COMPUTER SIMULATION OF "SPLASH CONTROL IN COMPETITIVE DIVING

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The purpose of the study was to examine the relationship between the hand pattern and the water splash height during a diver's entry using a computer simulation method. A physical and mathematical model of the impact of a wedged solid object with an ideal fluid was developed. The motion equation (interaction function of solid and fluid) of the solid was established with satisfaction of control functions and initial boundary conditions of the fluid. A finite element method was used to simulate the impact process, with the wedge angle changed from 4" to 80° during the impact. The results suggested that the fluid splash height is inversely proportional to the wedge angle. The "splash control" technique derived from the simulation was also applied in training professional divers and positive results were obtained.

KEY **WORDS:** splash control, impact, finite element method, simulation

INTODUCTION: In diving competitions, divers must employ certain techniques, so called "splash control", to minimize water splash at the entry. Through numerous trials and errors in practice, coaches and athletes have already explored and instituted various techniques for the "splash control". However, no research has been performed on the theoretical basis of the technique; many aspects of the technique including splash formation mechanisms and optimization of "splash control", deserve further study. Body water entry and splash formation are rather complicated phenomenon with interactions between the solid and the fluid. Research on interactions between fluid and solid are of special interests; enormous amount of work has been performed in the area of water airplane (Von Karman, T., 1929; Schnitzer, E., Hathaway, M. E., 1953), ship building (Vinje, T. & Brevig, P., 1981), and oceanic science (Faltinsen, O., et al.,1977; Zhao, R. & Faltinsen, O., 1993). Applications of a finite element method in simulating the "splash control" and the impact process between the diver and the water have not been reported. Therefore, the purpose of this study was to examine relationship between a diver's hand patterns and the minimization of water splash at the water entry.

METHODS: In order to examine the relationship between the hand pattern and the water splash height, the water was simplified as an ideal fluid and the human body as a wedge-shaped object during computer simulation (Figure 1). A mathematical model of the impact between the wedged solid object and the ideal fluid was established. Motion equations (interaction equations between the fluid and the solid) of the solid were developed with satisfactions of control functions and initial boundary conditions of the fluid. Computational software (FORTRAN) was developed using a finite element method to simulate the impact process of the wedged object with the ideal fluid; the comparisons were made from the results of computations with the wedge angle changed from 4° to 80°. In addition, "splash control" techniques derived from the results of the theoretical work were applied in actual training and competition of divers in a professional diving team in China.

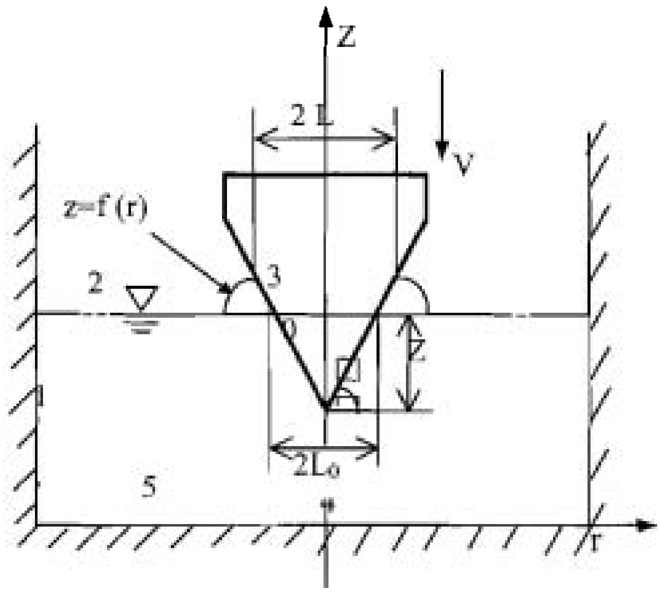

Figure **1 -** Impact model between object and fluid.

Computer Simulation of Impact: The human body was treated a wedge-shaped object and the impact process was simplified as the impact between the wedged object and the water. The basic equations of the impact was obtained and simplified with respect to the ideal and uncompressible fluid. The fluid motion must satisfy the following control function:

$$\Delta\varphi = 0$$

$$\frac{\partial\varphi}{\partial t} + \frac{\bar{V}^2}{2} + \frac{p}{\rho} + gz = f(t) \qquad (1)$$

where the equation is a combination of a second-order partial differential equation and a potential function, used to determines two unknown functions, φ (potential) and p (pressure). Since the solid object is modeled as a wedged object, the original 3-dimensional problem can be simplified as a 2-dimensional problem due to the symmetrical property of the cylindrical coordinate system. This process greatly reduces the complexity of computation. The opposite direction of the wedge's motion is labeled as the positive direction of the z-axis and the horizontal direction is labeled as the r-axis in Figure 1. The origin of the coordinate system is chosen at the intersection point between the z-axis and the bottom of the swimming pool. Equation (1) is then transformed into:

$$\frac{\partial^2\varphi}{\partial r^2} + \frac{\partial^2\varphi}{\partial z^2} + \frac{1}{r}\frac{\partial\varphi}{\partial r} = 0$$

$$\frac{\partial\varphi}{\partial t} + \frac{\bar{V}^2}{2} + \frac{p}{\rho} + gz = f(t) \qquad (2)$$

where φ and 22 p are of function of r, z, and t, $\varphi = \varphi\,(r,z,t)$ $p = p\,(r,z,t)$. The above equations have infinite numbers of solutions. However, only those solutions satisfying boundary and initial conditions are meaningful. At the instant of contact between the wedged object and the fluid, which is the starting point (t=0) of the whole impact process, the states of the object and the fluid are the initial conditions. As the wedge begins its entry into the water (t>0), dramatic changes occur to the unrestrained fluid surface during the impact process. The boundary exists at the contact surface between the solid and the fluid, and at the fluid surface. The fluid boundary conditions are intrinsic boundary conditions. Due to the characteristics of the motion equation of the object and the zero-velocity of the normal direction for the non-adhesive fluid along the wedge's wall, the boundary conditions can be determined for the fluid field. By combining equation (2) with the definite boundary and the initial conditions, it becomes a solvable problem.

The fluid is partitioned into finite amounts of elements using the finite element method. Assuming the approximated velocity-potential function φ (r,z,t) in an element e can be expressed as:

$$\varphi = \varphi_i(t)\,\Phi_i \qquad (3)$$

where Φ_i is an interpolating function of velocity potential, i = 1,2, ..., N_i^e, N_i^e the fixed-point function of velocity in the element, $\varphi_i\,(t)$ the value of the velocity potential function at the time t and the knot i. By selecting the interpolating function of the velocity potential as a weighted function and establishing control functions of r r r ΓΓ! Γ[integration, the strong form of integration of the velocity potential is found with consideration of the natural boundary conditions. In addition, the motion equation of the wedged object is combined into the equation (3). By setting $\delta\varphi = \Phi_j$ in the equation for the element e and through proper simplification, the following finite-element equations of the element are derived:

$$[k_\varphi^e]_{ji}\,\varphi_i(t) = [k_F^e]_j \qquad (4)$$

where i = 1,2, ...8 and j = 1,2, ... 8.
By using a difference method, a discrete solution is sought for terms as function of time in (4) and the unsteady motion is converted into a steady motion within the unit time. Then a general matrix of the finite element functions is derived through assembly of global matrix of finite element system:

$$[K]_{NN}\,\{\varphi\}_N = \{F\}_N \qquad (5)$$

This is a set of N-order linear equations. By solving this set of linear equations within the boundary conditions, the velocity potential for the entire fluid field at the time of $l+1$ $[\varphi(r,z,l+I)]$ and velocities of V_r and V_z within all knots across the fluid field can be found. Therefore the pressure p can be solved for every knot.
For the unrestrained surface of the fluid during the impact process, its shape is solved using an iteration method. Assuming the curve function of the unrestrained surface as $z = f(r)$, the pressure $P^{(n)}$ can be approximated by verifying the boundary conditions of the unrestrained surface. The error pressure between the approximated pressure and the actual pressure for the unrestrained surface is given as: $\Delta P^{(n)} = P_0^{(n)} - P''''$, the water splash height can be then computed as:

$$\Delta h = \frac{P^{(n)} - P_0^{(n)}}{P_0} H_0 \qquad (6)$$

When the error (Ah) is within a predetermined range, it is considered a successful solution. Otherwise, proper corrections are made to the unrestrained surface functions. Once Ah is solved, the shape of the unrestrained surface is determined. Through repeated iterations, the unrestrained fluid surface shape at every instant during the entire impact process is obtained.

RESULTS AND DISCUSSION: The water splash height was estimated for a wedged object of seven different oblique angles (4° to 80") during the impact with the water (Table 1). The splash height for each of the seven wedge angles was expressed in percent of the maximum height obtained during the impact for an 80° wedge. The results indicated that the highest point of the unrestrained wave surface after the impact increased with an increase in the wedge (oblique) angle. The sharpest wedge angle (smallest) elicited the greatest water splash during the impact. Therefore, a diver must externally rotate the arms with both hands forming a flat surface and with the palms facing the water surface (a rectangle, oblique angle = 0) to minimize the splash at the time of water entry. In addition, a separate simulation was run for wedged objects of 30 kg and 60 kg. The result suggested that the greater body mass and impact force increased the splash. This result provides a practical criterion for athlete selections.

Table **1** Percent Splash Heights **from** Different Oblique Angles

	Oblique Angle						
	4	10	20	30	451	60	80
Percent Splash Height	5.0%	12.5%	25.0%	31.31	50.0%	62.5%	100%

The results obtained from the above theoretical and simulation work were summarized in a "splash controluote technique of a combination of "Push" and "Massage" and used in experimental training of divers in a professional diving team in Jiangsu Province, China. Twelve participating divers had all made significant improvement of their "splash control" technique and won several gold medals in several domestic and international competitions.

CONCLUSION: 1. It was attempted in this study utilize a computer simulation method to study the "splash control" in diving. A mathematical impact model between the human body and the water was formulated; a finite element method was used to solve for the impact problem associated with the interaction of the fluid and object. Initial results through numerical analysis were obtained. 2. The magnitude of the impact force and the decay of the wedged object's velocity are inversely proportional to the oblique wedge angle of the object. However, the splash height is proportional to the angle. The splash height is differed by almost 20 times between 80° and 4" wedge angles. 3. The splash height at the time of water entry is directly related to the hand pattern. The hand pattern with a sharp angle formed by the palms facing each other can reduce impact force but also introduce significant water splash. A "rectangular" hand formation with extended and externally rotated shoulder joints can effectively reduce the water splash. However it also increases the impact force and caution for injury prevention is warranted. 4. In addition, the splash height is proportional to the diver=s body weight and the body shape, providing a criterion for athlete selections.

REFERENCES:

Von Karman, T. (1929). The impact on seaplane floats during landing. NACA TN321, National Advisory Committee for Aeronautics.

Schnitzer, E. & Hathaway, M. E. (1953). Estimation of Hydrodynamic impact loads approximating elliptical cylinders with special reference to water landing of helicopter. NACA TN-2889.

Vinje, T. & Brevig, P. (1981). Nonlinear tow-dimensional ship motions. In: Proceeding of 3 rd International Conference on Numerical Ship Hydrodynamics. Paris, 257-266.

Faltinsen, O., et al. (1977). Water impact loads and dynamic response of horizontal circular cylinders in offshore structures. OTC-paper 2741.

Zhao, R. & Faltinsen, O. (1993). Water entry of tow-dimensional bodies. Journal of Fluid Mechanics, 246:593-612.