Physics of Swimming: Conditions that Affect the Passive Drag on a Swimmer in Streamline Position

Evan Hagedorn
Physics Department, The College of Wooster, Wooster, Ohio 44691, USA
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The purpose of this experiment is to explore the variables that affect the efficiency of a swimmer in the streamline position. There are various factors that affect the drag of a swimmer such as: the type of suit, wearing a cap or not, and the depth of the push off. The hydrophobicity of a fast suit and a regular suit was measured to show which one will be the most effective in the water. The contact angle of the fast suit was 20° less than that of the regular suit meaning it is more hydrophobic and will produce better times in competition. The effects of suit and cap were tested by having the swimmer push off of the wall wearing two different types of suits and wearing a dome cap versus not wearing a cap at all. The depth was tested by having the swimmer push off deeper than one normally would to see the effects of pressure drag. The results showed a 44% decrease in drag while wearing a fast suit and cap compared to wearing a regular suit without, and the push off at a deeper depth yielded a 49% increase in drag compared to the original push off depth.

I. INTRODUCTION

For years there has been a debate on how much of a difference wearing a specific suit actually makes on the speed of a swimmer in the water. The same has been discussed about caps. Caps are supposed to reduce drag by eliminating the aspect of hair on the persons head, but how much of a difference does all this really make?

There is no doubt that swimming has gotten much faster over the years. Records are being broken constantly, but how much of that is due to new technology and how much is credited to better training regimens?

Swim suit technology has definitely developed over the years. In the 1930s, male Olympic swimmers wore baggy swimsuits made of cotton. They developed into smaller and tighter suits in hopes that decreasing the amount of material would decrease the drag on their body and make them go faster. In the 1980s swimmers started wearing swim briefs made of spandex, similar to the regular suits that are used for training now. In 2000, water repellant fabrics began to take hold of the swimming community [2]. They began developing suits that would cover almost the entirety of the swimmers body, attempting to maximize the hydrophobicity of the swimmer and therefore helping the swimmers body become more buoyant and cut through the water. Full body suits were made illegal in 2008 because they were said to be taking away the talent element of the sport and making it too easy to break records. Male swimmers were reduced to wear suits that covered the area from the waist to above the knees.

There have been new swim suit designs that are believed to significantly reduce drag while still using the legal amount of material. The theory is that these suits are made with a complex hydrophobic material that allows the swimmer to glide through the water with minimal resistance. The material for the fast suit that I will test is composed of a nylon microfiber/elastane two-way stretch woven fabric. This type of material and the way it is woven makes it very light weight and thin.

New designs for swim caps have supposedly turned them into more efficient pieces of equipment for swimmers. Dome caps are an example of this new technology and are better because they get rid of the standard rippling effect that occurs in regular swim caps. Dome caps have a piece of flexible plastic going down the middle of the cap that reduces this effect. The idea is to minimize the drag created by these ripples and therefore support faster swimming.

The drag is also affected by the depth of a swimmer as they push off the wall. The theory is, that if they push off too high, then their buoyancy ends up forcing some of their body to break the surface too early and therefore significantly increasing drag, but if they push off too deep, then there is an added pressure drag acting upon the swimmer.

In this experiment, I test two types of suits: a fast suit and a regular suit. I seek to test the hydrophobicity of the suit as well as the drag force present on the swimmer while wearing it to see if there is a significant change from a regular nylon and spandex suit. The maximum amount of material allowed on the body is from the waist to the knee for male swimmers, this type of suit is called a jammer style suit. These suits are meant to be worn very tight so there is no loose material causing unwanted resistance. The other type of suit is a racer style suit and is the classic “Speedo” that wears similar to briefs. To keep consistent with the amount of material, both types of suits that will be tested will be the jammer style.

II. THEORY

Hydrophobicity is the ability of a material to repel water. This is commonly measured using something called the contact angle. The contact angle is defined as an interaction between the water droplets’ liquid/gas interface coming into contact with the solid surface of the material being tested [4]. The contact angle is measured by finding the angle between the horizontal surface that the drop of water is placed on, and the tangent line of the

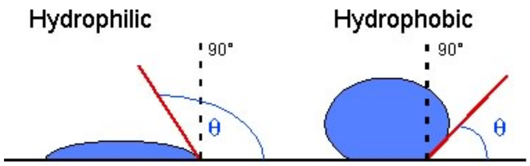

FIG. 1: This figure illustrates the difference between a drop of water on a hydrophobic material and a hydrophilic material.

droplet which intersects the horizontal line at the base of the droplet (Fig. 4). If the contact angle is greater than 90° it is said to be hydrophilic and if the angle is less than 90° it is hydrophobic [4] as seen in Fig. 1.

The hydrophobicity of the material is theoretically supposed to repel the water and therefore allow the swimmers hips to rise to the surface. Having hips on the surface is key to the success of almost all of the strokes. The idea is to make a near frictionless surface to the water so that there are no obstructions such as hair or even skin that could slow the swimmer down.

This experiment will be testing the amount of drag in the streamline position and ways to reduce it. The streamline is when a swimmer is the fastest in the water because they have made themselves as hydrodynamic as possible, as seen in Fig. 2.

Another component of this experiment is understanding the concept of drag and its effects on underwater moving objects. The type of drag that will be effecting the swimmer during the streamlined glide is called passive drag. Passive drag is a type of hydrodynamic drag affected by the size, shape, and cross sectional area of the body as well as the velocity and depth of the swimmer [9]. Originally, I was going to use the equation for drag of underwater objects defined as

$$F_D = \frac{1}{2} D \rho A v^2, \tag{1}$$

where D is the viscosity constant for the water, ρ is the density of the water, A is the cross sectional area of the object, and v is the velocity of the object. This equation, however, only showed me the effect of velocity on the drag force, not the effect of the variables that I wanted to test. So a better method for finding the relationship of the variables on the drag force was using the Work-Kinetic Energy Theorem where,

$$W = \Delta KE \tag{2}$$

and

$$W = F_{avg} d. \tag{3}$$

W is the work done against the swimmer and is equal to the swimmer's change in kinetic energy, ΔKE. Work is defined as a force over a distance, so the work in this case is equal to the average drag force F_{avg} over a distance d.

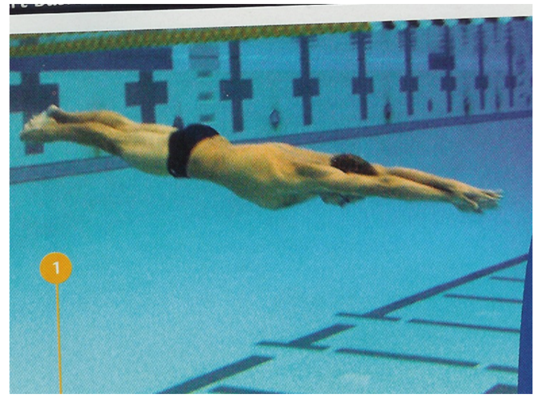

FIG. 2: Swimmer in streamline position, attempting to minimize the amount of drag by making his body as thin as possible [11].

This method uses the initial velocity and the final velocity of the swimmer to determine the change in kinetic energy and relating that to the average drag force on the swimmer through the work done to slow them down. This method of analysis omits the struggle of finding out the temperature, density, and viscosity of the pool water because the loss of energy will be related to the drag making the calculations a much simpler process.

III. PROCEDURE

A. Measuring Hydrophobicity

The hydrophobicity was measured by viewing a droplet of water on the suit material through a microscope. The fast suit material was clamped down onto a lab jack and the droplet of water was placed in the path of the microscope. The apparatus used can be seen in Fig. 3. The camera was set up to take a picture of the droplet through the microscope so the contact angle could be measured using the Canvas program on the computer. This process was repeated for three different droplets on the fast suit as well as for three different droplets on the regular suit material.

B. Drag Measurements

Four different conditions were applied to the swimmer to test the effects of various components on the drag force. The suit drag was determined by timing the swimmer over a specific distance. Their hands were measured from their extended streamline position, just before pushing off of the wall, to a mark 7.87 meters from the wall. The total distance measured was 5.6 meters. The swim-

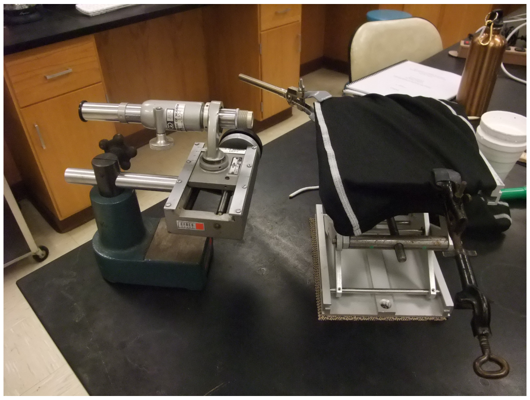

FIG. 3: This image shows the set up for measuring the hydrophobicity of the two suits.

mer pushed off consistently on the center of the cross on the wall of the pool (0.43 meters below the surface) and parallel to the bottom of the pool. Their times were recorded for ten trials. This process was repeated while wearing a regular jammer without a cap, a fast suit jammer without a cap, and a fast suit jammer with a dome cap. The swimmer's initial velocity was calculated by recording a video of the first second of the streamlined glide and using the Logger Pro program. Using their head as a reference point between frames, a mark was placed on their head from right after they had pushed off of the wall. This mark was tracked between frames of the video and the program gave velocities at each point. The velocities were averaged for the first second to give the average initial velocity.

The same procedure was performed to test the effect of depth on the efficiency of the underwater streamline glide. The swimmer pushed off at a depth of 1 meter and wore a fast suit and dome cap for all ten trials to compare to the values received at 0.43 meters below the surface.

All results were from a single swimmer on one day of testing to avoid other factors that could jeopardize the consistency of the experiment. The swimmer also rested in between each trial until they felt ready to push off again.

IV. RESULTS AND ANALYSIS

A. Measuring Hydrophobicity

The angle was determined by using the Canvas program to make a line on the horizontal surface that the water drop is on and a line that is tangent to the droplet while intersecting the horizontal line at the base of the water droplet and measuring the angle between them as seen in Fig. 4. The results are shown in Table I.

The contact angle for the fast suit was less by about 20° meaning that it repels water to a greater degree than the regular suit. Both of these materials, however, are hydrophobic because any material with an angle less than 90° is considered hydrophobic.

TABLE I: The contact angles measured for each droplet on the two types of suits.

Droplet	Contact Angle Fast (°)	Contact Angle Regular (°)
1	41.6	63.2
2	44.1	59.2
3	42.0	66.2

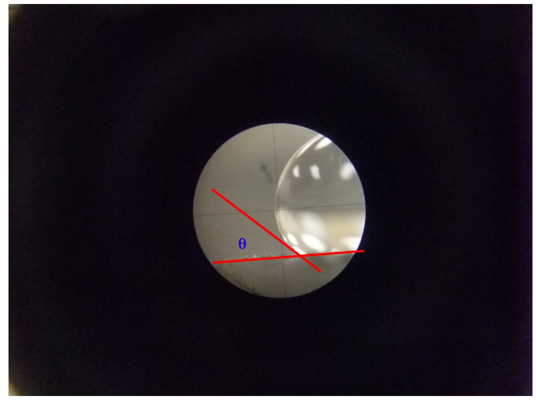

FIG. 4: This image shows how the contact angle was measured. This is droplet number 1 on the fast suit.

B. Drag Measurements

The individual times for each trial can be seen in the plot in Fig. 6. The spread shows a clear difference between the regular and the fast suit trials, but only a slight difference between the fast suit and fast suit plus dome cap trials. The fast suit plus dome cap trial has more times bunched up at around 3.4 seconds while the fast suit trial has more times grouped at around 3.5 seconds. The averages were taken to find the velocity and drag forces on the swimmer as seen in Table II.

The average time it took the swimmer to travel 5.6 meters with a regular suit and no cap was significantly slower than it took the swimmer to travel that distance with a fast suit. The difference is around 0.22 seconds,

TABLE II: The times, average velocities and drag force for each set of conditions.

Condition	t (s)	avg. v (m/s)	F (N)
Regular	3.72 ± 0.11	1.50 ± 0.04	9.84 ± 0.16
Fast	3.50 ± 0.12	1.60 ± 0.05	6.30 ± 0.19
Fast/Cap	3.45 ± 0.14	1.62 ± 0.07	5.53 ± 0.25
Fast/Cap at 1 m	3.80 ± 0.14	1.47 ± 0.05	10.80 ± 0.19

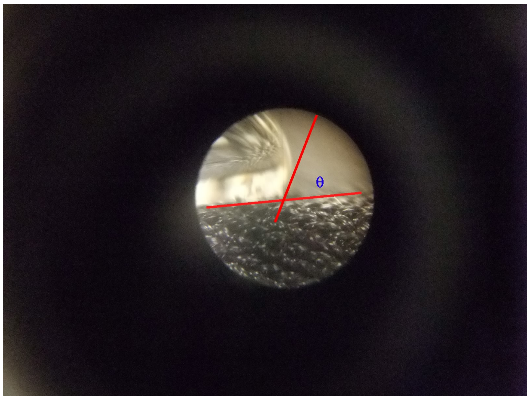

FIG. 5: This image shows how the contact angle was measured. This is droplet number 1 on the regular suit.

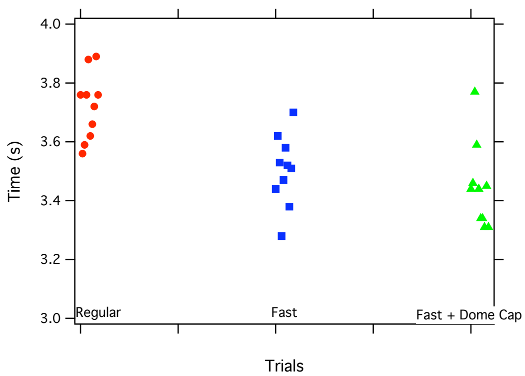

FIG. 6: Graph of the individual times for the trials for each condition.

which is a lot relative to the short distance traveled. The difference between the fast suit and the fast suit and dome cap was much less significant, only a 0.05 second difference. The initial velocity was calculated and found to be 1.75 ± 0.04 m/s, so using Eq. 2 and Eq. 3 and the times recorded, the swimmer's average velocities were measured as seen in Table II, and then used to find the drag force also portrayed in Table II. These results show that there is a 36% decrease in drag from the regular suit to the fast suit without a cap and a 12% decrease in drag from the added dome cap.

The same method of analysis was used to find the effect of depth on the drag of a swimmer and the results, shown in Table II, show a 49% increase in drag when comparing the swimmer wearing a fast suit and dome cap at a depth of 0.43 meters below the surface, to when the swimmer is wearing the same materials 1 meter below the surface.

V. CONCLUSION

Although these values seem very significant, they are not as impressive as they might first appear. The drag forces calculated only account for the streamlined glide, not the entire race. The streamlined glide is only a small portion of the race. The drag from the suit and cap do not account for much of the drag when the swimmer is actually performing their stroke. At that point in the race the majority of the drag is something called wave drag which deals with the water around the swimmer at the surface of the pool.

However, these findings show a large amount of energy being lost due to drag while wearing a regular suit compared to wearing a fast suit and dome cap. Although the forces are small, a 48% decrease in drag is a large percentage of the forces at work, and when added up for an entire race, wearing these suits can be the difference between going a minute versus going under a minute for 100 meters. This is a huge benchmark for swimmers to surpass.

The contact angles of the two suits show that the fast suit is better suited for fast swimming than the regular suit. The degree of hydrophobicity for the fast suit is very high compared to the 20° higher angle of the regular suit. This means that the fast suit will provide a much less resistant surface to the water and allow for faster and longer streamlines.

Some sources of error are present in the experiment. Ideally it would have been better to have multiple swimmers to test instead of just one. A larger sample size almost always proves to yield more accurate results. It would help to eliminate the effect of body shape and size on the results. The amount of hair present on a swimmer also effects the drag, for example, a woman with long hair versus a man with a shaved haircut. These would both yield very different results. The age of the suit plays a role in the hydrophobicity of that suit. Fast suits are said to be fastest the first time you wear them and the one used in the experiment had been previously worn. It would be financially improbable to perform all of these tests with a different fast suit because they are fairly expensive. This loss of hydrophobicity would then lead to possibly more drag on the swimmer. The same concept goes for the regular suit; the older that they are the more stretched out they become meaning that they do not fit as tightly around the swimmer and therefore cause extra drag.

VI. ACKNOWLEDGMENTS

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