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P4_4 Swimming Efficiency

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Abstract
The claim that it is easier to swim with the head completely out of the water is investigated, comparing the extra drag created with this position with the extra energy created through being able to breathe constantly. It is found that the best position to use depends on the velocity of the swimmer.

Swimming Efficiency

It has been suggested that – contrary to the accepted style in competitive swimming – it is easier to swim front crawl with the head out of the water (see Fig.1).

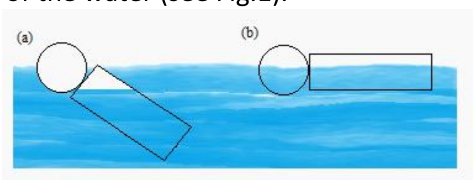

Figure 1. It has been suggested that the extra drag created by position (a) is compensated for by easier breathing due to the head being out of the water, thus making position (a) favourable to (b).

In order to investigate this claim, it is assumed that for a position to be "easier", less energy is needed to maintain it. It shall be examined whether the extra energy needed to overcome the drag force in position (a) is equal to the energy that is created by being able to breathe continuously.

A Simple Model

It can be seen by observation that a body is able to float horizontally on the surface of water, but when intentionally attempting to keep the head above the surface, the lower half of the body tends to drag downwards (as in Fig. 1).

First let us consider the force needed to overcome the extra drag in position (a). By simplifying the human body as much as possible, the drag coefficient of positions (a) and (b) can be estimated.

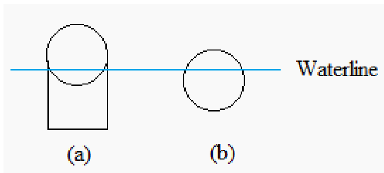

Figure 2. Simplified cross-sectional areas of positions (a) and (b) considering the swimmers head-on. It is estimated that the drag coefficients, C_D, are ~1.0 and ~0.5 respectively [1].

The drag equation must be used [2]

$$\boldsymbol{F}_D = -\frac{1}{2} C_D\, A\, \rho\, \boldsymbol{v}^2, \quad (1)$$

where C_D is the drag coefficient, A is the surface area perpendicular to the direction of motion (calculated by estimating the head to have a diameter of 20cm and torso of 40cm by 60cm), and ρ is the density of water (taken to be 1000 kgm^{-3}[3]). Using these values, we can see how the drag force changes with respect to the velocity of the swimmer (Fig.3).

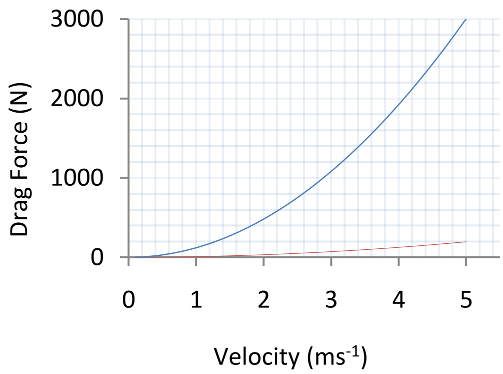

Figure 3. The relationship between the drag force and the velocity of the swimmer. Position (a) is in blue, and (b) is in red.

Let us now consider the energy that is created when breathing. It can be assumed that in position (a), the swimmer may breathe continually, whereas in position (b) the efficiency of creating energy through breathing is the same, but the swimmer is only breathing (say) 30% of the time. An approximation for the energy available for mechanical work from breathing for a 60kg person is around 24 000 J per minute [4].

Considering a person swimming for 1 minute, and using a relation between work done and force [2]

$$W = \int F \cdot ds, \qquad (2)$$

allows the difference in energy (energy created when breathing minus the energy needed to overcome drag force) to be plotted against velocity (Fig. 4).

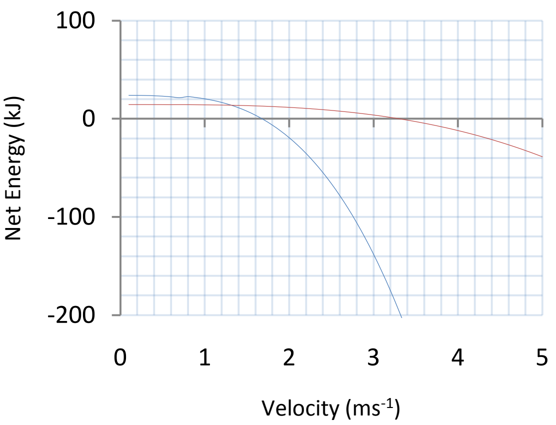

Figure 4. The net energy against velocity. It can be seen that initially, position (a) is favourable in terms of net energy gain, but at ~1.4 ms^{-1} this is no longer the case.

Discussion

It has been shown that for less that 1.4ms^{-1} position (a) does indeed make swimming "easier" as there is a larger net gain in energy than for position (b). However, it is more difficult to reach higher speeds with position (a). Fig. 4 implies that it would be impossible to reach a speed of greater than 1.7ms^{-1} with position (a), and 3.4ms^{-1} with position (b). The fastest recorded speed of a swimmer is approximately 2.4 ms^{-1} [5], so this does not contradict the results (as competitive swimmers would be closer to position (b)).

This is obviously a very simplified model, and could use many improvements to obtain more accurate results. The drag coefficients of the two positions could be found more accurately by doing experiments, and the effect of actually swimming the stroke could be examined, rather than just propelling simplified shapes through the water. Also, professional athletes incorporate the act of breathing into their stroke, so that they may breathe when needed without expending unnecessary energy.

Conclusion

It has been found that swimming with the head above the water is indeed more favourable in terms of energy expenditure, up to velocities of 1.4ms^{-1}. It is then more favourable to be as streamlined as possible rather than to breathe as much as possible.

References

[1]http://www.engineeringtoolbox.com/drag-coefficient-d_627.html (viewed 02.11)

[2]G. Woan, *The Cambridge Handbook of Physics Formulas*, (Cambridge University Press, 2003 edition), p. 85

[3]http://www.engineeringtoolbox.com/water-density-specific-weight-d_595.html (viewed 02.11)

[4]*Physics Challenge,* (University of Leicester, Department of Physics and Astronomy)

[5]http://www.swimnews.com/news/view/6827 (viewed 02.11)