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EDITORIAL

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To Scull or Not to Scull: Implications of Bernoulli's Principle

James "Doc" Counsilman is one of my heroes. I am sure I am not alone in that sentiment, certainly among swimmers and aquatic professionals of my generation. On top of being one of the all-time great college swimming coaches, as well as a national-caliber competitive swimmer in his own right and for a time the oldest person to have swum the English Channel, Doc was, first and foremost, a top-notch scholar. Right up to the end, he had an abiding and consuming curiosity, as well as a need to explore and inquire—all characteristics of great scientists. I remember hearing the story of Doc's wife, Marge, coming downstairs to his study at 2 a.m. to insist that he come to bed, only to discover him absolutely immersed in studying film of a swimmer, or a frog, or an alligator, as he tried to discern what allowed the organism in question to move through the water. The consuming urge to keep asking why and how was certainly one of Doc Counsilman's many outstanding qualities as a coach and scientist (Counsilman, 1968).

I am proud to know that before gaining fame in Bloomington at Indiana University, Doc had been SUNY-Cortland's swim coach a decade before I enrolled there and was a swim-team member. Our own coach at Cortland, Jack Boehm, had been one of Doc's swimmers at Indiana so we enjoyed hearing the many stories about Doc and his unique coaching and motivational practices. I will never forget the first time I was introduced to Doc's fascinating treatise, "The Application of Bernoulli's Principle to Human Propulsion in Water" (Counsilman, 1970). I had absolutely no understanding at the time of what Bernoulli's principle meant, so it was heartening to know that Doc said it took him 20 years to understand the principle himself. I took comfort in not feeling like a complete dolt since it had taken the great Doc Counsilman 20 years to figure it out! Of course, I first heard of Bernoulli's principle well over 20 years ago, and, should I mention, I am still trying to figure it out myself?

In this issue's editorial musing, I explore Bernoulli's principle, consider why Doc Counsilman might have been interested in it, and surmise what it might have to do with swimming strokes, in general, and with the swimming skill of sculling, specifically. I am delving into Bernoulli's principle and sculling to further my own understanding and hopefully for the edification of some readers. To that end, I examined a few authoritative sources, and I also chose to employ one of Doc Counsilman's favorite methodologies: using underwater video. Through the innovation of digitization, I can share several of my examples with online readers of *IJARE*. If you are reading this in the print version, please consider getting an online subscription. You won't want to miss the videos starring a celebrity model.

Bernoulli's Principle

Bernoulli's principle is named in honor of Daniel Bernoulli, one of a large family of talented Swiss scholars and mathematicians, who applied mathematics to mechanics, especially fluid mechanics. Rather complicated and relying on differential equations and calculus (hence why it took Doc, me, and others so long to figure out), the principle is a variation on the principle of the conservation of energy as applied to incompressible fluids such as water. Simplistically, it states that there is a direct but inverse relationship between the velocity of a liquid and pressure. As the velocity of a liquid increases, the pressure decreases, and vice versa (Maglischo, 1993).

As in all systems, objects tend to move away from areas of high pressure to areas of lower pressure along linear gradient lines. These gradients are called streamlines. They are theoretical sets of points in a fluid, all of which have the same mechanical energy. I think of streamlines as similar to contour lines on a topographic map. Contour lines represent points all sharing the same elevation above sea level. Similarly, fluid streamlines represent points in a fluid sharing the same velocity, pressure, and mechanical energy. One can map the streamlines in a moving fluid like contour lines on a topographic map. When fluid moves around an object or, conversely, an object moves through the fluid, the surface of the object becomes part of several streamlines. When an asymmetrical object such as the curved surface of an airplane wing, a propeller, a sail, or even a kite moves through a fluid such as air or water, a pressure differential occurs, with lower pressure on the curved (i.e., top or front) surface of the object. The pressure differential creates a force known as lift.

According to Bernoulli's principle, an object moving relative to a fluid tends to travel, or to be lifted, in the direction of the lower pressure. The notion of lift is really the opposite of Newton's law of action–reaction, which sees an object's movement to result from a "push" force, not a "pull." The curved airplane wing is lifted upward because the pressure on the top of the wing is lower as air passes over it. A sailboat moves forward, not because the wind pushes it forward as is often mistakenly presumed but because wind traveling over the sail creates lower pressure on the front, curved surface of the sail, thus lifting or pulling the sailboat forward in the direction of the lower pressure.

Applying Bernoulli's Principle to Swimming Arm Actions

Bernoulli's principle thus describes and explains how the concept of lift works. It is the formula that explains the relationships between objects moving in fluids (or fluids moving around objects). Lift is, according to Doc Counsilman and others (Counsilman, 1970; Counsilman & Counsilman, 1994), a significant factor in explaining how elite swimmers are able to move through the water so quickly and efficiently. As Doc pointed out in his original study (Counsilman, 1970), most people presume that we move through the water under Newton's law of action–reaction by using our hands in a manner similar to how oars or paddles move a small boat over the surface of the water by creating sufficient backward drag forces. Put another way, many people assume we swim forward by creating a large amount of pressure backward on the water with the palms of our hands. Our bodies then move forward in the water as a "reaction" to the initial backward "action" drag forces created by our hands and arms against the water. After all, we do create backward action forces to move forward when we walk or run or even push off the wall of the swimming pool after making a turn.

Indeed, it is likely that less advanced or lower skilled swimmers tend to move through the water using some variation of this "paddle propulsion." In Figures and Videos 1 and 2, I illustrate Level 2, short downward push action, and Level 3, long push–pull pattern, as identified by Langendorfer and Bruya (1995) in the arm-propulsion component of their developmental Aquatic Readiness Assessment (ARA) instrument. These arm patterns are characterized by a straight, linear movement path through the water just like one would use with an oar or paddle. Of course, such action–reaction or push–pull actions on a fluid produce very inefficient and ineffective propulsive forces. This is one explanation of why most beginning or novice swimmers take a large number of arm strokes to cover a distance and they move quite slowly for all their effort.

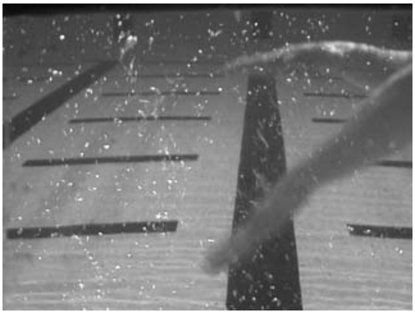

Figure 1 — Level 2, short downward push action.

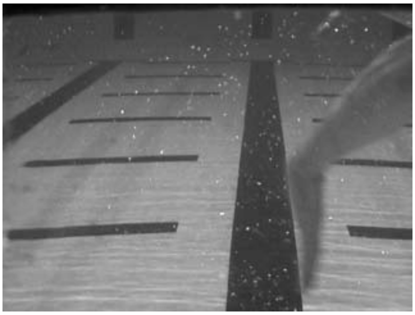

Figure 2 — Level 3, long push–pull pattern.

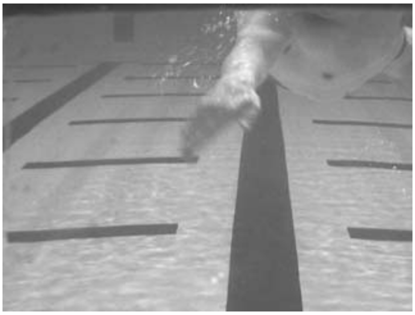

Figure 3 — Level 4, lift propulsion.

In contrast, Figure and Video 3 illustrate a more advanced swimmer using ARA arm-propulsion Level 4, lift propulsion, to swim a front-crawl stroke. The video illustrates the medial and lateral movements associated with this swimmer's hand and arm throughout the arm-stroke action. This lateral movement produces different pitches of the hand in relation to the water and is what produces the lift force in a manner similar to an airfoil, propeller, or sail. Because the water is relatively dense, the lateral hand motions can produce lift with much smaller velocities and accelerations than are needed in the much less viscous air to produce lift by airfoils and propellers.

It is useful to consider that the cross-section of a human hand is roughly similar to that of an airplane wing. The palm is flat like the bottom of the wing, and the back of the hand is slightly rounded like the curved top of an airfoil. Therefore, the back of the hand, which faces mainly forward and upward in relation to the direction of travel of a stroke, has lower pressure on it than the palm. Essentially, the lower pressure on the back of the hand has the effect of pulling or lifting the hand and the swimmer's body forward.

Applying Bernoulli's Principle to Swimming Leg-Kicking Actions

Although the application of Bernoulli's principle is most often associated with arm actions in swimming, I believe that the feet actually produce lift, as well, although not as efficiently and effectively as the hands, largely because of the less flexible ankle compared with the hand and wrist. Figure and Video 4 illustrate a stationary flutter kick, the video in both prone and supine positions. The up-and-down "finning" action of the ankles produces alternating patterns of low pressure on the ventral (top) and plantar (bottom or sole) surfaces that assist forward propulsion. Various studies have demonstrated that even in sprint crawl using a rapid six-beat flutter kick, the forward propulsive forces generated by the flutter kick amount to only 10–30% of the total force. Those propulsive forces come at a huge energy cost because of the large muscle mass in the legs.

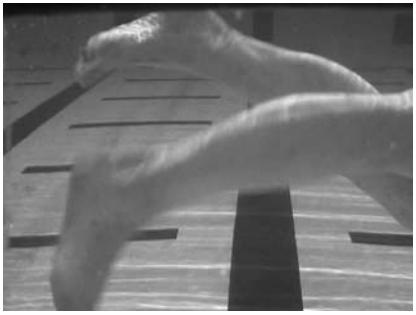

Figure 4 — Stationary flutter kick.

Figure 5 — Whip kick.

The so-called "whip," or breaststroke, kick (Figure 5) also appears to rely on Bernoulli's principle and lift for its capacity to move the body forward. In a more extreme example than the cross-section of the hand, the cross-section of the human foot likewise bears a strong resemblance to an airfoil—flat on the plantar surface and curved across the top of the arch. In fact, as you can note in Video 5, the rapid "squeezing" action that brings the feet together at the end of the whip kick allows the cross-section of the foot to generate a large low-pressure area on the front-facing ventral surface. The lift generated by this medial acceleration of the feet and legs in the whip kick is responsible for pulling the body forward.

Sculling

I am often surprised how many swimmers do not understand and even lack skill in sculling. The American Red Cross (2004) says, "Sliding the hands back and forth through the water creates a force perpendicular to the direction of motion (lift). This

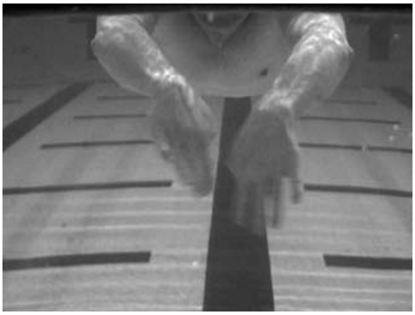

Figure 6 — Sculling.

action is known as *sculling*. . . . It is like spreading sand on a hard surface" (p. 49). I think is important to note that sculling produces a forward movement of the body in the water without the hands or arms ever moving backward or forward, but only in a side-to-side fashion (see Figure and Video 6). Envision if you will the palm of the hand facing back toward the feet and moving along a high-pressure streamline while the top of the hand, which faces toward the head, moves along a low-pressure streamline. The constantly changing pitch of the hand guarantees that this pressure differential is maintained and that the body is lifted in the direction of the head. It is the best evidence that I know refuting the action–reaction drag hypothesis while demonstrating elegantly that lift indeed moves us forward in the water.

Over the past year or so, our BGSU Masters swim team has had several coaches who regularly included sculling drills as part of our warm-up and other training drills. Recently I even began inserting more sculling into my workouts wherever possible. I am positive that my stroke lengthens and my speed increases after I have engaged in sculling drills. I am becoming more and more convinced that this stroke improvement is not just a coincidence (or, heaven forbid, superstition). Johnson (2007) strongly encourages Masters swimmers to use sculling drills to promote a superior "feel" for the water. In my case, I suspect that the sculling drills produce a positive transfer that improves my basic stroke mechanics by increasing the lift action of my arm action, perhaps through better motor-unit recruitment. I am only speculating as to the reason, but I am sure of its positive impact on my own swimming performance. It sounds like a research project begging to be done, doesn't it? We might also extend the question to see whether learning sculling earlier could improve stroke mechanics for beginners and novice swimmers. If any reader knows of such studies, I would love to hear about them.

Paddles and Fins: Does Bernoulli's Principle Apply?

As I have pondered how Bernoulli's principle applies in arm and leg actions of my swimming strokes, I was reminded that whenever I use my hand paddles or swim fins while training, I take fewer strokes to cover a pool length and go considerably faster. This observation raises the question of whether and how Bernoulli's principle applies to the use of hand paddles and swim fins. I suppose skeptics could argue that the larger surface area of both paddles and fins simply produces more backward drag action, which causes greater forward reactive forces. In contrast, I would like to suggest that the larger surface areas associated with paddles and fins simply enhance the Bernoulli lift forces.

Hand Paddles

Note that the sculling action observed in Video 7 looks almost identical to the sculling action of the hand in Video 6. One can see the same constantly changing pitch of the hand as it makes its figure-8 motion around the forearm axis. The only difference is that when one is wearing hand paddles, the motion produces faster movement through the water. Because the palm of the hand never creates a direct backward "action" against the water, as would happen with a finning arm action, Bernoulli's principle must be at work while a swimmer wears paddles.

Swim Fins

If you compare the flutter-kicking action illustrated previously in Video 4 with the flutter kick with fins in Video 8, you can observe a rather startling difference. First of all, the very flexible long fins produce an accentuated up-and-down whipping motion that enhances the production of lift forces. Second, the extended surface area of the fins produces much greater plantar flexion of the ankles than the flutter kick without fins. Finally, the combination of the plantar-flexed ankle and the whipping action of the fin creates greater forward lift forces.

I realize that Bernoulli's principle and lift forces are not universally accepted as explanations for advanced stroke mechanics, especially among some competitive-swimming experts. I would be interested in further discussions about the current conception of what explains how advanced swimmers are so efficient and effective in moving quickly. I certainly invite research manuscript submissions on this topic, with the caveat that such submissions can be applied widely to swimming instruction, as well as fitness and recreational swimmers, and are not simply oriented toward competitive swimming (which is beyond *IJARE*'s scope and mission).

Figure 7 — Sculling with hand paddles.

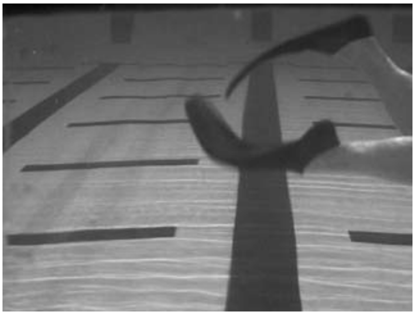

Figure 8 — Flutter kick with fins.

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In Volume 2, Issue 2

I am pleased to introduce a wide variety of quite interesting aquatic articles appearing in this second issue of our second volume of the *International Journal of Aquatic Research and Education*. These contents have been enriched through several papers and studies originally presented last September at the World Water Safety Congress in Porto, Portugal. Regular readers may recall that our November 2007 issue, *1*(4), featured the 2007 World Drowning Report, which was initially disseminated at that international gathering. I am sure readers will notice that this issue has a decided focus from "down under," with the first three research papers coming from either Australia or New Zealand.

Bernadette Matthews of Life Saving Victoria and Alistair Thom and Richard Franklin, both from the Royal Life Saving Society of Australia, have co-authored "Injuries in Public Swimming Pools in Victoria: A Pilot Study," which presents a survey of various injuries reported around 22 pool facilities in the Australian state of Victoria. I think readers will find the analysis of the results particularly illuminating. Despite the fact this is merely a pilot study, the methodology and results should have implications for many aquatic professionals who are in charge of various facilities.

Kevin Moran from the University of Auckland in New Zealand is the author of two research studies he has conducted that both appear in this issue. The first, "Will They Sink or Swim? New Zealand Youth Water Safety Knowledge and Skills," is a survey of over 2,000 New Zealand youth. Kevin ascertained that there is a lack of water-safety knowledge being acquired by males, those from lower socioeconomic status, and Asian and Pacific Islanders in New Zealand. He describes efforts needed to address these deficiencies as one way to reduce drownings and other aquatic injuries among the youth in New Zealand. His results, I believe, should easily generalize to many other countries. Kevin's second study takes an in-depth look at "Rock-Based Fishers' Perceptions and Practice of Water Safety" to try to identify causes and, hopefully, preventive measures to reduce the high rate of drowning among people who fish from rocks on New Zealand's rugged west coast.

W. Matt Silvers and Denny Dolny, both from the University of Idaho, are the co-authors of a study involving their line of work with aquatic exercise and underwater treadmills. Their current study specifically examines the reliability of physiological responses to aquatic exercise performed on underwater treadmills. I found this to be a particularly interesting and potentially important study because of the need for more focus on the consistency of performance measures we make in aquatic environments.

Our research section concludes with the study, "Comparison of the Health Aspects of Swimming With Other Types of Physical Activity and Sedentary Lifestyle Habits," submitted by Nancy Chase, Xuemei Sui, and Steven Blair, all from the University of South Carolina. The cross-sectional data are drawn from the Dallas Cooper Clinic's Aerobics Center Longitudinal Study, in which over 45,000 people's physical activity and health status were examined to compare sedentary individuals with those who walked or ran and with those who were regular swimmers. The results demonstrate what most aquatic professionals would fondly hope and believe: Regular swimming, like walking and running exercise regimens, provides a number of significant health benefits when compared with sedentary lifestyles.

Our second issue wraps up with three interesting educational articles. J.B. Smith, from Indiana University of Pennsylvania, provides us with some of his insights into difficulties experienced by seasonal aquatic facilities in hiring fully qualified aquatic facility directors during the summertime that represent part of the current national crisis surrounding aquatic staffing.

Lee Yarger, from Ball State University, rounds out this issue by providing readers with two more of his typically insightful professional contributions. His first article is a strong logical plea for the many aquatic agencies in the United States to recognize aquatic-certification equivalencies offered by other agencies. He helps readers understand that the failure of our agencies to cooperate and recognize each other's certifications hurts employers and potentially puts swimming participants at risk. Lee's second article describes the various uses to which oxygen can be put in medical emergencies and calls for more research to be done so that there is a common understanding about how and when to administer emergency oxygen.

I hope readers find the different contributions in Issue 2 to be as interesting and valuable as I and our journal reviewers did. We heartily recommend these varied research and educational articles to our readers. I think you will find that *IJARE* is continuing to attract some fascinating and important articles of interest to a broad spectrum of aquatic professionals.

As I have mentioned previously, I invite anyone who would like to become even more involved as a reviewer or author for the *International Journal of Aquatic Research and Education* to log on to our Manuscript Central Web site (http://mc.manuscriptcentral.com/hk_ijare) to create your own account, making sure to identify your interests and expertise areas in aquatics by selecting the appropriate keywords. Thanks to all of our editorial board members and the many reviewers who provide such valuable insights and reviews of the articles published in the journal. I will be writing to you again in 3 months in the next issue, but more briefly because we are anticipating several guest editorials to appear in the next several issues, as well as a number of other excellent studies that are currently under review. Until then, keep your collective heads above water!

Stephen J. Langendorfer
Editor