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RESISTANCE OF A CATAMARAN PLANING HULL WITH HYDROFOIL

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ABSTRACT

By mounting hydrofoils in the center part near the botton of a catamaran planing hull, the hydrodynamics characteristics of catamaran planing surface were calculated. Resistance and running trim of a prismatic model were measured by the free to pitch and heave method.

It is observed that the drag to lift ratio can be reduced by proper selecting the position and the angle of attack of setting of the hydrofoil.

RESUMO

Montando os hidrofólios no plano central de Catamaran, as características hidrodinâmicos do Catamaran foram calculados. Resistência e o RT de um modelo prismático foram medidas usando dois métodos. Foi mostrado que a relação do arrasto à sustentação pode ser reduzida se a posição e o ângulo de ataque do hidrofólio foram bem selecionados.

1. INTRODUCTION

The fundamental research on the hydrodynamics of planing surfaces has been carried out for many years. Numerous experimental as well as theoretical results have been published. Apart from providing resistance and powering information, the influence of hull form on stability is also one of the major interest in craft design. The most common form of planing hulls is a v-shaped body. It is obvious that catamaran planing hull has much greater transverse stability than the v-shaped form. The deck area can also be increased by the presence of a catamaran hull. Under the same running conditions, the drag-lift ratio of a catamaran planing hull is larger than that of the v-shaped planing hull. And the catamaran also presents structural difficulty to the designer.

The results of Satitsky [1], Murray [2] and Clement and pope [3] enable the designer to calculate the resistance and equilibrium running characteristics. There is very little information available for catamaran planing hulls; in fact, only the works of Clement [4], Wang et al [5], and Liu et al [6] are known to the writers. The interference effect of catamaran hulls was discussed by Satitsky and Dingee [7] and more recently by Liu and Wang [8]. But the problem of interference is far from being solved.

Clement [9] proposed a lifting surface approach to planing boat design. Based on this approach the lift to drag ratio can be much increased. It is the propose of the study to present some theoretical and experimental results of the effect of hydrofoil on the planing characteristics of a catamaran hull. A set of equations showing the running characteristics of a catamaran planing hull with an hydrofoil mounted in the middle of the hull are derived. Interference effect of the catamaran hull was considered. But no considered has been made to the interference effect of the hydrofoil to the hull. Both theoretical and experimental studies show that the drag to lift ratio is markedly decreased by presenting an hydrofoil in the bottom of hull.

2. ANALYSIS

At an moderate separation distance, the equations for the lift coefficient, C_{LO}, and center of pressure, C_p, were reported by Liu and Wang [8]. The forms are

$$C_{LO} = (0{,}012\lambda^{1/2}/A + \frac{0{,}0055\lambda^{5/2} A}{C_v^2\, r})\, r^{3/2}\, \tau^{1.1} \qquad (1)$$

and

$$C_p = 0{,}45 - \frac{1}{2{,}39 + 5{,}21\,\dfrac{C_v^2\, r}{A^2\lambda^2}} \qquad (2)$$

where

λ = mean wetted length beam ratio, L_m/b

C_v = speed coefficient, $V/\sqrt{bg}$

τ = the trim angle

r = separation ratio, b_1/b

A = interference factor ($1 \leq A \leq \sqrt{2}$)

b_1 = distance between the two inner surface

b = beam of the hull

It is known that in a certain range of Reynolds number and a given configuration, the lift coefficient of an hydrofoil C_{Lh} depends only on the angle of attack τ

$$C'_{Lh} = A + B\tau + C\tau^2 \qquad (3)$$

where A, B and C are constants which could be determined experimentally. Within a small range of $\tau (0<\tau<6^{\circ})$, C_{Lh} can be approximately represented by

$$C'_{Lh} = A + B'\tau^{1.1} \qquad (4)$$

the values of A and B' for NACA 4415 section were found to be [10]

$$A = 0{,}4 \quad \text{and} \quad B' = 0{,}082$$

Then the lift force Lh can be written as

$$L_h = \frac{1}{2} \rho V^2 C'_{Lh} b_2 \bar{C}$$

where

b_2 = span of the hydrofoil

$\bar{C}$ = chord length

ρ = density of the water

V = velocity of the hull

In order to define a consistance lift coefficient with planing hulls, the lift coefficient of the hydrofoil is defined as

$$C_{Lh} = \frac{L_h}{\frac{1}{2} \rho V^2 b^2} = E + F\tau^{1.1} \tag{5}$$

where

$$E = \frac{Ab_2 \bar{C}}{b^2} , \quad F = \frac{B' b_2 \bar{C}}{b^2} \tag{6}$$

If $b_2 = \bar{C} = 5$cm and $b = 15$cm togather with the values of A and B', Eq. (4) assumes the form

$$C_{Lh} = 0{,}0444 + 0{,}0091\tau^{1.1} \tag{7}$$

The drag coefficient of NACA 4415 wing section in the small range of angle of attack is equal to 0,007. Therefore the drag of the hydrofoil is given by

$$D_h = 0{,}007 \frac{1}{2} \rho V^2 b_2 C \tag{8}$$

The total lift coefficient of the catamaran planing hull with hydrofoil, C_L, is made up of the lift coefficient of the catamaran and that of the hydrofoil.

$$C_L = C_{L\beta} + C_{Lh} \tag{9}$$

where $C_{L\beta}$ is the lift coefficient of a planing hull with deadrise angle β,

$$C_{L\beta} = C_{LO} - 0{,}0065\beta\, C_{LO}^{0.6} \tag{10}$$

And the overall drag-lift ratio of a catamaran with hydrofoil is obtained,

$$\frac{D}{\Delta} = \frac{D_\beta}{\Delta} + \frac{D_h}{\Delta} \tag{11}$$

where $\frac{D_\beta}{\Delta}$ is drag lift ratio of the catamaran with deadrise angle β. Its form is

$$\frac{D_\beta}{\Delta} = \tan\tau + \frac{(V_m/v)^2 C_f}{C_L \cos\tau}\left(\frac{r}{\cos\beta} + 2\lambda \tan\tau\right)\lambda \tag{12}$$

where

v = speed of the catamaran

V_m = the average bottom relative velocity

C_f = skin friction coefficient

Eq.(2) can be used to calculate the center of pressure without hydrofoil. If the center of gravity of the hydrofoil (located at a distance x from the center of pressure of the hull is located at $C_p b\lambda$), the overall center of pressure from transom, ℓ, can be calculated by

$$(L_\beta + L_h)\ell = C_p b\lambda L_\beta + (\ell - x)L_h$$

or

$$\ell = C_p b\lambda - x\frac{L_h}{L_\beta} \tag{13}$$

where ℓ must be equal to the overall center of pressure of the system and x is positive when the center of pressure of hydrofoil is located behind the center of gravity. If $x=0$, $\ell=C_p b\lambda$, which is as expected. Under this condition, Eq. (2) still can be used, but the values of C_{LO} and $C_{L\beta}$ are changed due to the lift contributed by the hydrofoil. Thus C_{LB} is defined as

$$C_{L\beta} = \frac{\Delta - L_h}{\frac{1}{2}\rho V^2 b^2} = \frac{\Delta - L_h}{\frac{1}{2}\rho C_v^2 b^3 g} \qquad (14)$$

Equating Eqs. (9) and (13), it becomes

$$\frac{\Delta - L_h}{\frac{1}{2}\rho\, C_v^2\, b^3\, g} = C_{L0} - 0{,}0065\ \beta\ C_{L0}^{\ 0.6} \qquad (15)$$

With the aid of Eqs.(4) and (9), Eq.(14) becomes

$$\frac{\Delta}{\frac{1}{2}\rho\, C_v^2\, b^3\, g} = E + (F+m)\tau^{1.1} - 0{,}0065\beta(m\tau^{1.1})^{0.6} \qquad (16)$$

where m is the ratio of $C_{L0}/\tau^{1.1}$ which can be found from Eqs. (1) and (2) for given values of A, C_v, C_p and r. Since E and F are all positive, Eq.(16) shows that the trim angle is decreased due the effect of hydrofoil.

If β=0, a simple equation for trim angle can be obtained. Its form is

$$\tau^{1.1} = \frac{\Delta - \frac{1}{2} Em\rho\ C_v^2 b^3 g}{\frac{1}{2}\rho\ C_v^2\ b^3\ g\ (F+m)} \qquad (17)$$

which, again, shows that the trim angle is decreased.

3. COMPARISION AND DISCUSSION

Some results of experimental study of catamaran planing hulls with and without hydrofoil mounted in the middle of the hull was performed in a small towing tank of the University of Singapore [10]. The model was made in mild steel plate. It was 40 cm long and 15 cm wide. The separation ratio was 0.667 and the deadrise angle was 15 degree. A hydrofoil of NACA 4415 wing section was mounted in the middle space of the hull under the center of gravity of the hull. The mass of the model togather with its support was 1.795 kg. A counter mass of 1.25 kg was used to reduce the effective mass to 0.545 kg. The free to pitch and heave method was used to measure the drag and the trim angle during steady running. The drag was measured by a strain gauge balance mounted at the same section of center of gravity. The load coefficient of the model for all the measurements was approximately 5.39.

Figure 1 shows the variation drag-lift ratio and trim angle with velocity coefficient without hydrofoil. The calculated results for A=1 and A=√2 are also shown. Figure 2 shows the results with hydrofoil for the same model under the same conditions. It can be seen that both the drag-lift ratio and trim angle of the model with hydrofoil are smiller than those without hydrofoil.

Figure 3 shows that the calculated results of a catamaran planing hull with zero deadrise angle. The following data was used to perform the calculation:

Δ = 0.545 kg

b = 15 cm

b_1 = 5 cm

E = 0.0444

F = 0.0091

A = 1

r = 0.667

t = temperature of water = 26 $^{\circ}$C

β = 0

Figure 3 again shows that the trim angle and the drag-lift ratio are decreased for the case with hydrofoil. In this calculation, the hydrofoil was assumed to mount under the center of gravity. The center of gravity is located at 18cm from the transom.

The location of the hydrofoil mounted will effect the result of calculation, as was shown in Eq. (13). The trim angle can be decreased or increased by proper adjusting the position of the hydrofoil. From this results, it can be seen that to locate the hydrofoil directly under the center of gravity of the hull can reduce both the trim angle and the drag-lift ratio. The amounts of reduction depend the relative size of the hull and hydrofoil and the shape of the wing section as well.

The interaction between the hydrofoil and the hull is a problem. It is impossible to fund the interference between them theoretically. In this study, no interference between the hull and the hydrofoil was considered.

4. CONCLUSION

By mounting a hydrofoil in the proper position of a catamaran planing hull, the drag-lift ratio can be reduced. The amount of reduction depends the relative size of the hull and the hydrofoil and the shape of wing section being used.The preliminary calculation shows that the drag lift ratio can be reduced about 10 ~ 20%.

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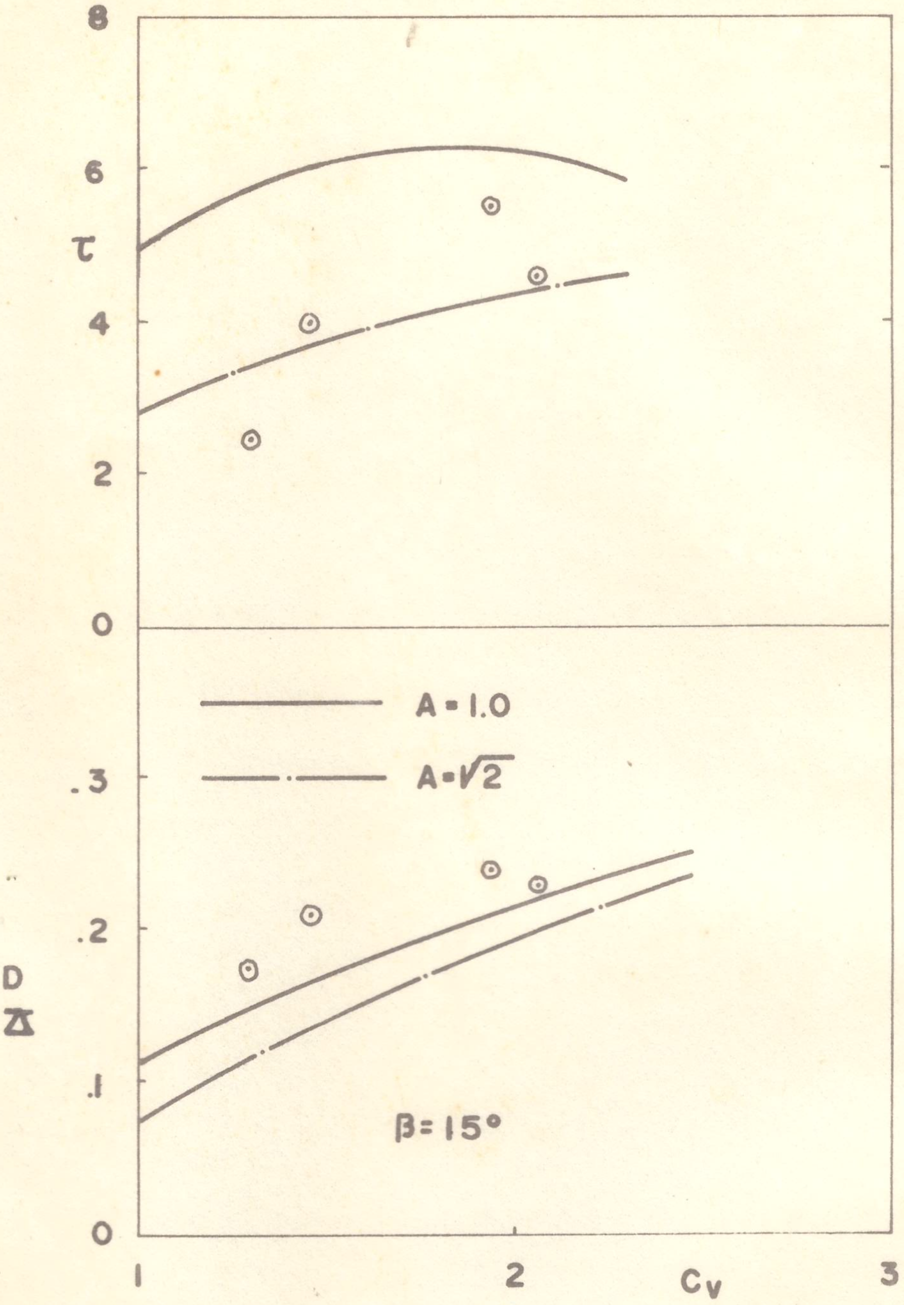

Figure 1. Comparison with experimental results without hydrofoil

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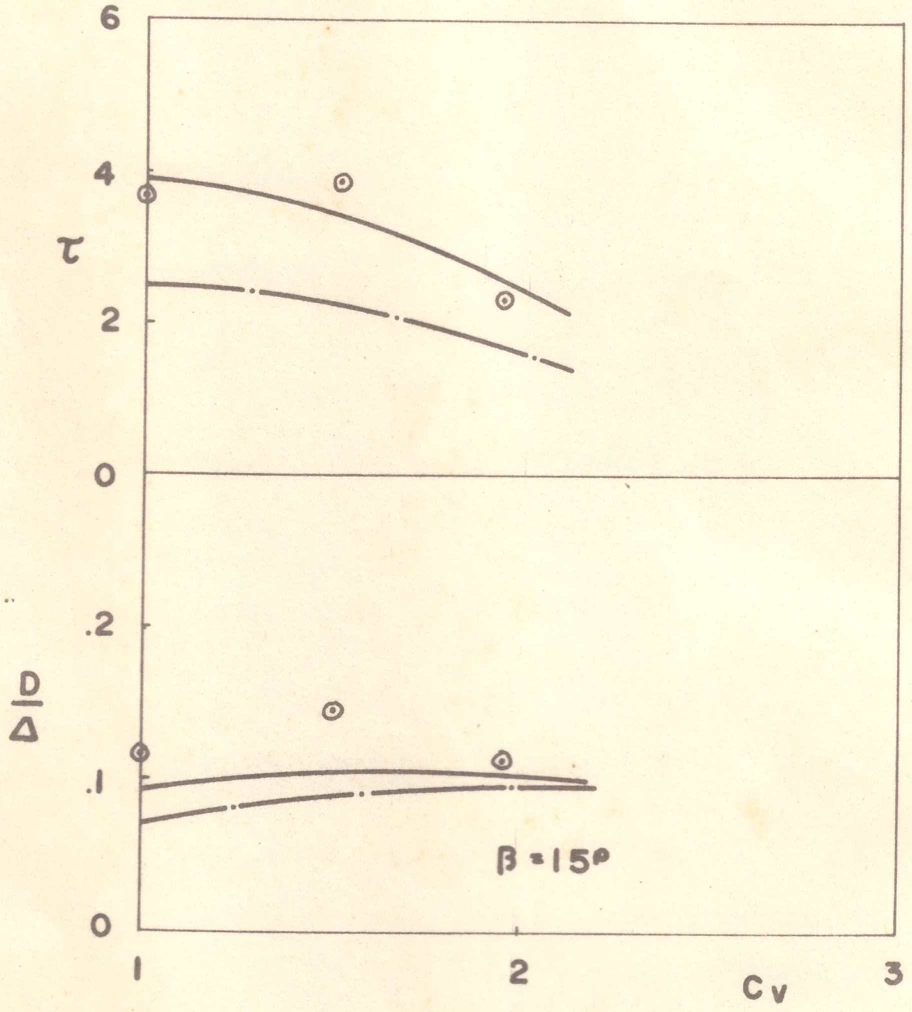

Figure 2. Comparison with experimental results with hydrofoil

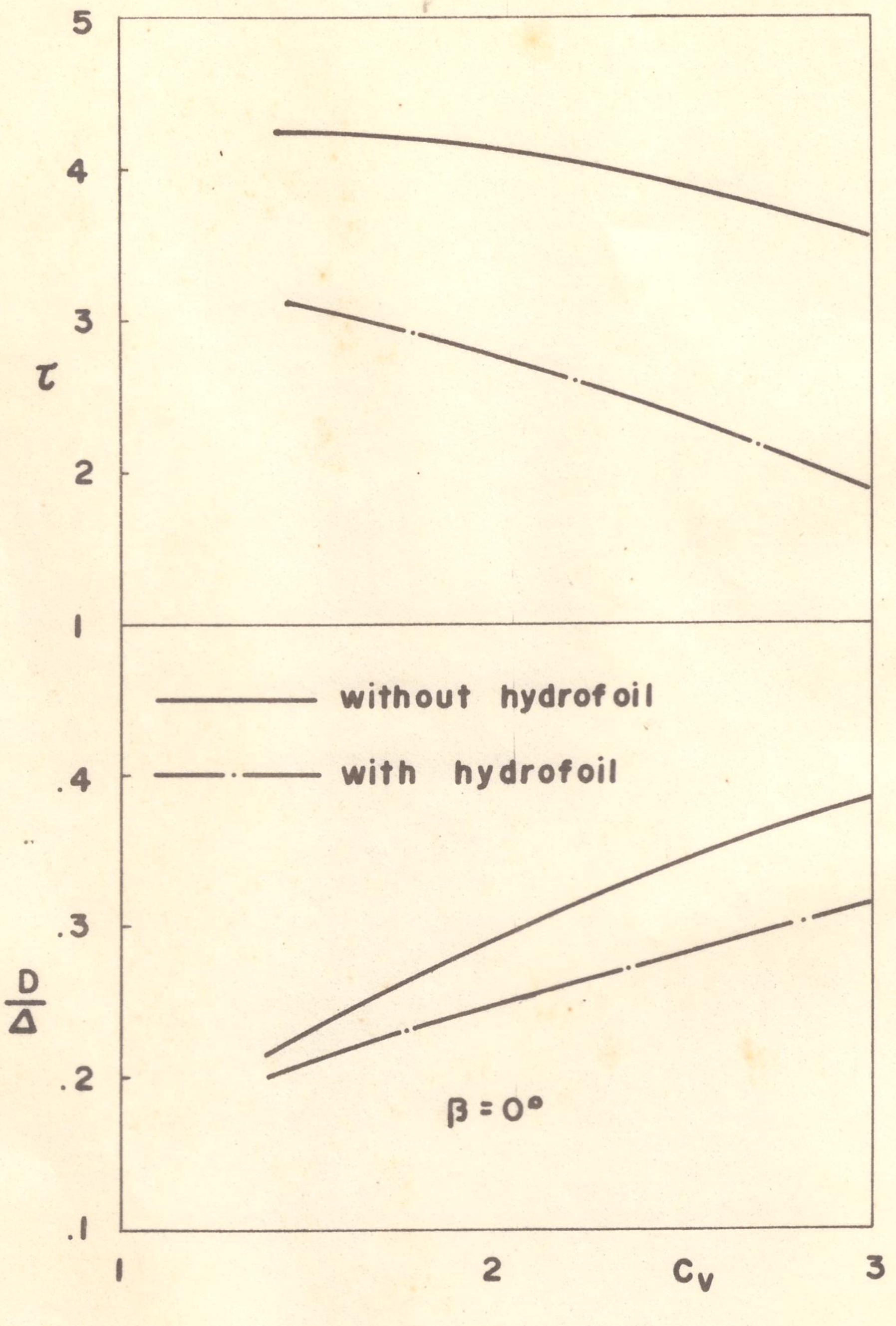

Figure 3. Comparison of catamaran planing hull with and without hydrofoil