Measuring the Drag Coefficient of a Swimmer with a Parachute

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Resistance training with parachutes is common method used by swimmers to build strength. In this experiment a swimmer was towed by a constant force with two different square parachutes in order to determine the drag due to the parachute as well as the from the swimmer's position in the water. The swimmer's positions were all positions associated with the breaststroke pullout. The velocity of the swimmer was dependent on the drag exerted by the water. This force depended on the drag coefficient of the swimmer and parachute as well as the surface area of the swimmer and parachute. A parachute or position with a higher surface area resulted in a lower velocity. From the measured velocities, the drag coefficient surface area was calculated. The drag coefficient are of the swimmer was then subtracted from the parachute trials and the drag coefficients of just the parachutes was found. I saw that as the parachutes area increased, the drag coefficient tended to decrease. The different positions also had an impact on the drag coefficient. Depending on the position, the velocity of the swimmer would change. This would then change the drag coefficient because it is dependent on inverse velocity squared.

I. INTRODUCTION

In order for a swimmer to perform their best, they need to maximize their propulsion in the water while minimizing their drag. With endless hours of practice, swimmers can fine tune their technique to reduce their drag, but each motion of the stroke will cause the drag on the swimmer to change. Swimmers have to power through against this force in order to succeed, and one way they do that is by adding more resistance.

Most athletes use resistance training as part of overall training. A broad definition is "a type of exercise that requires the bodies musculature to move against an opposing force" [1]. The most common form of this type of training is weight lifting. The goal of this type of training is to strengthen muscles in order to increase power output. However, swimmers can use this type of training both in and out of the water.

While swimming, a resistive drag force acts in the opposite direction the swimmer is moving. As a way of incorporating resistance training into a swimmers overall training, coaches will have swimmers increase their drag in the pool. A common method used is to attach a parachute to the swimmer. This increases the swimmer's surface area and drag. Parachute drills are used most commonly by sprinters. These types of swimmers need more propulsion than endurance due the short distances they swim. Different strokes have different areas where propulsion needs to be maximized. For example, in the breaststroke event the most propulsion is needed during the underwater pullout portion of the race.

Here we have measured a swimmer's drag in various portions of the breaststroke with and without parachutes. A swimmer was towed by a constant force while attached to a parachute. The swimmer would hold various positions associated with the breaststroke pullout. Video tracking was then used to find the velocity of the swimmer in each position. By using that velocity, the drag coefficient area of the swimmer with the parachute was found. The area of the swimmer was unknown but the area of parachutes were measured. The values observed for the swimmer and parachute were reduced by the values seen with just the swimmer to give an estimate on the drag coefficient of the parachute in each position.

II. THEORY

A swimmer being towed through the water has four forces acting upon them. These are the force exerted by the towing device F_{T}, the drag of the swimmer F_{D}, the force of gravity F_{g}, and the buoyancy of the swimmer F_{B}. For this experiment, motion was observed only in the direction that the swimmer was being towed in, so gravity and buoyancy were ignored. The overall equation of motion becomes

$$ma = F_{\mathrm{T}} - F_{\mathrm{D}}. \tag{1}$$

Newton's law says the acceleration a of the mass m of the swimmer is given to be the sum of these two forces. In the experiment, the swimmer has a short acceleration phase before reaching a constant velocity. When there is a constant velocity, the acceleration of the swimmer goes to zero and Eq. (2) goes to

$$F_{\mathrm{T}} = F_{\mathrm{D}}. \tag{2}$$

The towing device that was used was a pulley system allowed for a weight to fall. The system was a 5:1 pulley setup. Therefore

$$F_{\mathrm{T}} = \frac{1}{5}W. \tag{3}$$

The pulley system allows for the total weight W of the system to be lifted with 1/5 the force, but that force had to be applied to five times the distance that the mass weights were being displaced. Substituting Eq. (3) into

Eq. (2) gives

$$\frac{1}{5}W = F_{\rm D}. \tag{4}$$

Drag comes in many forms and it could be linear or quadratic. Linear drag means that the drag is proportional to the velocity v of an object and can be expressed as

$$F_{\rm lin} = -bv. \tag{5}$$

The velocity is multiplied by a constant b which depends on the viscosity of the fluid the object is traveling through as well as the objects size [2]. Quadratic drag on the other hand is proportional the velocity of the object squared. It is given by

$$F_{\rm quad} = -cv^2 \tag{6}$$

where the constant c is depends on the object's area and the density of the medium [2]. The total drag can be given by combining Eq. (4) and Eq. (5) to give

$$F_{\rm D} = -bv - cv^2. \tag{7}$$

However, with large objects, the quadratic drag is much greater that the linear drag which allows for the linear component to be ignored. Quadratic drag depends on both the cross sectional area A of an object as well as the density ρ. As seen in [3], it can be rewritten as

$$F_{\rm D} = \frac{1}{2}C_D\rho v^2 A. \tag{8}$$

By substituting Eq. (4) into this equation, the drag coefficient C_D area can be solved as

$$C_D A = \frac{2}{5}\frac{W}{\rho v^2}. \tag{9}$$

Water's density is a constant 997 kg/m^3 for a pool with an approximate temperature of 26.7°C [4].

III. PROCEDURE

A. Equipment

In this experiment, a swimmer was towed by a device called a power rack. This device is a weight system placed at the edge of the pool. A swimmer wears a belt attached to a cord. The main use for the device is to have the swimmer swim against the force exerted by an adjustable stack of weights which range from 6.8 to 45.4 kg. An arrangement of pulleys are used to lift the mass such that the swimmer can move five times the displacement of the weights while only using a fifth of the force exerted by the weights. The power rack was placed between two pool lanes and the lane line which divides the lanes was removed. This was done due to the parachute blending into the black tiles that are located at the bottom of the pool in the middle of each lane. A camera was set up on a tripod up in the stands such that the swimmer would move parallel to it as seen in FIG. 1. Once the camera was turned on, I then had ten minutes to collected data before the recording stopped due to my camera's limitations.

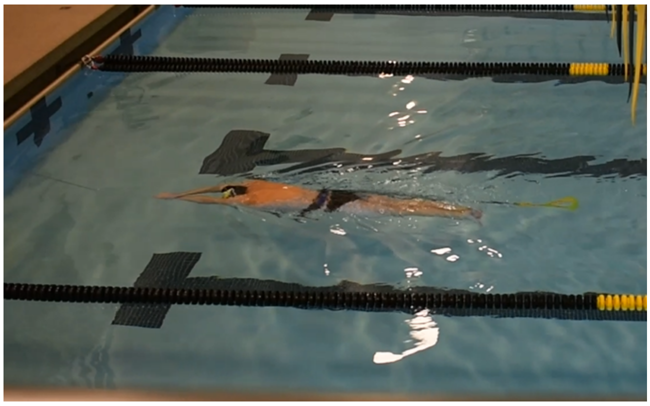

FIG. 1: A screen capture of the streamline position with the small yellow parachute. The swimmer is wearing two belts. One connects him to the power rack and the other connects a parachute to him. The yellow portion on the swimmers cap was used as a reference while tracking. The black portion of the lane line above the swimmer was used to calibrate the distance on the tracking software.

B. Experiment

I used two types of parachute in this experiment. The first was a larger square parachute with an area of approximately 0.109 m^2. The second parachute was another square parachute but this one had an area of 0.032 m^2. The parachutes were attached to a belt which would tow the swimmer through the water. In order to prevent unnecessary currents, data were collected while I was the only one in the pool. I walked out to approximately the ten yard marker and waited for a few seconds in order for any currents to die down. I would then get into the position I wanted to test and be towed by the power rack.

The positions I chose were three common positions associated with the breaststroke pullout. This portion of the stroke is at the beginning of each lap just after the swimmer had pushed off the wall. The swimmer pushes off the wall in the streamline position and holds it for about a second. This was the first position I tested. The rules in swimming state that you can do a single dolphin kick during the pullout portion of the race as long as the swimmer is not in streamline. Most swimmers take this kick after slightly separating their hands above their head. This was the next position I looked at. When the swimmer starts losing speed they can pull their arms down to their hips. The third position was halfway through this pull and the fourth was hands at the swimmer's sides. To complete the pullout, a swimmer will shoot their arms forward back into position two. I decided to use breaststroke, because it is the stroke that I am most comfortable with as well as it is the most inefficient stroke so minimizing drag is a huge part of the technique.

IV. RESULTS & ANALYSIS

A. Tracking

Using the video footage, I used Tracker to measure the velocity of the towed swimmer through the water. Tracker is a program that allows manual or automatic tracking of uploaded video [5]. By manually tracking a reference point on the swimmer each frame of the video, Tracker could find the velocity of the swimmer. The reference point I used was a yellow portion of my swim cap. The program also had to be calibrated in order to track distances accurately. What I used to calibrate the video was the black section of the lane line. This portion of lane line has length 4.572 m. This calibration was used in all videos to maintain consistency throughout the experiment. After calibrating the videos, I plotted the position of the swimmer against time to find the velocity of the swimmer.

B. Streamline position

The first position I looked at was streamline position. As expected the swimmer's velocity decreased as area increased. The observed velocities can be seen in Fig. 2. There are two plots for my test with the large parachute due to the parachute not catching water. This is why the slope of its plot stabilizes later than the other plots. All the velocity plots have this curve in the graph due to the parachute not catching water immediately so I omitted this portion from the graphs and the fits.

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C. Hands apart

The next position I looked at was when the swimmer's hands were apart above their head. In this position, the swimmer has a slightly higher surface area. Because of this, the velocities seen in Fig. 3 tended to be slower than

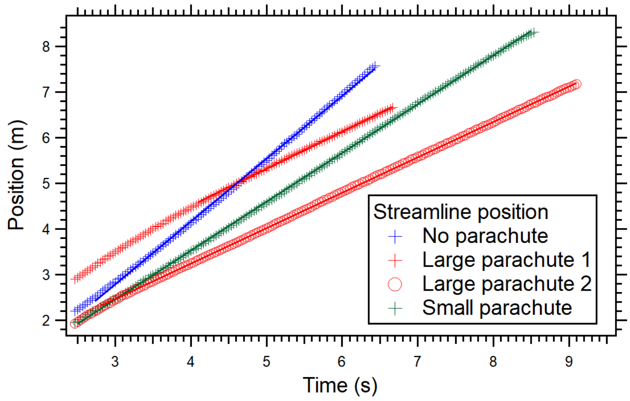

FIG. 2: Measured position vs. time of a swimmer in streamline position without a parachute (blue crosses), with a large parachute (red crosses), with the same large parachute (red circles), and with a small parachute (green crosses).

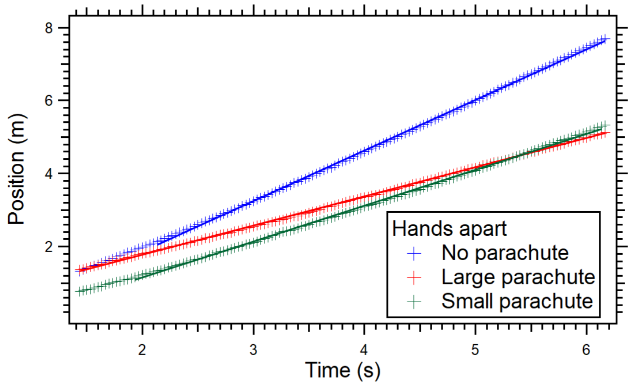

FIG. 3: Measured position vs. time of a swimmer with their hands apart above their head without a parachute (blue crosses), with a large parachute (red crosses), and with a small parachute (green crosses).

Fig. 2. However, the velocity without a parachute in this position was faster than the velocity without a parachute in streamline position. This comes from the difficulty to be in perfect position each run. A possible factor may have been the swimmer's legs may sinking during the streamline position trial. This would have added extra surface area and drag. It is an unknown if this was the only factor that causes this, but I believe that it was due to the swimmer's body position. I was still able to use the velocities found and measure the drag coefficient area which can be seen in TABLE I.

D. Hands out

The third position looked at was when the swimmer's hands were out as if the swimmer were in the middle of a breaststroke pull. This was the position were the swimmer had the most area so the slopes observed in FIG. 4 were much smaller than those seen in the previous

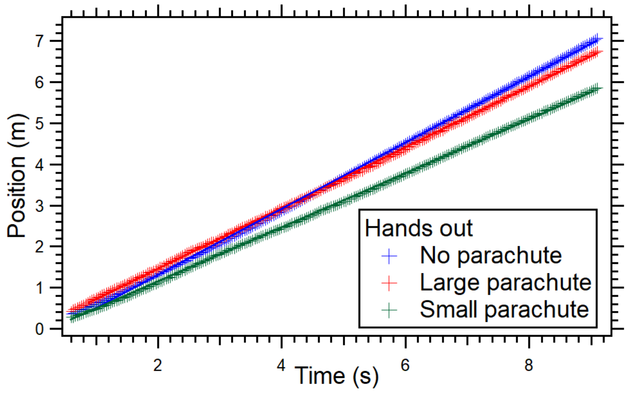

FIG. 4: Measured position vs. time of a swimmer while their hands were in a mid pull without a parachute (blue crosses), with a large parachute (red crosses), and with a small parachute (green crosses).

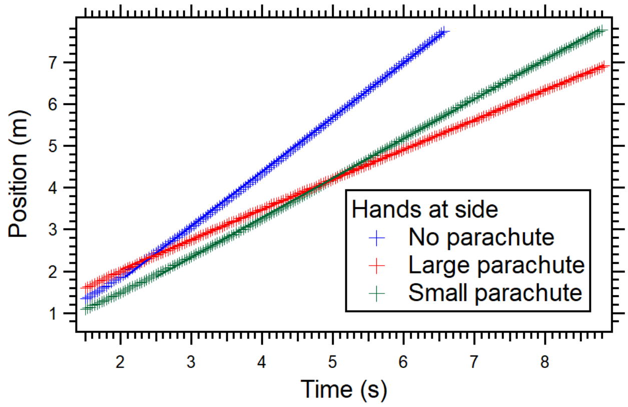

FIG. 5: Measured position vs. time of a swimmer with their hands at their side without a parachute (blue crosses), with a large parachute (red crosses), and with a small parachute (green crosses)

positions. There was another case where the data did not match the expected result while testing this position. The observed velocity with the large parachute was larger than the velocity with the smaller parachute. I went back and looked at the video footage and noticed that the swimmer's body slightly drifted to the side which would have increased their area and resulted in slower speeds. The values of the velocities observed can be seen in TABLE I.

E. Hands at side

The last position I looked at was when the swimmer's hands were at their side. This position had less drag then when the swimmer's hands were out but more drag than when their hands were above their head in the first two positions. There were no cases in this run which were unexpected, so in FIG. 5, the swimmer had the highest velocity while the swimmer with the large parachute had the slowest velocity. The velocities were then used to find the drag coefficient area in TABLE I.

F. Drag coefficient for a the parachutes

By assuming the swimmer's position is the same for each group of runs, the drag coefficient of just the swimmer can be subtracted from the drag coefficient of the swimmer and the parachute. What is left is the drag coefficient of the parachute times the area of the parachute. This can be solved to find the drag coefficient of the parachute. The values found can be seen in TABLE II. I wanted to see if the drag coefficient of the parachute changed due to my position The accuracy could be improved if more runs were performed. As seen with the large parachute in streamline position, the drag coefficient can vary. Since only one of each run was performed the uncertainty in variation is unknown. One overall conclusion I was able to make was that as the parachute size increased the drag coefficient decreased. I had cases where this did not happen, but I believe that is due to there being a large margin of error due to the assumptions I made.

TABLE I: The velocity values given by the fits of of the position vs. time graphs as well as the the associated drag coefficient areas.

Position	Parachute	Velocity m/s	Drag coefficient area m^2
Streamline	None	1.34	0.055
	Small	1.07	0.085
	Large 1	0.856	0.134
	Large 2	0.770	0.165
Hands apart	None	1.41	0.050
	Small	1.017	0.095
	Large	0.817	0.147
Hands out	None	0.813	0.145
	Small	0.665	0.222
	Large	0.752	0.173
Hands at side	None	1.32	0.056
	Small	0.948	0.109
	Large	0.711	0.194

I also wanted to see how the velocity and drag coefficient were related so I plotted velocity over the drag coefficient and area in FIG. 6. This plot shows the runs without added drag were faster than the runs with more drag other than a few exceptions. These exceptions are the lowest velocity point of a swimmer without a parachute and a swimmer with a small parachute. The two points were both from my hands out trial. This trial was the one where the swimmer had the most drag. It was also the hardest position to hold in the water. These points may be off due to that uncertainty. Overall the figure follows a decaying trend which is due to the drag coefficient being related to the inverse velocity squared.

TABLE II: The associated drag coefficients for the large and small parachute during each test. The drag coefficient is a dimensionless constant.

Position	Large parachute	Small parachute
Streamline	0.729	0.966
Streamline 2	1.01	
Hands apart	0.89	1.41
Hands out	1.26	1.65
Hands at side	0.0257	2.41
Average	0.783	1.61

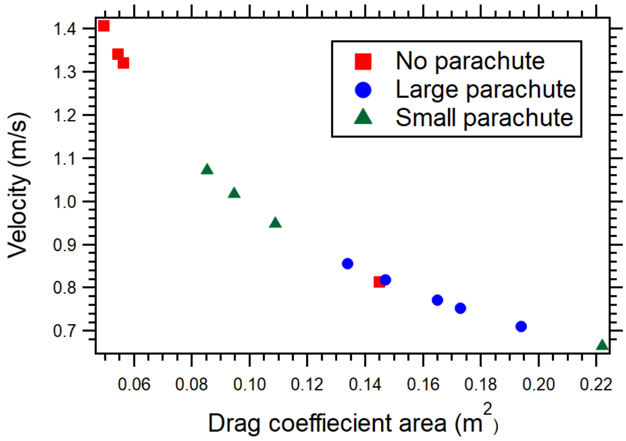

FIG. 6: A plot of the drag coefficient times area vs. velocity. The red square markers are data points from the runs with no parachute, the green triangles are the runs with the small parachute, and the blue circles are from the large parachute. The graph shows that the trials without the parachute tended to have the highest velocities with the lowest drag coefficient. While the larger parachute resulted in slower velocities and larger drag coefficients.

G. Uncertainty

Due to the nature of the drag force, uncertainty can come from many areas. In the experiment, keeping the same position in the water was challenging especially for the slower velocities. At the slower velocities, the swimmer would start to sink which would increase their overall area and drag. While the same position was attempted to be held for each trial to keep the area constant, the probability of the area being constant each time is low.

Uncertainty could also arise due to the assumptions of the forces on the system. The forces in the direction of the motion were the only forces observed. However, other outside forces may have impacted the system. The first being that velocity was also seen in the directions perpendicular to the tow velocity. The parachute was also observed to change depth in the pool. When this happened, the parachute was observed to have a slight rotation. The change in direction also implies that there is an acceleration in those directions. The change in directions mostly likely was caused by currents in the pool. While factors were done to minimize currents, a swimmer moving in the water could have resulted in unnecessary currents being formed.

V. CONCLUSION

The science of swimming is a difficult area test due to the properties of drag. What is known is that greater surface area results in a greater force exerted by the drag of the water. I was able to confirm this in this experiment. I also attempted to find the drag coefficient for both parachutes. What I observed was as the parachute's area increased, it's drag coefficient deceased. There are many future directions that the research presented could build into. For a longer experiment, more runs could be performed in the same position would help reduce uncertainties. I would also like to see how much variation is in the drag coefficient of just the parachute with multiple trials.Finally, more types of parachutes could be used as well as other positions for different strokes. Using parachutes in swim practice is common practice to many upper level swimmer and while adding drag may see counter intuitive to getting faster, using parachutes are cheap and effective method for getting faster [6].

VI. ACKNOWLEDGEMENTS

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