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P3_5 Ah-Buoy!

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Abstract

The film *Pirates of the Caribbean: The Curse of the Black Pearl* depicts two pirates who use an upturned rowing boat to escape to a ship anchored offshore. This paper investigates the feasibility of this submersible using two methods. When considering the buoyancy of the boat to see if they could walk along the sea bed, it was found that the volume of water displaced by the boat and pirates was too large for the pirates to hold the boat underwater. Secondly by considering the amount of oxygen available to the two pirates inside the boat, it was concluded that they would be able to remain underwater for 2 hours and 56 minutes. Therefore there would be more than enough oxygen for them to cross a small bay underwater.

Introduction

In the film *Pirates of the Caribbean: The Curse of the Black Pearl*, two pirates use an upturned rowing boat as a breathing apparatus to enable them to walk along the bottom of the sea to sneak onto a ship anchored offshore [1]. This paper analyses the feasibility of this submersible by two methods; firstly considering the buoyancy of the boat and pirates to see if they could walk along the sea bed, as depicted in the film *(fig. 1)*, and secondly by considering the amount of oxygen available to the two pirates inside the boat.

System

For both methods, the rowing boat was assumed to be an air-tight cuboid of length 4m, width 1m and depth 0.5m, and the effects of the pirate's heads and shoulders on this cuboid are neglected. Therefore the volume of air inside the boat is 2m^3.

Sea Stroll

The pirates will float to the surface if the buoyancy force F_b is greater than the force of gravity on the boat and pirates F_g, as given by inequality 1:

$$F_b > F_g \,,$$
$$\rho_w V_{disp} g > (m_p + m_b) g \,, \tag{1}$$

where ρ_w is the average density of seawater (1030 kgm^{-3} [2]), g is the gravitational acceleration and V_{disp} is the volume of water displaced by the boats and pirates. The masses of the two pirates and the rowing boat are given by m_p and m_b respectively. Assuming that the mass of 2 pirates is 160kg and the mass of a boat is 200kg, equation 1 can be rearranged to give an inequality for the volume of water displaced by the boat and pirates' bodies that will cause the system to float as

$$V_{disp} > 0.36\text{m}^3. \tag{2}$$

Breathing Lessons

The gases inside the boat that are relevant are oxygen, which the pirates need to breath, and carbon dioxide, which can be harmful if inhaled in large quantities. Composition of air that is breathed in is made up of around 21% oxygen and 0.04% carbon dioxide, the air that is breathed out is composed of 16% oxygen and 4% carbon dioxide [3]. The remaining 1.04% is water vapour. Therefore 3.96% of the air in each breath is converted from oxygen to

Figure 1: A frame from *Pirates of the Caribbean: The Curse of the Black Pearl* showing the two pirates with their homemade submersible. © Walt Disney Pictures 2003.

carbon dioxide, this will be called the conversion percentage and is assumed to be constant with every respiration.

When the carbon dioxide concentration reaches 7-10%, poisoning can occur with the symptoms of suffocation, dizziness and unconsciousness. [4]. Therefore it is assumed that the pirates reach critical conditions when the percentage of carbon dioxide reaches 7%.

Tidal volume, the volume of air breathed in each breath, of an average adult at rest is 0.5L [3], or $5 \times 10^{-4} m^3$. This is multiplied by a factor of 2 to account for both pirates. If the combined tidal volume is multiplied by the conversion percentage this will give the volume of oxygen converted to carbon dioxide with each breath to be $3.96 \times 10^{-5} m^3$.

The breathing frequency of an average adult at rest is between 12-20 breaths per minute [5]. The assumption is made that the two pirates breathe at a rate of 20 breaths per minute, as although they are only walking it is harder to move underwater than it is on land.

Breathing Discussion

Using the percentage composition of air stated in the previous section, the volume of oxygen and carbon dioxide initially in the boat is $0.42 m^3$ and $8 \times 10^{-4} m^3$ respectively.

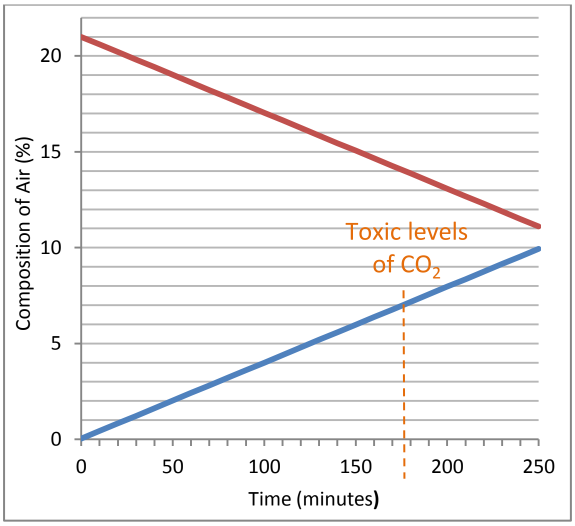

Figure 2: A graph to show how the composition of air inside the boat varies with time. The pink line represents the decreasing oxygen levels and the blue line represents carbon dioxide levels.

Using an iterative process the percentages of oxygen and carbon dioxide every minute (at a rate of 20 respirations per pirate) were found. These percentages are shown in *fig. 2*, which indicates that the carbon dioxide reaches toxic levels after 176 minutes. Therefore the pirates could walk under the boat for 2 hours and 56 minutes.

Conclusion

The minimum value of water displaced by the boat and the pirates that would cause them to float is $0.36 m^3$. This is a much smaller volume than the estimated volume of air inside the boat, even neglecting the volume of the pirates, so the pirates would be unable to hold the boat underwater.

In the film the boat appears to be quite far away, but it is expected that two men could cross a small bay in almost 3 hours. If the pirates had to move quickly to reach the boat, their respiration rate would increase, decreasing the time until carbon dioxide toxicity occurs. However, even as an underestimation of the time they could survive underwater, the use of an upturned boat is still feasible.

In conclusion, the air in the boat would be too buoyant for the pirates to hold it underwater but if they could, there would be more than enough air available in the boat to allow two pirates to traverse a small bay, without needing to come up for air!

References

[1] *"Pirates of the Caribbean: The Curse of the Black Pearl",* 2003, Gore Verbinski (Director), Walt Disney Pictures, USA.

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[4]www.epa.gov/ozone/snap/fire/co2/co2report.html accessed on 05/11/2012.

[5] G. Tortora, *Principles of Anatomy and Physiology* (Harper-Collins, New York, 1990), Ed. 6, p. 707.