Ocean Engineering 96 (2015) 181–191

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Numerical and experimental studies on hydrodynamic performance of a small-waterplane-area-twin-hull (SWATH) vehicle with inclined struts

Peng Qian, Hong Yi*, Yinghui Li

State Key Laboratory of Ocean Engineering, School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, China

ARTICLE INFO

Article history:
Received 6 July 2013
Accepted 20 December 2014
Available online 20 January 2015

Keywords:
SWATH
Inclined struts
Hydrodynamics
RANS
Model tests

ABSTRACT

A small-waterplane-area-twin-hull (SWATH) vehicle with inclined struts was investigated by numerical and experimental methods. Seakeeping performance was studied firstly based on the STF (Salvesen, N., Tuck, E. O. and Faltinsen, O. M. (1970). Ship motions and sea loads. Transactions–Society of Naval Architects and Marine Engineers. No. 78:250–287) strip theory. Results show that the inclined struts demonstrates improved seakeeping performances by comparison with a vertical-strut SWATH and an NPL (National Physical Laboratory) catamaran. 3D numerical simulations adopting an RANS method and model tests in the towing tank were carried out both in calm water and in regular waves. Numerical simulations have been validated by comparison with laborotary tests. As negative added resistance has been observed both in the model tests and in the numerical simulations, it can be concluded that the inclined struts, which could make use of wave energy, can give rise to a reduction of power required in waves.

1. Introduction

Small Waterplane Area Twin Hull (SWATH) ships are an innovative concept of vehicles and special configuration: their hulls consist of two parts distant to each other featuring two or more slender struts that are actually piercing the free surface, while the major part of the displaced volume is concentrated well below the free surface in torpedo-like underwater bodies (Brizzolara and Vernengo, 2011b). In such a way they possess much smaller ratio of design waterplane area to hull volumetric displacement than those single hull ships or classical catamarans. The most attractive advantages of SWATH ships are their superior ride quality and comfort since excellent seakeeping performance leads to acceptable level of acceleration for human habitability. Nowadays, this SWATH has been widely used to construct passenger ferries, cruise ships, oceanographic research and diving support vessels and patrol vessels with different variations and increasing sizes (Subramanian and Beena, 2002).

Though the small water-plane area guarantees good seakeeping performance, this special structure can also lead to the fact that heave-pitch motions are sensitive to load changes. The primary advantage of the SWATH hull forms is actually to reduce the frequency of maximum response in waves, but this may be at the expense of a larger magnitude of peak response. The SWATH gives the low MSI (Motion Sickness Incidence) at the lower wave heights, but this rises rapidly as 3 m-wave height (rougher than sea state 4) is approached and in rough seas this design will clearly lose any advantage. This would seem to be due to the increase of wave period with wave height so that the modal encounter frequency reduces towards the frequency of maximum response for this hull in larger seas (Davis and Holloway, 2003). In this paper, a SWATH with inclined struts was proposed aiming at improving the seakeeping performance of the SWATH vehicles.

Plenty of studies have been carried out on the hydrodynamic performance of the SWATHs. Beena and Subramanian (2003) studied the seakeeping performance of a set of SWATH forms with varied parameters, aiming at providing a tool for rapid assessing new designs with fully consideration of the advantages of this hull typology. With respect to the hydrodynamic resistance, which is one of the weakest points of SWATHs compared with conventional hull forms, Gaggero and Brizzolara (2006) report a unique computational tool that can be used both for the preliminary concept design and for the detailed hydrodynamic analysis of a SWATH ship, making it possible to design very efficient SWATH ships. On the basis of the scale effect in the model tests, Dubrovsky and Matveev (2006) analyzed the form drag with emphasizing on the factors influencing the residual

* Corresponding author. Tel./fax: +86 21 3420 7165.
E-mail addresses: qianpeng2015@gmail.com (P. Qian), Yihong@sjtu.edu.cn (H. Yi), liyinghui@sjtu.edu.cn (Y. Li).

http://dx.doi.org/10.1016/j.oceaneng.2014.12.039
0029-8018/

Nomenclature

a	wave amplitude
a_k	wave steepness coefficient
a_L	Wavelength proportionality coefficients
A_{jk}	$j=3,5; k=3,5$, added mass coefficients
b	Beam demihull
B	beam overall
B_{jk}	$j=3,5; k=3,5$, damping coefficients
C_{jk}	$j=3,5; k=3,5$, hydrostatic restoring coefficients
d	draft
F_3	heave exciting force
F_5	pitch exciting moment
FFT	Fast Fourier transform
Fr	Froude number; $\frac{v}{\sqrt{gl}}$
H	average water depth
H_w	wave height
I_5	moment of inertia for pitch
k	wave number
KB	vertical center of buoyancy above keel
KG	vertical center of gravity above keel
KMl	longitudinal metacenter above keel
KMt	transverse metacenter above keel
l	ship length overall
LCB	longitudinal center of buoyancy
M	mass of the SWATH vehicle
RAO	response amplitude operator
P	Pressure
R_{addedt}	added total resistance
R_f	friction resistance
R_r	residual resistance
R_t	total resistance
ρ_m	total added resistance
s	hull separation
S_w	wetted surface area
t	time
T_e	Encounter Period
u	longitudinal wave velocity
v	ship velocity
w	vertical wave velocity
WL	waterline
ϕ	velocity potential
λ	wave length
ω	wave frequency
ω_e	encounter frequency
δ	Wave initial phase
∇	displacement
ρ_α	fluid density
ρ_m	mixture density
r_α	volume fraction of phase α
μ_m	mixture dynamic viscosity
η_3	Heave displacement
$\dot{\eta}_3$	Heave velocity
$\ddot{\eta}_3$	Heave acceleration
η_5	Pitch displacement
$\dot{\eta}_5$	Pitch velocity
$\ddot{\eta}_5$	Pitch acceleration

resistance of SWATHs. Some other researchers also stated their study results on this hull type comparing with other ship hull types, which are worth being mentioned here, e.g. Yeung and Wan (2007), Burns (2002), Sikora et al. (1983) and Davis and Holloway (2003).

However, all the aforementioned studies just dealt with the SWATH ships with the vertical struts except Brizzolara and Vernengo (2011b) who focused on ASV based on canted-strut SWATH. In fact, most of their works (Brizzolara, 2004; Brizzolara et al., 2011, 2012; Brizzolara and Vernengo, 2011a) focused on the resistance optimization of the submerged bodies. In the present study, an unconventional SWATH with inclined struts was designed, and both numerical simulations and model tests were conducted to investigate its improvements on hydrodynamic performance.

Actually, the original idea of inclined struts came from the flapping foils (Techet, 2008), which are considered as new and effective marine propellers. The research results show that the flapping foils can produce a propulsive force due to the heave and pitch motions, this entails a general assumption: transferring the vertical struts of SWATH to inclined ones may decrease the energy consumption in waves, as the well designed inclined struts can make use of the wave energy just like the flapping foils (Barrett et al., 1999; Krylov and Pritchard, 2007; Liu et al., 2011b).

The rest of the paper is organized as follows. Section 2 gives the description of the inclined-strut SWATH including its parameters and layout. Section 3 presents the seakeeping performance based on the STF strip theory and gives some suggestions on selecting the wave frequency in the following model tests and numerical simulations in waves. In Sections 4, 3D numerical simulations adopting an RANS method and model tests in the towing tank have been carried out both in calm water and in regular waves. Experimental results of the SWATH are presented for the first time in technical journals. Theory for numerical simulations have been validated by comparison with laborotary tests. The seakeeping and resistance performances are analyzed and discussed. Finally, Section 5 draws the conclusion.

2. Description of the inclined-strut SWATH

Based on the preliminary study on conventional SWATH vehicle (Liu and Yi, 2010), a new SWATH with inclined struts was designed. The waterline, the side profile and the body plan are presented in Fig. 1, and the principal dimensions and parameters of the new design are listed in Table 1.

Scale ratio for model tests and numerical simulations was set to be 1:10.

Following the idea of the bionic hydrodynamics (Wu, 2011) and the shape of fish, the inclined struts are set close to the stern, in which way the struts can make full use of the wake flow stirred by the torpedo-like underwater bodies. In fact, the inclined struts are to the SWATH vehicle what the fins and tails are to the fish. The significant difference is that the fins and tails are flexible flapping foils while the inclined struts are rigid bodies. The inclined struts are designed to imitate the relative motions of the flapping foils, aiming at absorbing the wave energy.

The initial design of this innovational SWATH focuses on the function of the inclined struts—it should be able to steer in extreme sea state as an autonomous surface vehicle (ASV). Due to this special purpose, its superstructure, which is not shown here, is purposely designed to be so small that it can be treated as several connecting poles. As tabulated in Table 1, the center of gravity of this SWATH is very low. All main engines, fuel, batteries, and other deadweight are placed in the lower hulls. Additional 12 ton weights, such as detection equipment, information collectors and data receivers/senders, can be loaded on the upper deck. All these extraordinary designs can