Wind Tunnel Investigation into the Drag Characteristics of A Pair of Demihull Catamaran in Proximity

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ABSTRACT

An experimental investigation into drag characteristics of a pair of demihull catamaran was carried out using low-speed wind tunnel at Department of Mechanical Engineering, Sepuluh Nopember Institute of Technology (ITS), Surabaya. Full viscous drag investigations were performed without and with turbulence transition strip at the range of Reynolds numbers $2.9\text{x}10^5 - 4.5\text{x}10^5$. The model hull forms comprise a twin model of hull similar to NPL 4a along which are separated laterally. The results obviously demonstrate the effect of hull separation. The experimental work shows that the pressure coefficient increases while the flow velocity decreases when the hull clearance was closer. Furthermore, viscous drag of model with turbulence strip was higher 1.8% than that of non turbulence strip. The experimental results are presented in tables and graphical forms and the drag characteristics and interference effects are discussed and compared with published data in which show good agreement.

KEY WORDS: Wind tunnel; catamaran; viscous; drag; hull separation.

NOMENCLATURE

Demihull	One of the hulls which make up the catamaran
L	Demihull length between perpendiculars
C_F	Coefficient of frictional resistance [ITTC-1957 correlation line]
C_P	Pressure coefficient
CSA	Cross sectional area [m^2]
C_V	Coefficient of viscous resistance [$R_V/(0.5\rho(WSA)V^2)$]
C_{VP}	Viscous pressure resistance or normal force
ds	Distance between C_Ps
Re	Reynolds number [VL/ν]
R_F	Shear force [N]
R_V	Viscous resistance [N]
R_{VP}	Viscous pressure or normal force [N]
S	Separation between catamaran demihull centrelines [m]
V	Velocity [m/s]
WSA	Wetted surface area [m^2]
(1 + k)	Form factor, demihull
(1 +βk)	Form factor, catamaran
β	Viscous resistance interference factor
ø	Pressure field change around the demihull
ρ	Fluid density
ν	Kinematic viscosity of fluid [m^2s^{-1}]
σ	Velocity augmentation between the hulls

INTRODUCTION

Fine ships at higher speeds such as commercial catamarans, the total resistance is dominated by viscous resistance which can constitute between 50 and 80 per cent of the total (Couser et al, 1997). The viscous resistance is made up of skin friction and viscous pressure (or form) drags.

The use of wind tunnels for slender body of catamaran investigations is described. This approach, in which the free surface is treated as a solid plane, allows the isolation of the viscous resistance but does not take account of any influences that surface waves may have on viscous resistance. Lackenby (1965) carried out a number of tests on a catamaran model in a wind tunnel. The overall results of this work would indicate that the influences of surface waves on the viscous resistance are not large and that it should be acceptable to treat the viscous components and form effects. The reflex model was a technique pioneered by others (Joubert et al., 1970) where the resistance of the hull is measured in a wind tunnel. An implicit assumption, for the reflex model, is that the waterline is level. The investigation has been extended to BSRA trawler series (Joubert et al., 1979). Then, Utama (1999) conducted an experimental investigation on a single ellipsoid (as a reflex model) and a pair of ellipsoids in close proximity in a low-speed wind tunnel.

The experimental work was carried out using a wind tunnel on symmetrical catamaran for various hull clearances, without and with turbulent stimulator at the range of Reynolds number between $2.89\text{X}10^5$ and $4.46\text{X}10^5$. A parametric study was carried out on tests without transition strip because of the mixing of laminar and turbulence flows.

This experimental investigations was performed in order to improve the fundamental understanding of the viscous drag and viscous interference effects between twin bodies, such as the hulls of catamarans, and to provide design data.

MODEL DESCRIPTION

The catamaran model was a reflex model as shown in Fig.1. The study objective is to determine the viscous interferences due to pressure (ø) and flow velocity changes (σ).

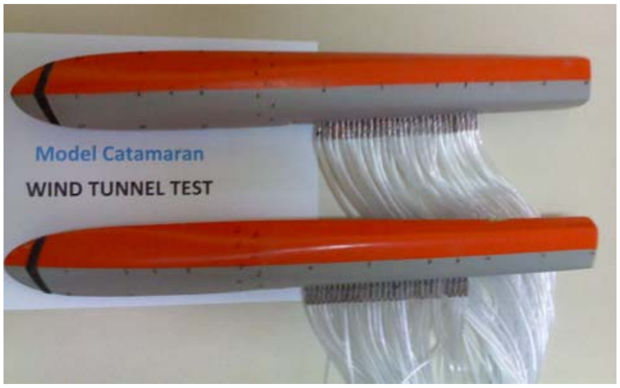


Figure 1. Reflex model of catamaran with turbulance stimulator

The use of reflex models in wind tunnel provides an approximate neans of directly measuring the viscous resistance of the model and without the generation of waves, as there is obviously no free surface present.

The model catamaran with two identical hulls was constructed from wooden materials with identical dimensions. The demihulls had an overall length of 457 mm, a wide of 475 mm and a surface area of 0.0284 m^2.

Leading edge roughness (a turbulence strip) was applied to each demihull. The turbulence stimulation comprising sand grain strips of 0.2mm diameter and 4mm width. The strips were situated about 5 per cent aft of the leading edge of each demihull.

The static pressure is a constant value that is determined by the flow outside the boundary layer. The velocity varies from its free stream value to zero at the wall. The total pressure also varies from free stream to the wall in the same way that the velocity varies.

To measure the total pressure, long thin tubes connect the rake tubes to a pressure transducer located outside of the wind tunnel model.

The blockage effects were minimized by keeping the cross-sectional area small when compared with the tunnel cross-sectional area (<7%), and the interference effects of the support structure were minimized by the use of a minimum of support and by shaping the support structure for minimum drag (Armstrong, 2003).

WIND TUNNEL FACILITY

Physical model testing in wind tunnel is focused to determine the changes in pressure and flow velocity between the two hulls of catamaran in various clearances. The test set-up model at wind tunnel was shown in Figure 2.

In the wind tunnel simulation, the model assumed stationary and the fluid (wind) moving at a pace that is determined. Air flow in wind tunnel test section has move laterally homogeneous, longitudinally and vertically good speed, static pressure and intensity turbulence.

Location of test models the front (on the wind tunnel test section) is facing in the direction flow. Then the pressure and flow velocity between the hulls can be measured very well. Air flow velocity can be determined by measuring the static-pressure drop between the two parts of the wind tunnel, which among the setting chamber and test section.

Figure 2. Test set-up model of catamaran with no turbulence stimulator in the wind tunnel.

The models were tested in demihull (monohull) and catamaran forms at separation length ratios (S/L) of 0.2, 0.3 and 0.4.

The lay-out of wind tunnel with an open circuit system as shown in Fig.3. Thise wind tunnel, in the Mechanical Engineering Department of ITS, has dimension of test section 660 x 660 mm and length of test section 1800 mm.

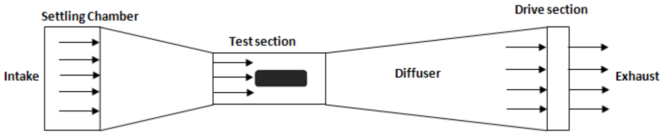


Figure 3. Open circuit wind tunnel.

TEST PROGRAMS

The experiments were carried out in the 1.8 m×0.66 m low-speed open circuit wind tunnel at the Institute Technology Sepuluh Nopember, ITS. The demihull could be adjusted laterally to alter the separation between the two hulls. The circumferential and longitudinal positions of the pressure tappings are given in Fig. 4. One of the demihull was fitted with 57 pressure tappings in order to measure the pressure distribution over its surface. Then, a plot along the lateral static-pitot tube locations is shown in Fig. 5. The models were tested at separation–length ratios (S/L) of 0.2, 0.3 and 0.4.

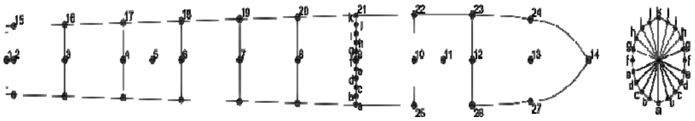


Figure 4. Circumferential and longitudinal location of pressure tappings

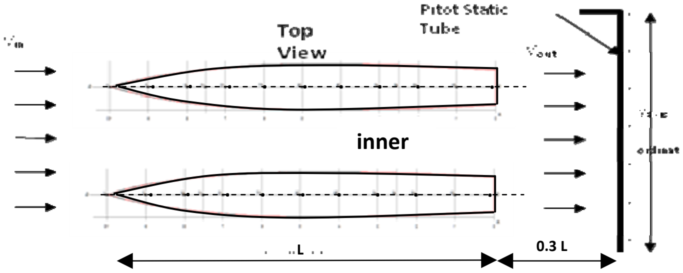


Figure 5. Lateral location of pitot-static tube.

Pressure on the surface of the hull models as measured by some position on the pressure tap with water loaded (draft) along the hull to determine the pressure distribution around (between) the ship's hull. Then the flow rate is measured with a pitot-static tube connected to a manometer, pitot-static tube which is placed behind the stomach by a shift in the lateral direction of the Y-axis as shown in Fig. 5.

Flow velocity was measured at the back of the model with a distance of 30% of the length of the ship and the slide laterally against the hull centerline to be covered more than the width of the hulls. In this case there are 25 measurement points to 60 points for monohull and catamaran configurations, respectively.

Wind speed was set using the wind tunnel controller and measured using a manometer. The current research was carried out at the range of Reynolds numbers 2.89 x10^5 – 4.46x10^5 for models with turbulence and without turbulence stimulators.

Wind tunnel correction was applied according to Glauert's formula (ESDU, 1980). The only significant correction was that due to solid-body blockage, but this amounted to a correction to the drag of up to only 0.2% for catamaran configuration.

RESULTS AND DISCUSSION

The technique of testing in a wind tunnel allows the pressure and flow velocity on the demihull and catamaran models to be measured directly. The pressure and flow velocity changes due to change of catamaran hull clearance were determined using wind tunnel tests.

In the case of the catamaran, the pressure and flow velocities that occur on the outer and inner side along the hull show a difference. The interference factor ratio (inner/outer) for flow velocity (σ) shows that the larger the hull clearance the smaller the velocity difference and vice versa for the pressure ø ratio, as shown in Figs. 6~7 and Table 1.

The pressures were integrated over the hull surface to determine the viscous pressure drag. The total viscous drag at given wind speed could thus be determined in which comprising of the frictional drag or shear force (R_F) and the viscous pressure or normal forces (R_{VP}), as shown in Equation (1).

$$R_V = R_F + R_{VP} \quad (1)$$

The frictional drag was determined by using ITTC'57 correlation line (ITTC, 2002; Utama, 1999). The viscous pressure drag is caused by the development of a boundary layer along the model owing to the viscosity of the fluid, and the consequent changing of pressure which increases in magnitude as the boundary layer develops. This causes a drop in the pressure recovery in the after part of the hull (Armstrong, 2003).

The viscous resistance coefficient of a demihull could be expressed by the Equation (2). By using of two hulls, the effects of viscous drag of separation of the hulls in a catamaran configuration can also be expressed by the Equation (3).

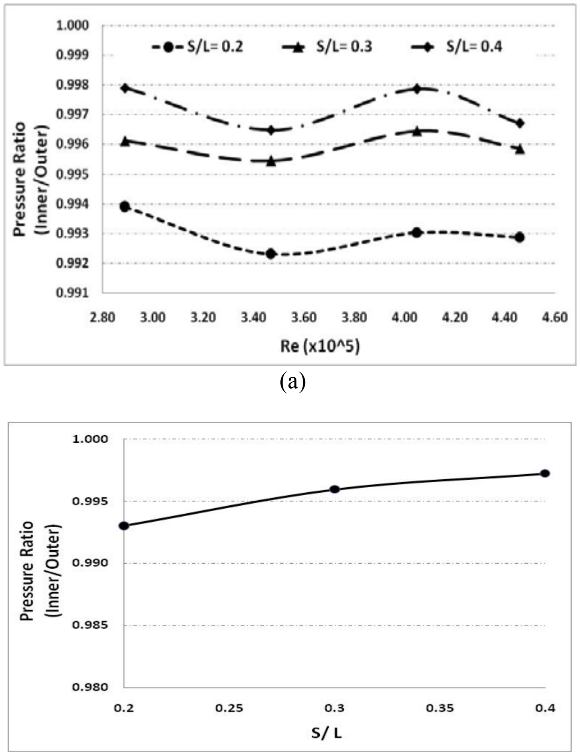
$$(C_V)_{DEMI} = (1+k)\,C_F \quad (2)$$

$$(C_V)_{CAT} = (1+\phi k)\sigma C_F \quad (3)$$

The tests with demihull and catamaran demonstrated clearly a form effect on the single hull (demihull) and a viscous interaction between the two hulls of catamaran, as shown in Table 1.

Table 1. Interference of Flow velocity (σ) and pressure (ø) from wind tunnel result (on model with turbulence stimulator).

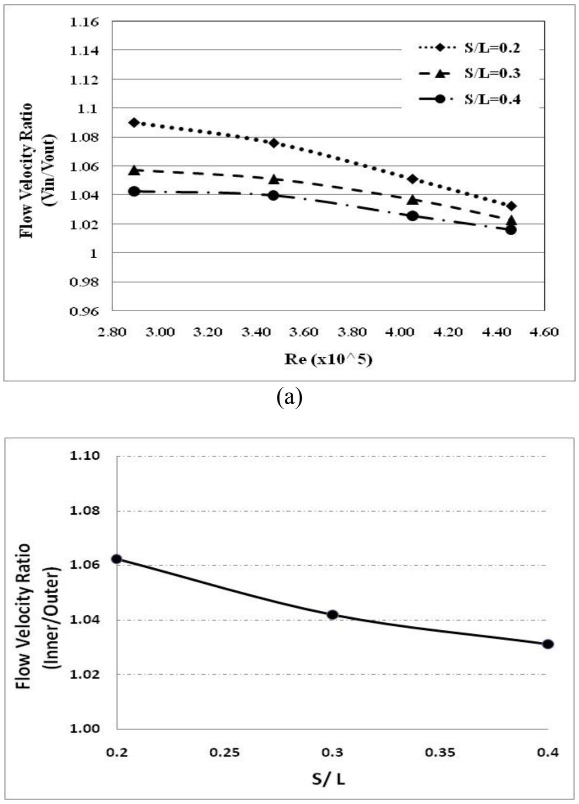
Reynolds number	Sc/L=0.2	Sc/L=0.3	Sc/L=0.4
		Inner/Outer	
Flow Velocity (σ)			
2.89×10^5	1.0899	1.0571	1.0427
3.47×10^5	1.0761	1.0512	1.0399
4.05×10^5	1.0511	1.0369	1.0257
4.46×10^5	1.0324	1.0228	1.0159
Pressure (ø)			
2.89×10^5	0.9939	0.9961	0.9979
3.47×10^5	0.9923	0.9954	0.9965
4.05×10^5	0.9930	0.9964	0.9979
4.46×10^5	0.9929	0.9959	0.9967



(a)

(b)

Figure 6. Ratio of pressure changes based on Re and S/L (on model with turbulence stimulator)



(a)

(b)

Figure 7. Ratio of flow velocity changes based on Re and S/L (on model with turbulence stimulator)

The factor ø has been introduced to take account of the pressure-field change around the demihulls and σ takes account of the velocity augmentation between the hulls and would be calculated from an integration of the local frictional resistance over the wetted surface, while (1+k) is the form factor for the demihull in isolation.

For practical purposes (Molland et al, 1992), ø and σ in Equation 3 can be combined into a viscous interference factor β where (1+øk) σ= (1+βk). Hence

$$(C_V)_{CAT} = (1+\beta k)C_F \tag{4}$$

In wind tunnel case, pressure resistance (along with the skin friction resistance) contributes to the total drag, as written:

$$(C_V)_{CAT} = C_{VP} + C_F \tag{5}$$

Pressure resistance may be estimated by integrating pressure coefficients over the hull (Utama, 1999; Armstrong, 2003), as written in Equation 6.

$$C_{VP} = \int C_P \, .ds \tag{6}$$

Where C_P is pressure coefficient, C_{VP} is viscous pressure resistance coefficient and ds is distance between two C_Ps.

Since C_P is based on maximum cross-sectional area, CSA (whilst C_{VP} is based on wetted surface area, WSA), the results must be multiplied by a factor (CSA/WSA). The new C_{VP}' is then:

$$C_{VP}' = \frac{CSA}{WSA} x C_{VP} \tag{7}$$

where , CSA= 0.0007778 m^2 dan WSA= 0.028444 m^2. The results obtained, in addition to skin friction resistance, are shown in Table 2. The viscous resistances were corrected due to blockage correction by using the formula of Glauert (1933).

The variation in Cv with decreasing separation ration S/L is quite large, and it isquite obvious from Fig. 8 that it is almost entirely because of variations in the value of Cvp (Fig. 9). This phenomena is also described by Armstrong in his experimental work on NPL catamaran model (Armstrong, 2003)

At low speed regime, the viscous resistance effect is more significant than that of at higher speed regime.

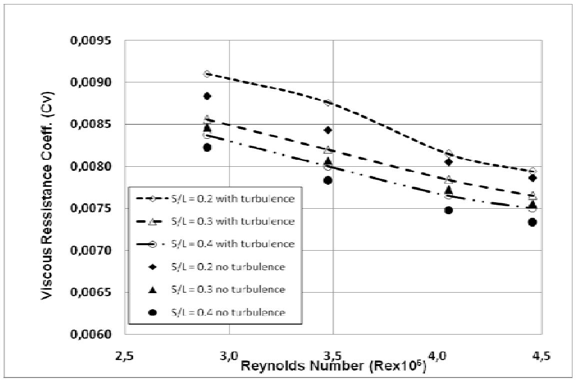


Figure 8. Effect of hull separation on viscous resistance for models with turbulence and without turbulence stimulators.

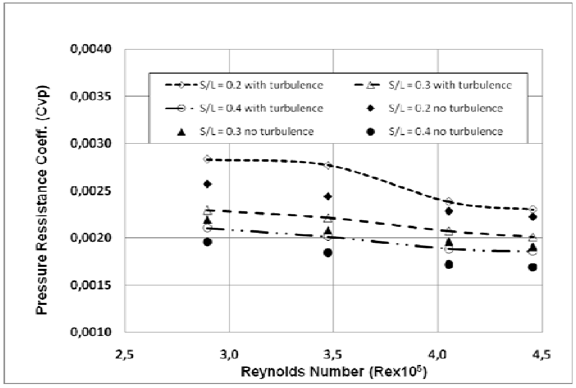


Figure 9. Effect of hull separation on viscous pressure resistance with turbulence and without turbulence stimulators.

Fig. 8 and 9 shows that viscous resistance and pressure resistance catamaran with turbulence strip is higher 1,4% - 2,2% than that of without turbulence strip. Then, the difference of viscous form factor between catamarans with turbulence and without turbulence strip is about 1.8% average.

Figure 10 and Table 2 show the test results for the viscous form factor for demihull (monohull) and catamaran for models both turbulence and no turbulence stimulators. The form factor for demihull (1+*k*) and catamaran (1+βk) are derived from C_V/C_F using Equation (2) and (4).

Table 2. Experimental viscous form factor values

Model	1+k	1+βk Catamaran Hull Clearances		
	Demihull	0.2	0.3	0.4
Turbulence	1.268	1.417	1.409	1.406
No Turbulence	1.254	1.385	1.378	1.394

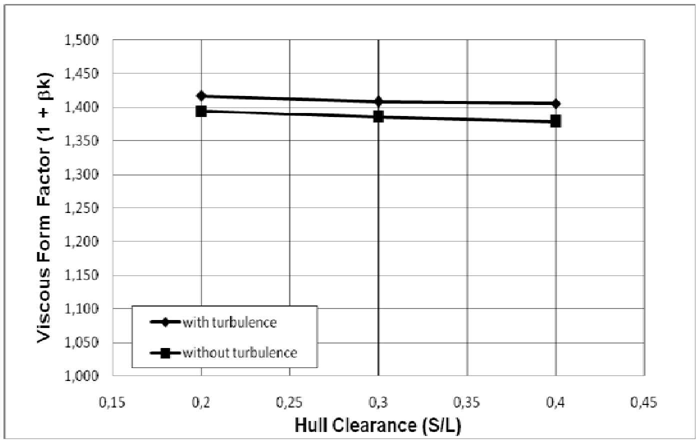


Figure 10. Comparison viscous form factor (1 + βk) for models with turbulence and without turbulence.

The present study indicated that the ratio of total viscous resistance for catamaran over that demihull is obout 1.12 and decreased relatively slowly to about 1.10 as the separation-length ratio S/L is increased up to 0.4. These values were found to be broadly similar to published data (Utama, 1999; Molland and Utama, 2002), which their value is about 1.10 and decreases to about 1.08 as S/L is increased up to 0.47. Utama (1999) investigated the drag of ellipsoids in proximity using a low speed wind tunnel with separation- length ratio (S/L)= 0.27, 0.37, 0.47 and 0.57.

The tests with demihull and catamaran demonstrated clearly a form effect on the demihull and a viscous interaction between the hulls. The results indicate a viscous interaction of the order of 10-12 per cent of the demihull viscous drag and that there is little effective change in (1+βk) with a change in hull separation S/L.

CONCLUSIONS

The effects of various hull separations were analysed in wind tunnel. From the results, the following conclusion can be drawn that:

From the results at wind tunnel, the following conclusion can be drawn that:

- The experimental and numerical techniques employed have provided a better understanding of the physical flow processes when two bodies, such as the hulls of a catamaran, are in close proximity.
- The base pressure coefficient showed a rapid rise when the hull clearance was closer while the flow velocity showed decrease.
- The effects of hull separation on form factor at model are significantly different. The results show that the viscous resistance are affected by the change of hull clearance (S/L). It indicates that the smaller the clearance (S/L), the higher the resistance.
- The viscous form factor of catamaran is higher up to 12% than that of demihull. The magnitude is depended on hull separation ratio (S.L).
- The viscous resistance of catamaran with turbulence stimulator is higher 1.8% than that of catamaran without turbulence stimulator.

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