FULL SCALE TESTS ON A HIGH SPEED WATERJET CATAMARAN: MONITORING AND ANALYSIS OF THE WORKING CONDITIONS, EVALUATION OF THE SHIP – MODEL CORRELATION PROCEDURES

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ABSTRACT

The monitoring of the propulsion and navigation of a ship has become more and more important with the enhancement of the performance required to propulsion plants and, on the other hand, with the restriction of rules for the safety at sea and the protection of the marine environment.

In this scene, a research has been financed by the Regione Campania (Italy) with the aim of studying a 43m - 34 kn waterjet catamaran in order to achieve a picture of its behaviour during the service in the Neapolitan gulf; the main parameters linked to the propulsion and navigation have been logged and a synthesis of the data collected onboard is presented in this paper.

Moreover, the measured values of trim, speed, power and rpm have been used to evaluate the ship - model correlation procedures in the particular case of high speed catamarans.

INTRODUCTION

The experimental prediction of performances of catamarans even if it is the most reliable, suffers from the consequences of the procedures affecting, somehow, also the experimentation on traditional monohulls. In particular, two effects coexist:

- the difficulties to obtain the actual direction of the propeller thrust on the model;
- the scale effects due to the reduced length of the models which is essential to obtain high related speed in the towing tank (a condition to be observed for all high speed vehicles).

Furthermore, it is not clear how much, in the towing tank experimentation, the complex flow around the demihulls causes a dynamic which is not in scale with the physical model in full scale.

Moreover, most of the present catamarans are propelled by waterjets, which complicates the situation from the point of view of the evaluation of the propulsive efficiency; indeed, such condition makes it more difficult to evaluate the power to be installed on board since, generally, only the effective power is known from the towing tests.

For these reasons, the "Dipartimento di Ingegneria Navale " (DIN, Naples), is carrying out a research with the main aim of evaluating both the influence of the application point and the direction of the towing thrust and, more generally, the reliability of the predictions obtained by associating the ship-model extrapolations with the OPC (Overall Performance Coefficient) values, today commonly deemed efficient. In order to obtain the desired results, a full scale test procedure was set up and carried out on a catamaran previously tested in the Dept. towing tank.

Thus, strictly connected with this activity, a research on a 43 m catamaran connecting Naples to the islands of the gulf, has been carried out in the DIN with the objective of highlighting the overall behaviour of the ship from the points of view of the propulsion, navigation and, in general, of all those conditions which can influence the ship design. Also the exhaust emissions will be logged and analysed in the near future.

THE SHIP UNDER INVESTIGATION

The catamaran under study has a hard chine hull whose transverse sections are shown in Fig. 1

The following table shows the main geometric characteristics of the ship (referred at $\Delta = 137$ t)

S/L_{WL}	0.225
L_{WL} [m]	35.867
T [m]	1.580
B_{WL} [m]	11.370
B_{WL} demihull [m]	3.300
S_W [m^2]	272.0
∇ [m^3]	133.7
L_{WL}/B_{WL}	3.154
B_{WL}/T	7.196
$L_{WL}/\nabla^{1/3}$	7.014

Table 1 - Geometric characteristics of the ship

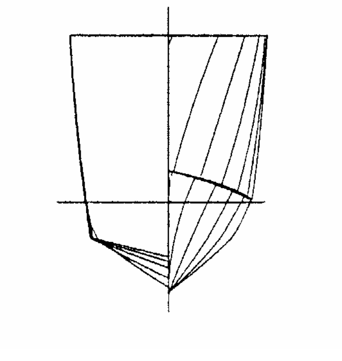

Figure 1 - Transverse section of the catamaran

As regard the propulsion, the following table gives its main characteristics:

n. 2 MTU 16V396 TE74L main engines	
P_B [kW]	2 x 2000
@ rpm	2000
n. 2 ZF BU 755 gearboxes	
reduction ratio	2.33
propeller rpm	860
n. 2 KaMeWa 71 SII waterjets	

Table 2 - Characteristics of the propulsion of the ship

METHODS AND INSTRUMENTS

The towing tank

The resistance tests have been carried out at the DIN towing tank having the following characteristics:

lenght	136 m
beam	9 m
water depth	4.5 m

The difficulty in predicting the performance of catamarans suggested to carry out a series of tests on the studied hull, varying the displacements, the distance between the demihulls, the longitudinal trims and, for a given displacement, testing the hull with and without stabilisers and flaps (with several trim angles) and setting the tow in three conditions:

a) horizontal force at the height H = 6.110 m on the baseline (H/T = 0.170)
b) horizontal force at the height H = 1.845 m on the baseline (H/T = 0.051)
c) towing force in the direction of the waterjet thrust applied in their action point (H = 1.470 m $\Rightarrow$ H/T = 0.041)

In the condition a), the force was permanently horizontal and applied on cross deck, thus preventing any problem due to the particular geometry of the ship.

However, when this system is used, the application point is remarkably higher than the centre of the resistance and this creates a couple which reduces the longitudinal trim and creates undesired change in the resistance to the motion of the model that are rather unpredictable.

In the condition b) the force (permanently horizontal as in the previous case) was applied at the lowest height allowed by the hull geometry; thus, it is possible to evaluate the influence of the difference of trims (due to the different application points in the towing) on the measurement of the resistance.

The towing condition c) reproduced the full geometric similitude of the propeller thrust.

The c) condition has been set by using a particular equipment – designed and built in the DIN – capable to control the inclination of the towing rod as a function of the value of the longitudinal trim of the running model.

The model had a scale ratio $\lambda = 13$, so obtaining Rn = 5.6 x 10^6 at the minimum test speed (V_s = 17.5 kn; Fn = 0.48) and Rn = 9.3 x 10^6 at the nominal speed (V_s = 28 kn; Fn = 0.77).

The data logging system

The data logging system set up for the test on the catamaran includes four sections, each measuring one type of parameter that affects the behaviour of the ship.

Table 3 gives the parameters measured together with the sensors used; figure 2 gives a scheme of the data logger.

inlet air temperature	J T/C
exhaust gas temperature	K T/C
propeller torque	torquemeter
engine rpm	pick-up
freeboards	manual
static and dynamic longitudinal trim	electronic level
ship speed	GPS

Table 3 - Parameters used, sensors and signal

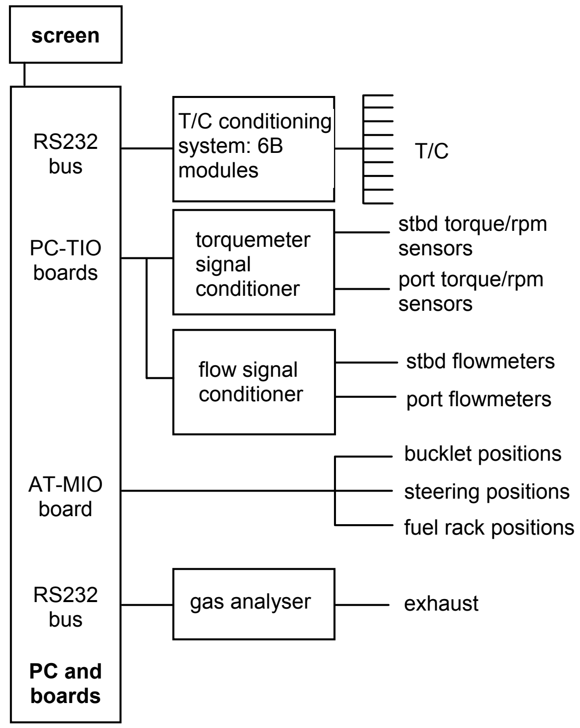

Figure 2 - The data logger

The measurement of the torque was made by a strain gauge torquemeter unit; the measurement point was set in the part of the final axle between the gearbox and the gland (fig. 3). Thus, the measured power coincides with the P_D without considering the loss in the gland.

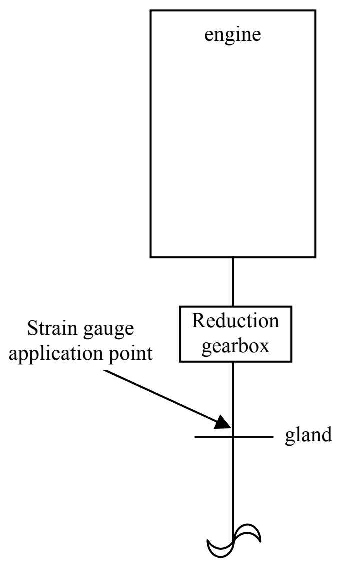

Figure 3 - Position of the torquemeter unit

THE DATA LOGGED

The towing tank tests

The following table reports the characteristics of the tests that are more relevant in the present study, chosen among the large number of tests carried out in the tank.

Test	Δ [t]	τ [°] (at rest)	Flap [°]	Stab [°]	S/L	Tow Cond	**Cat** DH
1	133	-0.2	NO	NO	0.196	a)	Cat
2	137	0.0	NO	NO	0.224	a)	Cat
3	137	0.0	NO	NO	0.224	b)	Cat
4	137	0.0	NO	NO	0.224	c)	Cat
5	137	0.0	0°	0°	0.224	a)	Cat
6	153	0.0	NO	NO	0.196	a)	Cat
7	165	0.0	NO	NO	0.196	a)	Cat
8	68.5	0.0	NO	NO	/	a)	DH
9	68.5	0.0	0°	0°	/	a)	DH

Table 4 – Tests in towing tank

In order to highlight the effects of the towing techniques, figure 4 shows the values of the power of the bare hull (P_H) and the dynamic trim (τ). The figure 5, shows the ratios

$$\frac{\tau_{a)}}{\tau_{c)}},\frac{\tau_{b)}}{\tau_{c)}} \quad \text{and} \quad \frac{P_{H\,Sa)}}{P_{H\,Sc)}},\frac{P_{H\,Sb)}}{P_{H\,Sc)}}$$

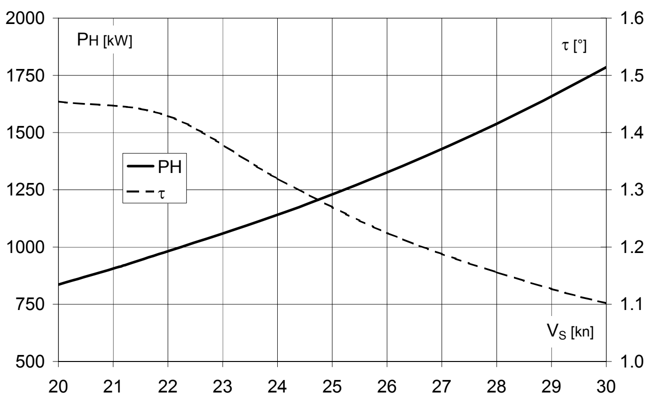

Figure 4 - τ and P_H in c) towing conditions

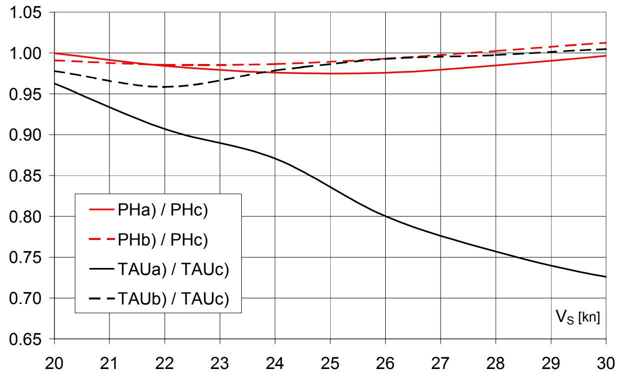

Figure 5 – Effects of the towing position on τ and P_H

The particular shape of the curves in fig. 5 shows that the position of the towing point is more important than the towing direction itself.

Indeed, it is reasonable to think that the weak dependence of τ on the towing direction (ε) is due to the small value of τ of the studied ship: probably, boats with ε remarkably different from zero and τ higher, would be more sensitive to the towing direction.

In figure 4, the maximum difference in the read values of P_H is a little more than 2%. As said above, in this case as well it is possible that the low influence of the trim of the model on the value of the resistance depends on the geometric characteristics of the ship (and, in particular, on L/B).

The full scale tests

As regards the full scale tests, a very long and complex phase is represented by setting up the data logging on board and the arrangement of the site to make it fit to lodge the tools for measuring the various parameters to be logged.

In the appendix, a sample of the results of the data logging campaign carried out on the catamaran are reported in form of power vs. time diagrams.

As a general consideration about the test conditions, it is worth to anticipate some remarks.

The reading of the torque always creates serious problems: indeed, the strain gauge measurement of the strength requires a good knowledge of the characteristics of the axle where the gauge is stuck and, in particular, its transverse modulus of elasticity (G). But, in general, this value is not available in the technical literature of the material constituting the axle and must be drawn by specific (and accurate) calibration.

In the near future of this research, we plan to carry out a calibration of the axle of the catamaran; for the moment, starting from the type of stainless steel (and its correspondence with the equivalent type in the AISI standard) we could reach a reasonable value of the Poisson module ν that allowed the determination of the value of the modulus G.

In order to validate the reading of the torque, since we have the results of the bench tests of the engines, after the full scale tests, we made a comparison between the values of the torque coming from the bench tests where the engines were run in the same conditions; in other words, we chose those points where the engines were operated quite in the same way (from the point of view of the rpm, the SFOC and the fuel rack setting) and compared the values of the torque coming from the bench test and the full scale ones: the results had been very encouraging since the mean difference between these data is less than 4% , thus confirming a reasonable accuracy in the measurement of the shaft torque. A better accuracy can be achieved only by calibrating the strain gauge on the axle, thus preventing the data logging from every inaccuracy due to the imperfect knowledge of the torsional characteristics of the material of the axle.

Table 5 shows the data logged during the full scale tests.

test	V_S [kn]	P_D [kW]	τ (at rest) [°]	τ [°]	Δ [t]
1	26.5	3371	-0.9	0.6	134
2	27.0	3403	-0.9	0.6	136
3	26.8	3558	-0.8	0.8	130
# 4	28.2	3548	-0.8	0.7	130
## 5	20.0	2508	-0.8	0.7	129
6	24.1	3078	-0.8	0.7	129
7	27.2	3584	-0.8	0.7	129
8	21.3	2588	-0.8	0.7	128
9	27.6	3541	-0.8	0.7	127
# 10	28.9	3588	-0.8	0.7	127
11	28.1	3591	-0.8	0.7	126
12	28.1	3586	-0.8	0.7	126
13	20.3	2521	-0.8	0.7	121
14	25.5	3070	-0.8	0.7	121
15	29.0	3545	-0.8	0.7	121
16	29.0	3564	-0.8	0.7	123

Table 5 – Synopsis of the full scale tests
possible influence of shallow water
light wind ahead (~ 3 m/s)

The full scale tests were carried out in calm water and wind; trim and freeboards were recorded on the ship at rest and without passengers onboard. The number of coming passengers has been always recorded so as to correlate permanently the speed readings with the ship displacement.

EFFECTIVE POWER PREDICTION

The load conditions of the ship at sea were lighter than those set in towing tank on the model; in order to obtain the actual values of P_H (sea conditions) the showed procedure has been followed.

The overall towing resistance and the effective power of a hull are to be considered as:

$$P_{E_S} = R_{T_S} V_S$$

$$R_{T_S} = R_H + R_{AP} + R_A$$

Where R_H is the resistance of the bare hull, R_{AP} the resistance of appendages, R_A the resistance of the air.

R_H was evaluated according to the ITTC ’57 where:

$$\Delta C_F = 4\ 10^{-4}$$

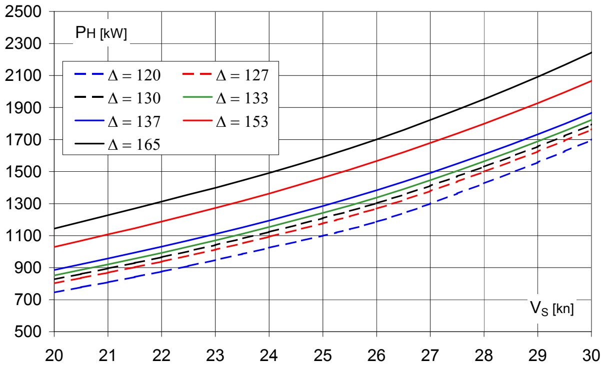

Figure 6 – P_H: experimental and extrapolated curves

In order to obtain the resistance of the bare hull, the results of the towing tests were extrapolated to the displacement of the ship at sea. In figure 6 the experimental curves (continuous lines) and the extrapolated curves (dotted lines) are given.

The resistance of appendages

In order to evaluate the resistance due to appendages, the towing tank tests – with and without appendages – have been carried out. The percentage increases of resistance have been determined as well.

The tests were made at a displacement different from the ones token in full scale. Thus, in order to extend the influence of appendages to the ship displacement, the abovementioned percentage increases of resistance were applied for each examined displacement at sea.

It might be interesting to observe that the presence of the appendages influences the phenomena of interference between the demihulls.

The following figure shows:

- the $\dfrac{P_{H+AP}}{P_H}$ ratios (for the catamaran and the demihull)
- the global interference coefficient IT

$$IT = \frac{P_{H_{CAT}}}{2P_{H_{DH}}} = \frac{R_{H_{CAT}}}{2R_{H_{DH}}}$$

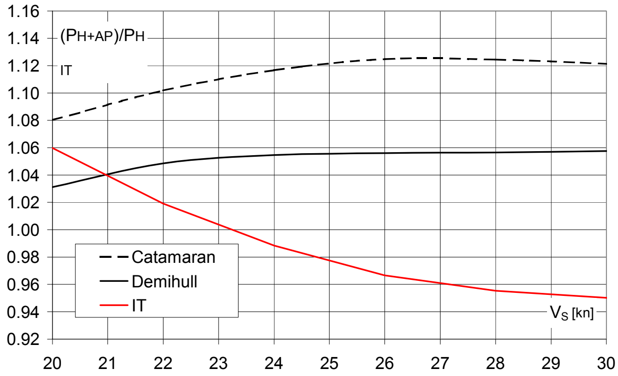

Figure 7 – Influence of the appendages and Total Interference Coefficient

The higher weight of the appendages – revealed in the case of the catamaran – may have, at least, two reasons:

- the action of the transversal component of the flow which, in the catamarans, appears in the tunnel between demihulls, generates lift and induced resistance (acting on the vertical elements of the stabilizers) and
- the effect of the hydrodynamic interference between demihulls which causes a (proportionally) lower resistance to the catamaran and, consequently, a higher weight of the share of the resistance due to the appendages.

The resistance of air

The resistance to the air has been evaluated by the Hughes formula without considering any wind effect (as during the full scale trials).

CONCLUSIONS

Figure 8 reports the values of the P_E/P_D ratios drawn out from full scale tests; such figure summarises the developed work.

In order to evaluate the information it contains, it’s worth to keep in mind the following considerations:

- the validity of the results depends on the approximations made for the calculation of P_E and for the evaluation of P_D;

- the perception of the quality level of predictions depends on the values assumed by the PE/PD ratio and those commonly deemed acceptable.

Of course, with future studies and experimental sessions it will be possible to confirm the data obtained; in particular, towing tests at the displacements corresponding to those read in full scale will be carried out.

Nevertheless, the displacement of the points in figure 8 does not contrast with the data available in literature; they are only a little bit lower than those supplied by [7] and showed in fig. 9.

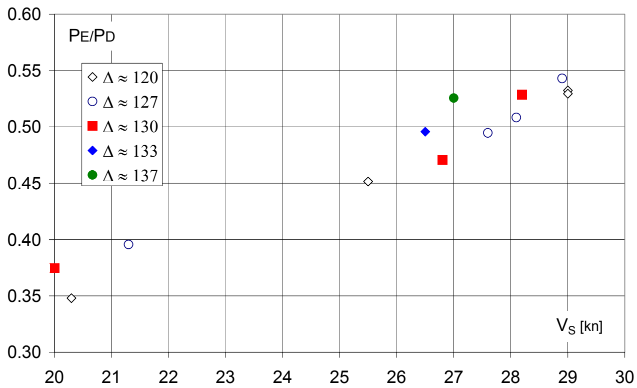

Figure 8 – Synthesis of towing tank and full scale data

Furthermore, the raising efficiency with the speed perfectly matches the published data and it seems to be confirmed that the range of speeds tested during the full scale tests (V_S 26 ÷ 28 kn) is very critical for the water-jets which works rather well at speeds over 30 kn.

Finally, the influence of appendages on the resistance to the motion seems to be conditioned by the presence of the twin hulls; this matter is evidently very important in the prediction of the performances and it will be studied in the near future.

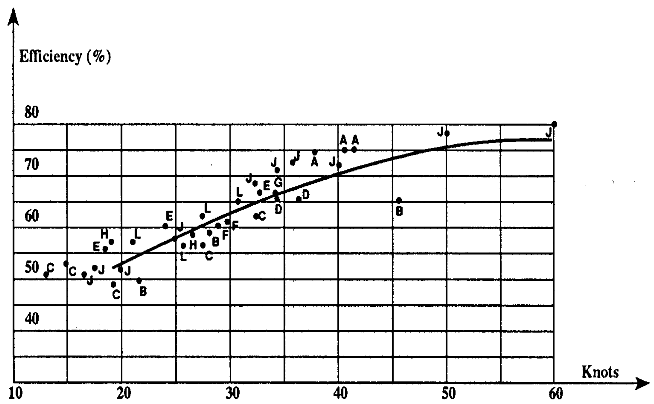

Figure 9 – Typical efficiency results for KaMeWa water-jet propulsion system [7]

As regards the future of the research, (whose final goal is the definition of a precise energetic balance of the ship), in order to give a significant contribution to the investigation on the air pollution in very inhabited zones, a complete campaign of data logging on the main pollutants (NOx, CO, THC) is planned for the next tests onboard.

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APPENDIX

The following diagrams report a synopsis of the data logged in form of total shaft power vs. time graphs.