

Parametric design and multi-objective optimisation of containerships

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ABSTRACT

The fluctuation of fuel price levels along with the continuous endeavour of the shipping industry for economic growth has led the shipbuilding industry to explore new designs for various types of ships. In addition, the introduction of new regulations by the International Maritime Organisation frequently triggers changes in the ship design process. In this respect, proper use of computer-aided ship design systems extends the design space, while generating competitive solutions in short lead time. This paper focuses on multi-objective optimisation of the design of containerships. The developed methodology is implemented on CAESES[®] software and is demonstrated by the conceptual design and optimisation of a 6500 TEU containership. The methodology includes a parametric model of the ship's external and internal geometry and the development and calculation of all required properties for compliance with the design constraints and verification of the key performance indicators. The latter constitute the objective functions of the multi-objective optimisation problem. The energy efficiency design index, the ratio of the above to below deck number of containers, the required freight rate, the ship's zero-ballast container capacity and the total ship resistance were used in this study. Genetic algorithms were used for the solution of this multi-objective optimisation problem.

1. Introduction

1.1. Container shipping industry

Global containerised trade has been on constant growth since 1996. It is worth mentioning that in 2015, there was a 2.4% growth, which can be translated to a total movement of 175 million TEUs in one year (UNCTAD, 2016). The fluctuation of fuel price has caused changes in the operation of ships. Since 2008, the fuel price has dropped and nowadays heavy fuel oil (HFO) costs as low as 250 \$/t. Marine diesel oil (MDO) has been following similar course and can be found at prices of around 450 \$/t (Ship and Bunker, 2017). However, this does not always result in lower shipping rates. The introduction of emission control areas (ECAs) has affected the fuel type ships use. Use of low sulphur fuel is now required in certain parts of the world. The price difference between fuel types can be significant. In addition, the recent landmark decision by the International Maritime Organisation (IMO) Marine Environment Protection Committee to implement a global sulphur cap of 0.5% m/m (mass/mass) from 1 January 2020 has introduced a step change to the framework of designing and operating ships (IMO, 2016).

In the years before 2014 and the collapse of the fuel prices, the shipping industry was adopting several practices to reduce fuel consumption. One of them was slow steaming (SS) (Tozer, 2008) and super slow steaming (SSS) (Maloni et al., 2013; Bonney and Leach, 2010). In comparison to some years ago -when operational speeds of around 25 knots were common-containerships nowadays travel at around 18–20 knots in slow steaming and at 15 knots in super slow steaming. Ship design for lower speeds has major impact to fuel savings and may reduce their energy efficiency design index (EEDI) levels (White, 2010).

The recent improvements in technology and engineering have made the introduction of ultra large container vessels possible. A new trend, known as cascading, resulted from the high number of new building programmes initiated by many liner companies. These orders consisted primarily of very large containerships. The continued influx of such large vessels into the market has led to a large number of vessels being cascaded onto trade lines that historically have been served by smaller vessels (Köpke et al., 2014). Hence, routes where 2000–3000 TEU containerships are preferred by charterers at the moment may attract larger vessels in the near future. Since the former category of ships is mainly used for the purpose of short sea shipping, ships in the 6000 TEU

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category could become widely popular among the ship owners and the charterers. In addition, the recent opening of the new Panama Canal locks means that the Post-Panamax containerships can be utilised in more transport routes, including the trans-Panama services (van Marle, 2016).

Although container carriers do not spend considerable amount of time in ports, port efficiency is considered as one of the most important factors in containership design. The less port time they spent, the more time is available for cruising at sea, which means that vessels can operate in lower speeds and consequently reduce fuel consumption. Usually, the transport efficiency is optimised by focusing on the schedule of the ships visiting a specific port (Kurt et al., 2015). However, in our case the optimisation focuses on the ship itself, making the incorporation of the port efficiency in the holistic optimisation of containerships possible. In this study a simplified approach was used, namely monitoring the ratio of the above to below deck containers' number. As Soultanias (2014) has found, the larger the ratio, the faster the loading and unloading of containers; thus, the time spent by ships in port is reduced.

1.2. International regulatory framework

Recent developments in the international maritime regulations are going to greatly affect future ship designs and particularly containerships. One major development is the introduction of the EEDI, in 2012 (IMO, 2012a, c, b). This is a major step forward in implementing energy efficiency regulations for ships, limiting greenhouse gas emissions, through the introduction of the EEDI limits for various ship types. The EEDI relates the CO₂ emissions of a ship to her transportation work and is in fact an indicator of a vessel's energy efficiency. The determination of EEDI is based on a rather complicated looking (but indeed simple) formula, while it is required that the calculated value is below a reference line set by the IMO regulation for the specific ship type and size. The EEDI requirement for new ships started with some baseline values in 2013, and is being lowered (thus becoming more stringent) successively in three steps until 2025, when the 2013 baseline values will have been reduced by 30%. It is evident that EEDI is a ship efficiency performance indicator that should be minimised in the frame of a ship design optimisation.

New rules have been recently developed regarding the control and management of ships' ballast water and sediments and will be applied to

all ships as of September 2017 (IMO, 2004). Although various systems and technologies aiming at the minimisation of the transfer of organisms through ballast water to different ecosystems are currently available, their installation on board ships increases their capital and operating costs. Therefore, research has been focusing lately at solutions to reduce the amount of required ballast water. This problem is more severe for containerships, which inherently carry more ballast water, even at the design load condition, for which the ratio of the containers carried on deck to those carried under deck should be maximised. Thus, design solutions for modern containerships that consider zero or minimal water ballast capacities are very appealing to the ship owners. Nevertheless, attention should be paid to the overall cargo capacity as well, so as to maintain competitive values in all respects.

Finally, as far as safety regulations are concerned, a new generation of intact stability criteria is currently being developed by the IMO (IMO, 2015). The introduction of ships with newly developed characteristic and operation modes has challenged the assumption that the current criteria are sufficient to prove their stability. Hence, the new criteria will be performance-based and will address five modes of stability failure; parametric roll, pure loss of stability, excessive acceleration, stability under dead ship condition and surf-riding/broaching (Peters et al., 2011). As far as containerships are concerned, parametric roll is considered to be one of the most important modes of stability failure (Spyrou, 2005). Hence, the draft criteria of level 1 and 2 for parametric roll failure mode according to SDC 2/WP.4 (IMO, 2015) are applied as part of the optimisation process in this study.

2. Parametric CAD modelling

In recent years, several researchers have presented significant computer-aided design (CAD) methodologies dealing with ship design process and inherently its optimisation (Brown and Salcedo, 2003; Campana et al., 2009; Mizine and Wintersteen, 2010). A common characteristic of most of the earlier presented works is that they are dealing with specific aspects of ship design or with new system approaches to the design process. On the other hand, the present study deals with a fast, holistic optimisation of a Post-Panamax, 6500 TEU containership, focusing on optimisation of the ship's arrangements, while considering all

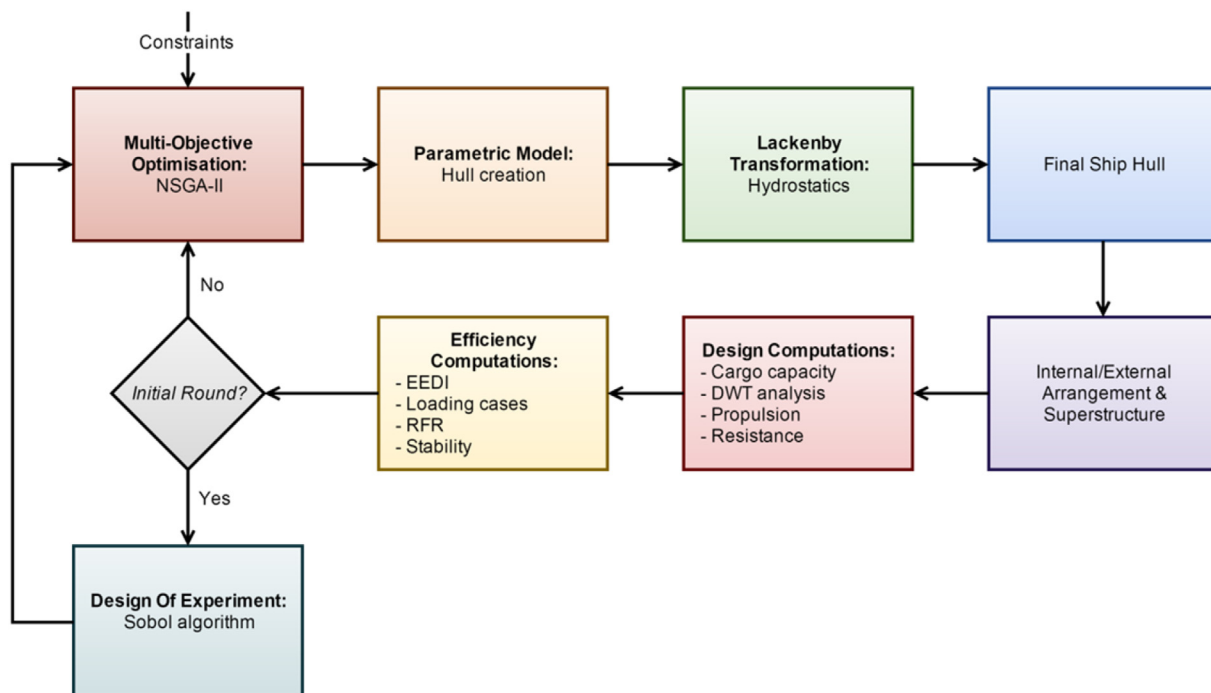


Fig. 1. Design optimisation procedure.

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