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EXPERIMENTAL INVESTIGATION ON THE RESISTANCE CHARACTERISTICS OF A HYDROFOIL SUPPORTED CATAMARAN

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Abstract: *A detailed experimental investigation was carried out by conducting the model tests on a 1:20 scale geosim model of a typical hydrofoil supported catamaran (HYSUCAT) formed by two asymmetric demihulls fitted with different foil configurations such as straight and dihedral foils. The resistance tests were conducted in Towing tank at Ocean Engineering Department IIT Madras. Using the model test results, the interference factor (IF) was calculated to study the effect of wave interference for the catamaran with different foil configurations and presented with discussions in this paper. Based on the present experimental investigation, it is found that the catamaran fitted with straight foil has better resistance characteristics.*

Keywords: *Catamaran; foil configuration; model test; resistance; interference factor.*

INTRODUCTION

Now-a-days, catamarans are being used for transportation, sports and defense purpose. The catamarans are very much popular because of their inherent features. The catamaran consists of two demihulls separated by a certain distance to provide several advantages over mono hull vessel, such as large deck area, better stability and lower wave-making resistance at high speeds, simplicity of their design and construction. The catamarans may be formed either connecting two symmetrical demihulls or by splitting a mono hull into two hulls to form two asymmetric hulls.

In the speed range for usual working condition, the propulsive power of a catamaran is relatively high because of the resistance of the two demihulls. The reduction in resistance becomes possible if the catamaran is fitted with a hydrofoil in between the demihulls which takes up a part of the vessel's weight at high speeds. Since, the propulsive power of any marine vehicle depends mainly on its resistance characteristics; it is required to predict the resistance of the vessel either theoretically or experimentally.

Calkins (1984) conducted a series of model tests to characterize the smooth and rough water performance. Miyata (1989) conducted experiments, to predict the resistance characteristics and seakeeping properties were examined. Two prototype of hydrofoil are designed for a 200 t passenger or ferryboat operating at 40 knots conducted experiments in towing tank. Almost 90

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per cent of the weight is supported by the hydrofoils, and the total resistance coefficient is much smaller than that of conventional high-speed craft. Hoppe (1989) carried out model tests for catamaran with different configurations in circulating tunnel indicated best foil positioning, resistance improvements and qualitative functioning of the HYSUCAT in flat water and in waves. To achieve more reliable absolute resistance date several towing tank test series on different Hysucat designs were conducted such as Catamaran without foil, with straight foil and with sweep dihedral foil. Gee (1991) conducted a series of flume and tank tests, in calm water and in waves, have confirmed the performance, and motions and accelerations of the basic hull design. Payne (1995) constructed a simplified model of a hydrofoil craft with the assumption that it has heave only motion; no surface proximity effect on the foil; no foil broaching. He showed that a fully submerged hydrofoil, mounted at the bottom of rigid struts, can transmit large vertical force fluctuations to the hull, even in an idealized sinusoidal seaway because of the orbital velocity field in the water.

In this paper, a detailed experimental investigation has been carried out on a 1:20 geosim model of a typical hydrofoil supported catamaran (HYSUCAT) without hydrofoil and with straight and dihedral hydrofoil configurations.

MODELING PROCEDURE

In the present experimental investigation, Froude's law has been followed to conduct the model tests as detailed below:

i. Geometrical similarity:
   - The model is made to linear scale ratio of L_p/L_m and run over a range of corresponding speeds such that $V_p/\sqrt{L_p} = V_m/\sqrt{L_m}$,

   Where,

   L_p = Length of the prototype,
   V_p =Speed of the prototype,
   L_m = Length of the model and
   V_m = speed of the model.

ii. The total resistance of the model (R_{TM}) is measured for each speed of the model.

iii. The frictional resistance of the model (R_{FM}) is calculated from ITTC 1957 line.

iv. The residuary resistance of the model (R_{RM}) is found from:

$$R_{RM} = R_{TM} - R_{FM}$$

v. If the model is run/towed at the corresponding speed ($F_{nm} = F_{np}$) of the prototype, then

$$R_{RP} = \lambda^3 R_{RM} \qquad \text{or} \qquad C_{RP} = C_{RM}$$

DESCRIPTION OF THE MODEL

For the present experimental investigation, the principle particulars of the prototype and model details of a typical hydrofoil supported catamaran (HYSUCAT) are given in Table 1. Geosim catamaran model was fabricated in 1:20 scale with FRP material. The body plan, profile and half breadth plan of the model are shown in Figs. 1. to 3. Hydrofoil model of NACA 0021 series was chosen with a span length equal to the tunnel of the catamaran model and fitted to the catamaran model with 7^0 angle of attack exactly at the L.C.G position coinciding with the C_p (35% of chord length from the leading edge) of the hydrofoil model. The different hydrofoil model configurations are shown in Fig. 4. The views of the demihull model, catamaran model without hydrofoil and with different hydrofoil configurations are shown in Figs. 5 to 8 respectively.

Table 1. Details of the model and prototype of the HYSUCAT

Description	Prototype	Model (scale 1:20)
Length$_{oa}$	38.08 m	1.90 m
Length on waterline	35.84 m	1.79 m
Beam(mld)	11.58 m	0.58 m
Depth(mld)	5 m	0.25 m
Draft(mld)	3.84 m	0.19 m
Displacement	200 t	25 kg
Vessel Speed	25 knots	2.9 m/s
Fn	0.71	0.71
Fn_∇	1.70	1.70
Span of hydrofoil	6.4 m	0.32 m
Chord of hydrofoil	2.0 m	0.10m

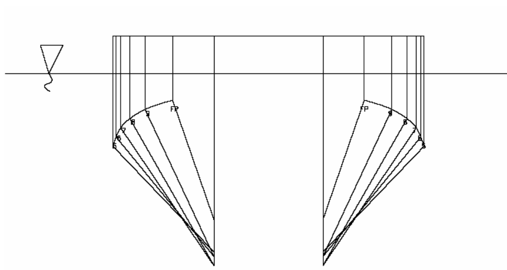

Fig. 1(a). Fore body plan

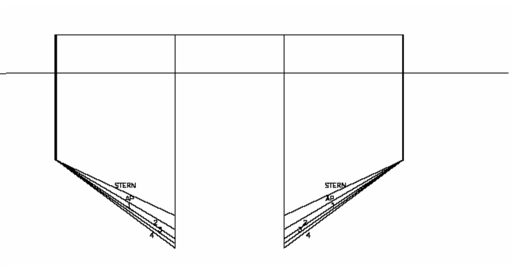

Fig. 1(b). Aft body plan

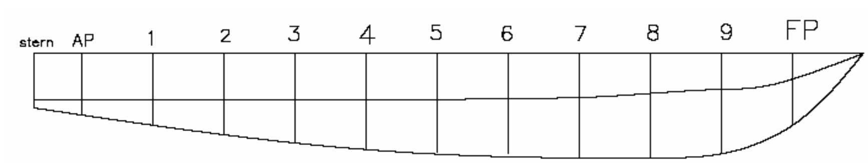

Fig. 2. Profile view

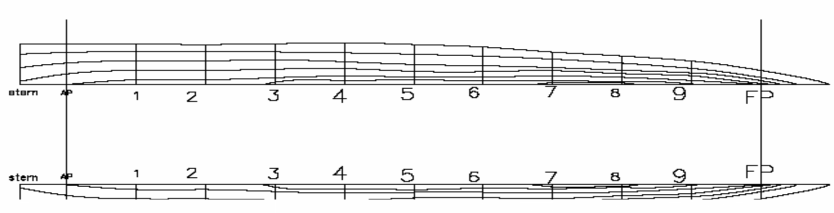

Fig. 3. Half breadth plan

Fig. 4. Straight and Dihedral hydrofoil model configurations

Fig. 5. Demihull model

Fig. 6. Catamaran model without hydrofoil

Fig. 7. Catamaran model with straight foil

TEST

Fig. 8. Catamaran model with dihedral foil

FACILITIES

Model experiments were conducted in the towing tank (82m x 3.2m x 2.5m) at Department of Ocean Engineering, IIT Madras and speed of the towing carriage is 0.05 - 5.5 m/s. At the forward end of the towing tank, a trimming tank is provided to facilitate proper ballasting of the model to the desired draft. The towing carriage can be operated in the low speed range by a low duty D C. motor (manual control only), whereas at higher speed range, it can be operated by a heavy duty D C. motor fed by a Ward-Leonard set, (both by manual and electronic control) and the A C./D C. power supplied through overhead bus bars. The towing carriage is provided with braking system for stopping the model at any position in towing tank. Also for safety purposes, emergency braking rails are provided at both the ends of towing tank, which retard the towing carriage.

EXPERIMENTAL SETUP AND DATA ACQUISITION SYSTEM

A load cell was used to measure the resistance of the model. The load cell is a full bridge strain gauge transducer to measure the applied load. Prior to the calibration of load cell, the primary adjustments to carrier frequency amplifier must be carried out and these included the balancing of the range measurements and amplification factor. Then, the load cell was calibrated for both loading and unloading conditions. The calibration curve for the load cell was drawn as shown in Fig. 9. Suitable clamping arrangement is provided in the towing carriage to fit the model. The clamping arrangement will prevent the model from sway, roll and yaw motions. An aluminium frame, which was mounted on the towing carriage, was used to fix the load cell rigidly in order to connect it to the data acquisition system which consists of data logger and computer. The model was connected to the load cell by means of a steel wire from the tow hook attached to the model through pulley arrangement. The output from the load cell was fed to the carrier frequency amplifier. The output of the carrier frequency amplifier was stored in the computer with the help of the data logger. A detailed line diagram of the experimental setup and data acquisition system is shown in Fig. 10.

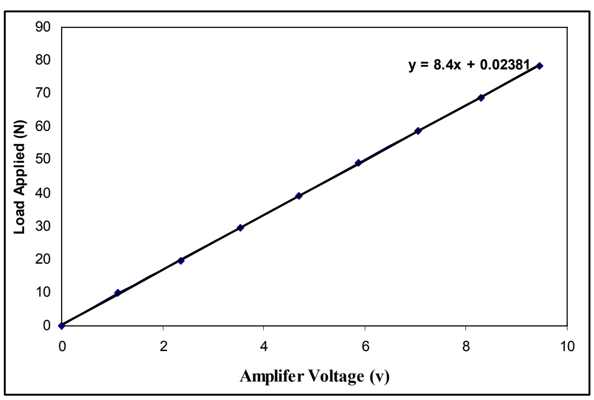

Fig. 9. Load cell calibration curve

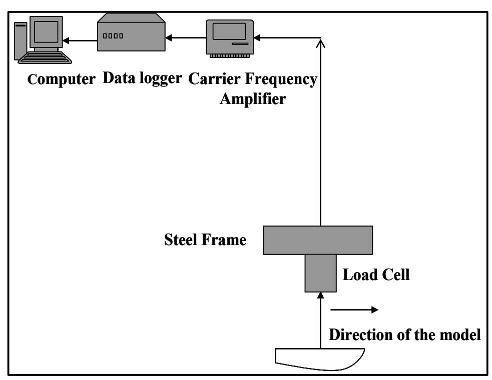

Fig. 10. Detailed line diagram of the experimental setup and data acquisition system

MODEL TESTS

First, the catamaran model without hydrofoil was ballasted to the required draft and fixed to the towing carriage. The load cell was attached with the model and the resistance was measured by running the towing carriage for the speed range of 0.85 m/s to 3 m/s *i.e.,* $0.47 < F_{n\nabla} < 1.77$. Then, the catamaran model with different foil configurations *i.e.,* straight and dihedral foils was ballasted to the required draft and fixed to the towing carriage and same procedure was followed to measure the resistance of HYSUCAT model. Typical flow patterns around catamaran without hydrofoil, with straight and dihedral foils are shown in Figs. 11. to 13 respectively. From the present experimental investigation, the resistance of the prototype has been obtained for $F_{n\nabla}$ ranging from 0.47 to 1.77. The total resistance of the prototype is normalized with the still water displacement of the prototype.

Fig. 11. Flow pattern around Catamaran without hydrofoil

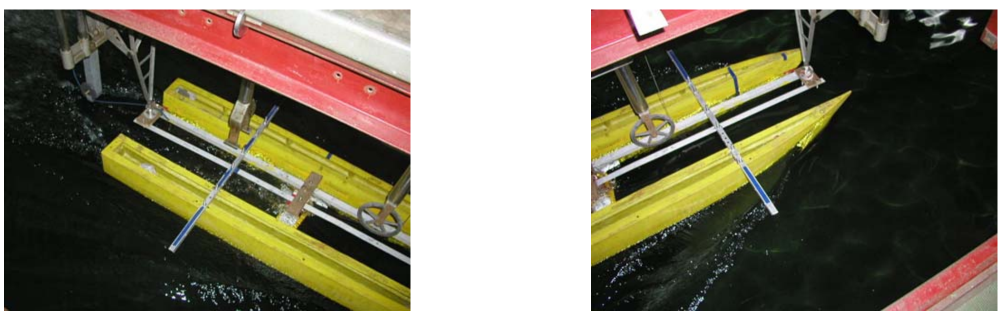

Fig. 12. Flow pattern around the catamaran model with straight foil

Fig. 13. Flow pattern around the catamaran model with dihedral foil

RESULTS AND DISCUSSION

Catamaran without Hydrofoil

The resistance test results of the catamaran without hydrofoil is given in Table 2. The variation of the normalized resistance of the catamaran without hydrofoil is shown in Fig. 14. From Table 2, it can be observed that with increase in $F_{n\nabla}$, the coefficient of frictional resistance is reduced due to the lift produced on the catamaran whereas the coefficients of residuary resistance and total resistance are increased with increase in $F_{n\nabla}$.

Catamaran with different Foil Configurations

The variation of the normalised resistance of the catamaran fitted with straight and dihedral foils with $F_{n\nabla}$ are shown in Fig. 14. From Fig. 14, it is observed that with increase in speed range, total resistance is increased. It is observed that with increase in volumetric Froude number, the coefficients of frictional resistance, residuary resistance and total resistance are reduced due to the lift produced on the HYSUCAT with different foil configurations.

Comparison of Normalized Resistance Characteristics of Catamaran without and with different Foil Configurations

From Table 3, it is observed that the resistance of the catamaran without and with different foil configurations increases non-linearly with the increase in speed for $F_{n\nabla}$ ranging from 0.47 to 1.77. Fig. 14. shows that higher volumetric Froude number, there is a tremendous reduction in the total resistance of the catamaran fitted with the straight and dihedral foils as compared with the catamaran without hydrofoil.

Table 2. Resistance test results of the catamaran without hydrofoil

SL.No	F_{nv}	R_{Tm}(N)	C_T	C_F	C_R	R_{Rc}(kN)	R_{Fc}(kN)	R_{Tc}(kN)
1	0.47	5.19	0.0094628	0.0041975	0.005265349	14.96	5.70	20.98
2	0.65	6.80	0.0086367	0.0039357	0.004701004	25.26	10.31	36.11
3	0.80	9.21	0.0087122	0.0037801	0.004932091	39.91	15.10	55.86
4	0.94	14.80	0.0088709	0.0036579	0.005212975	59.25	20.73	81.25
5	1.06	19.71	0.0090702	0.0035767	0.005493513	79.03	25.83	106.54
6	1.24	23.82	0.0091619	0.0034743	0.005687518	111.36	34.45	148.19
7	1.36	26.00	0.0091967	0.003416	0.005780687	135.77	40.83	179.50
8	1.54	29.38	0.0092692	0.0033397	0.005929487	177.97	51.35	233.12
9	1.65	34.50	0.009618	0.0032948	0.006323278	220.11	58.99	283.79
10	1.77	38.27	0.0098629	0.0032538	0.006609101	264.10	67.12	336.84

Table 3. Comparison of normalized resistance of the catamaran without foil and with straight and dihedral foils

SL.No	F_{nv}	Normalised resistance of catamaran (R_T/Δ)		
		Without foil	Straight foil	Dihedral foil

1	0.47	0.0107	0.0121	0.0126
2	0.65	0.0184	0.0119	0.0133
3	0.80	0.0285	0.0105	0.0132
4	0.94	0.0414	0.0156	0.0184
5	1.06	0.0543	0.0236	0.0261
6	1.24	0.0755	0.0371	0.0434
7	1.36	0.0915	0.0477	0.0491
8	1.54	0.1188	0.0568	0.0606
9	1.65	0.1446	0.0653	0.0708
10	1.77	0.1717	0.0742	0.0802

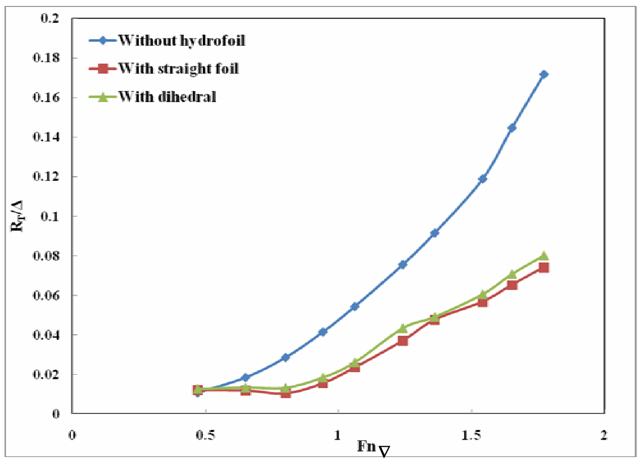

Fig. 14. Comparison of R_T/Δ for catamaran without foil, straight and dihedral foils with Fn_∇

INTERFERENCE EFFECT

The effect of wave interference on the wave making resistance can be found from the interference factor (IF) which is defined as:

$$IF = \frac{R_R - 2R_{Rde}}{2R_{Rde}} \tag{6.2}$$

Where,

$R_R = R_T - 2R_{Fde}$

R_R = Residuary resistance of the catamaran

R_T = Total resistance of the catamaran

R_{Fde} = Frictional resistance of the demihull

R_{Rde} = Residuary resistance of the demihull

The frictional resistance and residuary resistance of the demihull are given in Table 4. The wave interference effect of the catamaran with different foil configurations at various speeds is shown in Fig. 15. From Fig. 15, it is observed that the variation of interference factor is non-linear with humps and hollows. The wave interference effect is negative for the volumetric Froude number ranging from 0.85 to 1.10 and positive in the volumetric Froude number ranging from 1.10 to

1.65 and thereafter the volumetric Froude number is again negative.

Table 4. Frictional and residuary resistance of the demihull

SL. No	F_{nv}	Frictional resistance of the demihull (R_{Fde}) (kN)	Residual resistance of the demihull (R_{Rde}) (kN)
1	0.47	0.8281	1.2697
2	0.65	1.3165	1.1994
3	0.80	2.1669	1.0907
4	0.94	2.5888	1.0995
4	1.06	3.3667	1.1668
5	1.24	4.2358	1.3053
6	1.36	4.9957	1.6704
7	1.54	6.2413	2.4038
8	1.65	7.1411	3.6738
9	1.77	8.0956	4.5591

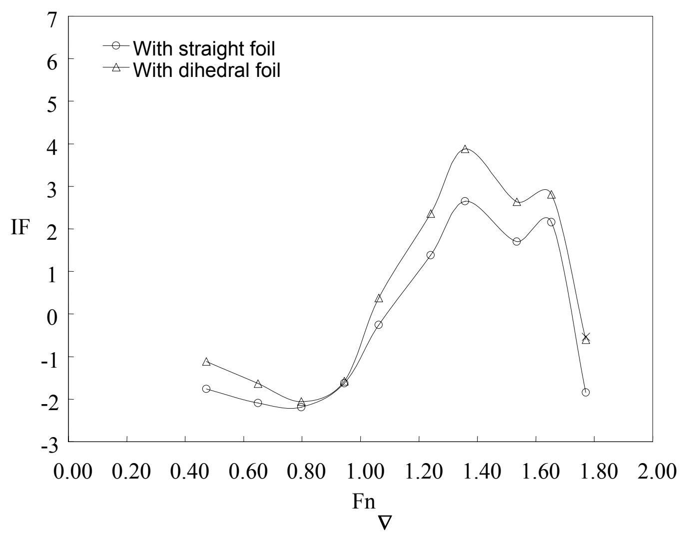

Fig. 15. Variation of the interference factor of the catamaran with straight and dihedral foils with Fn_∇

CONCLUSIONS

Based on the present experimental investigation, the following conclusions are drawn:

- As the speed of the catamaran increases, the resistance of the catamaran without foil and the catamaran with different foil configurations also increases.

- The variation of the resistance of the catamaran without hydrofoil is much higher than the catamaran fitted with straight and dihedral foils.
- At higher volumetric Froude number, there is a tremendous reduction in the total resistance of the catamaran with different foil configurations as compared with the catamaran without hydrofoil.
- With increase in the volumetric Froude number from 0.47 to 1.77, the average reduction in the total resistance of the catamaran fitted with straight and dihedral foils is 49% and 44% respectively as compared to the catamaran without foil
- With increase in the volumetric Froude number from 0.47 to 1.77, the average reduction in the total resistance in the catamaran fitted with straight foil is 10% as compared with the catamaran fitted with dihedral foil.
- The variation of the interference factor (IF) with $F_{n\nabla}$ is non-linear with humps and hollows. The wave interference effect is negative in the volumetric Froude number ranging from 0.85 to 1.10 and positive in the volumetric Froude number ranging from 1.10 to 1.65 and thereafter the volumetric froude number is again negative.

Finally, it is concluded that the HYSUCAT fitted with straight foil has better resistance characteristics in comparison with other foil configuration due more wave cancellations.

REFERENCES

1. **Hideaki Miyata** (1989) Development of a new–type hydrofoil catamaran, *Journal of ship Research*, **33**, No. 2.
2. **Hoppe, K.G.W** (1989) The Hysucat Development, *Internal Report in university of Stellenbosch*.
3. **Nigel Gee** (1991) The Catafoil A Foil Assisted Catamaran for fast ferry and Yacht Applications, FAST'91.
4. **Calkins, D.E., F. Van Walree, C. Buccini** and **P.A. Genova** (1984) HYCAT Hybrid Hydrofoil Catamaran Concept by The Prediction of the Hydrodynamic Performance of Hydrofoil Craft in Waves, *Ocean Engineering*, **11**, No.1.
5. **Payne, R** (1997) The response of a hydrofoil to wave orbital velocity fields, *Ocean Engineering*, **24**, 235-263.
6. **Matveev. K.I** (2002) Tone generation on a hydrofoil of a high-speed ship, *Ocean Engineering*, **29**, 1283-1293.
7. **Hoppe, K.G** (1995) Optimisation of hydrofoil supported planning catamarans, *Third International Conference on Fast Sea Transportation* (FAST '95), Mechanical Engineering Department, University of Stellenbosch.