# Fundamental Study on Optimum Position of Outriggers of Trimaran from View Point of Wave Making Resistance

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## NTRODUCTION

years, many ideas are proposed in order to pursue the design of high speed vessel em are based on unconventional concepts such as the application of hydrodynamic ted by wings or air cushion pressure. In those cases, however, we have many prob- we aim at sizing up and long distance voyage. To overcome these situations, new high speed vessels based on the displacement type are also proposed and studied DA et al. 1992, 1993; SUZUKI and IKEHATA 1992; SUZUKI et al. 1992 ). In con- ases based on the displacement type concept, very slender hull forms are generally For the hull of such type, however, stability problems are recognized so serious that l. for example, a catamaran is well known as one of the solutions.

paper, a trimaran with small outriggers at both sides are introduced in place of the In the case of this trimaran, the wave making interaction between the main hull and s expected to reduce the wave resistance. Resistance characteristics of the trimaran gated by Seo et al. and Narita ( SEO et al. 1973; NARITA 1976 ). however. discussed in their works are too large for the practical purpose. In the present work. small outriggers are optimized from the view point of the minimization of wave y means of nonlinear programming. The mathematical hull form whose water lines nes are cosine curve and parabolic curve respectively is adopted for this fundamental trimaran. Model tests based on the optimization results are carried out to verify the nical effect of outriggers, including towing tests, wave analyses, and measurements sinkage.

## ALCULATION OF OPTIMUM POSITIONS OF TRIGGERS

Figure 1, the trimaran which consists of the main hull and two small outriggers is in this paper. For this type of the trimaran, positions of outriggers are optimized in imize the wave resistance, as explained above. Before describing the statement of the coordinate system and some definitions are introduced. Principal particulars, th, breadth and draft of the main hull are defined as $L$, $B$, $T$ respectively, and iggers are defined as $L_0$, $B_0$, $T_0$ respectively. The main hull and each outrigger ement $\nabla$ and $\nabla_0$ respectively. The coordinate system normalized by $\ell = L/2$ with positive $x$ toward the bow, $y$ athwart ships, and $z$ positive upward is taken like Fig which the origin is placed on the still water plane at the midship of the main hull. The position of the outrigger in the port side is defined as $(x_0, y_0)$ and another outrigger is at its opposite position, $(x_0, -y_0)$. For the sake of convenience, the following normaliz are employed.

$$b = (B/2)/\ell = B/L$$

$$t = T/\ell$$

$$\lambda_0 = (L_0/2)/\ell = L_0/L$$

$$b_0 = (B_0/2)/\ell = B_0/L = \lambda_0(B_0/L_0)$$

$$t_0 = T_0/\ell$$

In this paper, Froude number is defined by using the length of the main hull such as.

$$F_n = U/\sqrt{gL},$$

where $U$ is the advancing speed of the trimaran.

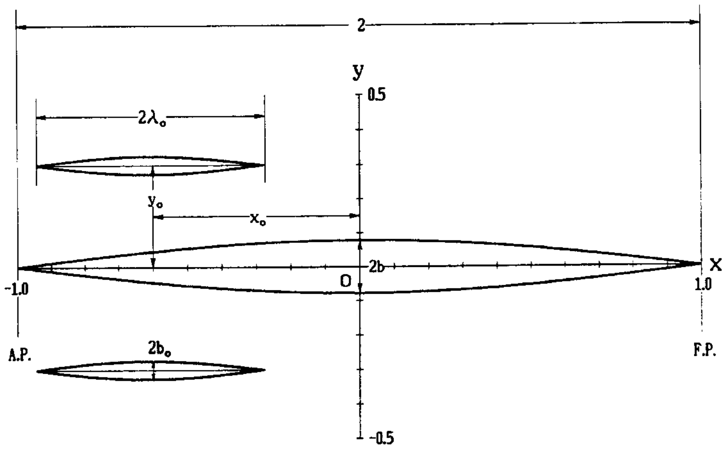

Figure 1 Coordinate system for arrangement of trimaran.

As introduced in the previous section, resistance characteristics of the trima vestigated by Seo et al. and Narita ( SEO et al. 1973; NARITA 1976 ). Accord theoretical considerations under the assumption that the main hull and outriggers wave making characteristics, a favorable wave cancellation can be expected to red resistance, if the following conditions are satisfied.

$$\nabla_0/\nabla = 0.6 \sim 0.7, \qquad x_0 = 2\pi F_n^2, \qquad y_0 = 0.4$$

In these conditions, however, the ratio of the displacement of the outrigger to that hull is too large for the practical purpose. In the present work, objective outriggers than those in equation (7).

For the sake of simplicity, both the main hull and the outrigger are taken as elementary ships in the present study. The equation of the main hull is given as

$$y = f(x)g(z),$$

f the outrigger is given as

$$y \pm y_0 = f_0(x - x_0)g_0(z). \tag{9}$$

n (8) for the main hull, the shape of the water line $f(x)$ is given by Fourier series like

$$f(x) = \pm \sum_{n=1}^{N} \left( a_n \cos \frac{2n-1}{2}\pi x + b_n \sin n\pi x \right), \tag{10}$$

ape of the frame line $g(z)$ is given by the parabola with the order $\beta$ like

$$g(z) = 1 - \left| \frac{z}{t} \right|^{\beta}. \tag{11}$$

he water line $f_0(x - x_0)$ and the frame line $g_0(z)$ of outriggers in equation (9) are s in similar forms. As explained in subsequent sections, numerical examples about m positions of outriggers are given for the hull form having the water line of cosine rresponding to only first term of equation (10).

ng to the above hull form expressions, the optimization problem of the outriggers are formulated. In the present optimization problem, the objective function is defined resistance coefficient as follows,

$$C_w = 8\pi\gamma_0^2 \int_0^{\pi/2} (\{P(\theta)\}^2 + \{Q(\theta)\}^2) \sec^3 \theta d\theta, \tag{12}$$

$$\gamma_0 = g\ell/U^2 = 1/2F_n^2. \tag{13}$$

ization process, this wave resistance coefficient (12) is evaluated by means of ave resistance theory based on the thin ship assumption, because very slender hull ployed in general as the high speed ships of displacement type. In case of the linear tude functions $P(\theta)$ and $Q(\theta)$ can be represented by the linear superposition such

$$\left. \begin{array}{c} P(\theta) \\ Q(\theta) \end{array} \right\} = \left\{ \begin{array}{c} P_M(\theta) \\ Q_M(\theta) \end{array} \right\} + \left\{ \begin{array}{c} P_0(\theta) \\ Q_0(\theta) \end{array} \right\}. \tag{14}$$

m of the right hand side of equation (14) represents the wave making effect of the and its second term represents total wave making effect of outriggers at port and es. Respective amplitude functions can be integrated by Michell's theory based ship assumption as follows.

$$\left. \begin{array}{c} P_M(\theta) \\ Q_M(\theta) \end{array} \right\} = -\frac{1}{2\pi} \int_{-1}^{1} \frac{\partial f(x)}{\partial x} \begin{array}{c} \cos \\ \sin \end{array} (\gamma_0 x \sec \theta) dx \cdot \int_{-t}^{0} g(z) e^{\gamma_0 z \sec^2 \theta} dz \tag{15}$$

$$\begin{aligned} \left. \begin{array}{c} P_0(\theta) \\ Q_0(\theta) \end{array} \right\} = -\frac{1}{2\pi} \int_{x_0-\lambda_0}^{x_0+\lambda_0} \frac{\partial f_0(x - x_0)}{\partial x} & \left[ \begin{array}{c} \cos \\ \sin \end{array} \{\gamma_0 \sec^2 \theta (x \cos \theta + y_0 \sin \theta)\} \right. \\ & \left. + \begin{array}{c} \cos \\ \sin \end{array} \{\gamma_0 \sec^2 \theta (x \cos \theta - y_0 \sin \theta)\} \right] dx \cdot \int_{-t_0}^{0} g_0(z) e^{\gamma_0 z \sec^2 \theta} dz \end{aligned} \tag{16}$$

The above equation (16) can be transformed as follows.

$$\left.\begin{array}{c} P_0(\theta) \\ Q_0(\theta) \end{array}\right\} = -\frac{1}{\pi}\cos(\gamma_0 y_0 \sec\theta\tan\theta)\int_{x_0-\lambda_0}^{x_0+\lambda_0}\frac{\partial f_0(x-x_0)}{\partial x}\begin{array}{c}\cos\\ \sin\end{array}(\gamma_0 x\sec\theta)dx$$
$$\cdot\int_{-t_0}^{0} g_0(z)e^{\gamma_0 z\sec^2\theta}dz$$

Formulae for numerical calculations of these amplitude functions can be easily obtained substituting equations (10) and (11) to equations (15) and (17) ( SUZUKI and IKEH 1992; SUZUKI et al. 1992 ). The present optimization problem can be described as : to the optimum position of outriggers $(x_0, y_0)$ to minimize the wave resistance coefficient $C_w$ some design constraints. Since the wave resistance coefficient $C_w$ is a nonlinear function respect to $x_0$ and $y_0$, our problem becomes a nonlinear programming problem with two d variables.

In this fundamental study, the above nonlinear optimization problem is solved und following simple constraints for two design variables $x_0$ and $y_0$.

$$x_\ell < x_0 < x_u, \qquad y_\ell < y_0 < y_u$$

The respective upper and lower bounds can be selected as the practical range. In the fo section discussing numerical examples, the optimization of $y_0$ under given value of $x_0$ carried out to discuss about the variation of the optimum transverse position of outriggers the longitudinal direction. Thus the problem is simplified to have only one design and it can be easily solved by means of the simple algorithm of one directional sea our study, the optimization is carried out by means of SUMT ( Sequential Uncons Minimization Technique ) ( KOWALIK and OSBORNE 1968 ) with Zangwill's direct method ( ZANGWILL 1967 ).

# 3 EXAMPLES AND EXPERIMENTAL VERIF TION

## 3.1 NUMERICAL EXAMPLES OF OPTIMIZATION

For the purpose of this fundamental study, optimizations of the positions of outri exemplified for mathematical hull forms of the main hull and outriggers expressed Both hull forms have water lines of cosine curve and frame lines of 4th order parab namely, the main hull is expressed as

$$y = \pm b\cos\frac{\pi}{2}x\left\{1-\left(\frac{z}{t}\right)^4\right\},$$

and outriggers are expressed as

$$y \pm y_0 = \pm b_0\cos\frac{\pi}{2\lambda_0}(x-x_0)\left\{1-\left(\frac{z}{t_0}\right)^4\right\},$$

all of which are fore and aft symmetric hull forms.

he determination of particulars of the main hull, the displacement length ratio is as

$$\nabla/L^3 = 0.002, \tag{21}$$

s about the lower limit of the actual value of high speed ships of displacemet type in In order to satisfy the condition (21), ratios of paticulars are determined as follows.

$$b = 0.07854, \qquad t = 0.1 \tag{22}$$

esent examples, outriggers are assumed as similar hull forms with 1/3 particulars of hull, that is,

$$\lambda_0 = 1/3, \qquad b_0 = (1/3)b, \qquad t_0 = (1/3)t. \tag{23}$$

ations are carried out according to this calculation plan, therefore the displacement of igger becomes 1/27 of the main hull, which is much smaller than the optimum value by Seo et al. and Narita as shown in equation (7). The authors are interested in the he wave making interaction between the main hull and these small outriggers.

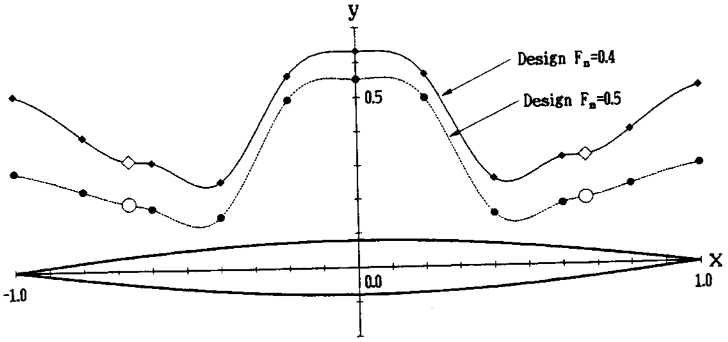

Figure 2 Optimum positions of outrigger.

zation results about the above model are shown in Figure 2, in which design Froude re 0.4 and 0.5. In this figure, results of two kinds of the optimization problem are The first one is the optimization problem of $y_0$ under given value of $x_0$, which is carried ss about the variation of the optimum positions of outriggers along the longitudinal n both design Froude numbers, tendencies of the variation of the optimum position same, while the outrigger of design $F_n$=0.5 takes inner position. Because of the ft symmetric hull forms, these variations become symmetric along the longitudinal n the second problem, both design variables $x_0$ and $y_0$ are optimized, whose results large symbols of white circles or squares in Figure 2. In this problem, the following s are imposed to keep the total length on the still water plane not to exceed the he main hull for the practical sense.

$$-2/3 < x_0 < 2/3, \qquad 0.10472 < y_0 \tag{24}$$

In respective design Froude numbers, two solutions at the fore and aft symmetric positions obtained. In both solutions, the optimum position about $x_0$ converges to the lower or up limit of the constraints (24). If these constraints are excluded, the optimum value of $x_0$ can expected to exceed ±1 as estimated from equation (7).

## 3.2 MODELS AND EXPERIMENTAL RESULTS

Resistance characteristics of the trimaran with the main hull and small outriggers at both s are investigated by model experiments for the purpose of the verification of the hydrodynam effect of outriggers. In those experiments, towing tests, wave analyses, and measurements trim and sinkage are carried out for the trimaran model whose position of outriggers ca changed freely. All model tests are carried out for free trim conditions. Particulars of the m hull and the outrigger are given in Table 1, in which coefficients of fineness of both hull fo are equivalent because of the similarity. At S.S. $9\frac{1}{2}$, namely 75mm behind F.P., of the m hull and 50mm behind F.P. of the outrigger, studs with 2mm hight are fitted at 10mm inte as turbulence stimulators.

Table 1 Particulars of main hull and outrigger.

| Particulars | Main Hull | | Outriggers | |
|---|---|---|---|---|
| Length | $L$ | 1.500 m | $L_0$ | 0.500 m |
| Breadth | $B$ | 0.118 m | $B_0$ | 0.039 m |
| Draft | $T$ | 0.075 m | $T_0$ | 0.025 m |
| Order of Parabolic Frame Line | $\beta$ | 4 | $\beta$ | 4 |
| Displacement Volume | $\nabla_M$ | 0.006750 m$^3$ | $\nabla_0$ | 0.000250 m$^3$ |
| Displacement Length Ratio | $\nabla_M/L^3$ | 0.002 | $\nabla_0/L_0^3$ | 0.002 |
| Wetted Surface Area | $S_M$ | 0.2929 m$^2$ | $S_0$ | 0.0325 m$^2$ |
| Block Coefficient | $C_b$ | 0.5093 | $C_{b0}$ | 0.5093 |
| Prismatic Coefficient | $C_p$ | 0.6366 | $C_{p0}$ | 0.6366 |
| Midship Coefficient | $C_m$ | 0.8000 | $C_{m0}$ | 0.8000 |
| Water Plane Coefficient | $C_w$ | 0.6366 | $C_{w0}$ | 0.6366 |

| | | |
|---|---|---|
| Displacement Volume of Trimaran | $\nabla$ | 0.007250 m$^3$ |
| Wetted Surface Area of Trimaran | $S$ | 0.3580 m$^2$ |

Table 2 Model names and positions of outriggers.

| Model Name | Design $F_n$ | $x_0$ | $y_0$ |
|---|---|---|---|
| MH-0 | - | without outriggers | |
| TR-0 | - | 0.0000 | ±0.9000 |
| TR-1A | 0.4 | −0.6667 | ±0.3220 |
| TR-1F | | 0.6667 | |
| TR-2A | 0.5 | −0.6667 | ±0.1950 |
| TR-2F | | 0.6667 | |

Model names and positions of outriggers are given in Table 2 and illustrated in F The model name MH-0 is assigned for the main hull without outriggers, namely the mo

In the case of model TR-0, outriggers are arranged at outside position as far as p rimental conditions in order to eliminate the effect of wave making interaction b n hull and outriggers. Models TR-1A, 1F of design $F_n$=0.4 and TR-2A, 2F of desig are trimarans with outriggers of the optimum position based on numerical examples n the previous section.

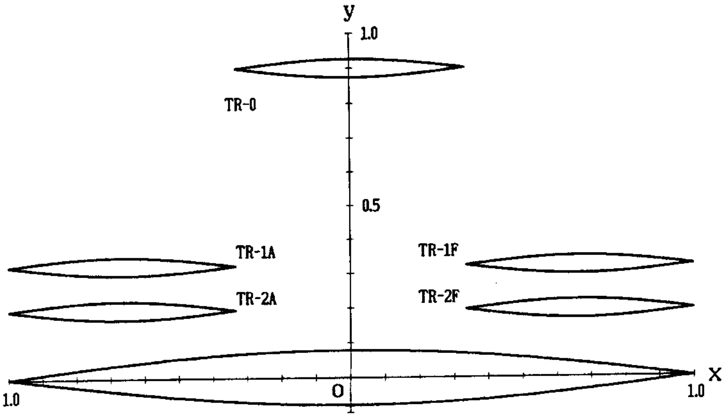

Figure 3 Positions of outriggers of trimaran models.

arisons of residuary resistance coefficients obtained from the towing test using Schoen- ion coefficients are shown in Figure 4 and 5, and comparisons of wave pattern resis- cients determined from the wave analysis by means of Newman-Sharma's longitudi- thod are shown in Figure 6 and 7. In respective figures, theoretical wave resistance s based on the thin ship theory are also displayed for the sake of reference. Theo- resistance coefficients of models TR-1A and 1F are equivalent each other, because f TR-1A are arranged at symmetric positions of TR-1F in the longitudinal direction. dels TR-2A and 2F are also equivalent because of the same reason.

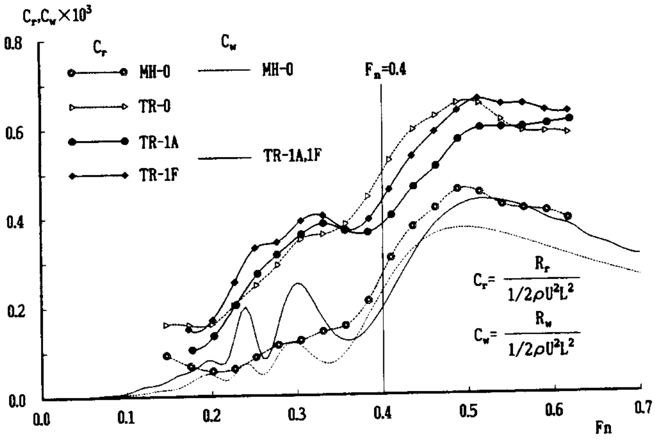

Figure 4 Comparison of residuary resistance.