PROPULSIVE FORCE ACTING ON A ROBOT ARM AND ITS FLOW FIELD

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INTRODUCTION

Our aim of this study was to clarify a mechanism about unsteady flow force generated by the human swimming motion. Therefore, we tried to compare the forces obtained for a robot arm in three methods which are a direct force measurement, a prediction by the quasi-steady theory and an estimation based on the flow visualization (PIV) data.

METHODS

The robot arm that mimics human upper limb reproduced a swimming motion of the front crawl. Figure 1 shows the top view of hand movement, hand velocity and position vector of thumb at every 0.07s. The visualization for flow and the force measurement were carried out simultaneously in each position of hand movement shown in figure 1. The visualization was carried out by means of the Particle Image Velocimetory (PIV) at a horizontal plane on the middle of a palm (MPC joints). The force generated by only right palm (area: 0.171m^2) during arm movement was obtained.

The predicted force value was obtained by using the quasi-steady theory developed by Schleihauf [1]. According to the analysis the lift and drag are described in terms of fluid density ρ, squared velocity V^2 relative to the fluid and its surface area S as follows:

$$|L| = \frac{1}{2}\rho V^2 C_L S, \quad (1) \quad and \quad |D| = \frac{1}{2}\rho V^2 C_D S, \quad (2)$$

where C_L and C_D are the lift and drag coefficients, respectively. These coefficients were determined in advance from the forces acting on a palm in steady flow condition.

The estimation of the force was based on the principle of conservation of momentum from the flow visualization data in a horizontal plane. The measurement space of PIV was $53 \times 54\text{cm}^2$ in area and 1cm in vertical depth. The momentum of the water in the area was calculated using PIV data. The sectional force $f(t)$ in the measurement space was determined by applying Newton's second law for the momentum variation. The force acting on a whole palm could be expressed as

$$F(t) = C_h L f(t), \quad (3)$$

where L is the length of a palm, $f(t)$ is a sectional force and C_h is an unknown coefficient taking account of varying cross section of a palm along the direction from fingertip to wrist. By comparing the right-hand side of eq. (3) with the measured force acting on a whole palm, the coefficient was determined.

RESULTS AND DISCUSSION

Resultant forces as functions of streamwise coordinate x are shown in figure 2. The force from momentum variation was shown by dividing three regions, because a whole swimming movement could not be obtained by PIV at once. The form coefficient C_h of a palm was determined as 0.5. The maximum force 13.8N was obtained soon after the start of stroke in the direct force measurement. The quasi-steady force was almost constant (about 5N) from the beginning to the end. On the other hand, the forces estimated based on the principle of conservation of momentum from PIV data are similar to those measured directly. These results reveal that the force acting on a palm in swimming is well explained by the momentum analysis rather than by the quasi-steady analysis.

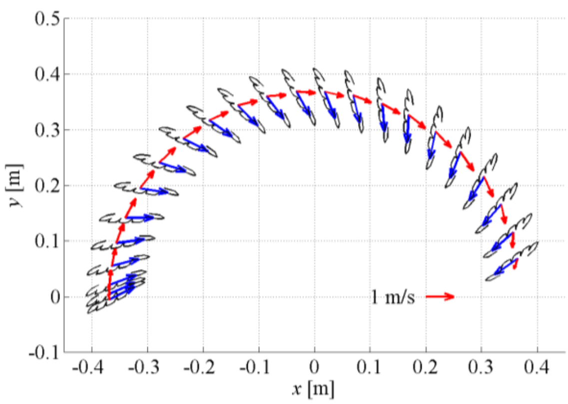

Figure 1: Top view of hand movement, hand velocity and position vector of thumb at every 0.07s

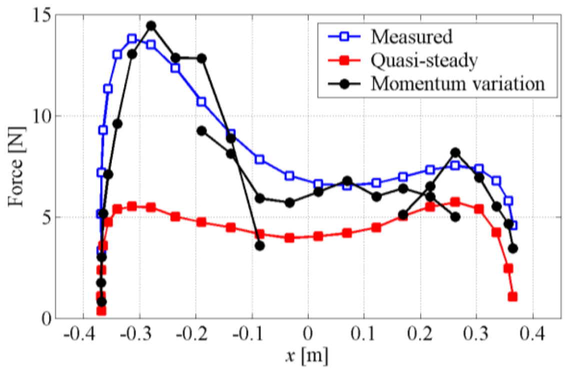

Figure 2: Resultant forces obtained by three different methods

CONCLUSION

The direct measurement of force showed a crucial difference from the force curve estimated from the quasi-steady analysis. On the other hand, the force estimation based on the momentum variation conformed to a profile of the direct force measurement. As a result, it is concluded that the resultant force is generated by momentum variations or flow unsteadiness occurred by arm motion.

REFERENCE

1. Schleihauf RE, et al., *Biomechanics and Medicine in Swimming*. Hollander AP, et al. (eds), 173-183, 1983 Human Kinetics, Champaign.