LEARN FROM NATURE'S COMPETITIVE SWIMMERS

M Edwin DeMont PhD

Comparative Biomechanics Laboratory, Biology Department, St Francis Xavier University, Antigonish, Nova Scotia B2G 2W5, Canada. Email: edemont=AT=stfx.ca

Sportscience 3(1), sportsci.org/jour/9901/med.html, 1999 (1559 words)

Reviewed by: Todd L Allinger PhD, The Resource Center, The Orthopedic Specialty Hospital, Salt Lake City, Utah, USA; Giannis Giakas PhD, Division of Sport, Health and Exercise, Staffordshire University, Stoke-on-Trent, UK

Two examples demonstrate how research on aquatic animals can benefit research on human swimmers. In the first example, work by comparative biomechanists studying animals that move through the air-water interface has shown that for competitive swimmers the optimal depth during the glide phase is the depth that minimizes surface waves. The second example contributes to the ongoing argument on the nature of thrust generation in freestyle swimming. The dominant view is that lift generates more thrust than drag. These forces arise from steady-state fluid dynamics, but the movement of the thrust-generating surfaces creates unsteady fluid motion. Recent work on aquatic animal locomotion has shown that unsteady mechanisms probably play an important role in generating thrust, so the thrust-generating mechanisms used by competitive swimmers should be reevaluated.

KEYWORDS: biomechanics, drag, fluid dynamics, force, lift, swim, thrust

Sport scientists studying competitive swimming may benefit from learning about Nature's competitive swimmers. In this article, two examples will be presented that demonstrate the potential benefits of this exercise. The first example will show that research on aquatic animal locomotion has already examined a question raised by sport scientists. The second example will suggest that an ongoing argument on the nature of thrust generation in freestyle swimming should be reevaluated using current knowledge generated from studies of aquatic animal locomotion.

Lyttle (1998) raised the interesting question "does a swimmer's depth in the water make a difference in glide speed?" In 1983 I participated in a project that generated an answer to the question. The research was focused on the energetics of leaping in aquatic animals (Blake, 1983).

The cost of swimming is a very important component of the energy budget of aquatic animals. A huge research effort has been devoted to understanding all aspects of the costs. This research effort is partially to provide information for fisheries managers, who attempt to sustain a global fisheries industry. Some of this work has shown that specific morphological and/or behavior traits have evolved to reduce the costs. For example, air-breathing cetaceans (e.g. dolphins), who need to surface to breathe, have developed a behavior that can minimize the costs of long migrations. The problem these animals have to cope with is that drag near the surface is significantly higher than for subsurface swimming. The behavior that some air-breathing aquatic animals exhibit is to
periodically leap out of the water during long migrations (Figure 1). This behavior minimizes the time at the air-water interface and, in certain conditions, can reduce the overall cost of the migration (Au & Weihs, 1980; Blake, 1983).

The air-water interface creates serious problems for aquatic air-breathing animals; indeed, it is so problematic that few animals spend time in this region (Vogel, 1994). Movement at the air-water interface generates surface waves, usually one in front and one behind the animal. Work is done to generate the waves, because the water in the waves has been lifted above equilibrium (Vogel, 1994). Thus energy is wasted in the generation of these waves, and that lost energy is manifest as an additional drag force called the wave drag. The contribution of wave drag to the total drag of structures moving through the air-water interface depends on several factors, such as the hull speed and wave celerity. An explanation of these factors can be found in Denny (1993).

The model developed by Blake (1983) to examine the drag-reduction potential of leaping in air-breathing aquatic animals used a drag-augmentation factor. This factor was based on published data collected from an object towed behind a boat at various depths below the surface. The drag-augmentation factor depends on the relative submersion depth (h/d), which is the ratio of the distance from the surface to the centerline of the body (h) to the maximum breadth of the body (d). Thus the drag-augmentation factor depends on the size of the body. It has a maximum value of 5, for an h/d ratio of 0.5 (near the surface), so a body moving near the surface would have a drag five times the value when fully submerged. The drag augmentation factor has a value of 1.0 at an h/d ratio of 3.0 (or greater), which means that the drag is the same as that for a fully submerged body. In practical terms the body is out of the influence of the surface, because no waves are generated, there is no wave drag, and total drag is minimized.

For competitive swimmers, glide speed will be reduced as soon as surface waves are generated. Thus during the glide and push-off phase, swimmers should train to swim at a depth that minimizes the generation of surface waves. The actual depth at which the minimum occurs will depend on the size (breadth) of a swimmer. I presented this idea to Canadian swim coaches during a course I teach as part of the National Coaching Certification Program for Swimming Canada.

The second example is based on arguments that have been presented for years supporting the view that either drag-based or lift-based mechanisms are used to generate thrust in freestyle swimming. Recently Sanders (1998) argued that sport scientists should be skeptical about the predominant view that lift-based mechanisms generate thrust in
freestyle swimming. Recent work in comparative animal biomechanics, however, has shown that in Nature, thrust generation by appendages of aquatic animals may be something substantially different from either lift or drag-based mechanisms (Dickinson, 1996).

The concept of lift and drag forces as applied to competitive swimming was taken from steady-state fluid dynamic theory. As in animal locomotion, the movement of thrust-generating limbs in human swimmers is inherently unsteady: phases of acceleration exist in the stroke. It is now recognized from comprehensive studies of animal locomotion (e.g., Cheng and DeMont, 1996; Cheng et al., 1996; Vogel, 1997) that new concepts associated with unsteady fluid dynamics are required to fully understand animal movement (Lauder and Long, 1996). Quasi-steady state applications, such as Sanders (1997), may have limited applicability in both animal and human aquatic locomotion, since force coefficients are not constant, but have complex time histories.

New observations on unsteady effects have shown, for example, that hydrofoils with an impulsive start and high angle of attack can produce significant transient lift forces (Dickinson, 1996). This finding suggests that the application of unsteady fluid dynamics to competitive swimming may rejuvenate the debate on the nature of thrust forces. But the debate should not be focussed on whether a lift-based or drag-based mechanism is used to generate thrust, but rather on how important these steady-state forces are at all. Colwin (1992) already introduced the general idea of applying unsteady fluid dynamics to understand the thrust generating mechanisms used by competitive swimmers, but with rapid advances in the development of theories of unsteady fluid dynamics in animal locomotion, his suggestions need to be updated. I suspect that significant advances will be made in the performance of competitive swimmers in most of the strokes used, when unsteady mechanisms are included in the analysis of thrust generation. The techniques for such an analysis are now available in the field of comparative biomechanics.

There is growing interest in applying what Nature does so well to the design of new technologies. This new field of science is called Biomimicry (Benyus, 1997). Sport scientists studying competitive swimming may benefit from learning about Nature's highly competitive swimmers.

REFERENCES


