HYDRODYNAMIC PERFORMANCE OF THE ROWING HULL

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The viscous resistance of the rowing hull was calculated by means of 8th ITTC formula; the wave-making resistance of the rowing hull at different velocity was calculated based on the Michell integral formula. The characteristic of the total resistance of the rowing hull was discussed. The results can guide coaches and athletes to train and compete.

KEY WORDS: resistance, Michell integral, characteristic

INTRODUCTION: The competition of the gold medal of the modern Olympic Games, Substantially, is the competition of the scientific and technical strength of various countries. To increase the achievement of the match of the rowing, on one hand, researchers use modern high-Tech in training athletes to increase their physiological function and technique to the maximum extent; on the other hand, they study sports mechanics of the rowing by means of the theoretical and numerical method, then improve the velocity of the rowing.
Scrag designed a kind of the rowing with 8 athletes for American rowing team in 1993, analyzed the composition of resistance of the rowing and the size of different composition of the resistance by contrasting the results of experiments and numerical simulation (Scrag C.A. & Bruce D. Nelson. 1993). In 1996, Tuck calculated the resistance of the rowing by some experience formulae. In china, Jiurui Han in 1999 overviewed the current internal and international development of hydrodynamic studies about the rowing. in 2000 (Han Jiurui & Zheng Weitao. 1999), Haiyang Xu performed a series of numerical simulations about rowing fluid dynamic by the method of CFD (Computational Fluid Dynamics) applying a kind of three-dimensional Rankine panel method for calculating wave-making resistance, and gained some valuable achievements in research. This article studies the characteristic of the total resistance of the rowing hull. The results can guide coaches and athletes to train and compete

METHODS: The total resistance of the rowing hull can be divided into frictional, viscous pressure and wave-making resistance (Han Jiurui & Zheng Weitao. 1999; Ecer, et.al. 1975; Li Y. L., et.al.1998; Amromin, et.al.1993; M. Bessho. 1994; Doctors & Lawrence J.; Scragg C. A. 2001; Cao Y., et.al1990). Because. the frictional and viscous pressure components are caused by the viscous of fluid, generally, they were jointly called viscous resistance (Han Jiurui & Zheng Weitao. 1999; Ecer, et.al. 1975; Li Y. L., et.al. 1998). Wave-making resistance results in the lost energy that produces wave and keep wave running as the rowing are moving (Amromin, et.al.1993; M. Bessho. 1994; Doctors & Lawrence J.; Scragg C. A. 2001; Cao Y., Schultz W. & Beck R. 1990). The size of different component will all change with the speed of ship. On the whole, frictional resistance is in the proportion of the 1.83rd power of speed; viscous pressure is in the proportion of the square of speed; wave-making resistance is in the proportion of the 4~6th power of speed (Ecer, et.al. 1975). The proportion of the frictional resistance is most, accounting for 70%~80% and even more at the low-speed; The proportion of viscous pressure resistance is fewer than 10% generally, it can even be decreased to less than 5% as considering the excellent shape of ship; the wave-making resistance composes more proportion with the increase of speed, sometimes account for 50% of the total resistance.
The Viscous Resistance: Presently there isn't a practical method that can determine the resistance of resistance theoretically. Model experiment is still the main means of studying the resistance of ship. Model experiment processes in the special pool where model of ship resembles the real ship geometrically and the size of model ship is smaller than that of real ship (Ecer, et.al. 1975; Li Y. L., et.al. 1998).
According to the current method in the field of international ship, the viscous resistance can

be determined using the 8thITTC formula, 1957: $C_f = 0.075(\lg R_n - 2)^{-2}$; $\mathrm{C_v} = (1+\mathrm{k})\mathrm{C_f}$ $\mathrm{R_v} = \frac{1}{2}\rho S U_0^2 \times C_V$, Where ρ is water density; U_0 is the speed of rowing; S is the wet area of the rowing hull under the still waterline. $R_n = U_0 L / \gamma$ is Froude number, L is the length of the rowing hull, γ is viscidity (Han Jiurui & Zheng Weitao. 1999; Ecer, et.al. 1975; Li Y. L., et.al. 1998).

The Wave-Making Resistance: According to the rules of International Rowing Association, the rowing of various level and kind has certain restrictions of weights. At the same time, it stipulates that the depth of water in the general match can't be lower than 3 meters. The speed of this kind is comparatively fast, generally at 5~6 m/s, in this way Froude number (Fn) is generally within 0.55~0.75 ,while Froude number of the depth of water can reach more than 1. The shapes of the rowing basically belong to narrow, long and thin bodies. $L/_B$ is in the range of 8~18, $B/_T$ is generally in the range of 0.6~1. Sometimes rowing can advance at high speed. As reaches the state of half-sliding, it differs from the ordinary shape of ship. Because hull is very smooth, viscous pressure is very little, viscous resistance is mainly the frictional resistance which depends on the wet area of the hull, and the wet areas between the different shapes of the same kind rowing is the same basically, therefore wave-making resistance plays a very important role in the different performance of resistance in different shapes of rowing. So, calculating the wave-making resistance and determining relations between its speed and shape, it is very important significance to offer theoretical foundation for design and guide the match (Amromin, et.al. 1993; M. Bessho. 1994; Doctors & Lawrence J.; Scragg C. A. 2001; Cao Y., Schultz W. & Beck R. 1990).

There are many methods applied in calculating wave-making resistance, but none can become standard. It has taken 100 years to study the wave-making resistance. It is the problem that has not entirely solved by researchers of the field of ship at present internationally. The method of Michell integral is one of those. As early as 1898, Michell had acquired the potential velocity under the condition of linear free surface, using the Froude integral method, consequently, came out a kind of formula which can be used to compute the wave-making resistance, that is, so called Michell integral formula (Doctors & Lawrence J.):

$$R_W = \frac{4}{\pi}\rho U_0^2 K_0^2 \int_1^\infty \frac{\lambda^2}{\sqrt{\lambda^2 - 1}} |A(\lambda)|^2 d\lambda; \; A(\lambda) = -iK_0\lambda \iint_s e^{K_0\lambda^2 z + iK_0\lambda x} f(x,z)dzdx$$

Wherepis the water density; g is the gravity acceleration; K0 = g/U02 is the number of wave; U0 is the speed of rowing; f(x, z) is the half breadth of ship; x, z is the horizontal coordinate and the vertical coordinate respectively; S is the ship surface under the still waterline.

Formula (Scrag C.A. & Bruce D. Nelson. 1993) relates the shape and the wave-making resistance. If the half width is known, it is convenient to determine the value of wave-making resistance. It can be applied to all kinds of thin bodies (breadth << draft) for arbitrary Froude number and to slender ships (breadth and draft << length) in case of high Froude number. Because of the thin and long body of the rowing, it is likely that the wave-making resistance can be fast acquired.

RESULTS: The main characters of the rowing are shown in following Table 1:

Table 1 The main characters of the rowing.

draft(m)	the waterline length (m)	the athlete weight (kg)	draft(m)	the waterline length (m)	the athlete weight (kg)	remark
0.080	8.70	72.0	0.084	9.00	81.7	the weight of the rowing:28kg
0.088	9.30	91.7	0.092	9.30	102.0	
0.096	9.30	112.7	0.100	9.60	124.0	the weight of the oar: 6kg
0.104	9.90	135.0	0.108	9.90	146.4	

In Figure 1, the curve shows the wave-making resistance related to the speed velocity Uo when the draft of the rowing T is 0.10m and the average weight of the athlete is 62 kg. To compare, the result of a three-dimensional Rankine panel method is also given in Figure 1.

In Figure 2, the curve shows the wave-making resistance of the rowing varies with the speed in condition of various weights.

In Figure 3, the curve shows the total resistance of the rowing varies with the speed in condition of various weights.

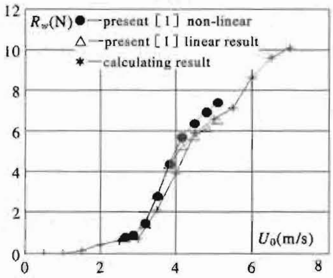

Figure1

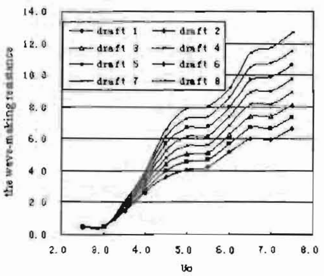

Figure 2

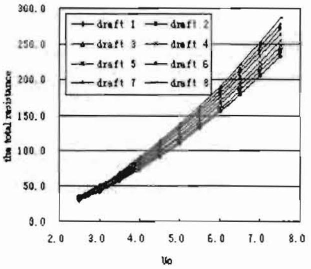

Figure 3

DICUSSION: In Figure 1, contrasting with the three-dimensional result of calculation and the result of applying the Michell integral formula, the result shows that method based on the Michell integral formula is comparatively simple and practical; also it helps to calculate the effect of shallow water and optimum design. We can see that the result of Michell integral method is smaller than of a three-dimensional Rankine panel method when the speed is low, but when 4 < Uo < 6 (m/s), the results of two methods are consistent. It indicates that Michell integral method is available if the rowing runs in normal scope of competing speed, but it is simpler than a three-dimensional Rankine panel method. It makes a base for optimizing design of new ship.

In Figure 2, it can be seen that the wave-making resistance increases with the increase of Uo. It can also be seen that no matter what the weight is, the resistance curve doesn't run a straight line and has obvious the hump and hollow, when the speed of the rowing is increasing. When the speed is between 3.0 m/s and 5.0 m/s, when the speed gets higher, the wave-making resistance becomes bigger rapidly. When the speed is between 5.0 m/s and 5.5 m/s, the rate of the wave-making resistance increasing becomes slower, and when the speed belongs to 5.5~6.5 m/s, the wave-making resistance hardly increases. There will be obvious hump near 6.5 m/s. After that, the change the resistance's increasing rate become slow.

Thus it can be seen that the range of speed suitable to the match is 4.5 ~ 5.5 m/s and the achievement of the match of 2000 meter corresponds with 5:30.0 ~ 6:40.0. Male athletes generally are easy to do it. Female achievement is generally the range of 6:40.0 to 7:10.0, corresponds with the range of 4.5 m/s to 5.0 m/s, which the resistance increases rapidly. The research indicates that the speed of the rowing changes 1.0 ~ 2.0 m/s when athletes make a stroke. Therefore this kind of the rowing is fit for male athletes, or female athletes use them in the free wind and water.

In the training of long distance, the average achievement of 2000 m is generally in the range of 8:00.0 ~9:00.0, corresponding with the range of speed of 3.7~4.0 m/s. Here, the speed changes little, but the resistance and power would change greatly. So the training is not the technical training, but is the most one of force and power. The speed of the rowing should be about 4.5 m/s to the technical improvement and confirmation of athletes.

In Figure 2 and Figure 3, It can be seen from the figure that at the same speed, there is the relation of the performance of rowing to its displacement, that the more the weight of athletes is, the more the resistance need.

In Figure3, the total resistance linearly increases with the increase of the speed; it's as same as the rule in the field of ship mechanics. At the same time, at the same speed, higher the draft is, bigger the total resistance is. So, if different athletes except the weight is same, lighter the weight of the athlete is, better his achievement is. That is, if the weight of athletes increases, but the ability to force doesn't increase, the achievement of the match of 2000m will be slower 2~3s. So athletes should control their weights, and especially, the fat could not be too great.

CONCLUSION: Hydrodynamic performance of the rowing hull can be calculated. The viscous resistance of the rowing hull was gained by means of 8thITTC formula; the wave-making resistance can be calculated using the Michell integral formula. The results and analysis show that the wave-making resistance results based on Michell integral method is consistent with that based on a three-dimensional Rankine panel method. It is simple and available based on Michell integral method to calculate the wave-making resistance of rowing.

By analysis the results of hydrodynamic performance of the rowing hull, it's indicated that, if different athletes except for the weight is same, lighter the weight of the athlete is, better his achievement is. So, Athletes should control their weights, and especially, the fat could not be too great.

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