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Trim effect on the resistance of sailing planing hulls

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ABSTRACT

Sailing skiffs are light-weight high-performance small boats of growing interest in competitive sailing. The present paper presents towing tank tests performed on the Aura skiff, which was a candidate for the 2016 Olympic games. Resistance, sink and trim were measured for different longitudinal positions of the crew weight and for Froude numbers (based on the boat's length over all) ranging from 0.30 to 1.03. For each test, detailed analysis of the measurement uncertainty was performed. The measured resistance was found in good agreement with the resistance computed with established empirical formulations developed for planing hulls. It was found that the optimum crew position moves from forward to aft when the Froude number increases. An incorrect longitudinal centre of gravity led to a maximum resistance penalty at Froude number around 0.4. These trends are in agreement with the sailor's experience and with measurements performed by other authors on large vessels.

1. Introduction

Sailing skiffs are high-performance lightweight competitive sailing craft. They have a large sail area compared to their displacement and, as such, they rely heavily on the weight of the crew to stabilise the vessel for optimal performance and also to avoid capsizing or pitch poling, where the bow buries itself in the water ahead of the vessel and the stern is lifted clear of the water up and rotates over the bow.

The Aura (Fig. 1) is a modern skiff designed by Ovington Boats, a world leader in the construction of high performance dinghies. The Aura was designed in response to a request by the International Sailing Federation for a new women's Olympic skiff class. The result is a very lightweight, small platform skiff that requires very dynamic sailing to perform at its optimal level.

The typical practice in modern skiff sailing is that when sailing at high speeds the crew moves aft thereby lifting the bow area clear of the water to reduce hydrodynamic resistance and enhance handling. Fig. 2 shows a typical high-speed condition with the crew position (*CP*) at about −40% of the length over all (*LOA*) from mid ship (*MS*), i.e. about 10% from the stern. The opposite is true when sailing at lower speeds, where the crew move closer to *MS* keeping the vessel as flat to the water as possible to reduce hydrodynamic resistance. For instance, Fig. 3 shows a typical low-speed condition with *CP* at about −20% from *MS*.

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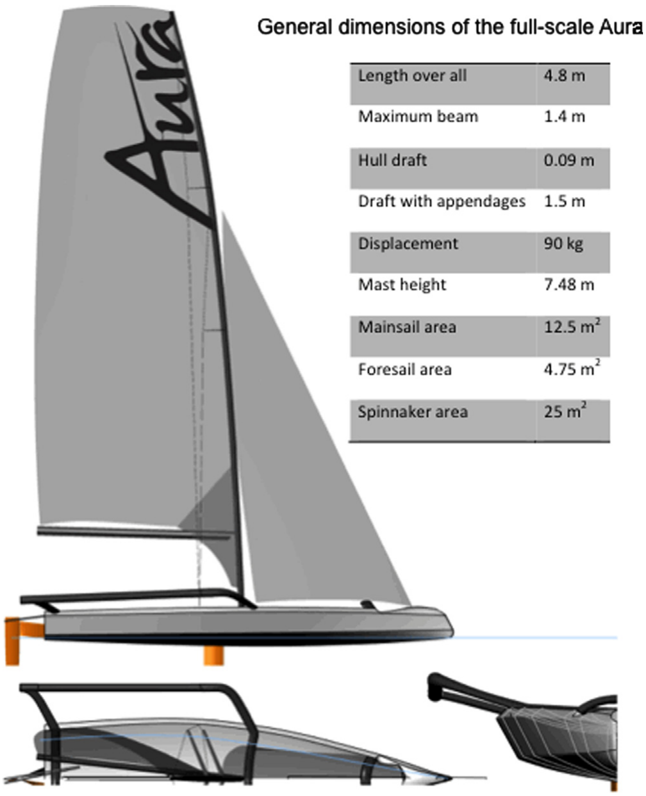
Use of towing tank model testing combined with computational fluid dynamics (CFD) is a common practice in sailing yacht design, see for instance Viola et al. (2012). Conversely, small dinghies are normally designed with low budgets: towing tank tests and CFD are rarely used while full-scale prototype field testing is more affordable than for large yachts. However, full-scale tests are difficult to interpret due to the variable environmental conditions. Successful examples of full-scale measurements are those reported by Bethwaite (1993). A transverse beam connects three parallel boats. The dinghy being tested is attached to one end of the beam, the towing powerboat is attached at the middle of the beam and a reference dinghy is attached to the other end of the beam. This technique was also adopted by Watin (2007) to test the effect of different pitch angles on the resistance of a 49er-class skiff, which was designed by Julian Bethwaite, Frank's son. Watin found that sailing with a lower pitch angle at low speed and a higher pitch angle at high speed allows a reduction of the total resistance.

As far as known by the present authors, this paper presents the first towing tank test on sailing skiffs. However, there has been extensive experimental and numerical investigation on the hydrodynamics of planing vessels in general, for instance, the systematic prismatic model testing undertaken by Savitsky (1964) and Savitsky and Brown (1976) and more recent hard chine test series undertaken by Taunton et al. (2010). Thornhill et al. (2003) conducted resistance tests to validate CFD results on a model that was similar to the Aura in regards to low deadrise angle, i.e. with relatively flat bottom that sharply turns at the side of the hull. The model was ballasted at different static trim angles and it was found that lower static trim angles initially reduce resistance but at higher speeds the resistance is greater than cases with higher static trim angles. While Thornhill et al.


General dimensions of the full-scale Aura

Length over all	4.8 m
Maximum beam	1.4 m
Hull draft	0.09 m
Draft with appendages	1.5 m
Displacement	90 kg
Mast height	7.48 m
Mainsail area	12.5 m^2
Foresail area	4.75 m^2
Spinnaker area	25 m^2

Fig. 1. Mathematical model of the Aura and her full-scale dimensions.

Fig. 2. Photograph of the Aura in full scale with an aft crew position.

Fig. 3. Photograph of the Aura in full scale with a forwards crew position.

(2003) tested a 1:8th scale model of a 15 t vessel, in the present paper a 1:4th scale model of a 90 kg boat is tested. Despite of the very different type of vessel, similar conclusions on the effect of the static trim angles on the resistance was achieved. The resistance of planing hulls was computed with CFD by several authors who found good correlation with towing tank data. For instance, Caponnetto (2000), Caponnetto (2001) and Azcueta (2003) showed that a Reynolds-averaged Navier–Stokes approach can be used to accurately predict the hull resistance at high Froude numbers modelling the free surface with a volume-of-fluid technique.

2. Experimental method

2.1. Model

In the present work, the hull shape was a 1:4 scale model of the Aura. It was constructed from carbon fibre using a computer numerical control milled mould. A carbon fibre base plate was fixed to the inside of the model such that its top surface was parallel with the still waterline defined by the design waterline. The hull surface was marked with the still waterline and 12 transverse sections, from Station 0 at the aft extreme of the model to Station 11 at the forward extreme of the model. Also 11 half stations were marked midway between the full stations. The marked transverse sections are visible in Fig. 4, which shows a photograph of the Aura model towed in the towing tank.

2.2. Experimental setup

The testing was undertaken in the Hydrodynamics Laboratory of the School of Marine Science and Technology, Newcastle University, UK. The facility features a towing tank of $L \times B \times D$, $37 \times 3.7 \times 1.25$ m^3 and uses a monorail carriage assembly on which all data acquisition and processing equipment is fitted.

Fig. 5 shows the experimental setup. The longitudinal centre of gravity of the model (LCG_0) was found by balancing the model longitudinally on a knife edge fulcrum. An aluminium towing plate was then attached to the carbon fibre base plate such that its central seating pin was on the intersection of LCG_0 and the boat symmetry plane.

Full-scale Reynolds numbers based on LOA ranged from 1.0×10^7 to 3.5×10^7 for the tested conditions, thus the boundary layer on the hull is mostly turbulent. Conversely, in model scale, Reynolds number ranged from 1.2×10^6 to 4.3×10^6 leading to a larger region of laminar boundary layer. Therefore, a 2.5 mm probe entering the water 0.1 m from the bow at the vessels still water condition was used as turbulence generator (Fig. 5).

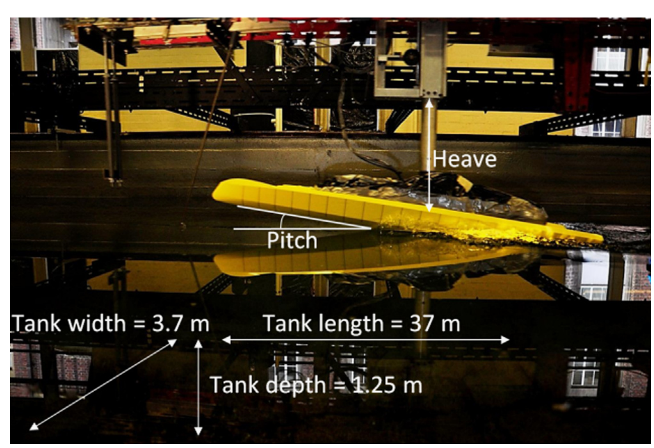


Fig. 4. Photograph of the Aura 1:4 model in the towing tank.