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How fast could a mermaid swim?

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Abstract

This paper investigates the potential swimming speed of the popular mythical creature, the mermaid. In order to calculate this speed, the motion of swimming was considered and the assumption that the tail of the mermaid would swim and produce the same amount of power as a bottle-nose dolphin's tail during swimming. Through the consideration of the forces of thrust, the power generated by one stroke and drag, the speed was calculated at 5.93 ms^{-1} .

Introduction

Mermaids are historic mythical creatures that are famous for being half human and half fish. This paper investigates the average speed at which a mermaid could swim and compares this to humans and dolphins. The classical representation of a mermaid is going to be used for calculations, with their upper bodies being a female human and their lower bodies being a tail. The assumption is made that mermaids have the same physiological features as humans, such as metabolism, with the only difference being the ability to live and breathe under water.

Swimming motion

There are two main modes of swimming; side-to-side and up-and-down motion. Fish tend to swim with tails moving side-to-side, whereas whales, dolphins and other mammals use the up-and-down motion. This is due to bone structure and the alignment of the hips in the organism. As mermaids would be mammals, their hips would be aligned like the aquatic mammals, and would therefore use the up-and-down motion [1]. The assumption is also made that the mermaid will be swimming with her hands placed in front of her head, making a pointed tip like that of a dolphin's nose. This would allow her to be in streamline. The mermaid will only use her tail to swim, mimicking the shape and motion of a dolphin.

Calculating the speed of swimming

The swimming motion of a mermaid will be modelled as the common bottle-nose dolphin, due to the assumptions made about her mode of swimming. The

head, arms and hands were modelled as a cone, the torso as an open cylinder, and the tail as a trapezoidal prism as shown in figure 1. The length of the mermaid was calculated at 188.54 cm [2, 3]. The surface area and mass of the major body parts of the mermaid were calculated, showing in table 1 [2].

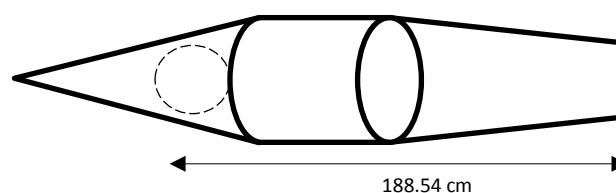


Figure 1 – An illustration of the model of the mermaid to calculate the surface area for different parts of the body (not to scale)

Body Part	Surface area (m^2)	Mass (kg)
Full body	3.71	83.84
Torso	0.56	21.79
Cone	0.78	15.21
Tail	2.37	46.84

Table 1 – A table to show the dimensions of the mermaid's body [2].

Newton's first law of motion was considered when calculating the swimming speed. This law states that an object at rest will stay at rest, and an object in motion will stay in motion, unless there is an external force applied [4]. In order to propel herself forwards, the mermaid must produce a thrust force which would have to be greater than the drag force exerted on her body. Drag is the force the fluid exerts on the mermaid as she moves through the seawater [4]. The

magnitude of drag is dependent on the position and shape of the body, as friction occurs as she moves through the medium [4]. As the model shows, the drag is minimised because the resistance to the fluid's flow is dramatically reduced by the shape of the mermaid, with her essentially cutting through the fluid.

Equation 1 showing power, P , was derived which considers all the physical forces that the mermaid experiences when swimming. The drag force is calculated by the following, where b is a constant, v is velocity, W is work done, and t is time [4].

$$\begin{aligned} F_D &= bv^n \\ P &= \frac{W}{t} = F \frac{dx}{t} = Fv = (bv^n)v \\ P &= bv^{n+1} \end{aligned} \quad (1)$$

Relating this power back to drag (equation 2), where ρ is the density of the medium, C_d , is the drag coefficient, A is the surface area, and F_D is the drag force [5],

$$F_D = \frac{1}{2}\rho C_d A v^2 \quad (2)$$

Therefore, b is equated to $\frac{1}{2}\rho C_d A$, and n is equal to 2 as the velocity is squared in equation 2. This is then substituted into equation 1 to give equation 3.

$$P = \frac{1}{2}\rho C_d A v^3 \quad (3)$$

As power is proportional to v^3 , the equation can be rearranged to give the swimming velocity, equation 4.

$$v = \sqrt[3]{\frac{P}{\frac{1}{2}\rho C_d A}} \quad (4)$$

As previously stated, the power output is generated by the muscles of the tail when they thrust downwards. It is assumed that the tail of the mermaid has the same muscles that dolphins have, so the power generated from thrust would be the same for the mermaid [6].

The thrust power generated per kilogram is valued at 30.50 Wkg^{-1} for a common bottle-nose dolphin [6].

This is converted to power by using the calculated mass for the mermaid's tail (46.84 kg) using table 1. This results in the power generated by the tail being 1428.62 W. When considering the drag coefficient, the one of a dolphin was used at 0.0036, due to the aforementioned assumptions of streamlined swimming [7]. The next parameter to determine would be the surface area of the mermaid's, which was calculated at 3.71 m^2 . The density of sea water was used which is 1025 kgm^{-3} (at $21 \text{ }^\circ\text{C}$) [8]. Then inputting these values into equation 4, swimming speed is found.

$$\begin{aligned} v &= \sqrt[3]{\frac{1428.62}{\frac{1}{2} \times 1025 \times 0.0036 \times 3.71}} \\ v &= 5.93 \text{ ms}^{-1} \end{aligned}$$

This is relatively fast, especially when compared to the average human swimming speed which is around 1.64 ms^{-1} [9]. The average swimming speed of a bottle-nose dolphin is 5.65 ms^{-1} [6]. This makes the mermaid 3.62 times faster than a human, and 1.05 times faster than a bottle-nose dolphin. It is expected that the mermaid only swims a little faster than dolphin, as the drag coefficient was that of a dolphin. However, a limitation of this model is although, the mermaid would have its hands pointed, this would not be aerodynamically the same as the shape of the dolphin. Further, the model assumes the drag coefficient of the mermaid would be that of the dolphin due to having a similar shape. However, due to differences in skin type, as the mermaid is half human and half fish, this not the case. If the drag coefficient was increased, as the friction of human skin in water is larger than dolphin's, the mermaid's swimming speed would be less than a dolphin's.

Conclusion

The speed of the mermaid was calculated to be 5.93 ms^{-1} which is faster than the average human and bottle-nose dolphin swimming speeds. This was then compared to the swimming speeds of humans and dolphins, making the mermaid the fastest. The mermaid was only slightly faster than a dolphin, which was expected when modelling her mimicking a dolphin's shape.

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