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Experimental investigation of interference effects for high-speed catamarans

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ABSTRACT

We have performed an experimental investigation aimed at assessing the relevance of hull interference effects on the total resistance of a catamaran model advancing in calm water. To this purpose, drag and attitude measurements have been carried out for several values of the hull separation, as well as for the monohull, at changing the Froude number in the range 0.1–0.8. Data concerning the two-dimensional wave field around the models have also been collected. Our results indicate that, except for a narrow range of conditions where favorable interference is observed, the interaction between the catamaran hulls usually results in a marked increase of the total resistance as compared to the monohull case. This penalization can be as large as 30% for the narrowest hull spacing at $Fr \approx 0.5$. At larger hull spacings, the effect is attenuated and occurs at smaller Froude numbers. Interference effects are less evident both in the small and large Froude number range, namely when $Fr < 0.3$ and $Fr > 0.7$ respectively. Insight into the mechanisms underlying this behavior is obtained by examining the relational dependence between the resistance variation and the data concerning attitude of the vessel and wave-field elevation.

1. Introduction

Multihull vessels are widely employed in military and commercial applications at high operational speeds, owing to competitive advantages in e.g., stability and payload capability. As the need to optimize the performances of these ships in terms of resistance- and sea-keeping characteristics is becoming compelling, additional efforts are required to characterize in more detail their salient hydrodynamics features (see, e.g., Faltinsen, 2005).

Many of the aspects related to the issue of resistance have already been investigated in a number of numerical and experimental investigations, where the role of design parameters such as demihull separation and dimension, hull geometry, beam-to-draft ratio, water depth and Froude number has been critically assessed. Notable experimental work has been carried out in particular by Insel and Molland (1992) and Molland et al. (1996), where the influence of many of the above factors has been examined and tested against theoretical predictions, and by Souto-Iglesias et al. (2007) and Souto-Iglesias et al. (2012), where resistance measurements have been combined with quantitative observations of the wave pattern with the main purpose of evaluating the effects associated with demihull separation and test conditions (fixed or free attitude of the catamaran).

From the numerical point of view, the use of steady and unsteady Reynolds Averaged Navier–Stokes (RANS) based solvers in recent studies such as those performed by He et al. (2011), Zaghi et al. (2011), Miller et al. (2006), Maki et al. (2007), Stern et al. (2006) and Campana et al. (2006) has allowed to extend earlier results based on potential flow techniques (e.g., Tarafder and Suzuki, 2007; Moraes et al., 2004; Lugni et al., 2004; Colicchio et al., 2005), and has allowed to provide valuable insight into the complex flow structure around multi-hull vessels.

As a result of the above investigations, hull separation has been clearly identified as the key parameter controlling catamaran resistance in a non-trivial way via a number of entangled mechanisms. First of all, hull separation determines the level of non-linear interaction between individual wave systems produced by each demihull, and hence the magnitude of the wave-drag component. For a given catamaran geometry, both destructive and constructive interferences may occur depending on the value of the Froude number, so that impressive reductions of the wave resistance can be obtained in particular conditions (see the remarkable case reported in Chen and Deo Sharma (1997) concerning S-shaped catamarans advancing at super-critical speeds in shallow waters).

Also, hull separation affects the catamaran resistance in a more indirect and subtle way, since the topology of the free-surface originated from wave interaction affects in turn the flow around each single hull. At sufficiently large values of the wave steepness, for instance, strong wave-breaking can occur and intense shear-layers can form beneath the free-surface. These high-vorticity

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regions typically extend deep into the fluid and interact with the boundary layers developing over the hulls, possibly leading to three-dimensional separations. Note that this process may be relevant for high-speed catamarans even at small Froude numbers, due to the typically low value of their draft.

Finally, aside from its bearing on the free-surface geometry, hull separation determines the extent to which the flow around each hull is perturbed by the adjacent one, thus fixing the degree of asymmetry of the velocity field about each hull axis. As far as the ship resistance is concerned, this effect can be conveniently parametrized in terms of an appropriate correction factor accounting for the increase of water velocity between the hulls, as done in Insel and Molland (1992) and Armstrong (2003).

Despite the important research progress achieved in the previous works, experimental knowledge on the flow structure around multi-hull vessels still remains incomplete, essentially because most results are restricted to global quantities (e.g., overall resistance) and to their dependence on some of the geometrical properties of the ship. In the present paper, we wish to partially fill this gap by contributing to understand interference effects for non-staggered catamarans with symmetric hulls advancing in calm water. To this purpose, the behavior of a catamaran (Delft 372 model) has been investigated in a towing basin at changing the values of hull separation and Froude number.

The paper is organized as follows: in Section 2, the details of the experimental setup and of the measurement system are reported. In Section 3, data concerning the total resistance and the attitude of the catamaran models, as well as the topology of the wave-field, are presented in comparison with the corresponding information pertaining to the monohull. The discussion of the set of results is provided in Section 5. Finally, Section 6 summarizes some of the main findings of the work and the future perspectives.

2. Experimental procedures

2.1. Catamaran model

The experiments reported here have been carried out at CNR-INSEAN in the towing basin #1, which is a 470 m long, 13.5 m wide and 6.5 m deep facility. The model used in our investigation is a 3.0 m fiberglass Delft 372 catamaran (van't Veer, 1998b, 1998a). This typical high-speed multi-hull vessel has been extensively characterized in a number of recent experimental and computational activities, where different aspects such as interference (He et al., 2011; Zaghi et al., 2011), maneuverability in deep a shallow water (Zlatev et al., 2009; Milanov et al., 2010, 2011), water jet propulsion (Milanov and Georgiev, 2010; Miozzi, 2011), hull form optimization (e.g., Peri et al., 2012), sea keeping (Castiglione et al., 2011; Bouscasse et al., 2013) and advancement in steady drift (Broglia et al., 2012) have been considered. A summary of the experimental activity conducted with this model at CNR-INSEAN is presented in Broglia et al. (2011).

The model is depicted in Figs. 1 and 2, and the relevant geometrical information is summarized in Table 1. Note in particular that the nominal gap between hulls is $H=0.70$ m, which corresponds to a dimensionless hull separation $H/L=0.167$. This figure could however be changed by sliding the hull clamps along the connecting transverse bars (see Zaghi et al., 2011; Broglia et al., 2011) in order to assess the relevance of interference phenomena. More precisely, comparative tests have been performed at the different values of hull separation reported in Table 2, as well as with a monohull (corresponding to $H=\infty$).

Each hull was equipped with turbulence stimulators in the form of small cylindrical studs (4 mm in height and 3 mm in diameter) spaced 30 mm apart from each other and located 70 mm behind the bow edge.

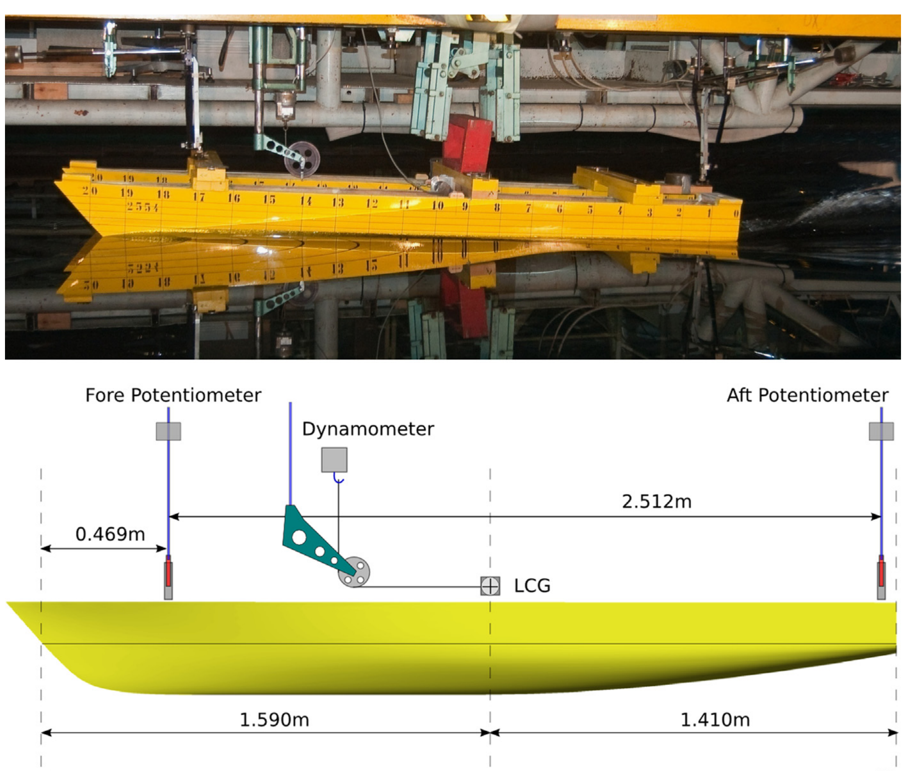

Fig. 1. The Delft 372 catamaran model used in the present investigation.