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Numerical investigation on the hydrodynamic performance of fast SWATHs with optimum canted struts arrangements

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ABSTRACT

Small Waterplane Area Twin Hulls (SWATHs) are known to have superior seakeeping performance but higher resistance compared to equivalent catamarans or mono-hulls. A way to improve their resistance characteristics is to use unconventional hull forms parametrically defined and optimized by CFD methods. This study builds on previous SWATH optimization studies proposing a comprehensive, systematic investigation on the effect of different shapes and canting angles of the struts. For the first time we demonstrate the importance of considering the shape of the strut that is fully parametrized in our study. The effect of the design speed on the best shape is addressed through a multi-objective optimization targeting the minimum total resistance at two very different speeds, namely the cruise and slow transfer speeds. Optimum hull shapes are discussed in terms of maximum resistance reduction, together with the predicted free waves patterns.

1. Introduction

SWATH ships have proven to be excellent platforms for particular marine vehicles where low motions at sea are of primary importance: this is the case of passenger ships [1,20], research vessels [2,3] and special navy vessels [4] among others. Recently Brizzolara et al. [5] have introduced an innovative design of a family of autonomous surface vessels based on unconventional SWATH hull that demonstrated their superior seakeeping performance with respect to equivalent catamarans [6]. As a downside to the excellent seakeeping behaviors, generally conventional SWATH vessels, having torpedo–like underwater hulls based on symmetric airfoil shapes do not meet high performance in terms of calm water resistance. A way to eliminate this drawback was first introduced by Brizzolara [7] and it relied on automatic parametric optimization algorithms exploring different unconventional shapes analytically defined that are able to maximize the positive interference effects between the wave trains generated at the bow and stern of the underwater hulls. The design by optimization method was then implemented with a fully 3D B-Spline modeling of the underwater hull [8] still allowing for unconventional 'wasp-body' like shapes of the underwater hulls but keeping the struts unchanged.

However, the wave resistance of a SWATH does not only depend on the submerged hulls; it is in fact affected by the struts shape and configuration, i.e. the structural elements that connect the SWATH superstructure to the lower hulls. No study has been made so far about the influence of strut shape on the hydrodynamic performance of SWATH. This kind of study has to consider some hydrostatic constraints, since the struts, in addition to their structural functionality, are elements that ensure a sufficient transversal and longitudinal stability to the vessel and do contribute to the total drag by a significant fraction. An additional contribution to wave cancellation effect, though, can come out from the customized design of the struts. The number of the struts used for each side of the hull, their longitudinal position, their dihedral angle and the shape of each of them represent additional degrees of freedom to play with in order to reach the goal of optimum performance.

In this framework, we present a study on the interference effects generated by canted struts in SWATH vessels designed to achieve best resistance performance at medium to high Froude numbers. The effect of the struts on optimum drag is isolated

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Table 1
Technical data of the unconventional SWATH.

L_{OA}	7.02	m
L_{WL}	5.90	m
B_{Max}	5.44	m
T	1.18	m
D	3.33	m
∇	4.34	t
V_{Max}	12	Knots

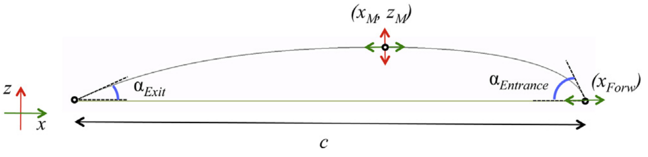

Fig. 2. Strut parametric section definition. Allowed movements of points are highlighted as well as possible angle changes.

through separate optimizations. The effect of the design speed is also investigated in the same way.

2. Canted multi-struts swath parametric design

The key for a successful hydrodynamic hull form optimization relies on an efficient parametric geometry definition. A full parametric model of the proposed unconventional SWATH has been developed extending the degrees of freedom of the geometric description initially proposed in Brizzolara et al. [5].

The main dimensions and characteristics of the unconventional SWATH design taken as reference for this study are listed in Table 1.

The fully parametric model of the SWATH is created using curves and surface primitives of the CAESES 3D parametric CAD (see for instance [9]. The parametric model is structured in two main blocks: one for the submerged body and the other for the two struts. The underwater part of the hull is an unconventional prolate ellipsoid whose generator curves (for the max and min semi-axes) are two B-Spline curves built on seven control points, shown in Fig. 1. The extremes ones (points P_0 and P_6) are used to define the length overall, L_{OA}, of the submerged hull. The two points directly adjacent to the two extremes, P_1 and P_5, are necessary to ensure the tangency of the curve (hence of the surface); as a consequence of this geometric construction these two points are allowed to move only in the vertical direction. The three remaining inner points, P_2, P_3 and P_4, directly drive the principal shape modifications of the underwater hulls. These three points can be freely moved along both vertical and longitudinal directions, creating humps and hollows along the length of the hull itself. This is the main feature of the parametric model for the submerged hulls that enables reaching low resistance values: there is a particular position relative minimum area section over the hull length that ensures the most favorable wave interference effect; this phenomenon helps reducing the wave resistance of a SWATH as first demonstrated in Brizzolara [7]. In addition to these eight parameters (three longitudinal coordinates and five vertical ones), the parametric definition of the BSpline curves requires a ninth parameter. This parameter, called *ellipticity factor*, $^{B}\!/\!_{H}$, never considered before (see for example [8], sets the beam to height ratio of all the transversal sections of the underwater hulls.

The two struts are modeled like three-dimensional airfoils, as shown in Fig. 2. The same parametric airfoil section (in the xy-plane) is repeated over the height of the struts. The section, of course, can differ for the aft and the forward strut, and it is generated on the basis of classic airfoil theory: the value and the position of the maximum thickness, X_M and Z_M respectively, the entrance and the exit angles of the section, $\alpha_{Entrance}$ and α_{Exit} respectively, the positions of the foremost extreme, X_{Forw}, and the section chord, *c*, are used as free parameters of the section. In addition to these parameters there are others controlling the global shape of the two struts: the transversal position of their leading edges with respect to the centerline of the submerged hull, Y_{Transl}, and the canting angles with respect to the vertical direction, ϑ, as shown in Fig. 3; the rotation of the symmetry plane of the struts is centered around the longitudinal axis of the underwater hull, in such a way that vertical struts correspond to $\vartheta = 0$. The transverse sections of the struts are actually translated in their horizontal plane (*xy*-plane). The aft and forward struts are inclined by the same angle.

In total, the global and local shape variations of the struts and of the submerged hulls of the unconventional SWATH depend on by a combination of 23 free parameters. The complete set of free parameters used to create the SWATH shape is listed in Table 2; to define a simple identification system, a progressive name from X_1 up to X_{23} is associated to the original name of each parameter;

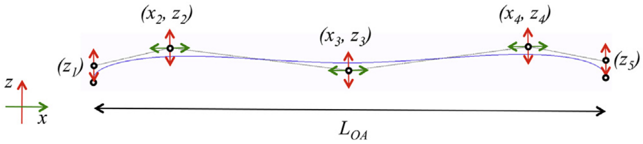

Fig. 1. Parametric definition of the B-Spline curve used to generate the shape of the underwater hull of the SWATH. Allowed horizontal and vertical motions of the points are highlighted green and red arrows respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

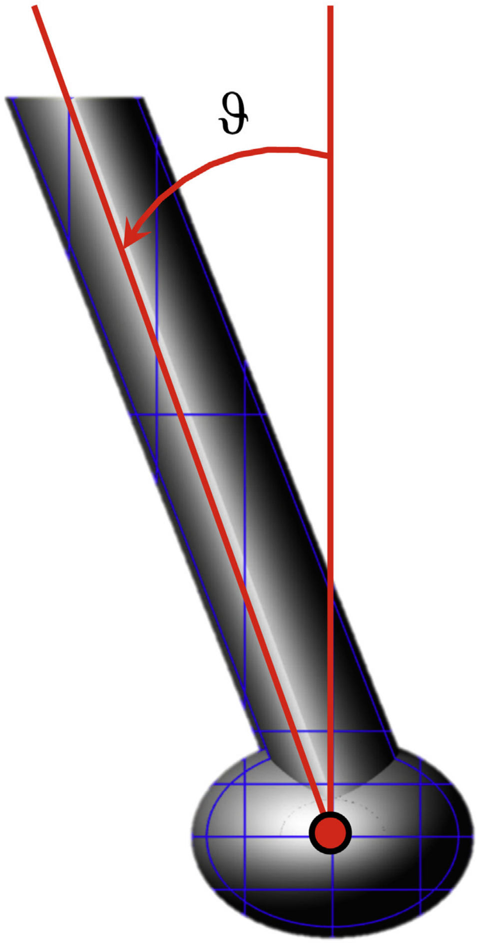

Fig. 3. Reference system for the strut rotation by the canting angle, ϑ..