

PRINCIPLE AND TWO FORMS OF SWIMMING PROPULSION

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Propulsion in water is primarily done by generating torque in the shoulder, hip, knee, and ankle. To do this water resistance is used as support. By the of arm movements the body is pulled through the water, by the leg movements it is pushed. Locomotion is also found without any direct backward motion of the water.

KEY WORDS: swimming, propulsion, water resistance, torque

INTRODUCTION: Analyses of swimming technique cover classical methods of three-dimensional (3D) analyses (Deschodt, Rouard, Monteil, 1996) as well as complex studies including the energy yielding process (Miyashita, 1996).

The swimmers move both in the water and above it: This makes the evaluation of the effect of the body parts above the water on the remaining body more complicated. But there is a trend in swimming, caused by a higher flexibility of all parts of the body, that all body parts actively act on water resistance. Additionally, the swimmers set water as a wave in front of them in motion.

Several authors have tried to define propulsion. Councilman (1968) described the Newton principle "actio est reactio" as an impulse transfer from the moving water to the body. This attitude has been revised ten years later by Schleihau's studies showing that backward moving water creates almost no hold for support (Councilman, 1980). He recommended an S shaped path of the pulling arm. For an explanation the lift force, deduced from the Bernoulli Principle, was introduced. Schleihau concluded that both principles (Newton and Bernoulli) contribute to propulsion.

Maglischo (1993) again trusts in Newton: "Swimmers must push water back to go forward". He considered the hydrostatic drag to be of secondary importance. But he introduced a new idea: If the hand moves linearly the boundary layer flow is disrupted to produce turbulence instead of laminar water flow.

In contradiction to this approach Colwin (1992) presented his vortex theory taking the water turbulences into account. In his opinion vortexes create a compact support to prop against (Fling-Ring-Mechanism). Colwin distinguished between three kinds of vortex: starting vortex, bound vortex and shed vortex. Hollander and Berger (1997) speculated that propulsion could be regained only from the water turbulences that are caused by the swimmer's propulsion.

In 1993 Prichard observed the active rolling of the hip in top swimmers. He explained a portion of the propulsion by the impulse generation caused by turning the hip is transferred to the arms.

METHOD: Data on body motion are gained from video recordings above and under water. All subjects are elite swimmers. The procedure is described in the paper by Drenk, Hildebrand, Kindler and Kliche (ISBS 1999).

The calculated 3D coordinates form the basis for our analyses. Especially the velocity of the centre of gravity is calculated (see lower curve in Figure 1). We try to relate the increase in velocity to propulsion measures. According to our opinion the propulsion measure can only be defined by water resistance. Below we will explain how it is possible to move without impulse transfer, e.g. without moving the water backward. In training, swimming movements are presented using animation programmes (chosen phases in Figures 1 and 2).

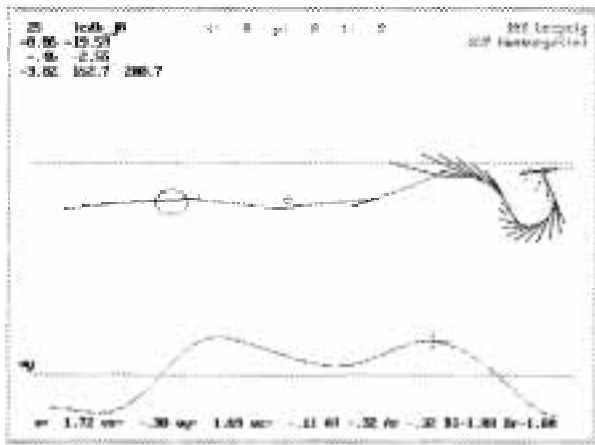


Figure 1 - Leg movement in butterfly swimming above: path and vector of velocity on ankle below: velocity of CM

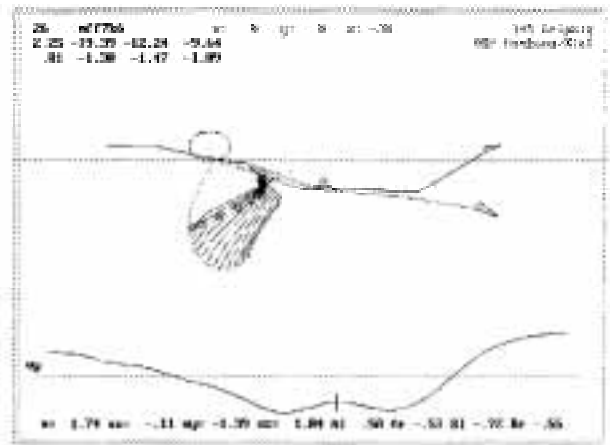


Figure 2 . Kinegram during crawl arm stroke, parts below the circle move backward against the water

When swimming, water molecules are moved by the body's motion. By overcoming inertial force the work generated by the swimmer is transformed into kinetic energy. This resistance is called 'form drag'. Form drag is proportional to water density and flow-streamed cross-sectional area. Since the drag directly corresponds to the kinetic energy of the water it is approximated well as the square of the velocity of the moved part of the body (head, shoulder, foot etc.). When calculating the resistance an empirical constant is introduced, the 'resistance value', which depends on the amount of moving fluid, on the form and the dimension of the flow-streamed cross-sectional area. For example this resistance constant amounts to $c = 1.1$ for a completely immersed quadratic area with a velocity of 0.2 to 0.4 m/s (Grimsehl, p. 249). This approach is only due to a laminar flow. Starting with a certain critical velocity other laws come into effect: one finds vortices behind the body causing a rearrangement of kinetic energy. In our studies we found that, even in this case, the resistance is proportional to the square of the velocities. Thus, the exponent of resistance's dependency from motion velocity should be smaller than 2. Takagi found a confirmation for that in his study.

Experience shows that the head is always attacking perpendicular to the plane created by the movement tangent. In case the head is attacking at an angle to motion direction form drag has to be divided into two components res. forces. They are perpendicular to each other and almost proportional to the cosine res. sine of the attacking angle (Schleihauf). These components are defined as propulsion component (in swimming direction) res. as lift force (perpendicular to swimming direction). But the conditions are even more complicated since the lift and drag coefficient also depend on the shape of the body (Grimsehl, p. 275). We apply the square of the velocity projection of an infinite plane element as measure for water resistance on this plane element. We explicitly underline that a change in motion direction other than the swimming direction always causes a loss in propulsion because of the force parallelogram of the hand. In fluids like water which cannot be compressed there are only normal forces, but no shearing forces.

RESULTS AND DISCUSSION: The analysis of 3D motion data resulted in two apparently different forms of propulsion in water.

1. We characterised the motion phases during which parts of the body are moved against the stillstanding water opposite to the swimming direction. Figure 2 presents an arm's kinegram during a front crawl arm stroke. The parts of the arm below the circle were moving backward against the water in just that moment. We use the flowstreamed area of the arm and the distribution of velocity value and direction on this area to estimate the

integral of that area as a measure for water resistance. Water resistance creates a support for hands and arms which is applied to generate torque in the shoulder ankle pulling the trunk forward. It becomes especially obvious in modern breast stroke swimming with the hands and moving backward arms only for a very short time.

2. When applying this procedure to leg movements in butterfly swimming – the subjects were swimming underwater and without using their arms – we found evidence for a second form of propulsion. Especially in skilled swimmers the resistance parameter has never been positive. Figure 1 shows that all parts of the body are moved against the flow though the swimmer moves forward (compare velocity curve of centre of gravity).

Our explanation is as follows: Leg movement in butterfly swimming is characterised by an upward res. downward movement of the lower leg res. of the more or less stretched legs. Synchronous to that movement pattern we find an increase and decrease of the centre of gravity's velocity in our animation programme. Velocity vectors are almost constantly pointing (exception and then only for a short time are foot portions) in the swimming direction (Figure 1). Thus water is never moved backward, the body is exclusively faced with resistance.

The resistance which originally is breaking propulsion is applied as support to generate torque in knee and hip. This makes it possible to stretch the ankles without working in accordance with the angular momentum conservation law. According to this law a movement of the centre of gravity with only such movements would be impossible in quasi airborne conditions. Consequently, the centre of gravity is moved forward by stretching the knee and hip ankle.

CONCLUSION: The question for real propulsion force values is still insufficiently answered (compare even Rouard et al.). This will be possible only after having a good procedure to determine the resistance coefficients.

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