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CFD based vortex generator design and full-scale testing for wake non-uniformity reduction

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A R T I C L E I N F O

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A B S T R A C T

Propeller-induced vibration on ships may originate from separation and wake non-uniformity and can be dealt with stern form redesign, wake adapted propeller design or wake modification devices such as fins, ducts or vortex generators. For an existing ship, the retrofit options are limited and vortex generators are the most cost efficient measure with quick and easy application. However, selection of the design parameters such as size, location and angle of attack relative to the flow are still not straightforward and can be very costly to be evaluated by model tests or full scale investigations. RANS based CFD methods can be used effectively to select these parameters. Current research presents a methodology through a full-scale test case consisting of initial numerical flow calculations and full scale testing, CFD calculations, final numerical flow calculations and full scale testing which shows significant improvements on the wake non-uniformity hence the suffered shipboard vibration.

1. Introduction

Shipboard vibration may be a major design problem for ships with high block coefficient hull forms such as tankers, bulk carriers etc. As the vibration severity increases with the ship speed and propeller loading, the speed is often restricted by the vibration rather than the thrust/torque capability of ship engine/propeller. This in turn forces to run the propulsion engine at a lower loading relative to the Engine Maximum Continuous Rating (MCR), resulting in high engine maintenance costs as well as high emissions.

A ship moving in calm water generates disturbances on the free surface, i.e. ship waves, and streamlined flow pattern, i.e. three-dimensional boundary layer on the ship surface, and flow separation from hull created vortices. As the ship hull moves in water, separation may occur in the cross flow direction creating longitudinal vortices. Generally the flow is downward and outward over the forward section of the hull and upward and inward towards the stern. This leads to various vortices including bow, bow dome, bilge and stern vortices as given in Fig. 1 by Lugt (1981) and explained by Gorski (2001). Boundary layer is in the nature of turbulent flow and responsible for the viscous resistance. Vortices are aimed to be minimised to reduce vortex generation resistance and to provide higher propulsion efficiency. The complicated interaction of thick boundary layer and bilge/stern vortex system may result in flow separation at the aft end. Additionally, the flow may separate due to wave breaking at the bow, and appendage sharp edges may stimulate separation.

The conventional propulsion arrangement for merchant ships causes the propeller to partially operate in the boundary layer or wake of the hull. This may result in complex inflow patterns to the impeller/propeller; possibly leading to vibrations, material fatigue, and reduction of the overall performance of the craft may be overcome by laborious propulsion system design. The strong circumferentially non-uniform wake distribution on the propeller disc will cause cyclic changes in flow incidence to each blade, cavitation, and strong pressure pulses at propeller blade frequency (Matheson, 1980).

2. Evaluation of propeller induced vibrations

Vibration on ships may be originated from the mechanical sources (i.e. main engine, generators, reduction gears etc) of from the hydrodynamic sources (i.e. propeller cavitation, wake non-uniformity etc). Fundamental mechanism and characteristics of hydrodynamic vibration sources can be stated as (BMT, 1979):

- Excessive levels of forced vibration are predominantly due to the flare up of cavitation on each propeller blade passing through the wake peak at the top dead center position.

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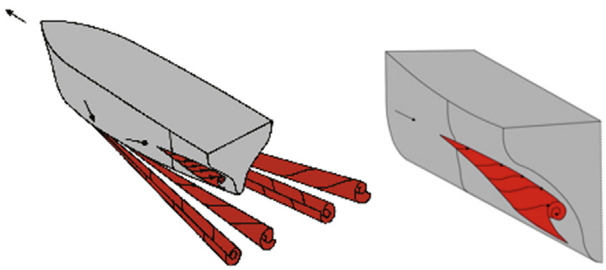

Fig. 1. Surface ship vortices (Lugt, 1981).

Table 1
Main characteristics of the case study ship.

Ship Waterline Length	86.515	m
Ship Breadth	13.500	m
Ship Draught	5.544	m
Design Displacement	5103.1	m^3
Block Coefficient	0.781	
Midship Section Coefficient	0.993	
Design Speed	12.5	knots
Main Engine Power	1838	kW
Main Engine RPM	265	rpm
Propeller Type	CPP	
Propeller Number	1	
Propeller Diameter	2.7	m
Propeller Number of Blades	4	
Propeller Pitch/Diameter Ratio (0.7 R)	0.681	
Propeller Expanded Area Ratio	0.57	
Propeller Skew Angle	25	degrees
Propeller RPM	265	rpm

- Rapid growth and collapse of sheet, tip vortex and propeller-hull-vortex cavitation transmits large, oscillatory pressures to the shell plating in the close vicinity of the propeller plane.
- Cavitation number and wake non-uniformity are critical parameters governing, respectively, the amount of vibratory excitation.
- Large, stable cavities tend to generate mainly blade rate oscillatory pressures, while rapid collapse gives rise to higher harmonic components.

In order to reduce the propeller-induced vibration, a number of design decisions may be taken:

- The after body hull lines may be designed in such a fashion that would accordingly reduce the wake non-uniformity.
- The choice of the engine dictates the operational rate of revolution and hence propeller diameter and cavitation susceptibility.
- Compatibility of wake and propeller design may be ensured by empirical, analytical, numerical and experimental methods.

Failure of accounting for these measures may result in propeller-induced vibrations that would be encountered during the sea trials, and the measures to reduce their effects are very limited after this point. Wake modifying solutions can be used to force the wake-propeller compatibility as a retrofit solution. Ducts, fins or vortex generators may be utilized if the propeller is kept unchanged. The technologies for the use of these measures exist for many years (Oledal, 1997) but there is still little knowledge about the design methodology, the scale effects and full-scale validation.

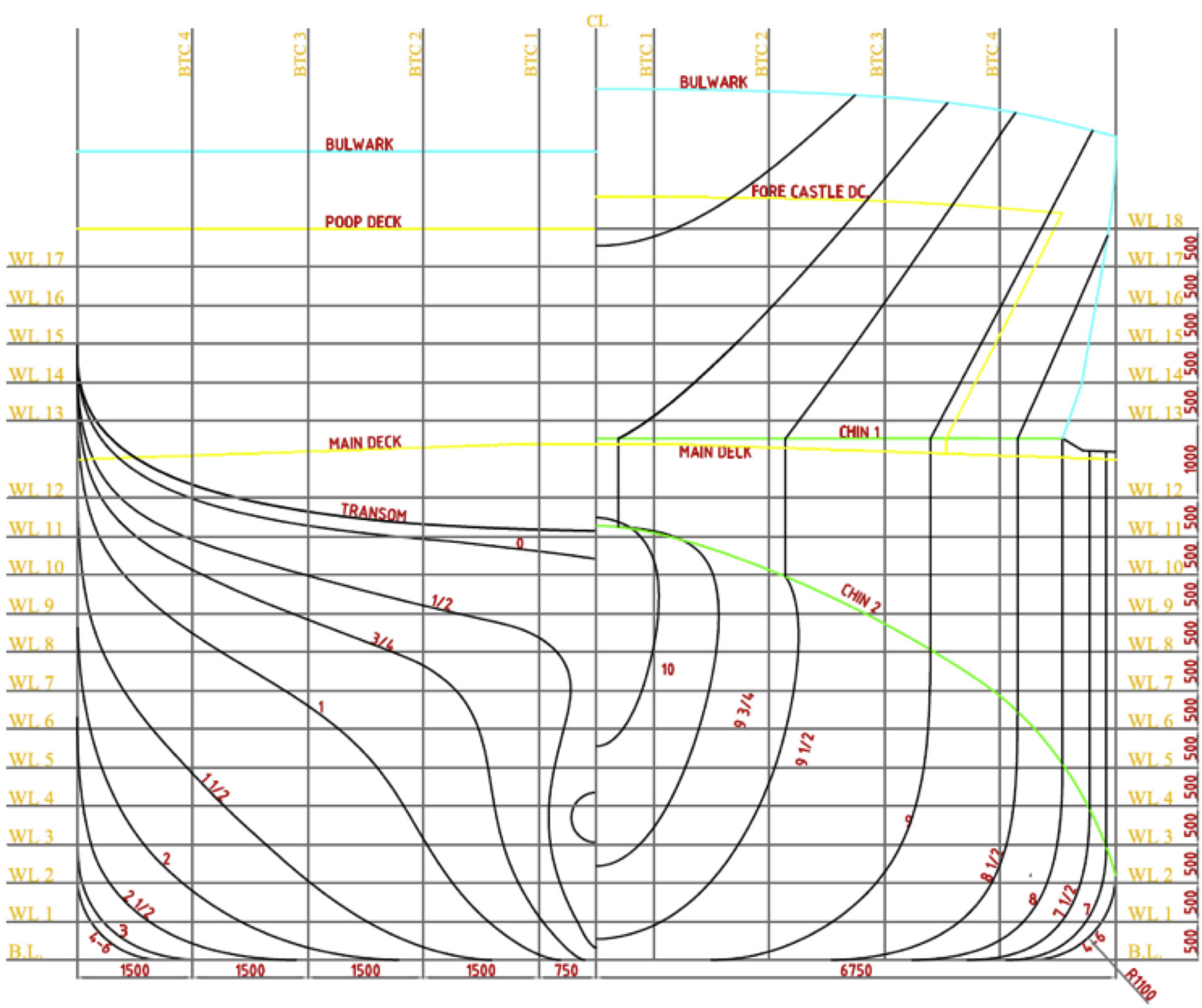

Fig. 2. Body plan of the ship selected for the case study.