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Passenger ship seakeeping optimization by the Overall Motion Sickness Incidence

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ABSTRACT

Wellness and comfort onboard are ones of the most important factors in ship design and may be considered the key criterion to achieve the best seakeeping performances for passenger vessels. In this respect it is possible to achieve appreciable seakeeping improvements by only varying several hull form parameters, even if ship main dimensions and displacement have been already fixed. In the paper a new index, namely the Overall Motion Sickness Incidence (OMSI), defined as the mean MSI value on the main deck, is proposed and assumed as parameter to be minimized in a single-objective optimization procedure. Parametric modelling is used to generate several hull forms derived by the NPL systematic series and, despite of classical methods where the optimization procedures are carried out in regular head waves, various heading angles and two operating scenarios are considered in a seaway, described by the JONSWAP Spectrum. The optimum hull is finally generated and relevant vertical accelerations at some critical points on the main deck, as well as heave, pitch and roll speed polar plots, are compared with the parent ones.

1. Introduction

Ship calm and rough water performance prediction is one of the most important concerns for naval architects, already at the earliest design stage. From this point of view seakeeping analysis has been widely applied after the development, in 1955, of the first practical strip theory, mainly based on the evaluation of the hydrodynamic characteristics of various hull sections by Lewis (1929) conformal mapping technique or Frank Close-Fit approach. In this respect any vessel with good seakeeping qualities has to perform in a seaway the expected mission that, in turn, depends on ship service and typology. For instance, naval ships seakeeping performances strictly depend on operational ability and use of weapon and sensor systems, while for passenger or cargo vessels wellness and comfort onboard, as well as crew safety, are the main factors to be accounted and optimized. Anyway, even if seakeeping qualities are not the only dominant aspect in the ship design process, it is always possible to achieve considerable improvements, even when displacement and main dimensions have been fixed. For this reason seakeeping optimization, in terms of habitability, operability and survivability, has become a popular research topic for the last three decades.

Bales (1980) optimized a destroyer-type hull form, in head seas and at various speeds, on the basis of analytical predictions, subsequently deriving by some regression formulas correlating relevant performances to form parameters, the optimum hull. Grigoropoulos and Loukakis (1988) developed a numerical method, based on a nonlinear direct search algorithm to minimize RAO peak values in head regular waves. Similar studies have been also carried out by Hearn et al. (1991), who developed an inverse design procedure, based on the optimum hull nonlinear direct search process. Kukner and Sariöz (1995) optimized the seakeeping qualities of a high speed vessel, generating by the Lackenby method (Lackenby, 1950), several derived hulls having different form parameters as regards the parent ones. Peacock et al. (1997) defined a mathematical model based on a multi-objective research algorithm for displacement monohulls. Sariöz and Sariöz (2006) proposed a new optimization procedure, based on a nonlinear problem solved by direct search techniques. Campana et al. (2009) proposed a new optimization technique for the heave motion of the S175 containership, adopted by the ITTC Seakeeping Committee as a benchmark test, considering two different optimization procedures, namely a filled function based algorithm and a Particle Swarm Optimization method. Diez and Peri (2010) presented a new approach for the robust optimization of a bulk carrier conceptual design, subjected to uncertain operating and environmental conditions, so extending the standard deterministic formulation for design optimization to take into account the uncertainty related to both design variables, operating conditions

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and computational results of the simulations. Finally Özüm et al. (2011) investigated the seakeeping qualities of fast ships, systematically varying both main dimensions and hull form parameters. Anyway, in almost all cases, optimization procedures were based on the assumption that the optimum hull is found when the absolute vertical acceleration in regular head waves due to combined pitch, heave and roll motions, is minimized, instead of analysing statistical responses in a seaway, so neglecting sea spectra and operating scenarios, and consequently reducing computational efforts.

In the paper a new index, namely the Overall Motion Sickness Incidence, defined as the mean Motion Sickness Incidence (MSI) value on the main deck, is proposed and chosen as a parameter to be minimized in a single-objective optimization procedure, accounting for both operating scenarios and sea spectra. The proposed method is applied to the hull form optimization of a passenger vessel, derived by the round bilge NPL systematic series: several alternative hulls have been generated, for fixed displacement and Froude number, by the Lackenby method, varying both some hull form parameters and the longitudinal centre of buoyancy position. Furthermore, despite of classical optimization procedures, based on RAO peak values minimization in regular head waves, various heading angles have been considered in a seaway, described by a JONSWAP Spectrum for all statistically relevant combinations of significant wave height and zero-crossing periods. The optimum hull is finally derived by means of the Pareto Principle, and relevant vertical accelerations at some critical points on the main deck, as well as heave, roll and speed polar plots, are compared with the parent ones.

Table 1
Parent hull main dimensions and form parameters.

Displacement	Δ	2781	t
Draft to baseline	T	4.00	m
Waterline length	L_{WL}	100.00	m
Waterline beam	B_{WL}	17.00	m
Prismatic coefficient	C_P	0.700	
Block coefficient	C_B	0.400	
Midship section coefficient	C_M	0.662	
Waterplane area coefficient	C_{WP}	0.781	
LCB from FP (+ve aft)	LCB	55.00	$\%L_{WL}$
Vertical centre of buoyancy	KB	2.791	m
Vertical centre of gravity	KG	7.000	m

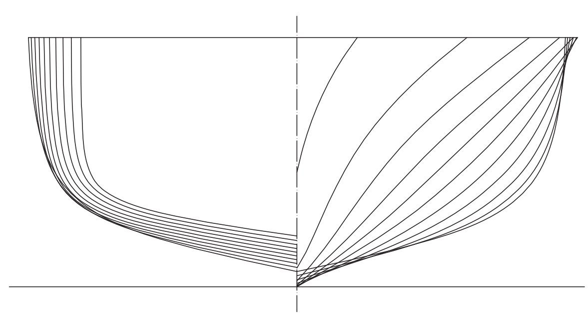

Fig. 1. Parent hull forms.

2. Seakeeping operability performance assessment

2.1. The Overall Motion Sickness Incidence index

Motion sickness generally indicates discomfort on a moving environment, having the peak of different associated symptoms in vomiting. It is related with motion perception in the vestibular system, providing the brain with information about self-motion not in accordance with those ones furnished by visual and/or proprioceptive systems, the first one located in the inner ear, the second one in the skin, muscles and joints (Pérez Arribas and López, 2007). Sickness is generally caused by these conflicting signals, according to sensory rearrangement (Reason and Brand, 1975) and neural mismatch (Benson, 1999) theories. Following the studies sponsored by the US Navy in the early 1970s, to investigate ship motion effects on humans, the first mathematical model for sickness was developed by O'Hanlon and McCauley (1974). A series of experiments were carried out on over 500 subjects, while seated with their heads against a backrest and eyes opened in an enclosed vertically oscillating cabin. During these experiments they were exposed to the effects of 25 combinations of 10

Table 3
Alternative hull forms adimensional parameters for fixed C_P=0.700 and LCB=55%.

	Hull 1 – C_B=0.390	Hull 2 – C_B=0.395	**Hull 0 – C_B=0.400**	Hull 3 – C_B=0.405	Hull 4 – C_B=0.410
C_B	0.390	0.395	**0.400**	0.405	0.410
C_M	0.650	0.656	**0.662**	0.675	0.681
C_{WP}	0.779	0.780	**0.781**	0.783	0.784

Table 2
Alternative hull forms adimensional parameters for fixed C_B=0.400.

	Hull 1 – LCB=53%	Hull 2 – LCB=53%	Hull 0 – LCB=53%	Hull 3 – LCB=53%
LCB from FP (+ve fwd)$\%L_{wL}$	53%	53%	53%	53%
C_P	–	0.650	0.700	0.750
C_M	–	0.700	0.662	0.621
C_{WP}	–	0.772	0.800	0.821
	Hull 1 – LCB=55%	Hull 2 – LCB=55%	**Hull 0 – LCB=55%**	Hull 3 – LCB=55%
LCB from FP (+ve fwd)$\%L_{wL}$	55%	55%	**55%**	55%
C_P	0.600	0.650	**0.700**	0.750
C_M	0.750	0.707	**0.662**	0.628
C_{WP}	0.734	0.760	**0.781**	0.801
	Hull 1 – LCB=57%	Hull 2 – LCB=57%	Hull 0 – LCB=57%	Hull 3 – LCB=57%
LCB from FP (+ve fwd)$\%L_{wL}$	57%	57%	57%	57%
C_P	0.600	0.650	0.700	–
C_M	0.750	0.701	0.662	–
C_{WP}	0.724	0.744	0.762	–