Part I: Is the Breaststroke arm stroke a "Pull" or a "Scull"?

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Abstract. *At the present time swimmers seem to be moving away from using sculling motions in their arm strokes. The trend is back toward the use of drag-dominated propulsion where the hand and arm operate more like a paddle than a foil. While this is true in three of the competitive strokes, a great number of coaches still think breaststroke should be the exception to this trend. They believe swimmers in this stroke should be sculling their hands out and in. In this paper I want to present a case for breaststrokers using drag-dominated propulsion during their arm stroke. My rationale for suggesting this will be given early in the paper, followed by the presentation of visual and graphic data that support that rationale. In the final section, I will describe how I believe the arm stroke should be performed together with a short video showing an Olympic Gold Medalist swimming this way.*

Introduction:

The debate continues, are swimmers pulling or sculling? Is lift the dominant propulsive force in swimming or is it drag? In Part I of this paper I will describe why I think drag is the dominant propulsive force. The use of drag-dominated propulsion in the breaststroke will be described in Part II.

Prior to the 1970's, the prevailing opinion was that swimming propulsion occurred because of Newton's Action/Reaction principle. That is, if swimmers pushed their hands directly back against the resistance of the water, (the action), their suspended bodies would be accelerated forward (the reaction). As a result, the hands were believed to act like "paddles" with which swimmers pulled, then, pushed against the resistance of the water in a backward direction from the start to the finish of an underwater stroke. Since "Drag" is the term used to designate water resistance, this method was called "Drag propulsion".

This all changed when research by Brown and Counsilman, in 1971, appeared to refute drag as the foundation for human swimming propulsion. Their groundbreaking study showed that swimmers' hands followed curved, instead of linear paths during their underwater strokes, (see figure 1). Therefore, these authors suggested that swimmers were using both lift and drag forces for propulsion, with the emphasis on lift. The lift forces were alleged to result from the Bernoulli effect.

Bernoulli's Theorem describes how lift forces are produced around foils. It has proven a useful concept in aerodynamics and hydrodynamics. The proposed application of Bernoulli's Theorem, to human swimming propulsion is illustrated in figure 2, by the drawing of a butterfly swimmer, viewed from underneath, performing what most refer to as the "pull" phase of his underwater arm stroke.

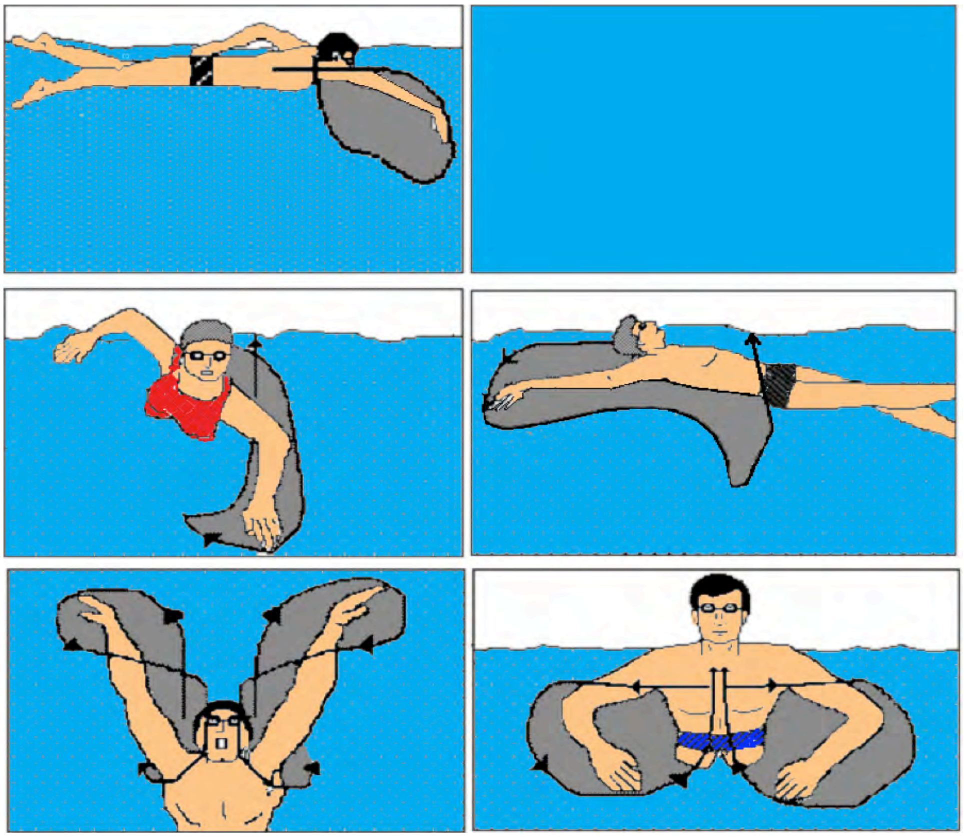

Figure 1. *Typical stroke patterns for the four competitive strokes from front, side and underneath views. These patterns represent two-dimensional paths of swimmers' hands as they travel through the water.*

The manner in which Bernoulli's Theorem was believed to produce propulsion can be described as follows. When a swimmer's hand travels through the water, a pressure differential is produced between the palm side of his hands, where the pressure is greater, and the upper side where the pressure is lower. Since the swimmer is pushing against the resistance of the water with the palms of his hands a force labeled "drag" will be produced opposite the direction his hands are traveling. Only drag force will be produced when a swimmer's hands travel directly backward. However, when they are traveling diagonally backward, as they are during all four competitive strokes, a force termed "lift" will also be produced. That lift force will be exerted perpendicular to the drag force, and in a direction from the area of higher pressure on the palm side of the swimmer's hand toward the area of lower pressure on the knuckle side.

That pressure differential results from an increase in water pressure under the swimmer's palm because he is pushing against the resistance of the water with it. The reduction in pressure over the knuckle-side of his hand is thought to occur because of an increase in the speed of water flowing over that surface. When combined, lift and drag forces cause force to be exerted in a number of other directions around swimmers' hand. That portion of the combined forces of lift and drag that is exerted in a forward direction is termed the propulsive force.

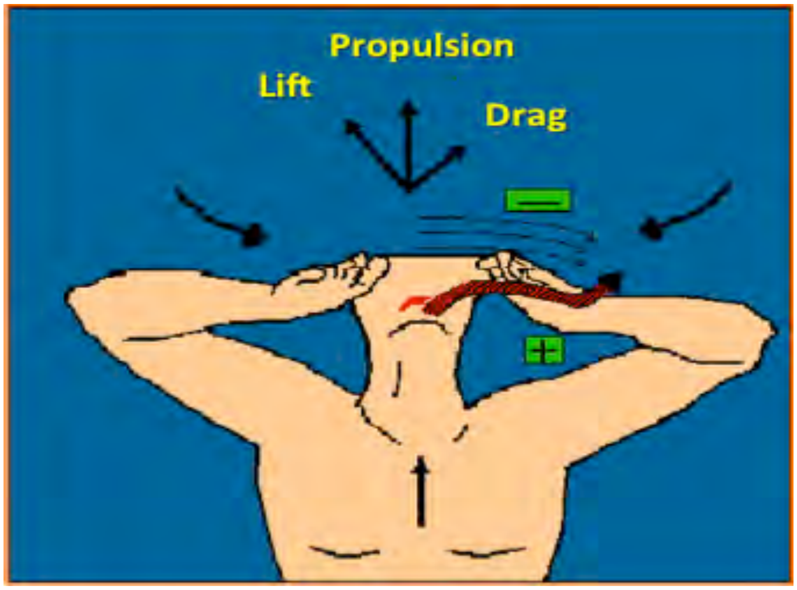

Figure 2. *The proposed application of Bernoulli's Theorem to human swimming propulsion.*

With the discovery that swimmers were actually stroking in curved paths, it seemed logical to assume, that lift, rather than drag was the primary source of their propulsion. After all, it was reasoned, world-class swimmers would not be using curved stroke paths if drag were the dominant propulsive force. Instead, they would be pushing their hands directly backward through the water. As a consequence of this reasoning, the majority opinion became that swimmers were sculling their hands through the water in order to maximize the influence of lift forces on propulsion.

Several research papers supported that opinion in the 1970's and 1980's (Barthels & Adrian, 1974; Schleihauf, 1979; Schleihauf, Gray, & DeRose, 1983) where the magnitude of propulsive force was determined from formulas that calculated it (propulsive force), from the parent forces of lift and drag. In nearly all cases, the contribution of lift to the propulsive force was reported to be greater. I have demonstrated this in figure 2 by drawing the lift vector longer than the drag vector (longer vectors indicate greater force). Thus, swimming propulsion was judged to be influenced more by lift than by drag forces. This, in combination with the circular stroke patterns of swimmers, led experts to believe that lift was the dominant propulsive force in swimming and that swimmers were propelling their bodies forward by sculling their hands through the water.

Both of those beliefs have come under serious doubt in the last two decades. The belief that human swimming propulsion is lift-dominated still persists in many parts of the world. However, the notion that drag is actually the dominant propulsive force is gaining credibility. This was, in part, because of research which suggested that the contribution of drag forces to swimming propulsion had been underestimated by the earlier formulas swimming researchers used to calculate lift and drag, (Bixler, 1999; Riewald & Bixler, 2001a, 2001b; Thayer, 1990), as well as by some additional research, and well-reasoned opinion pieces that challenged the beliefs that, (1) lift was the dominant force in human swimming propulsion, and that, (2) Bernoulli's Theorem played a role in producing lift during human swimming (Holt & Holt, 1989; Rushall, Sprigings, Holt & Capparet, 1994; Sprigings & Koehler, 1994).

In particular, Bernoulli's Theroem was discredited as a cause of propulsion because of research by Ferrell, (1991), and Riewald and Bixler (2001a and 2001b) which suggested that the boundary layer between the water and swimmers' hands separated when it (the water) traveled over the top of their hands. As a result the flow of water became turbulent, rather than laminar. Thus, the Bernoulli effect was denounced because laminar flow (non-turbulent water movement) over that surface is required to produce lift according to the Bernoulli effect, and these studies indicated that laminar flow does not exist over the hands when swimming.

This does not mean that swimmers do not produce lift forces. They do, but they are not produced because of the Bernoulli effect. Let me explain. While, drag forces are produced because swimmers push back against the resistance of the water with their hands and arms, lift forces are produced because they are not pushing *directly* backward with them. The pressure differential that is created occurs because pushing against water resistance with the palm of the hand increases the pressure on that side, until it exceeds the pressure on the other side, which is not pushing against the water. Consequently, lift is not produced because the flow of water is laminar over the knuckle-side, but instead because the drag force swimmers apply to the water with their palms, (and underside of their arms), causes the pressure on that side to exceed the pressure on the knuckle side of the hand. Therefore, it is the application of Newton's Action/Reaction principle, and not the Bernoulli effect that generates lift force when swimming.

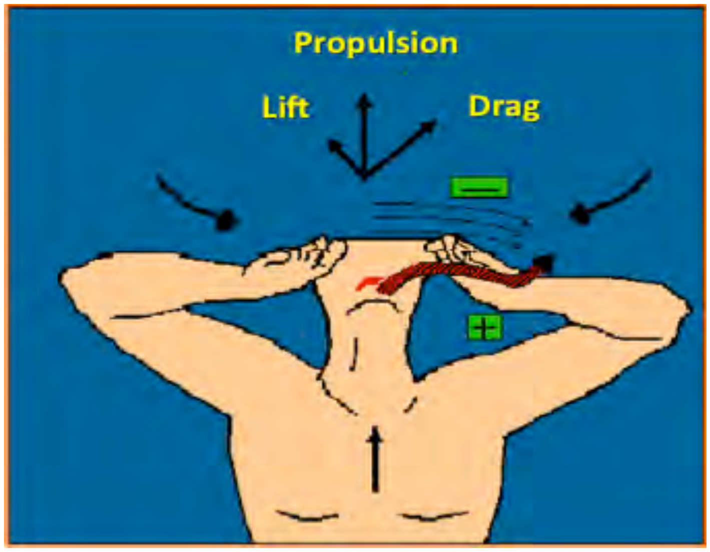

Figure 3. *An example of the relative magnitudes of Lift and Drag forces resulting from the application of Newton's action/ reaction principle.*

It follows from this explanation, that the major contributor to that pressure differential is an increase in the drag force, which, in turn, suggests that human swimming propulsion is really drag-dominated. Using the same illustration in figure 3 that was used in figure 2, the length of the force vectors have been changed to reflect, what, I believe, is a more accurate representation of the relative magnitude of lift and drag forces swimmers produce. In figure 3, the drag vector is drawn longer than the lift vector, indicating that the former force makes a greater contribution to propulsion than the latter.

Because Newton's Third Law of Motion is now being reconsidered as the basis for human swimming propulsion, many coaches are advocating a more straight-line pulling motion, at least in the freestyle, backstroke and butterfly strokes, with swimmers using their hands and arms like paddles to push water back instead of like foils that scull through it. Nevertheless, there are a considerable number of coaches and swimming experts who still believe that sculling is the preferred method of propulsion in the breaststroke

It is easy to see why they would think this. The stroke pattern in figure 4, drawn from an underneath view, shows clearly that breaststroke swimmers' arms travel out and in to a much greater extent than they move back. Even Capparet, (1993) whose research suggested that the hands paths of Olympic swimmers were not as curvilinear as once believed in the other three competitive strokes, except the breaststroke, stating that the arm stroke patterns in this stroke were "exceedingly curvilinear". The front view of the breaststroke arm pattern in figure 1 also shows the magnitude of down and up hand motion breaststroke swimmers use. Visualizing a combination of the underneath view stroke pattern in figure 4 with the front view breaststroke stroke pattern in figure 1 should allow readers to picture the three-dimensional stroke pattern that is actually used by breaststroke swimmers.

Figure 4. *A typical stroke pattern for breaststroke, drawn from an underneath view. The swimmer is Mike Barrowman. Modified from, Capparet, J., and B.S. Rushall, (1994). "Biomechanical Analyses of Champion Swimmers", with permission.*

Despite the predominance of lateral and vertical hand movements in this stroke, it has never seemed logical to me that breaststrokers would rely on lift-dominated propulsion when drag seems to be the dominant propulsive force in the other three competitive strokes. I believe there should be commonalities to the way athletes propel their bodies through the water. That is, the same motions and forces that produce propulsion from the arms in the freestyle, backstroke and butterfly should also be employed in the breaststroke.

I will make a case for drag-dominated propulsion in the breaststroke arm stroke later in this paper, but first, let me describe how I believe swimmers in the other competitive strokes are using drag- dominated propulsion in their arm strokes. The mechanism I believe they are using is an anatomical movement called *shoulder adduction*.

What is shoulder adduction and, how is it performed in freestyle, backstroke and butterfly?

In swimming, shoulder adduction is performed as a sideward, sweep of the arms from a position overhead to one at the side. In other words, the arms are *added* to the body. Charles Silvia first described shoulder adduction as a major propulsive movement in competitive swimming in 1970. However, his advice was largely ignored during the next three decades when most swimming coaches and swimming researchers, including this writer, became convinced that lift, the Bernoulli Principle, and sculling were the principle mechanisms for swimming propulsion. Now that this belief is in doubt, it may be time to reconsider Silvia's teachings.

The drawing in figure 5 shows a front crawl swimmer, from an underneath view, completing what most refer to as the pull, while I call it the "insweep." The pull/insweep has traditionally been taught as a down and in sweep of a swimmer's hand and arm, that begins with the arm extended straight ahead of his shoulder and just under the surface. From there, the swimmer gradually flexes the arm at the elbow as it is brought down and in, until, at the end, it (the arm), is flexed considerably, and under his chest.

In actuality, front crawl swimmers use a very different pattern of motion than the one I just described during the "insweep". They do begin by pressing down with their hand and flexing their arm at the elbow, but this is not the start of the propulsive phase of that arm stroke. Instead, the downward motion and gradual flexion of their arm is used to place their hand and arm in a backward-facing position where they can apply force effectively; that is, predominantly backward, during the insweep that follows.

The correct placement should be with their upper arm, forearm, and hand in a backward facing position that some refer to as a "high-elbow catch" and others call an "early vertical forearm". The swimmer's un-shaded arm is in that position in figure 5. Once that position is achieved, the swimmer accelerates his body forward by pressing his flexed arm back with a sideward, semi-circular sweep like the one shown in figure 5. The pull/insweep ends when his upper arm and elbow are coming in toward his ribs and his flexed arm is somewhere under his body (see the position of his shaded arm in figure 5).

It is my contention that swimmers are not sculling during this semicircular movement, even though their hand-paths are curvilinear. Instead, they are using their upper arm, forearm, and hand as a paddle to push back against the resistance of the water, at least during the first two thirds of the insweep.

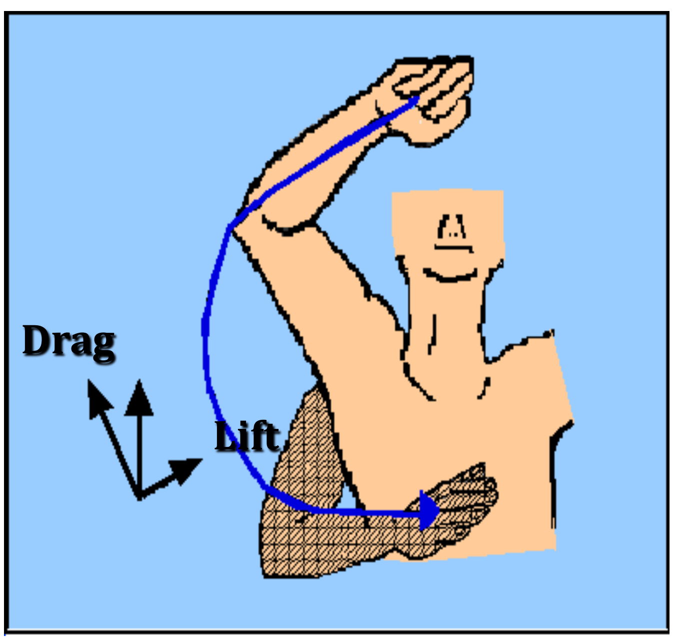

Figure 5. *Shoulder adduction during the insweep of the freestyle as viewed from underneath.*

Far from pulling the water down and in under the body with his hand while gradually flexing his elbow, the swimmer starts the insweep with his elbow already flexed and pushes back against the water with his entire arm by means of a sideward, semi-circular sweep. The side views of a multiple Short Course World Champion freestyle sprinter, in figure 6, demonstrate two important aspects of applying propulsive force during shoulder adduction. They are, first, that swimmers should not push their upper arm(s) down through the water any more

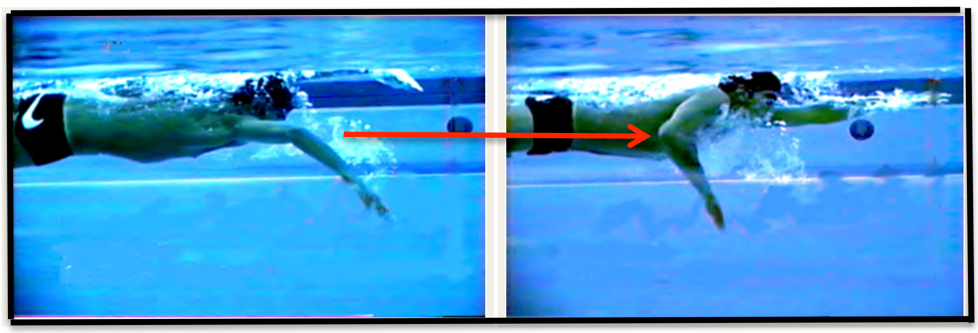

Figure 6. *The insweep in the freestyle from a side view (L to R). The swimmer is Francisco Sanchez; twice World Short Course Champion in the 50 m freestyle and once World short course Champion in the 100 m freestyle.*

than is necessary to achieve a backward-facing position while they are moving their forearm(s) and hand(s) into position for the catch (see photo on left, in figure 6). Secondly, they should press their arm horizontally backward during the insweep. The red arrow at the level of the swimmer's elbow in figure 6 has been used to demonstrate that his arm travels horizontally backward when he presses it back against the water. It should be obvious to the observer that he can only stroke this way by sweeping his arm around to the side, not down, in, and up, during the insweep.

Shoulder adduction is also the principal propulsive mechanism of the pull in butterfly and backstroke. The three underneath views of a former Olympic Silver Medalist in the 100 m butterfly in figure 7, show that her arms move in a similar shoulder-adducting manner during the pull/insweep of this stroke. They are flexed and positioned backward *before* she begins the pull/insweep, (see photo at extreme left in figure 7). After that, they are swept out, back and in under her body with a sideward, semi-circular and horizontal movement of her hands and arms (see the middle and right photos in figure 7).

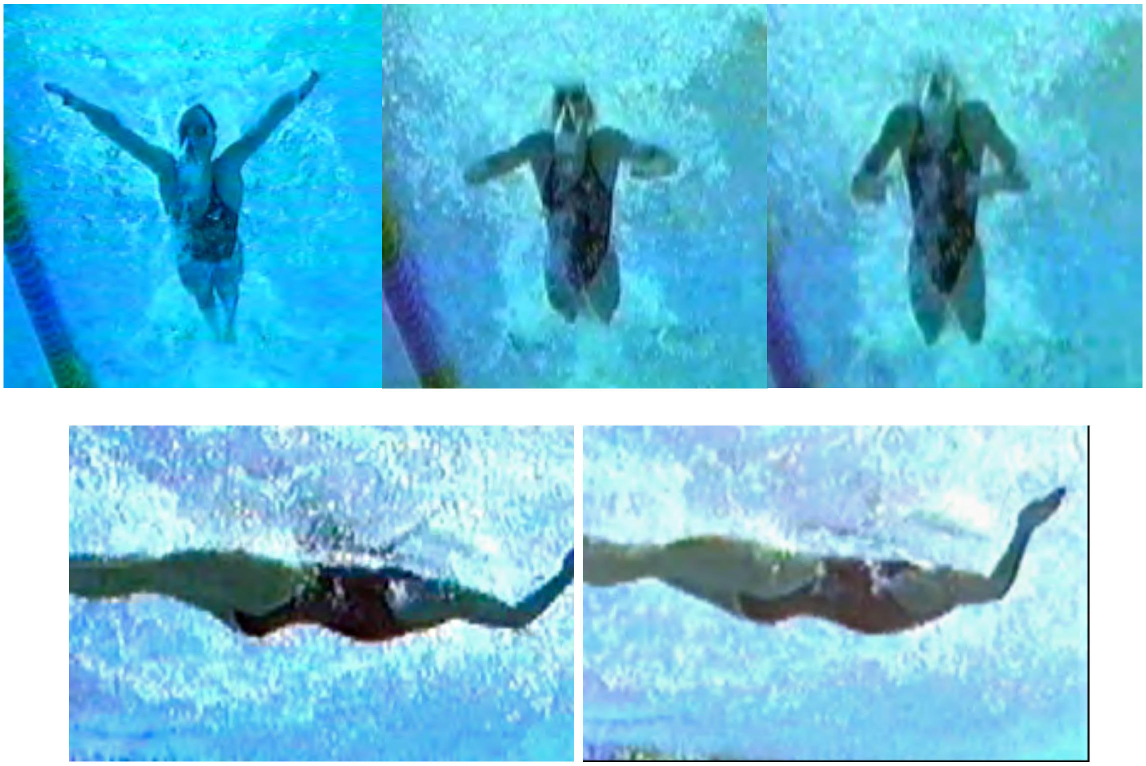

Figure 7. *Shoulder adduction in the butterfly and backstroke. The butterfly swimmer is Chrissie Ahmann, former Olympic Silver Medalist in the 100 m Butterfly. The backstroke swimmer is Multiple Olympic Gold Medalist and former World Record Holder in the backstrokes, Kristina Egerszegi.*

Also in figure 7, the two side views of a multiple Olympic Gold Medalist and former World Record Holder in both backstroke events, show that she uses a shoulder adducting motion during her pull. Because she is in a supine position, I call this movement an upsweep rather than an insweep. Nevertheless it performs the same function that the pull/insweep is used for in the other two competitive strokes. It is the first propulsive sweep following the catch. It is also a semi-circular, shoulder-adducting motion. Notice in the picture on the left, that she is in the catch position with her arm out to the side and flexed at the elbow. From there she pushes back against the water with her entire arm and hand, moving them through a semi-circular backward arc that ends when her arm is approaching her ribs (see right-side photo in figure 7).

Why is this same shoulder adducting motion used in each of the three competitive strokes? I believe it is because it is the most effective way to apply propulsive force during the pull/insweep. That is because, the undersides of the upper arm and forearm, as well as the palms of swimmers' hands can be used to form a paddle to push back against the resistance of the water in a largely horizontal direction. In several studies, combined hand and forearm models have been shown to increase propulsive force when compared to the hand alone. In one of these (Capparet, 1992), propulsive force was increased by nearly 38%, and it was increased by 27% in another (Riewald and Bixler, 2001a).

To my knowledge, no one has attempted to quantify the contribution of the upper arm to propulsion. I believe, however, that it will, in time, be found to contribute substantially to propulsive force during the insweep (upsweep in backstroke).

A second reason for using shoulder adduction is the large amount of trunk musculature swimmers activate when they perform the insweep in this way. The muscles primarily responsible for shoulder adduction are the large and powerful pectoralis major, and latissimus dorsi. I will discuss how, I believe, breaststroke swimmers also use shoulder adduction during their arm stroke in Part II of this paper.

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