TRANSFERRING APPLIED HYDRODYNAMICS TO TECHNICAL TRAINING: "THE SCULLING PROJECT"

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The purpose of this presentation is to show some ideas where swimming kinematics and hydrodynamics were combined to deal with the understanding of swimming propulsion/efficiency phenomena. The study is a complex combination of different methods to tackle the problem of understanding swimming propulsion: 3D kinematics, flow visualization, PIV and CFD. The hand's CM propulsive path differed between supportive and displacement sculling, finding the same situation in the wake generated. The forward zigzag path and the impulsive wake observed during displacement sculling opened a novel understanding of swimming propulsion.

KEY WORDS: 3D analysis**,** vortices, unsteady propulsion, swimming drills.

INTRODUCTION: The performance development in swimming sport is based on a complex dose adjustment (training plan) of physical loads, technical-biomechanical improvement, tactical awareness and psychological control. Most the swimming training programs devote unique attention to the physical loads in water and on land and with luck to the psychological element. Technical and tactical practice is considered an important part of the training program but rarely planned, dosed or evaluated applying a rational methodology. A cause of this situation is based on the technical preparation included in the coaches' courses where a mere description of body positions, limbs movements or body-parts coordination is taught without a clear understanding of complex hydrodynamics phenomena involved in swimming motions. This is caused by the lack of an understandable conceptual framework easily applied to the daily work of swimming coaching. How can hydrodynamics be useful for the coach, being so complex? To resolve this situation is a difficult task, not dealt with by the scientists. A few works try to give a plausible answer to the problem, as for example:

a) To spread the knowledge about these subjects using basic terms combined with the complex description of three-dimensional movements related to quasi-steady propulsive movements (J. E. Counsilman, 1979; Schleihauf, 1979).
b) To introduce the knowledge of flow movements around the human body and limbs, including the application of vortex induced propulsion theories based on unsteady propulsive mechanisms (Raul Arellano, 1999; Colman, Persyn, & Ungerechts, 1999; Colwin, 1985)
c) A general and intuitive description of this knowledge applied to animals Lauder, Dickinson and Fish (Dickinson, 1996; Drucker & Lauder, 1999).
d) New tools recently applied to understanding this problem in human swimming as Computer Fluid Dynamics (Bixler & Riewald, 2002; Rouboa, Silva, Leal, Rocha, & Alves, 2006), Flow visualization using different techniques (Raúl Arellano & Pardillo, 2001; Persyn & Colman, 1997) Particle image velocimetry (PIV) (Raúl Arellano, 2003; Matsuuchi, et al., 2009)

This sample is a demonstration of how the authors (in many cases not really hydrodynamic specialists or engineers) tried to translate complex concepts and equations that compose this area of knowledge to scientists, coaches and practitioners of this sport. Similar cases can be reported in each country where some swimming expert spread his knowledge to the interested colleagues in his country, but usually reported in a language different than English and unknown by the rest of us.

The purpose of this presentation is to show some ideas where swimming kinematics and hydrodynamics were combined to deal with the understanding of swimming propulsion/efficiency phenomena.

METHODS: The study is a complex combination of different methods to tackle the problem of understanding swimming propulsion: 3D kinematics, flow visualization, PIV and CFD. In this case, the paper will be devoted to the first two areas of research. Different research centres are involved in the study: the Polytechnic University of Barcelona (Spain), University of Tsukuba (Japan) and University of Granada, the project being supported by the Spanish Ministry of Science and Innovation.

The swimming technique analysed and considered a fundamental and simple propulsive movement was the "sculling" propulsion. Two types of sculling movements can be defined: supportive and in displacement. The first one keeps some part of the body out of the water supporting its weight without body displacement. The second one propels the body forward or backward, usually in a horizontal position. Four phases can be defined in the sculling action considering the unsteady propulsive mechanics that have been studied in similar biological propellers (Biewener, 2003): 1) inward; 2) pronation [stroke reversal 1]; 3) outward and; 4) supination [stroke reversal 2]. During supportive sculling different loads were added o a belt on the swimmer and during sculling in displacement the swimmer moved forward using different body velocities.

Experimental set-up: A typical 3D approach is applied in both cases including: Two or three cameras recording (50Hz) of the 3D reference frame and swimmers' performance. The digital video sequences captured were processed and analysed using the software Kwon3D (Version XP; Visol, Inc., Seoul, Korea), including: a) control point digitization; b) camera calibration (DSM) and calibration error assessment; c) Body modelling: primary point, secondary points, & user angle (angle of attack); d) trial digitization; e) trial reconstruction; f) coordinate interpolation and secondary point computation; g) digital filtering (Butterworth low pass – 6 Hz) and differentiation; h) variable computation (including user angle computation) and; i) analysis with reports (data exporting and graphics generation).

It is difficult due to the space limitations of this contribution to define every variable measured in the study. Variables related with the 3D pulling path dimensions and characteristics, velocity/acceleration of the hand and body, wake produced and visualized in the water and so on were collected and analyzed.

RESULTS: Figure 1 shows the pulling path of the middle finger of the right hand of the swimmer performing supportive sculling keeping the body vertical. The usual infinite path found in many synchronized swimming books is in this case observed but with a clear deformation and asymmetry. The outward path is more horizontal while the inward is preceded by a pronation/downward action that produces afterwards inward/upward displacement. As can be seen the supination is kept in a fixed position and the mid part of inward and outward displacements showed higher velocities as the vectors graphs demonstrates. Figures 2, 3 and 4 are commented in the discussion part.

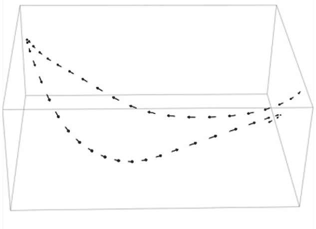

Figure 1: 3D views of the pulling path of the right hand middle finger performing supportive sculling (Pochon & Arellano, 2007).

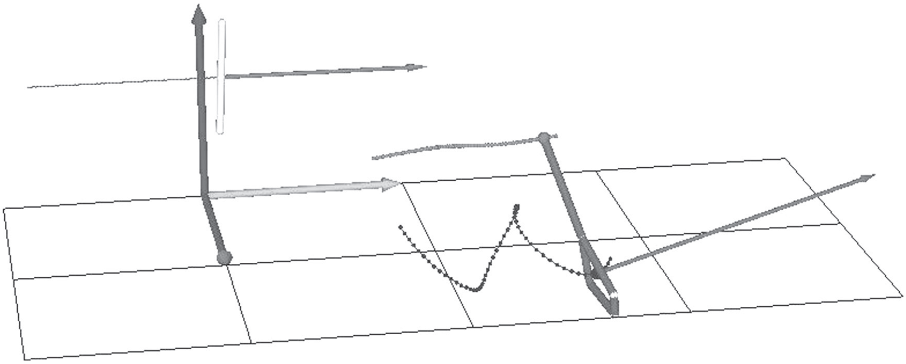

Figure 2: 3D view of the hand and forearm, buoy object, hand CM trajectory, elbow trajectory, centre of buoy object trajectory, and velocity vectors of the sculling displacement.

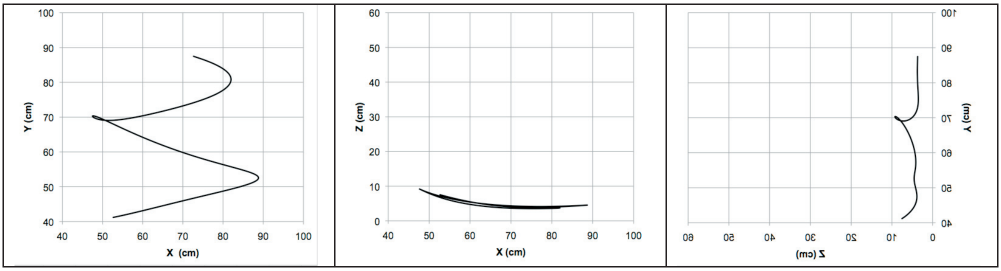

Figure 3: 2D view of the hand's CM displacement coordinates. Y axis means forward displacement, X axis means lateral displacement and Z axis means upward and forward displacement.

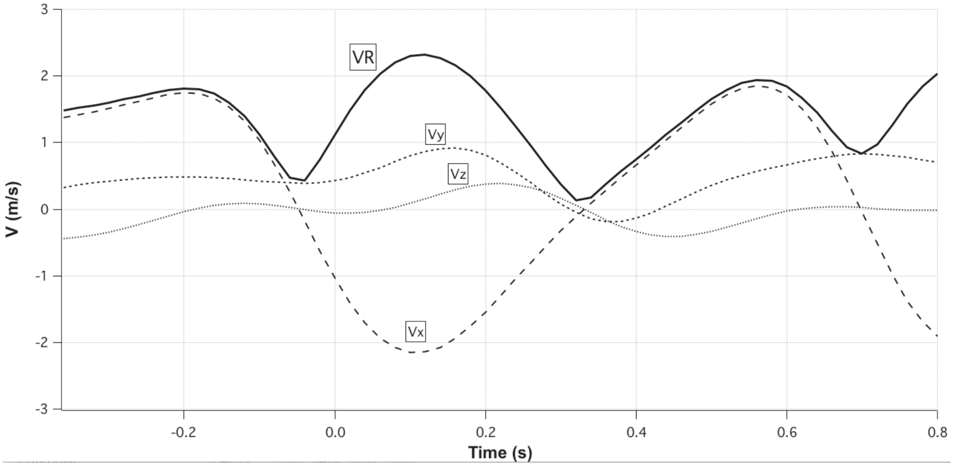

Figure 4: Time – Velocity graph of hand's CM. VR: Resultant Velocity. Peak inward and outward velocities (Vx) showed the highest values of velocities components.

DISCUSSION: The 3D analysis performed helped us to describe in detail a propulsive movement characterized by a short displacement diagonally directed forward. The peak velocity values obtained by the hand's CM (VR) during the mid part of the inward/forward and outward/forward displacements may explain the propulsion generated to move the whole body forward, considering the angles of attack and sweepback obtained (similar to the cited previous studies). The reduction in the VR values during the supination and pronation phases did not produce a relevant decrease in body velocity, while the angular changes in the hands were very big. Some unsteady propulsive mechanisms may explain this situation not adequately solved in the past. Surprisingly, the hand's path is always forward as the body. This could mean a new form of propulsive efficiency where the reduction of backward movement of the hand may provide a better support to the arm's muscles contraction to propel the swimmer forward. A detailed analysis of the wake may help to explain the results briefly detailed. An impulsive wake was observed during the trials, with a similar path than the hand's CM and counter-rotating vortices in the lateral ends of the zigzag path. These were similar than the wake found in fishes or human underwater undulatory swimming.

CONCLUSION: A multidisciplinary study of the sculling propulsive actions is introduced in this paper. Some results are briefly explained, showing that the hand's CM (or centre finger) propulsive path differed between supportive and displacement sculling, finding the same situation in the wake generated. The forward zigzag path and the impulsive wake observed during displacement sculling opened a novel understanding of swimming propulsion.

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