# The physics and hydrodynamics of swimming

Swimming is the self- propulsion of the body through water using arm and leg movements and flotation. The science of swimming involves the interaction of forces which allows the body to be propelled through the water. This research document focuses on Newton's Laws, the forces present between the water and the swimmer, kinetic energy and wave motion.

**Newton's Laws**

Newton's third law states that for every action, there is an equal in magnitude but opposite in direction reaction. Newton's third law is often present in swimming. For example, when a swimmer pushes off the wall, the swimmer accelerates in the opposite direction (Khan Academy). Another example is when swimming any specific stroke. When swimming any of the 4 main strokes the swimmer's hands pull the water backwards. The water then exerts an equal and opposite reaction and pushes the swimmer forward.
Newtons second law is Force = Mass x Acceleration. In swimming this means that swimmers with different masses exert different amounts of force and when swimmers generate different forces, they move at different speeds in the water.

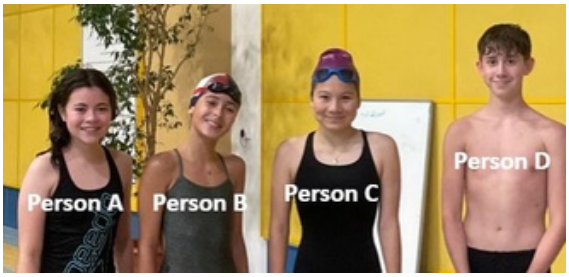


*Image 1. Marshall, Layla. Photo of self and 3 swimmers.*

As you can see in the image to the left, person A and B have a less mass than person C and D. Using the formula F= m x a, person C and D would need significantly more force to accelerate as fast as person A and B as they don't have as much mass as C and D.

Newtons first law states that an object at rest will remain at rest unless acted upon by an unbalanced force. For swimmers this means in order to start swimming, pushing off the wall or the diving block is required.

**Forces between the water and the swimmer**

There are four forces that are present between the water and the swimmer. The forces are drag, thrust, buoyancy and gravity.

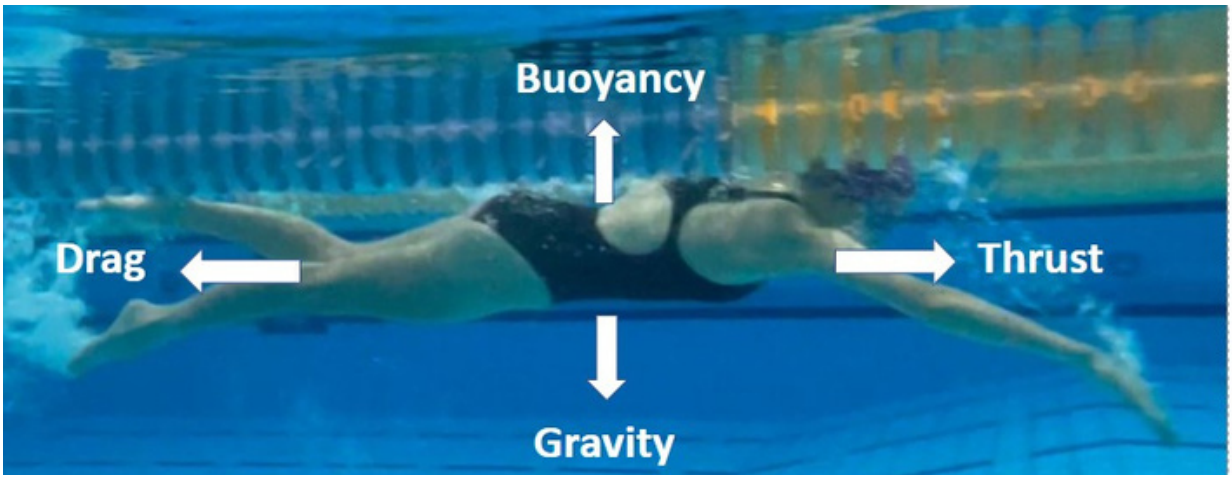


*Image 2. Marshall, Layla. Photo of self swimming.*

Drag is the force which acts opposite of the motion of an object. In swimming, the drag force is the resistance of the water on the swimmer. Swimmers face three types of drag when swimming, which includes frictional drag, pressure drag, and wave drag. Frictional drag is the drag between the water and surface. The water next to the swimmer flows in the direction the swimmer is moving, and the water that isn't flowing in the direction of the swimmer flows in the opposite direction which makes it hard to move forward. Pressure drag is the resistance caused due to different pressure distributed to different parts of the swimmer's body. The highest pressure is on their top of the body because the swimmer's head breaks through the water first. The lowest pressure is on the back. This force pushes back the swimmer because of the difference in pressure. The last drag force which a swimmer encounters is the wave drag. Wave drag happens because as a swimmer moves forward there is some water that is pushed in front of the swimmer which causes a barrier, and the swimmer has to swim over-top it. This barrier is known as the wave barrier (National Science Foundation). There must be a force which pushes the swimmer forward in order to balance the drag force. This force is called the thrust force. Force is a vector quantity meaning it has both magnitude and direction. When a swimmer moves their arms and kicks their legs the swimmer creates the thrust force which lets them move (Real World Physics Problems). In freestyle, the thrust force is predominantly created by the swimmers arms which include the hand, forearm and upper arm. The swimmers legs thrust the swimmer to move forward and also help the body stay in a streamlined position to reduce drag. The magnitude of the thrust is dependent on how fast the swimmers arms and legs move (NASA).

To minimize drag in the water, swimmers try to make their bodies as horizontal as possible and try to be as small as possible. This looks like breathing to the side (freestyle), having pointed toes, rotating the hips and shoulder at the same time and keeping head down at all times. Small things like this reduce drag and cause less resistance (ExplainThatStuff). The less area the swimmer takes up, the less resistance.

R= 1/2DpAv^2. R- resistance, D- drag coefficient, p- water density, A- reference area, v- speed. (SlideServe)

On top of this swimmers consider what they are wearing. This includes wearing specific types of goggles and swimsuits and thinking about hair. Most swimmers shave their body hair before competitions because hair creates drag. Removing body hair makes the swimmer more hydrodynamic. Swimmers also wear swim caps to reduce drag. The majority of swimmers wear two swim caps. Typically, swimmers put on an inner latex cap to ensure that it stays on, as latex sticks to the head and the second cap is normally a silicone cap as it wrinkles less than a latex cap. The silicone cap is much smoother which reduces drag (The New York Times). Swimmers also have special goggles that they wear when competing which are called 'competition goggles.' These goggles are low profile meaning they are very close to the eye-socket which reduces resistance and drag (Blue Buoy). Lastly, during races swimmers wear a certain type of swimsuit, a 'skin.' Skins are made of lightweight fabric, for example carbon fiber. This material does not weigh down swimmers. This material is also a water repellent which reduces water saturation and creates a friction-less surface. Additionally, skins are almost seamless. This gives the skin a tighter fit and reduces drag.


*Image 3. Arena skin.*

A study done by Journal of The American College of Sports Medicine, revealed that on average a swimmer's performance can improve by 3.2% when wearing a skin. The study also showed that wearing a skin can reduce drag by 4.4% to 6.2% and can reduce the amount of energy needed to swim by 4.5% to 5.5%. Another study done by Hartmutt Sandner, found that skins allow for longer glides because the material that skins are made of have little resistance. (Swimming World).

The gravitational force in swimming is the downward force which depends on the mass of the swimmer. Buoyancy force is when the water pushes the swimmer upwards which has a value that is proportional to the volume of water that is displaced by the swimmer. For a swimmer to stay on top of the water, the buoyancy force has to be equal in magnitude to the gravitational force (Wired). The buoyancy force “lifts” the object. This lift principal is based on Archimedes' principle which states that any object (regardless of its shape) that is suspended in a fluid (such as water), is acted upon by an upward buoyant force equal to the weight of the fluid that is displaced by the object. Additionally, the buoyancy force acts through the Center of Buoyancy. The center of buoyancy relates to the center of the object. For a body to maintain its orientation the buoyancy force must pass through the center of the body. Center of buoyancy is the 'centroid of the immersed part of a ship or other floating body,' (Oxford Languages). This is necessary because the pressure on both sides of the swimmer are equal in magnitude, but opposite in direction which allows the body to float on top of the water as they are able to cancel each other out (Center of Buoyancy: Definition & Formula, Study).

**Kinetic Energy**

Kinetic energy is defined as the "energy which a body possesses by virtue of being in motion" (Oxford Languages). In other words it is mass travelling at a certain velocity. Kinetic energy formula is K.E. = 1/2 m v^2. In swimming, initially the swimmer has potential energy in the muscles which propels the swimmer forward. The kinetic energy is the movement of the swimmer through the water. Ultimately, the swimmer will stop as all of the energy would have transferred into the water.

The kinetic energy available to the swimmer is made up of positive and negative kinetic energy. The positive type of kinetic energy is created when the swimmer kicks their legs and moves their arms in a straight line through the pool which propels them through the water. There is also negative kinetic energy in the water. This is when kinetic energy is created by ineffectual movement and decreases the positive kinetic energy. When this happens, and all the negative kinetic energy is added up, it significantly decreases the amount of positive kinetic energy created by the swimmer. This reduces the forward velocity (SwimSwam).

**Wave Motion**

As mentioned above, one of the types of drag is wave drag which is the resistance caused by turbulence on the surface of the water. However, does wave motion affect the swimmer? It depends. This is known as the wake effect. The "wake" is the water that goes to the side of the swimmer. If the swimmer is able to find the correct position relative to the swimmer in front, it can be beneficial. This is because the swimmer in front can create a current in favor of the swimmer. Wave motion can also be a disadvantage to the swimmer because if the swimmer is not timed properly they would need to tackle the waves. This can cause the swimmer to loose speed and even control. The faster the swimmer swims the more "wake" there is. In a pool, the swimmers who swim on the outside lanes are affected by the wake. There is rebound turbulence which bounces off walls and onto the swimmer, whether it be an advantage or not.

Having said that, modern pools have been designed to be as fair as possible. They are constructed so that the outer lanes are slightly wider than the rest of the lanes. This minimizes the rebound turbulence reflecting off the walls. Another new design are the lane ropes. The new style of lane ropes are anti- wave discs which break down the waves created in the pool. They waves are absorbed and the lane ropes provide a strong barrier. Lastly, pools are now three-meters deep rather than two- meters. This reduces the significance of the disturbance in the pool (BBC, Jon Rudd).

Swimming does not come naturally to humans. However, humans know about science and now we now understand the physics and hydrodynamics of swimming which we are learning how to apply in the water to swim more efficiently.

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