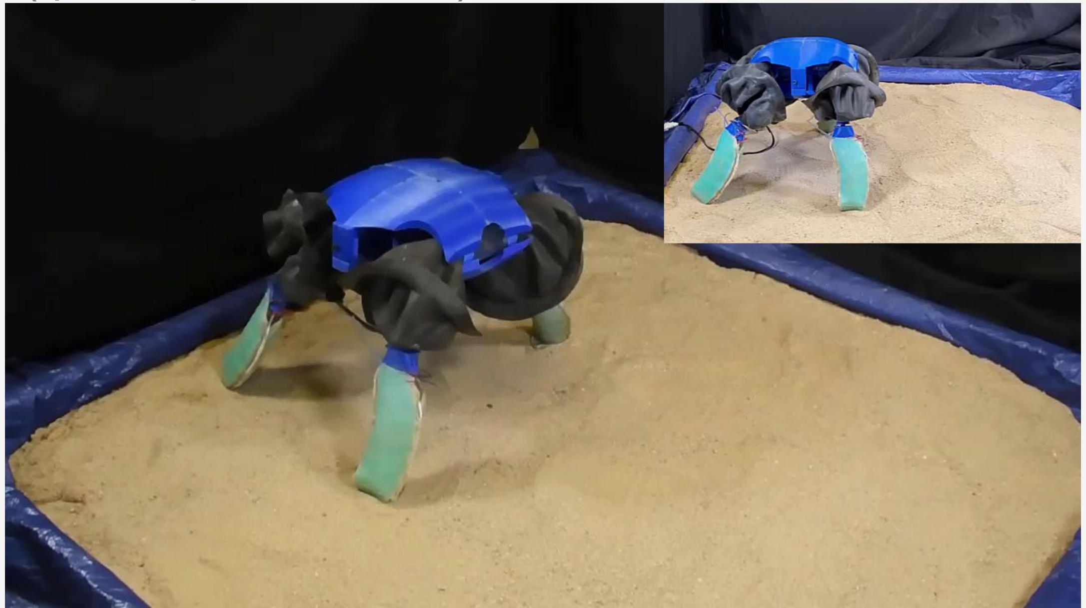
Unsuited!

creep on sand: slipped, burrowing its limbs into the sand

（沙上爬行） （滑倒，埋进沙里）

creeping on intertidal substrate: slippage on the pebbles

（伴水底物上爬行） （在鹅卵石上滑倒）



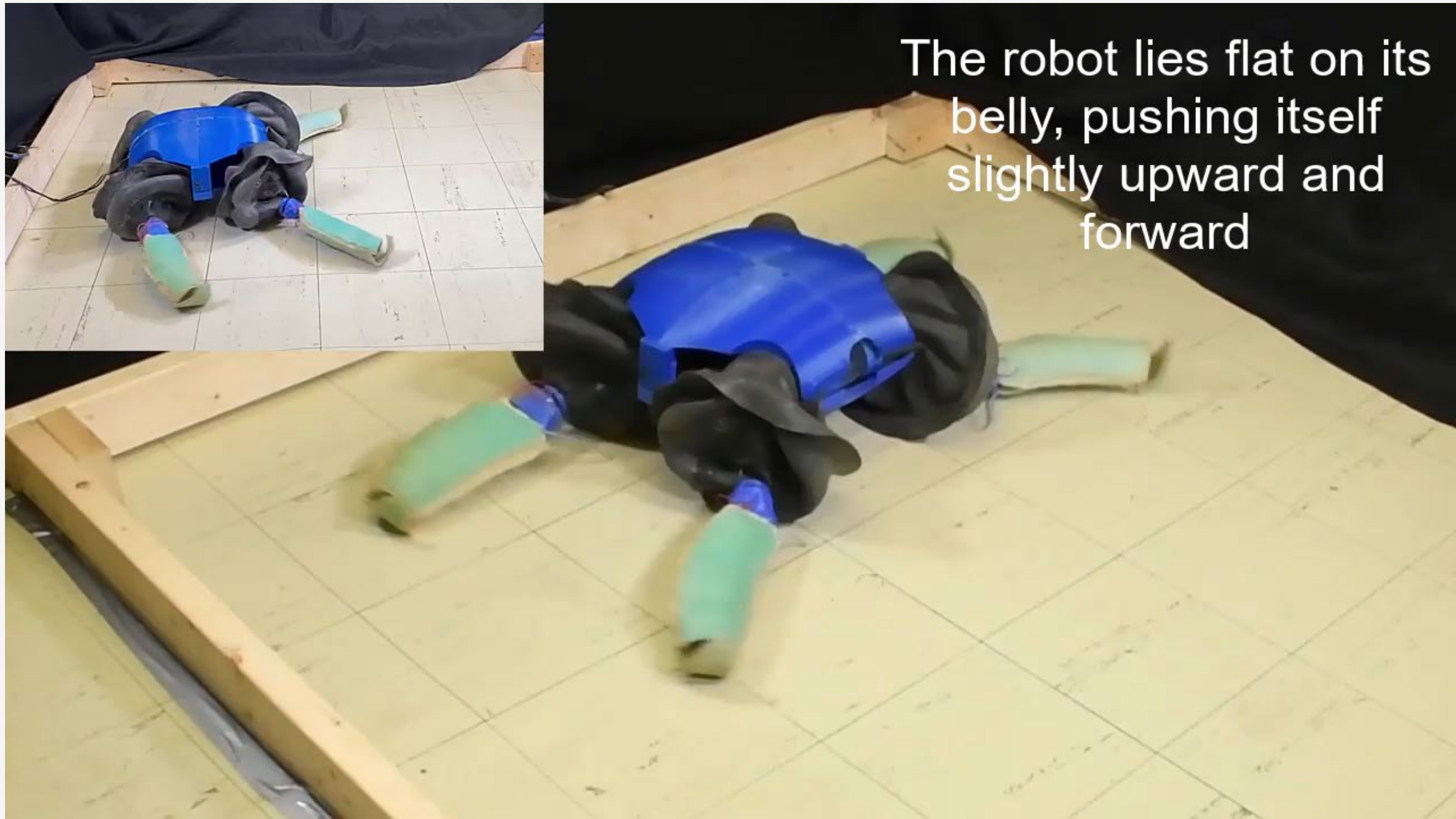
3 Test

- Transition-substrate tests
  - locomotion strategies：
    （运动策略）

crawling gait （爬行步态）
lie on its belly
（俯卧）
using both fore and aft limbs
（四肢发力）
push rearwards
（向后推获得动力）

advantages：
- distribute the weight
  （分散重量）
- mitigate catastrophic slip
  （避免滑倒）
- prevent ensnarement
  （防止困住）

but higher COT



3 Test

- Transition-substrate tests

  friction tests between the substrates and ART’s constituent materials

  （摩擦测试）（基底）（ART组成材料）

  – purpose： understand the elevated COT of crawling compared with creeping

  (升高)

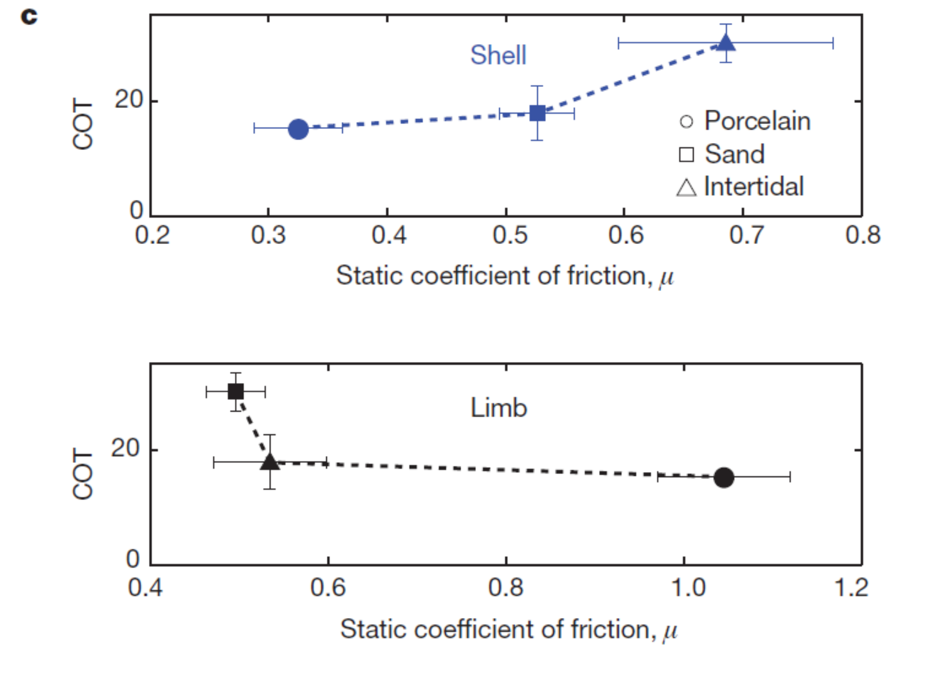
  – result：

  ➢ the shell ——COT & μ: positive

  （外壳）

  ➢ the limb material——COT & μ: negative

  （肢体材料）



  – suggest:

  dominant: sliding of ART’s carapace along the substrate

  （外壳与基底的滑动占主导）

4 Conclusion

ART's successful locomotion strategies in water, on land and on transition substrate were combined to create a policy for terrestrial-to-aquatic transition.

- leg mode and creeping when on the hard-packed soil section
  （坚硬的土壤）
- crawling when approaching the water and the substrate became more saturated
  （接近水时，基质吸满水，变得湿润）
- paddling for swimming when only partially submerged in the shallows
  （部分在水中）
- flapping when whole in water
  （全在水中）

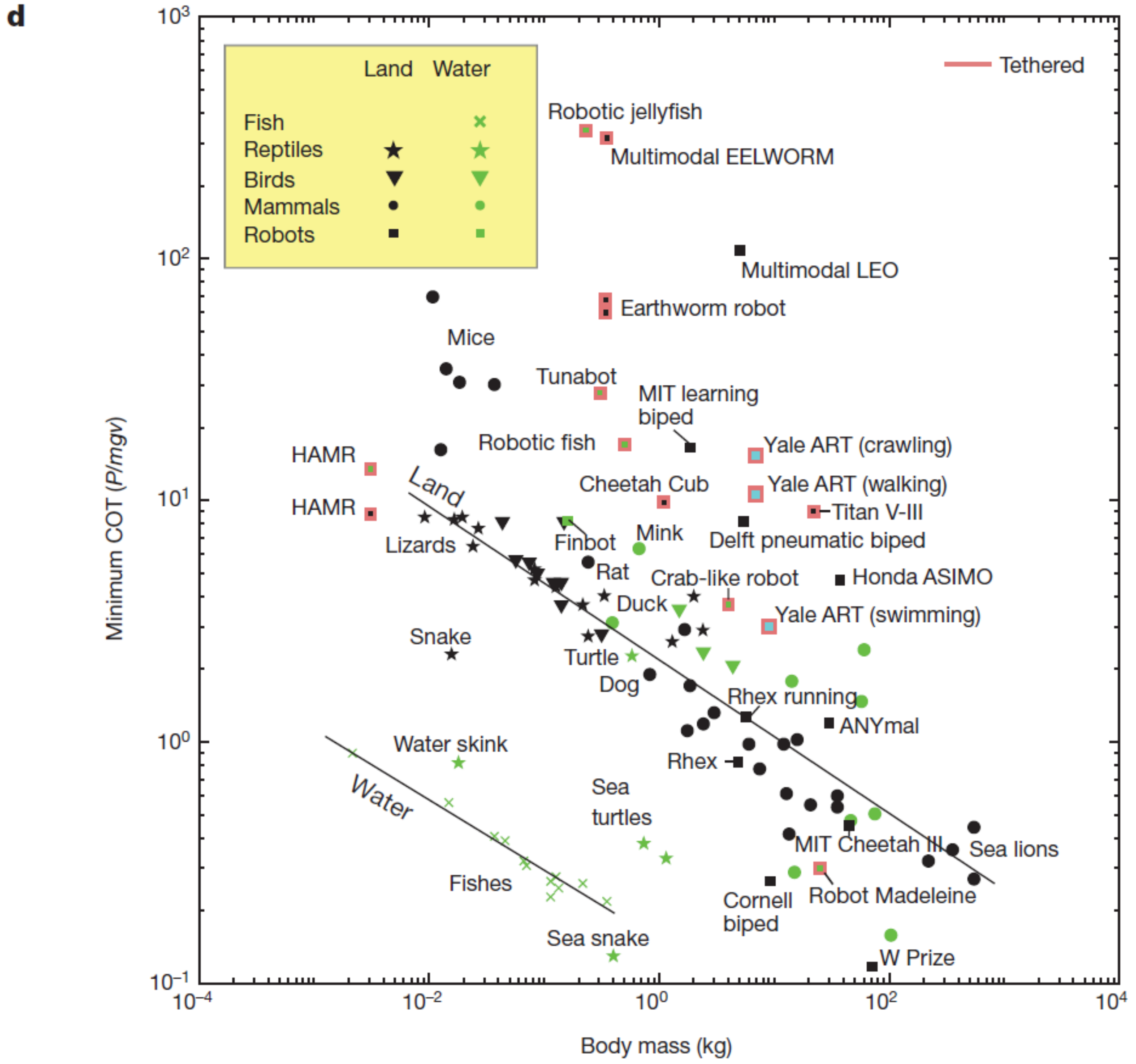
4 Conclusion

advantages：

environmentally friendly

（环境友好型）

perfect COT： 3 in water and 10 on land



5 Addition

$$\mathrm{COT} = \frac{\mathrm{P_{in}}}{\mathrm{mgv}} = \frac{\mathrm{P_{in}}t}{\mathrm{mgv}t} = \frac{E_{total}}{\mathrm{mg}d}$$

Calculation of COT

the energetic cost to move a unit mass a unit distance
（单位质量移动单位距离的能量消耗）

- ART's COT

m=9kg, g=9.81m/s^2,
v from high-definition video（高清视频）
the camera ⊥ forward movement direction, ≈4m away（垂直前进方向，4m远）
4 shoulder joints : 3 motors in each（4个肩关节，每个有3个电机）

$$\overline{P_{\text{in}}(t)} = \sum_{i=1}^{4} \sum_{n=1}^{3} \overline{I_{n,i}(t)}\, V$$

I：电机电流的安培数
V：电机电压

5 Addition

$$\mathrm{COT} = \frac{\mathrm{P_{in}}}{\mathrm{mgv}} = \frac{\mathrm{P_{in}}t}{\mathrm{mgv}t} = \frac{E_{total}}{\mathrm{mg}d}$$

Calculation of COT

the energetic cost to move a unit mass a unit distance

（单位质量移动单位距离的能量消耗）

- living organisms’ COT

  $E_{total} = \mathrm{V}_{o2}$ （呼吸代谢）

  measure oxygen uptake：

  （测量呼吸代谢）

  - intravenous probes inserted into their arteries and sometimes veins

    （向静脉或动脉插入探针）

  - in separate chambers to determine the gas composition

    （在不同实验舱分别检验各气体成分）

  - masks and analyse gas flows in and out

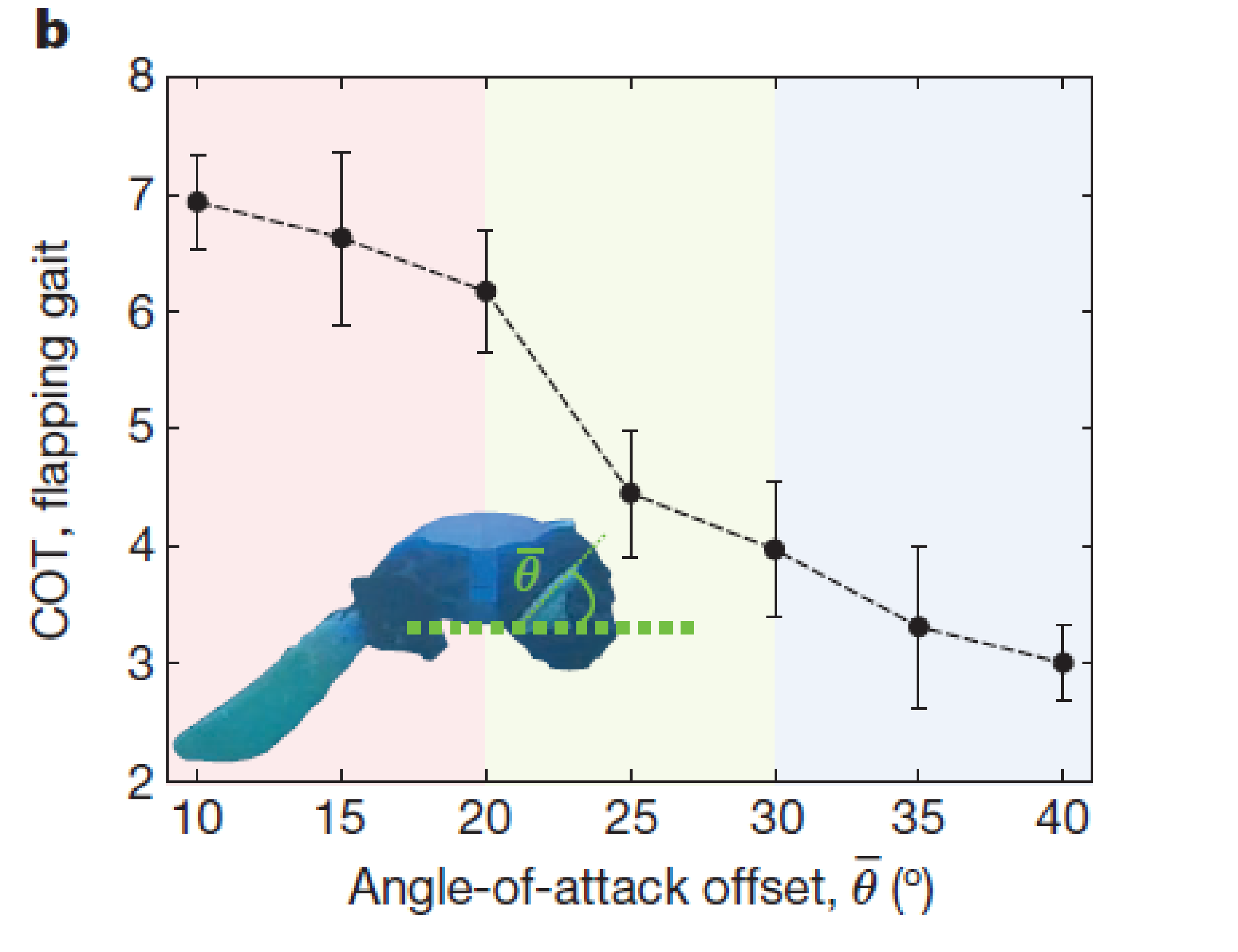
    （通过呼吸面具来分析进出气体）

5 Addition

In swimming tests

Why larger angle-of-attack offset?

hardware constraints
（硬件限制）
can’t twist too much!
（不能转太多）



6 Dissussion&Quesion

- ✓ When and where should transitions take place?
  （何时何地变形？）
- ✓ Can environmental perturbations in transition be harnessed to enhance efficiency?
  （能否利用变形所处环境的干扰来提高效率？）
- ✓ How close to optimal are the gaits studied herein?
  （本研究离最优的步态有多远？）

Thanks for listening!

復旦大學
FUDAN UNIVERSITY