Muscutt, L.E.,
Ganapathisubramani, B.,
Weymouth, G. D.,
Dyke, G.,
Palmer, C.

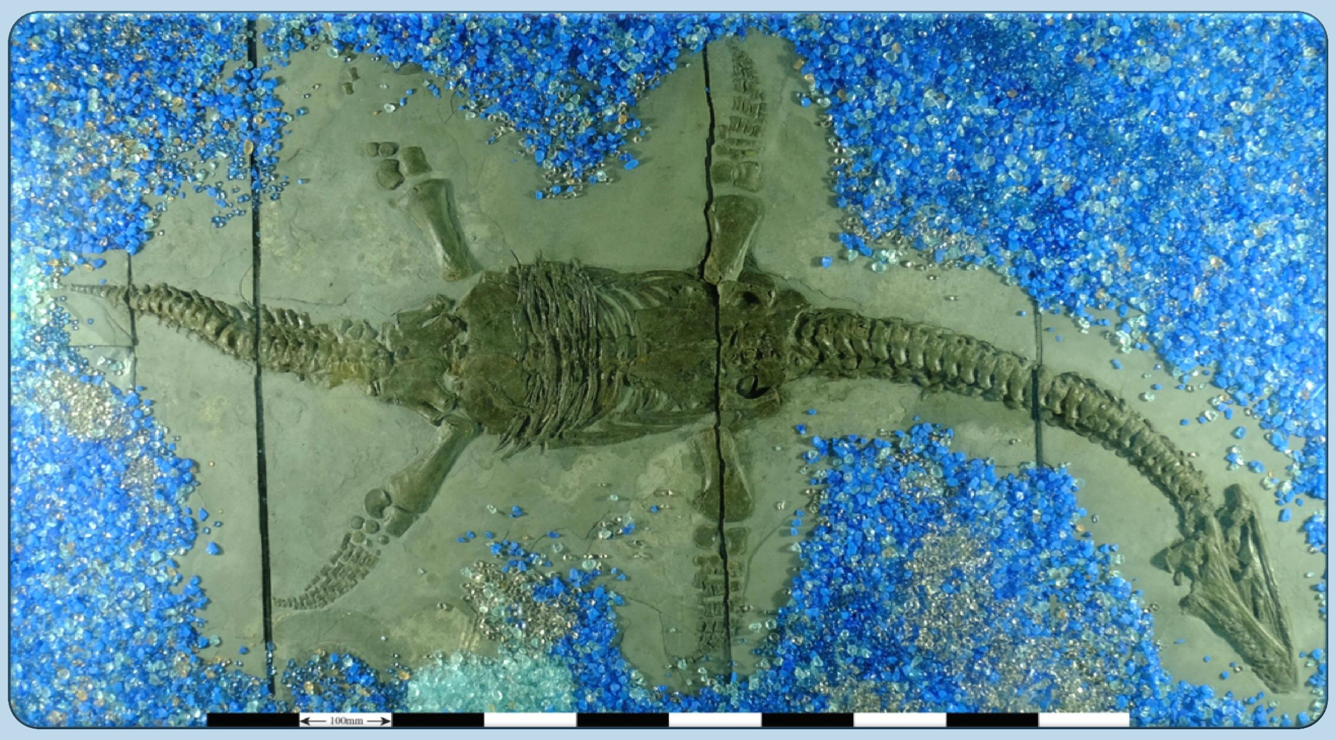
UNIVERSITY OF Southampton

The Hydrodynamics of Plesiosaurs

Plesiosaurs

Plesiosaurs are extinct **marine reptiles** that existed at the same time as the dinosaurs, during the **Mesozoic era** around 200 to 65 million years ago.

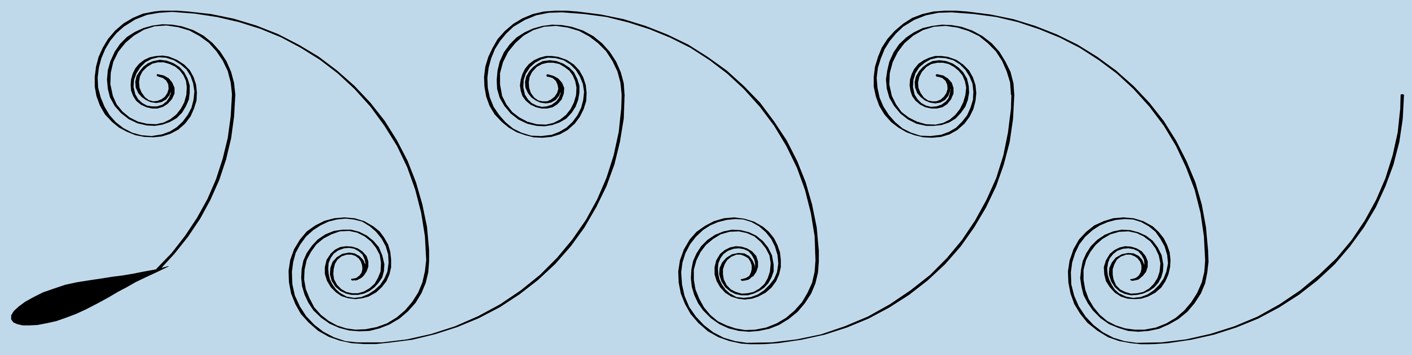
They are **unique** in the known natural world as they used **four flippers for propulsion**, although there has been much debate regarding their function.



It's all about vortices

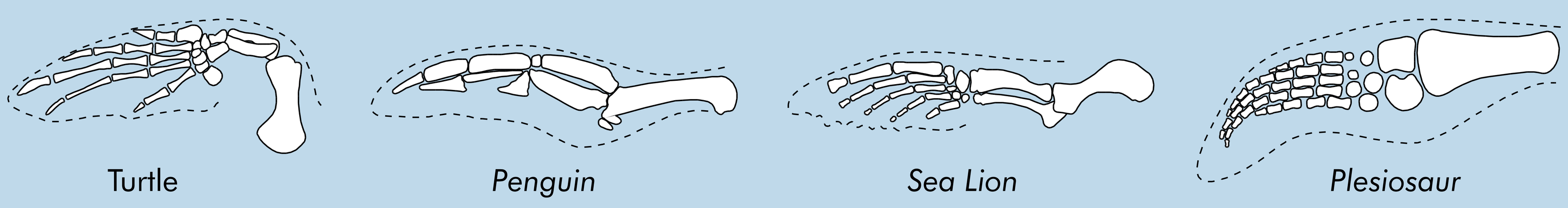
A **vortex** is just a region of **rotating fluid**. Flapping wings create alternating vortices, which produces **thrust**.

A **second wing** behind the first interacts with this unsteady wake, and its **performance** (thrust or efficiency) is **modified**.



Flipper Geometry

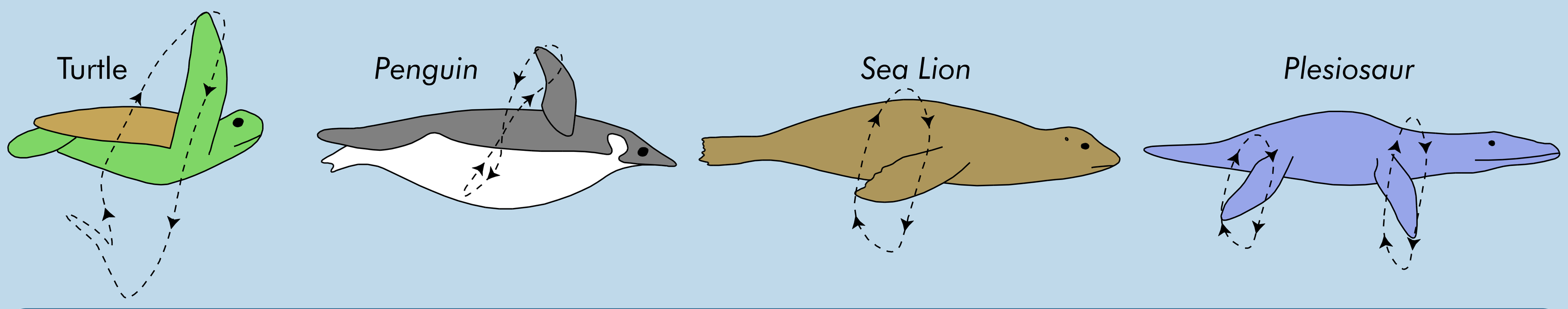
The plesiosaur **flippers** are modified limbs **specialised for aquatic locomotion.** As only the bones remain as fossils, the **soft tissue** such as the muscles and skin must be **reconstructed** to obtain the shape.



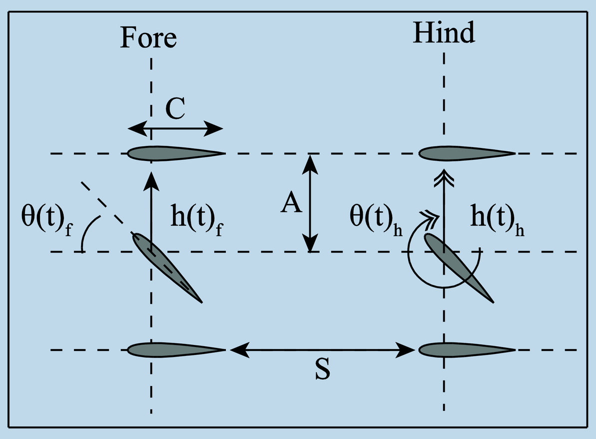
This was done by **comparing** the flippers of the plesiosaur to **extant animals** that swim using flippers such as **turtles, sea-lions, and penguins.**

Kinematics

All plesiosaurs would have used their flippers in a motion that is primarily **up-and-down** (dorso-ventral) rather than forward-back.



This motion is similar to the stroke of a turtle, penguin or sea lion, and can be modelled as **simple harmonic motion**.



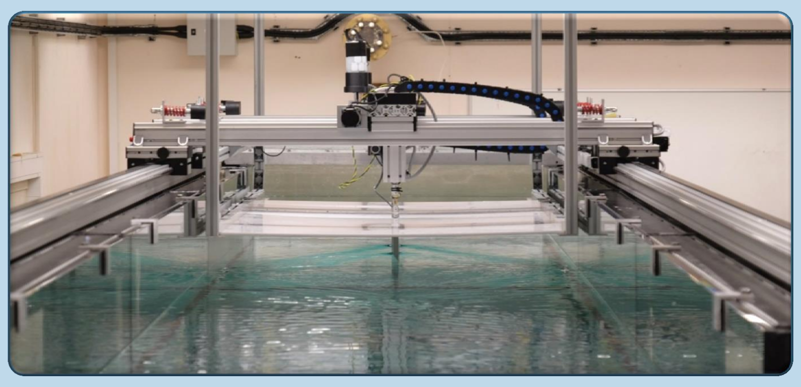
$$h(t)_f = A\,sin(\omega t); \qquad \theta(t)_f = \theta_{max}\,sin\left(\omega t + \frac{\pi}{2}\right);$$

$$h(t)_h = A\,sin(\omega t + \varphi); \qquad \theta(t)_h = \theta_{max}\,sin\left(\omega t + \frac{\pi}{2} + \varphi\right);$$

Where:
C = Chord Length
S = Spacing between wings
A = Flapping Amplitude
θ_{max} = Maximum pitch angle
ω = Angular frequency
φ = Phase between wings

The Robotic Plesiosaur

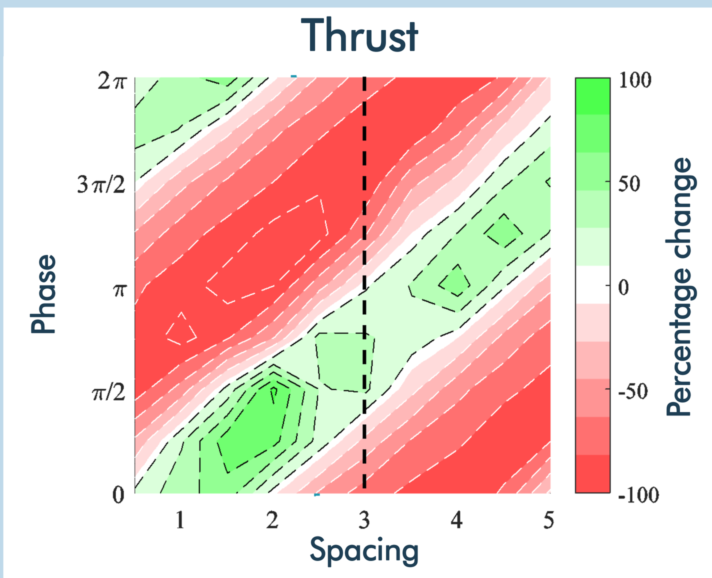
Flippers were **3D printed** in ABS with dye injection ports, they are around 1.2 scale.



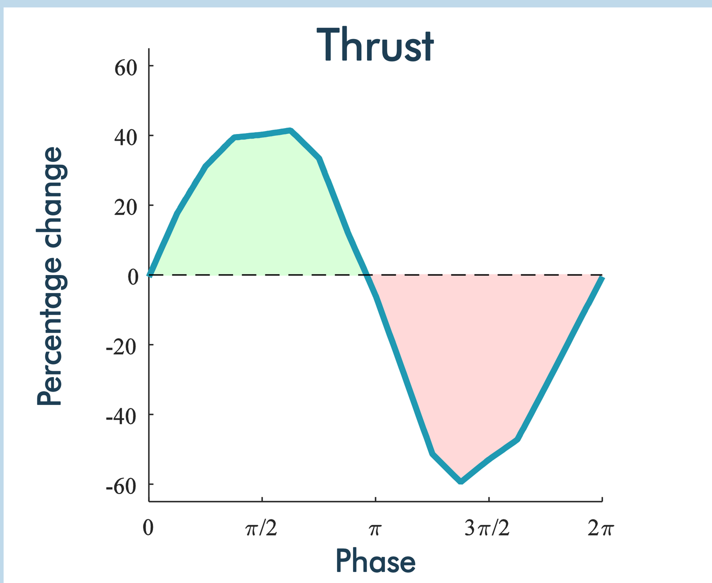
A **'robotic plesiosaur'** that provides **two axes of motion** to each flipper (pitch and heave) was built on top of the flume tank on level 1 of this building.

Results

Data from simulations show that the **thrust** of the hind flippers can be up to **twice as much as a single flipper**. This performance augmentation depends on the **phase** and **spacing** between the flippers.

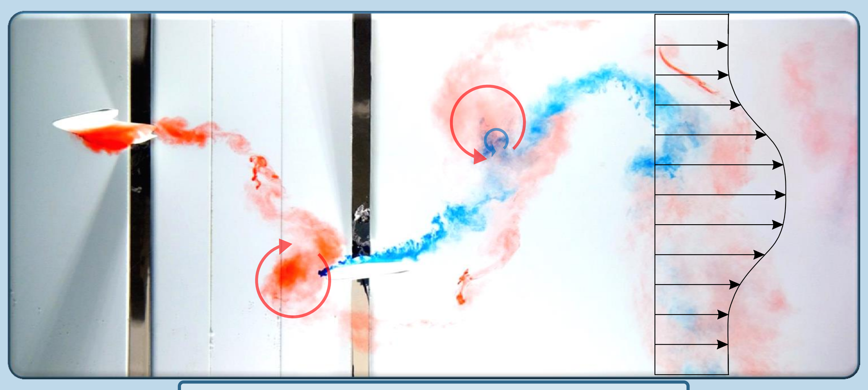


The experimental data at a spacing of three chord lengths show thrust **increases of 40%,** which is understandably lower than the simulations due to 3D and higher Reynolds number effects. Comparable **increases in efficiency** are also observed.



Flow visualisation reveals that the hind flipper has **high performance** (high thrust and efficiency) when it **weaves in between the vortices** that are shed from the fore flipper, but **low performance** when it **intercepts these vortices**.


High performance: hind flipper weaves between vortices


Low performance: hind flipper intercepts vortices

To summarise, the four-flipper system of plesiosaurs enabled them to generate substantially **higher thrust and efficiency**, giving them a crucial **evolutionary advantage**. Not only does this research provide the first **quantitative** data on the hydrodynamics of plesiosaurs, but it also advances our knowledge of the **fundamental mechanisms** of foil/wake interactions, whilst aiding the design and development of **underwater vehicles** and **energy extraction systems** that use tandem flapping flippers.

The Leverhulme Trust
EPSRC Engineering and Physical Sciences Research Council
erc European Research Council
Established by the European Commission