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Hydrodynamic characteristics of fast catamarans as results of model tests

SUMMARY

The paper shortly presents model test results of hydrodynamic characteristics of hull shapes adapted to fast passenger catamaran with the speed of 40 knots. This work, realized within the framework of a project sponsored by The Scientific Research Committee, comprises investigations of planing and „wave piercing" hull shapes. Ship resistance was tested in calm water and in regular and irregular head waves. Model tests of propulsive and manoeuvring characteristics were carried out on a lake using large self propelled models.

INTRODUCTION

During last years passenger sea-transport over short and middle distances has expressed increasing interest in unconventional fast ships . High-speed catamarans are among them which evidence uncommon development because of their various advantages. In Fig. 1 the number of units of unconventional types of passenger vessels , being in service over the world in the years 1975 , 1988, are shown. According to last reports the tendencies visible in the diagram are continued at the present time.

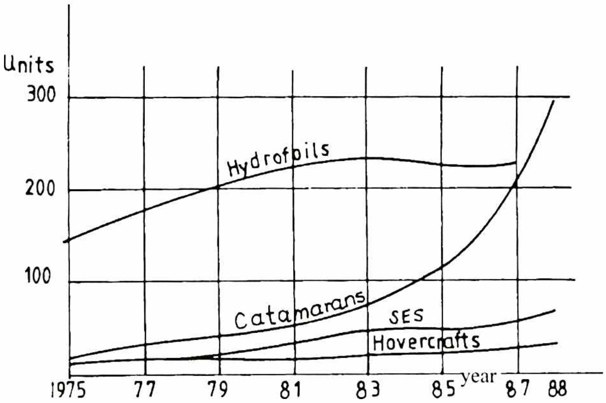

Fig. 1. The number of unconventional passenger ships in service over the world (USA, USSR, and China excluded)

Together with growing number of being in service and ordered catamarans their dimensions and speeds grow too. Catamarans with the length of about 100 m and speed of 45 knots are presently under construction.

Till 1985 all high-speed catamarans had the hulls of hard chine shape, typical for planing units, though their speeds commonly did not exceed Fn = 1,1 , 1,2. In 1985 a catamaran with so called „wave piercing" shape was built in Australia. The idea of this form is that the bow should pierce a wave (dive into a wave) and the bow deck should dip into the water when going in high seas. In calm water the bow deck should be dry, but in waves the catamaran behaves as a semi-SWATH. In the next years the number of designed „wave piercing" catamarans distinctly increases.

Hydrodynamic characteristics of planing catamarans are quite well recognized, but no publications at all can be found about „wave piercing" shapes. This is the reason that the author's team concentrates its efforts to investigate the hydrodynamic qualities of „wave piercing" shapes first of all.

RANGE OF INVESTIGATIONS

The work has been programmed to be realized in several stages. The first stage comprised comparative resistance tests, in calm water and in regular waves, of different hull shapes of planing and wave piercing type using small models of the scale 1:25. On the ground of these tests two basic shapes of both types have been chosen. The version denoted IC of the wave piercing form and IIC of the planing one were tested with respect of resistance and seakeeping qualities in the large model tank of OHO-CTO (The Ship Hydrodynamics Centre of the Ship Design & Research Centre, Gdańsk) with the use of the models of the scale 1:9,5 . The wave piercing shape appeared to be better.

Then the large (of the scale 1:5) self propelled model of this type has been made and the resistance, propulsive and manoeuvring tests were conducted on the lake.

In addition a wide analysis of catamarans stability has been presently conducted. There is a common opinion about very good stability of such type of vessels which however is not supported by any real data in the world literature of this subject; and some surprising results have been discovered from the above mentioned analysis . This problem will be the topic of a separate publication.

CHARACTERISTICS OF MODELS

A passenger catamaran with the displacement of about 125 t and with the speed of 40 knots, the most popular at that time (1991), has been chosen as a basis for investigations. In the first stage 4 shapes have been designed: two of the wave piercing shape, denoted IA and IB and two of the planing shape, IIA and IIB. The examples of their frame sections are shown in Fig. 2 and their dimensions are given in Tab. 1. The proportions of the planing shapes are different from these of wave piercing ones.

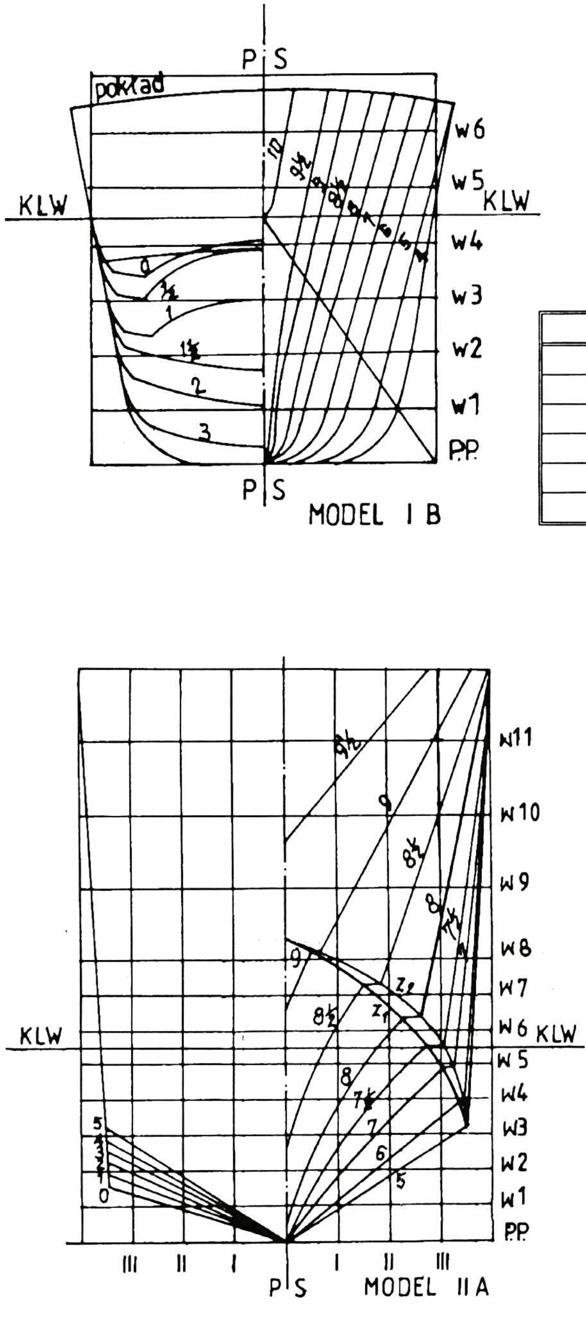

Fig. 2. Example of the tested model hull shapes

Tab. 1. Dimension parameters of the tested models

Model	I A	I B	II A	II B
C_B	0,450	0,513	0,598	0,594
LCB [%L_W]	-4,70	-4,80	-12,68	-14,00
L_W/B_W	15,54	19,04	11,88	11,85
B_W/T	1,66	1,27	1,826	2,066
$L_W/\nabla^{1/3}$	9,70	9,70	7,54	7,47
B_S/L_W	0,231	0,243	0,245	0,253

The reason is that such dimension parameters have been taken, which are most typical for existing planing catamarans, assuming that the parameters had been determined in result of some optimization. For wave piercing shapes the extremely high values of L/B and $L_W/\nabla^{1/3}$ have been intentionally taken to estimate their abilities possible to be reached.

The versions A and B of the planing forms differ mostly with the shape of sections and with the run of chine. All the models have the same displacement. The relative separation of demi-hulls B_S/L_W was assumed the same (B_S is the distance between the planes of symmetry of demi-hulls) because the problem of influence of this distance on resistance is well recognized at present.

For investigations in the large towing tank two models were chosen: slightly modified IB (without propeller tunnel) marked as IC and IIC, which was the medial of series II. The data of these models are given in Tab. 2. The self - propelled model was made according to the wave piercing shape IC.

Tab. 2. Dimension parameters of the self- propelled models

Model	I C	II C
C_B	0,513	0,628
LCB [% L_W]	-4,70	-10,09
L_W/B_W	19,04	10,93
B_W/T	1,27	2,21
$L_W/\nabla^{1/3}$	9,705	7,49
B_S/L_W	0,231	0,231

RESISTANCE IN CALM WATER

The results of the resistance tests of four small models in calm water are shown in Fig. 3a. Up to the speed of 30 knots, the planing models have higher resistance than the wave piercing; but at a higher speed all the models are practically equivalent.

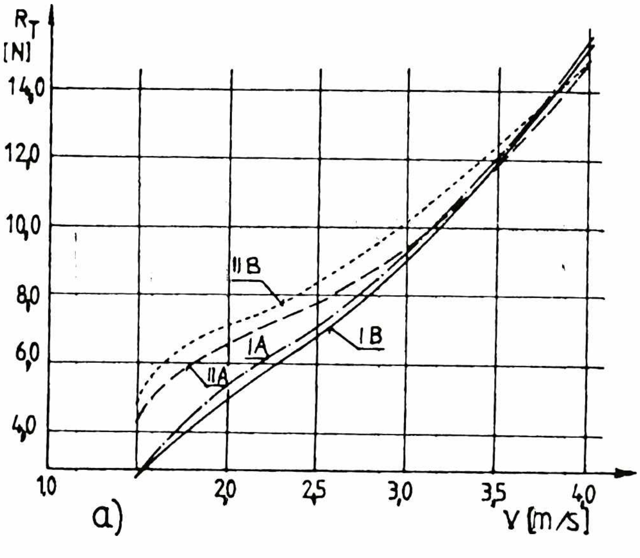

Fig. 3a. Total resistance of the small models versus speed

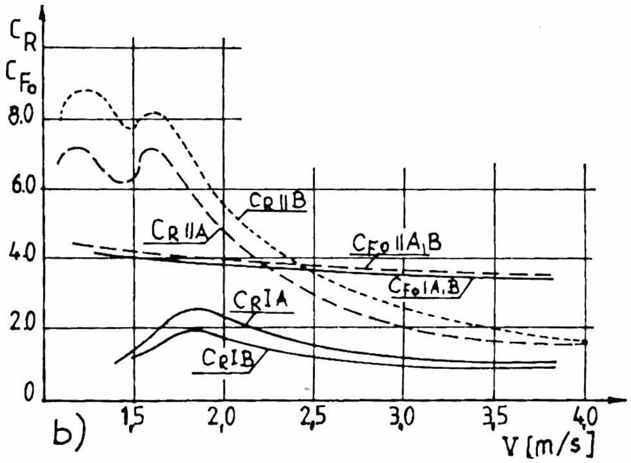

Fig. 3. b. Residuary resistance coefficients of the small models versus speed

Fig. 3 b shows that the residuary resistance coefficients C_R of planing models are distinctly higher in the full range of speed. It means that equivalence of resistance of both series is mainly result of a difference of wetted surface which is about 20% larger for the wave piercing shapes. The models of type I showed a lower bow wave and smaller spray when running in calm water, and in waves as well. All the models revealed very little trim by the stern (not higher than 1,5°).

Investigations of the modified shapes IC and IIC of the scale 1:9,5 in the large tank showed more favourable results for the wave piercing version as shown in Fig.4.

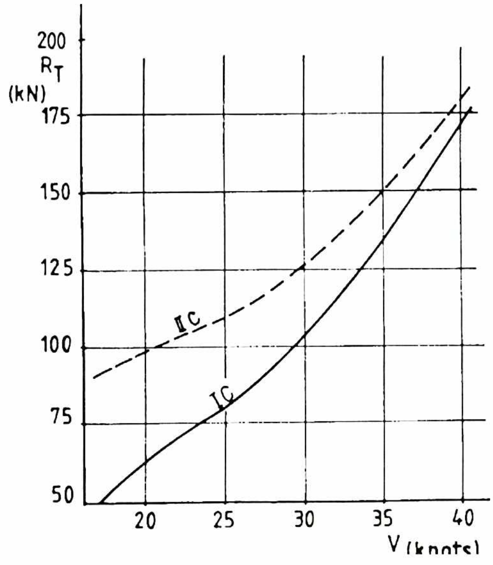

Fig. 4. Resistance of ships in calm water (large tank tests)

Here, in the whole range of the tested speed, i.e. up to 40 knots, the resistance of shape IC is lower than of shape IIC. This could indicate that the modification of shape B to C for the planing model was not very favourable. The resistance of model IC tested in the large tank was exactly the same as that obtained in the small tank tests.

It should be emphasized that the Froude's Number for the planning models at 40 knots was about Fn = 1,2 and the models did not start to glide. The Fn for the wave piercing models at the same speed was 1,05.

The resistance tests conducted on the lake using model of IC shape of the scale 1:5 gave the results, if extrapolated to full scale, exactly the same as the obtained in the large tank. The tests were made for three displacements: ∇_K, $1,1\nabla_K$ and $0,9\nabla_K$. It was stated that the resistance of this hull shape changed in the linear proportion to the displacement.

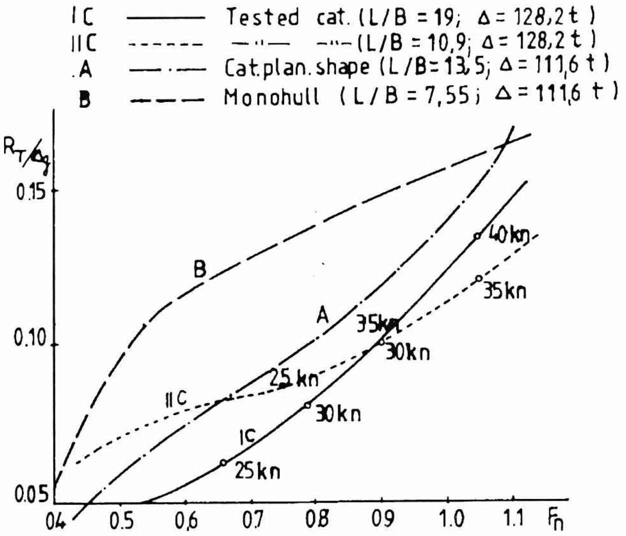

Fig. 5. Comparison of resistance of different ship types

Fig.5, presented to evaluate a resistance quality of the investigated hull shapes, shows curves of specific resistance of three similar catamarans and an equivalent monohull as a function of Fn. The data of forms A and B are taken from [1], but IC and IIC are the author's models. The models have different values of L/B ratio which makes the comparison a little difficult, but these proportions are typical for the considered types of ships at present. For instance, a higher L/B value is not often applied for monohulls because of its detrimental influence on stability which is one of the catamaran advantages.

RESISTANCE IN WAVES

The small models were tested in the small tank of the Technical University of Gdańsk in regular head waves with λ = 1,28 m and H = 0,048 m, which correspond to λ = 32 m and H = 1,2 m in full scale. All models were tested in the same waves, so that the ratios λ/L_W were different for each type: λ/L_W = 1,075 for series II and λ/L_W = 0,82 for series I.

Total resistance of the models in these waves is shown in Fig.6. At lower speeds up to 18 knots the wave piercing models had lower resistance than the planing ones. The observed pitching of models (but not measured) was smaller for the models of series I than of series II.

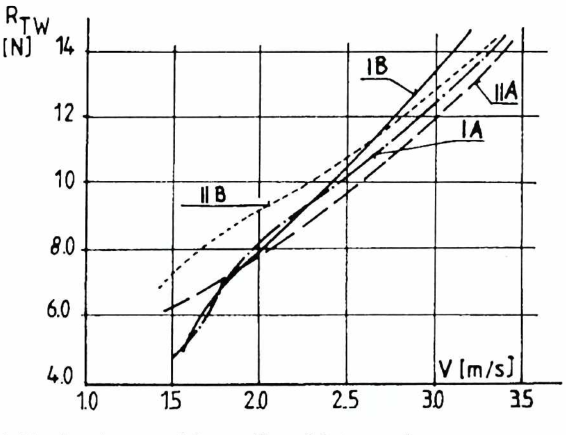

Fig. 6. Total resistance of the small models in regular waves

Two chosen models of both types IC and IIC, made of the scale 1:9,5, were tested in the large towing tank of OHO-CTO in three irregular head waves which were modelled according to the standard spectrum of the XV ITTC. The parameters of the wave spectra are given in Tab. 3.

Tab. 3 Wave spectra parameters

Sea state	$\zeta_{W_{1/3}}$ [m]	T_{01} [s]
3	0,8	4,1
4	1,3	4,8
4 - 5	2,0	5,6

The test results for some ship speeds are presented in Fig.7. It is easy to note that changes of resistance in irregular waves are not equivalent to these in regular waves.

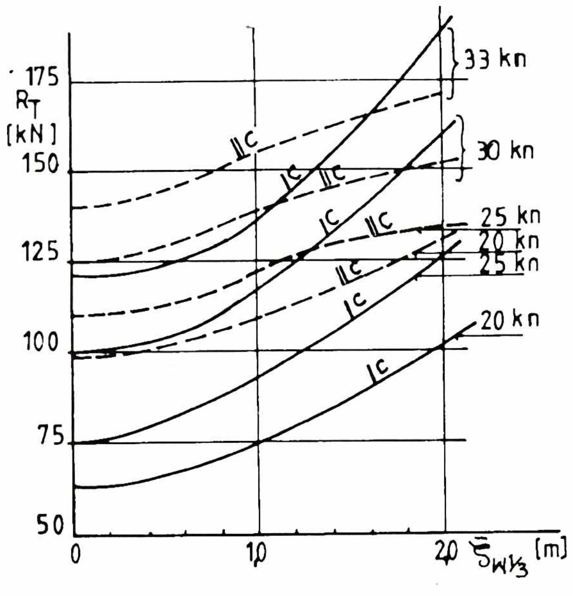

Fig. 7. Resistance of ships in irregular waves

The behaviour of the wave piercing shape is here more favourable than of the planing one. The resistance of the IC model is distinctly lower at speeds up to 25 knots in the whole range of wave heights. At the speed of 30 knots the wave piercing shape is better in the waves lower than 1,9 m; at the speed of 33 knots the planing shape appears to be better in the waves higher than 1,8 m. The higher speeds are not available for catamarans designed for the 40 knots speed in calm water.

MOTIONS IN WAVES

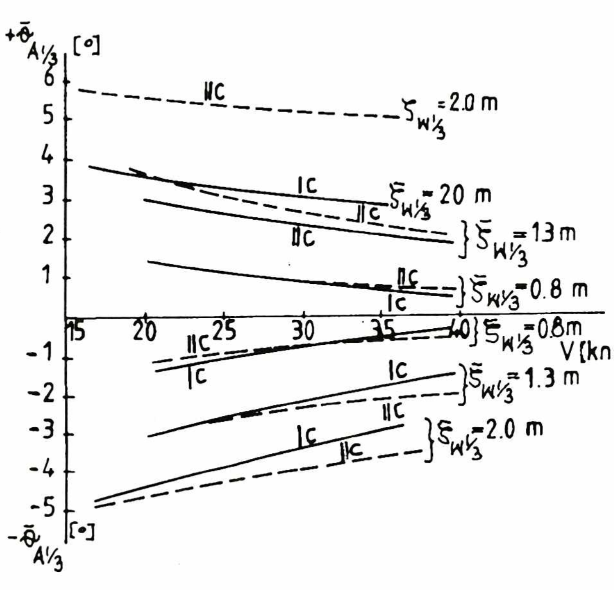

Fig. 8. Pitching of ships in irregular waves

During the tests in irregular waves the measurements of the following ship motion parameters were conducted: pitching, heave (measured at C.G.) and vertical accelerations at fore and aft perpendiculars.

In Fig. 8 the significant values of pitching amplitudes $\overline{\theta}_{A1/3}$ (the means of one third of the highest values) are shown; the sign (+) indicates trim by stern, (-) - by bow. The pitching amplitudes are rather small (4 , 5,5°) and they decrease with the growing speed. The essential differences between both models appear later at high waves.

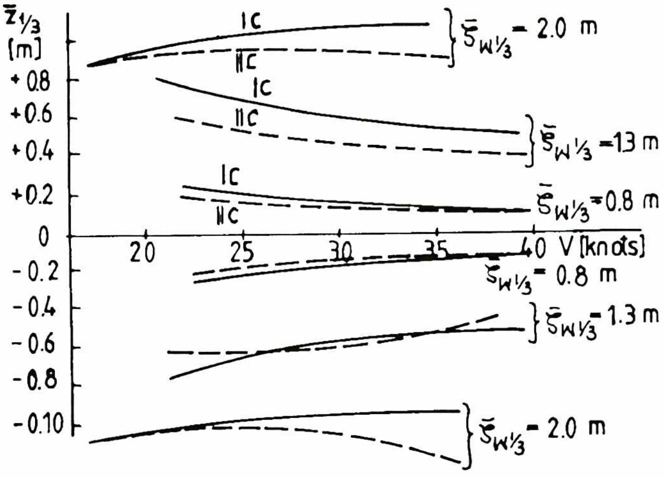

Fig. 9. Heave of ships (of ship's C.G.) in irregular waves

In Fig.9 the significant amplitudes of heave $\overline{z}_{A1/3}$ are presented. Their values can be recognized as the average ones and are similar for both shapes. They weakly depend on the ship speed.

The most important motion parameter for a passenger ship are vertical accelerations which have an essential influence on human feeling. The measured acceleration values are shown in Fig.10 and 11, where sign (+) refers to the motion up, sign (-) - down.

The significant values of bow accelerations $\overline{a}_{F1/3}$ and stern accelerations $\overline{a}_{A1/3}$ are shown in these figures.The higher accelerations appear at the bow when going down and they are everywhere higher for the planing shape (up to 2 g) than for wave piercing one (up to 1,2 g).

The accelerations at the stern are much smaller and they do not exceed 0,8 g. Obviously, the midship accelerations are evidently smaller.

The presented acceleration values seem to be very high but they are as high as that in extremely bad conditions only and they are the significant values; secondly, the values are similar to those obtained by other researchers. For instance, in his model tests of planing catamaran Müller-Graf [1] measured the accelerations at the bow in the range of 2,0 - 2,5 g in the regular wave of ζ_W/L_W = 0,06. During the tests of the similar full-scale catamaran in the rough sea (at significant wave height $\zeta_{W\,1/3}$ = 1,7 m) Sferazza [2] obtained accelerations in the range of 0,74 g. For the same catamaran Sferazza obtained $a_{F\,1/3}$ = 0,25 g at $\zeta_{W\,1/3}$ = 1,0 m.

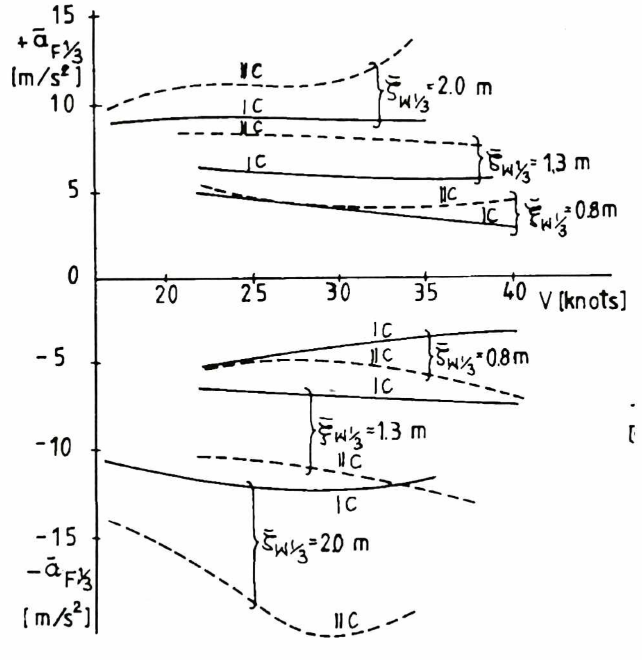

Fig. 10. Accelerations at the bow in irregular waves

For the author's catamaran IC the value $a_{F\ 1/3}$ is about 0,5 g in similar waves. The shape of Sferazza's catamaran and his wave spectrum is unknown.

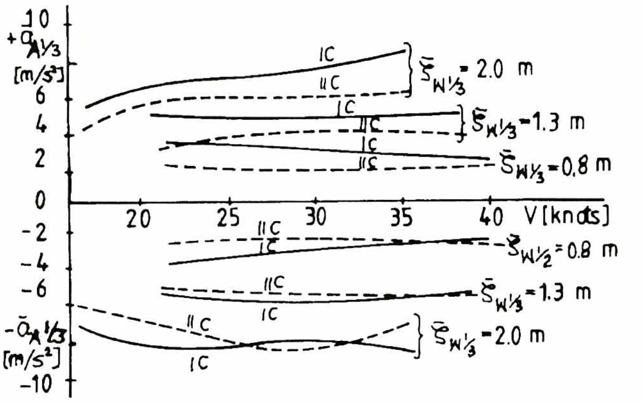

Fig. 11. Accelerations at the stern in irregular waves

PROPULSIVE CHARACTERISTICS

Propulsive tests were conducted with the self propelled model made according to the wave piercing shape IC of the scale 1:5, on the Jeziorak lake near Iława. The speed of model corresponding to 40 knots was about 9 m/s and a lake only gave a possibility to find enough long distances to reach steady measurement runs. The thrust deduction factor could be exactly estimated: it varied linearly from - 0,03 at 15 knots to + 0,03 at 40 knots. It means that it is of a negligible value for designing purposes. Because of some technical difficulties the wake fraction could be estimated in an approximate way only and it oscilated in a narrow range around zero. This is confirmed in publications dealing with planing shapes which should be similar in respect of interaction coefficients.

MANOEUVRING QUALITIES

The manoeuvring investigations were carried out on the lake using the same self propelled model as for the propulsive tests. The model was equipped with two hanging rudders located behind the propellers. The rudders' total area was A_R = 0,047 LT.

In Fig.12 the steady turning coefficients are presented for different rudder angles and different model speeds (6 m/s — 26 knots, and 3,5 m/s — 15,2 knots).

The turning ability of this catamaran, in spite of its exceptional slenderness, was not much worse than of typical merchant ships - minimal D/L ratios were in the range 3,5 ÷ 6, growing with the speed. To bring the ship out of turning it was enough to put the rudder to zero position. The value of advance A/D ≈ 1.15 is rather high.

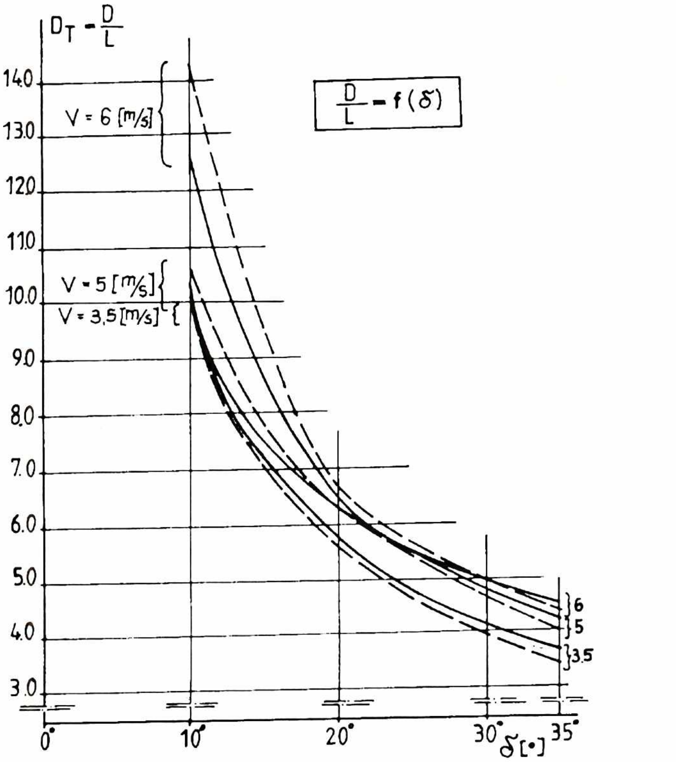

Fig. 12. Coefficients of turning

Using the propellers in the „ahead-astern" mode it was possible to turn the ship around its own axis.

The course stability was obviously very good. To keep straight course it was enough to use rudder angles 1 ÷ 2^o.

The „zig-zag" manoeuvres at 10^o rudder angle showed the nondimensional yawing periods τ = 10,0 for v = 15 knots and τ = 13,0 for v = 26 knots. These are upper limits for typical merchant ships having low turning ability and good course stability. However overshoot angles which reached 14^o at v = 15 knots and 12^o at v = 26 knots were relatively high.

It was impossible to make any comparison with other catamarans because of a complete lack of such data in the world literature.

CONCLUSIONS

The presented model investigation results showed that wave piercing shapes applied to fast passenger catamarans with underplaning speeds became worth of attention.

In respect of resistance in calm water they have had only a slight predominance over planing shapes but they have been significantly better in waves; especially in respect of the vertical accelerations in rough seas.

The work on this task is not yet finished . The investigations of the influence of L/B ratio on the resistance of catamaran and of the interference resistance are under way.

Acknowledgements

The author wishes to appreciate the fruitful assistance of his colleagues who cooperate in realization of this task.

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2. Sferazza M., Di Blasi D., Buccini C. : « Dynamic Behaviour: A Comparison between Hydrofoil and Catamaran » . MARIN Jubilee Meeting, Wageningen May 1992.

NOMENCLATURE

A - advance (longitudinal transfer at turning) [m]

A_R - rudder area [m^2]

B - ship breadth [m]

B_S - distance between planes of symmetry of catamaran hulls [m]

C.G. - centre of gravity

D - steady turning diameter [m]

Fn - Froude's Number

H - regular wave height [m]

L - ship length [m]

LCB - position of longitudinal centre of buoyancy

L_W - design waterline length [m]

R - water resistance against ship motion [N, kN]

R_T - total resistance in calm water [N, kN]

R_{TW} - total resistance in waves [N, kN]

T - ship draught [m]

$T_{0;1}$ - mean characteristic period of irregular waves [s]

$\overline{a}_{F1/3}$ - significant value of vertical bow acceleration [m/s^2]

$\overline{a}_{A1/3}$ - significant value of vertical stern acceleration [m/s^2]

C_B - block coefficient

C_{Fo} - frictional resistance coefficient

C_R - residual resistance coefficient

g - gravity acceleration [m/s^2]

v - ship speed [m/s, knots]

$\overline{z}_{A1/3}$ - significant heave amplitude [m]

Δ - ship mass displacement [hg, t]

∇_K - design ship volume displacement [m^3]

δ - rudder angle [°]

λ - wave length [m]

τ - nondimensional yawing period

$\overline{\theta}_{A1/3}$ - significant pitching amplitude [°]

$\zeta_{w1/3}$ - significant wave height [m]

Appraised by Miłosz Frąckowiak, D. Sc., N.A.

Conferences

Diving Technology Problems

Diving technology was the principal area of consideration during IVth Symposium held from 13 to 14 October 1994 in Gdynia, organized by the Naval Academy (its Diving Equipment and Underwater Technology Department of the Ship Structure and Propulsion Institute). The department is the strongest Polish centre carrying out a wide research program on diving technology. No wonder then that over 100 persons took part in the Symposium from 6 universities and research institutes, Polish Ship Salvaging Company, Polish Register of Shipping as well as all important training and coordination centres engaged in diving technology.

The three preceding Symposia dealt with saturated diving technique. The IVth Symposium was devoted to conventional diving in respect of diving techniques, equipment, research and medical aspects.

29 papers were read, a half of which was prepared by the authors (or co-authors) from Naval Academy in Gdynia and Technical University of Szczecin; the rest of the Polish papers were elaborated by the researchers from the Military Engineering Academy, Military Medical Academy, Marine and Tropic Medical Institute and Military Divers' Training Centre. Two papers were presented by the authors from Bohomolec Physiological Institute of Ukrainian Academy of Sciences in Kiev.

During the first day session some theoretical problems influencing diving techniques were discussed: a.o. medical and thermodynamic ones as well as work organization supporting processes.

The second day session was mainly devoted to underwater technology, being focussed at nitrox diving, alternative diving systems as well as application of underwater vehicles and decompression tables.

Interesting contributions were given by representatives of the following firms:

- COMEX, France: on a new generation of X-LITE diving helmets;
- DRAGER, Germany: on modern diving equipment;
- BALTIC CIRCLE, Poland: on diving hose construction and testing.

The IV Symposium proceedings have been published in a carefully edited book.

The Symposium participants were given an opportunity to be acquainted with the research equipment of the Naval Academy's department organizing the Symposium as well as with its recent research topics and achievements.