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Velocity Profile in Streamline Swimming

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Abstract

Experiments were done to analyze drag measurements of a swimmer in the streamline position. Drag readings were recorded at different velocities while the swimmer had two different head positions: ears between arms, and ears below arms. Several anthropometric measurements were taken to ensure accurate correlation analysis. Along with the drag investigation, fluid particle velocity measurement analysis was conducted. The Digital Particle Image Velocimetry (DPIV) technique was used to process digital video taken of a swimmer while he or she was tethered in front of an underwater window doing the freestyle stroke. Passive drag results indicated the drag did not significantly correlate with the head position. The velocity profile of the flow created by swimming was accurately created, suggesting further investigations of the underwater dolphin kick.

Introduction

In swimming, as in any sport, any edge an athlete can find to improve a time, score, accuracy, efficiency, etc. is key to becoming a champion. The average swimmer trains 60,000 yards per week, which equates to approximately 2400 flip turns in a standard 25-yard competition size pool. After the flip is complete, the push off the wall in a tight streamline position is a crucial part of every race.

The goal of studying the biomechanics of the streamline position is to find an optimal position of the head, i.e., one that produces the least amount of drag and the fastest time possible. There are two types of drag: passive and active (Figure 1). Passive drag is the resistance felt when the arms and legs are not moving, i.e. the streamline position. Active drag is the resistance felt when the swimmer moves the arms and legs .

The fundamental questions addressed in this investigation are which head position is optimal for sustaining maximum velocity while the swimmer is in the streamline position after a start and turn, and is it possible to obtain velocity profiles of the flow around a swimmer. Our experiments examined the effects of two different head positions on passive drag measurements. There are three main types of resistance associated with the passive drag on a swimmer, form, wave- making, and friction. The main focus of this experiment was to look at the form resistance, which has been found to make the largest impact on the total amount of resistance acting on a swimmer. It is extremely difficult to determine the frictional, wave making, and/or eddy resistance because the swimmer's propulsion along the water surface is regarded as a collection of numerous traveling pressure points (Miyashita, 1978).

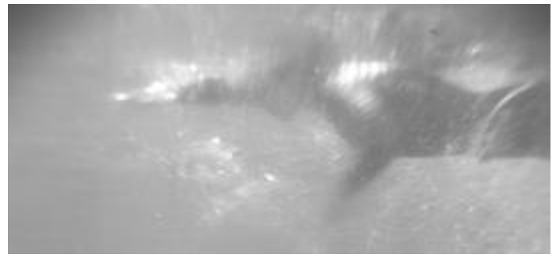

Figure 1a (left). A swimmer holding the streamline position experiences passive drag as water flows by.
Figure 1b (right). Active motion causes a swimmer to experience active drag.

Figure 2a (left, top). U.S. Olympic Training Center in Colorado Springs, Co.
Figure 2b (left, bottom). International Center for Aquatic Research.
Figure 3 (right). The flume.

Experimental Methods

Passive Drag Quantification

Fifteen swimmers from California participated in this portion of the experiment. The protocol developed by Russell Mark, Biomechanics Coordinator at USA Swimming Inc. was used. The athletes assume a streamline position in the flume (Figure 3) and hang on to a towrope (Figure 4) attached to a load cell and a tensiometer (Figure 5) . Measurements were taken (Figure 6) when the athlete reached a stable streamline position, which means no lateral movement and the body position was fully adjusted. Three sets of velocity drag measurements were collected for each head position for a flume velocity of 1.5 m/s and 2.0 m/s. This set of data was recorded also with a digital camera for a period of ten seconds.

Figure 4 (left). The Tensiometer.
Figure 5 (right, top and bottom). Towrope and load cell.

Figure 6 (left). Flume control panel.

The following anthropometric data were also collected:

- The weight (lbs) of the swimmer.
- The arm length, which is the distance from the fingertips to the widest section of the torso.
- The leg length, which is the distance from the hipbone to the tips of the toes in a streamline position lying on the ground.
- The maximum torso circumference, which is the circumference of the torso when the head is in front of the arms and when the ears are showing (Figures 7 and 8).
- The effective cross section of the swimmer (sq. cm), which gives an idea of the size of the 'hole' an athlete punches in the water when swimming, and which is measured around the upper body at the level of the shoulders (widest part) .
- The torso-streamline circumference, which is the circumference of the torso when the head is in between the arms and the ears are not showing. This is when the swimmer is in streamline position.
- The circumference of the head.

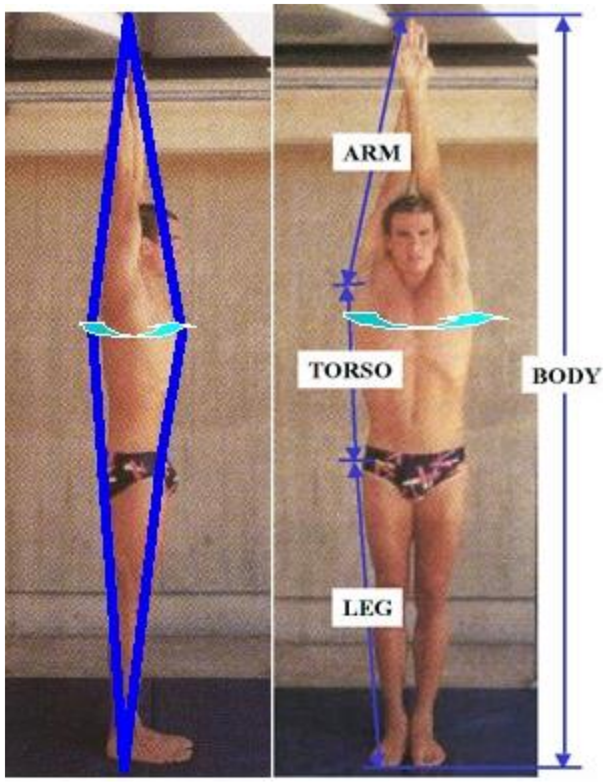

Figure 7. Anthropometric measuring points.

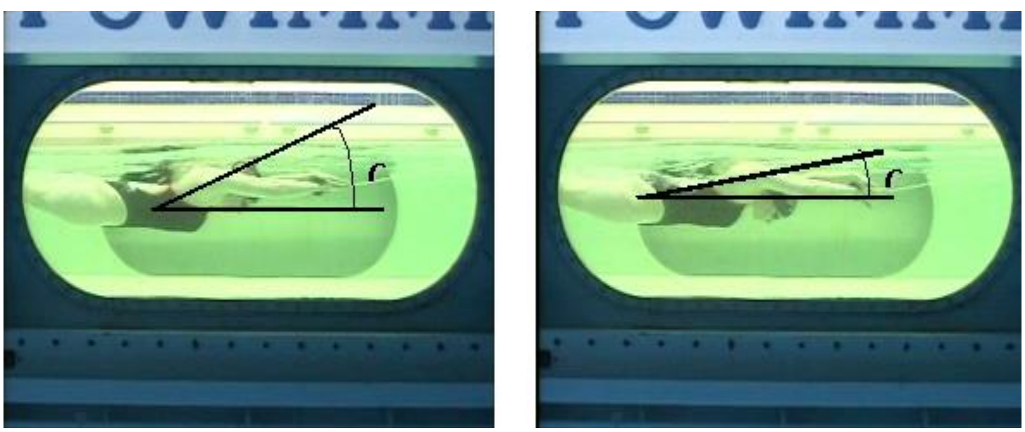

Figure 8. The angle of attack. The picture on the left denotes the swimmer with her head between her arms while the swimmer on the right has her head tilted forward, which lets her ears be exposed.

Velocity Profile Measurement

Experiments took place at the pool in the Sonny Werblin Recreation Center at Rutgers University (Figure 9) . The camera was located in an underwater viewing window located five feet below water surface level.

Figure 9a (left). Sonny Werblin pool
Figure 9b (right). Sonny Werblin Recreation Center.

After warming up, the swimmer was tethered with elastic tubing to ensure he/she would stay in front of the window. A Kodak Mega plus 18-108 mm camera with computer zoom lens and video capture boards was used to collect 500 two- dimensional sagittal images taken from several trials. During each trial the swimmer completed an average 100 arm cycles at maximum speed. Anthropometrics body segment measurements of the swimmer's arm were used to scale images. The time between picture frames was set at 0.03 seconds. In this manner, both time and distance were scaled appropriately to insure accurate velocity measurements.

A high-resolution video-based technique for obtaining two-dimensional fluid velocity field data known as the digital particle image velocimetry (DPIV) technique was utilized (Dong, 2001). Autocorrelations of individual video frames in an image pair yield two instantaneous velocity fields. Tecplot was used to graphically demonstrate velocity vector fields of each successive frame. Comparing the ability of the swimmer to the velocities found in the analysis validated the results.

Results and Discussion

Figure 8 displays the experimental setup and one of the parameters analyzed, the angle a. Figure 3 is a different view of the testing setup. The parameter a is graphically represented in Figure 10 with respect to the corresponding drag measurements. Comparison of the different drag values associated with the two head positions and other anthropometric measurements yielded insignificant differences.

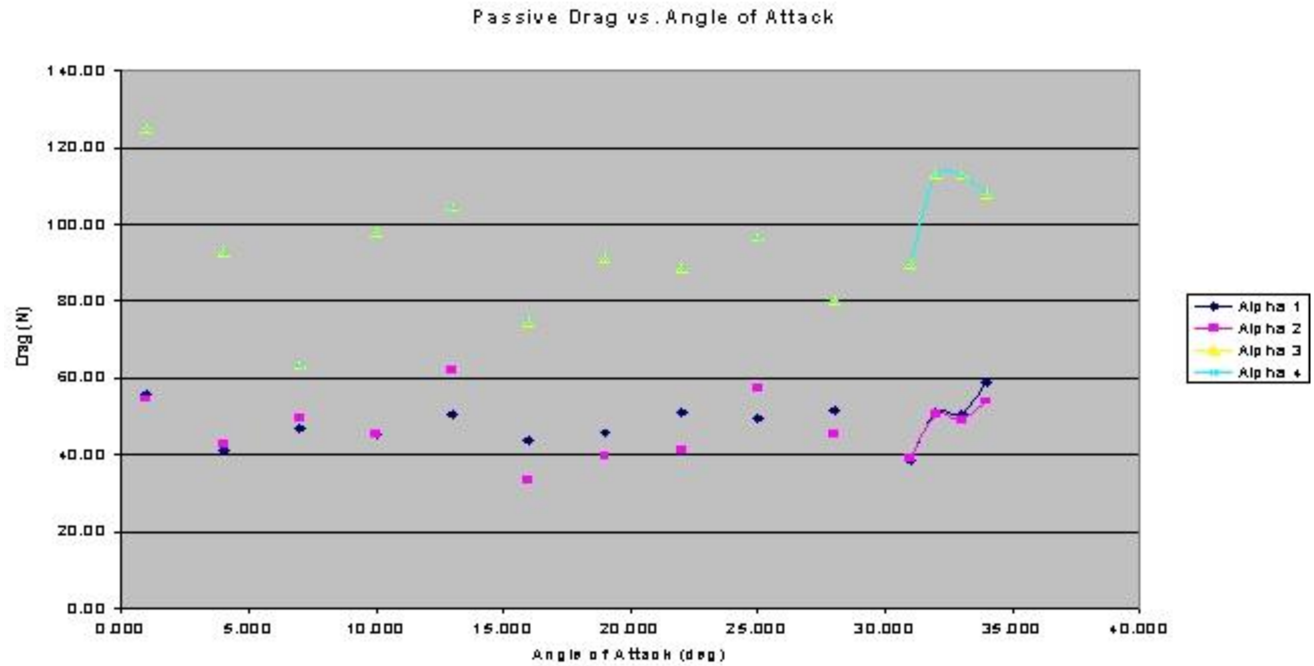

Figure 10. Angle of attack (the angle the swimmer makes with the oncoming water flow) and the corresponding drag values.

The upper panels of Figure 11 display digital images of a tethered swimmer. Below them appear the corresponding velocity profiles for each part of the swimmer's body. The velocity in yards per second of the hand position in the second arm position in Figure 1 corresponds to a speed of 1.79 yards per second, which is reasonable for the level of swimmer participating in the experiment. Analysis of several stroke cycles indicated an uncertainty for the velocity magnitudes of the second arm position ± 0.2 yards per second. The swimmer in these images can swim at maximum speed of 1.9 yards per second.

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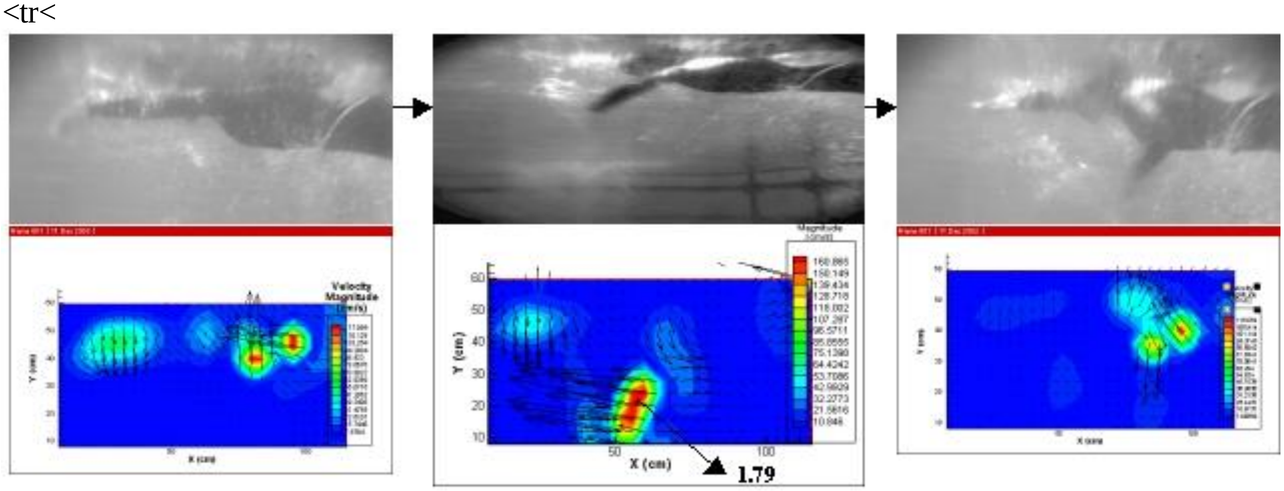

Figure 11. Digital images of a tethered swimmer (above) and the corresponding velocity profiles (below). Thin black arrows in the velocity profiles indicate both the direction and the magnitude of the motion. The second profile shows a hand/arm velocity of 1.79 yds/sec. This value is similar to a value determined for the swimmer under racing conditions.

The angle of attack that the swimmer makes with the oncoming water has been studied previously without changing the head position (Vorontsov, 2000). Figure 12 looks at the average angle of attacks at the two different flow velocities and the different head placements. The angle of attack varied more for the younger swimmers at the slower flow rate for the different head positions, as the swimmer put his/her head down the body became more aligned with the flow. As the flow rate increased the angle of attack increased with larger differences for the different head positions being caused by the greater force on the body when having the head up more leading to a dropping of the hips.

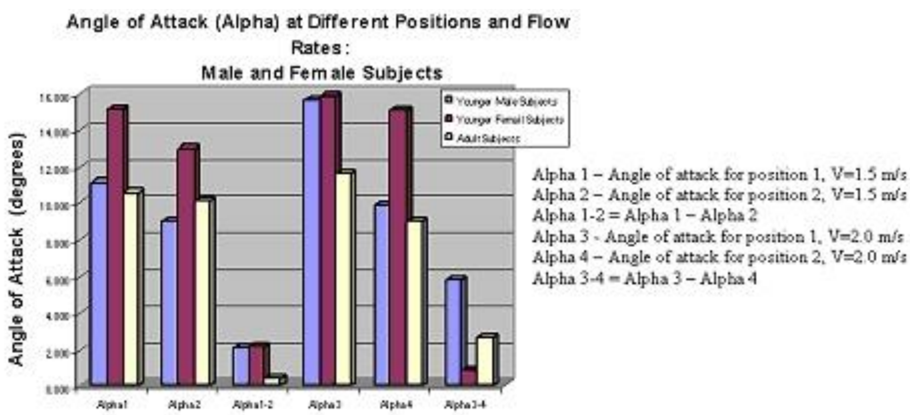

Figure 12. Average angle of attack for the subjects as a function of head position and flow velocity.

Comparison of the total overall drag is displayed in Figure 13. The magnitude of the difference between the drag produced by the different head positions increases with an increase in flow velocity for all male subjects. The magnitude of the difference in drag produced by the different head positions was not statistically related to flow velocity for all female subjects.

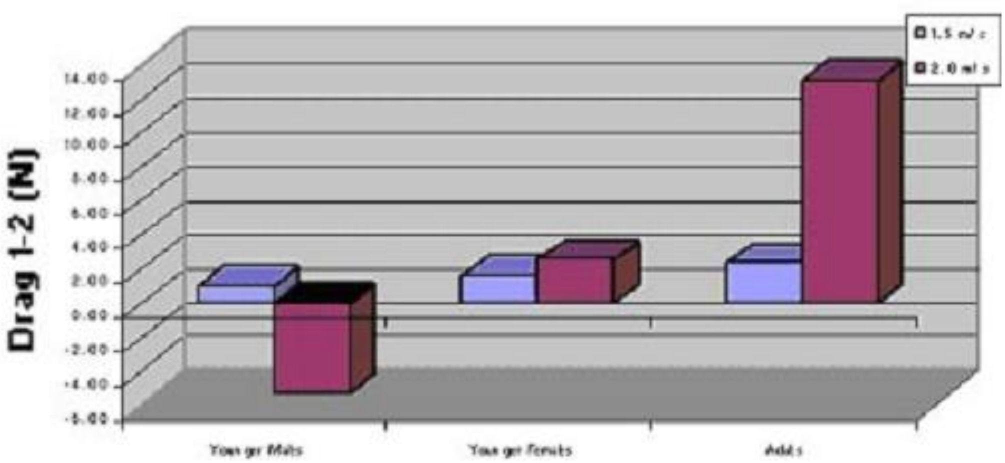

Figure 13. Average difference in drag based on sex, age, and flow rate for the test subjects.

Summary

The drag force on a swimmer increases linearly with increase in flow velocity, but different head postures in the streamline position do not significantly affect drag.

Velocity profiles of a swimmer in freestyle motion, provide both qualitative and quantitative data summarizing the motion of the fluid particles displaced and surrounding the swimmer. Consequently, DPIV processing can be useful in the comparison of different swimmers' motions and speeds. The next step in our experiment will be to look at velocity profiles for freestyle motion.

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