The Effects on the Operating Condition of a Passenger Ship Retro-fitted with a Composite Superstructure

Karatzas, Vasileios; Hjørnet, N. K. ; Kristensen, Hans Otto Holmegaard; Berggreen, Christian; Jensen, Jørgen Juncher

Published in:
Proceedings of the 13th International Symposium on Practical Design of Ships and Other Floating Structures (PRADS'2016)

Publication date:
2016

Document Version
Peer reviewed version

Link back to DTU Orbit

Citation (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.
The Effects on the Operating Condition of a Passenger Ship Retro-fitted with a Composite Superstructure

V. Karatzas 1), N. K. Hjörnet 2), H. O. Kristensen 1), C. Berggreen 1) and J. J. Jensen 1)

1) Department of Mechanical Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark
2) Niels Hjörnet Yacht Design, Sæby, Denmark

Abstract

As sustainability and climate change have come on the political agenda, the shipping industry will have to be operating energy efficient ships. An appealing step to achieve this goal is by designing superstructures made out of Fiber Reinforced Plastics (FRP) aiming at the reduction of the ship’s lightship weight. The benefits of a light superstructure become most prominent in large passenger ships, as the superstructures constitute a significant percentage of the lightship. Additionally, depending on the size of the ship, the superstructure may tower several decks above the weather deck, affecting the stability of the ship. In this work, the superstructure of a RoPax ferry has been redesigned using composite materials emphasizing the effects on the ship from an operational perspective. The weight reduction has been calculated for a realistic average operating condition quantifying the effects on the stability and the fuel consumption of the retrofitted ship compared to the original design.

Keywords

Superstructure, Composites, Passenger Ship

Introduction

Composites exhibit several appealing characteristics being lightweight, corrosion resistant and exhibiting good performance under fatigue loading. These characteristics make them an excellent choice for marine applications. Until now composites have been predominantly used in maritime applications in small crafts and military vessels given that their implementation onboard SOLAS vessels was restricted. However, in 2002 the Regulation 17 (SOLAS 2002) was introduced in the SOLAS convention enabling the use of combustible materials provided that the achieved level of safety is equivalent of a steel structure. This regulation has allowed for alternative designs surpassing several limitations that were imposed by the use of traditional metallic materials. Despite the potential benefits from the implementation of lightweight materials, to this day this regulation has been rarely used in practice as both the technical aspects and the appropriate regulatory approval related to the implementation of composites have proven to be complex, time-consuming and therefore not appealing to the ship stakeholders. The work presented in this paper has been performed within the context of the COMPASS project. In the project, the superstructure of an existing RoPax ferry has been redesigned using composite materials. While, previous works from the same authors (Karatzas et al 2015a, 2015b) on this topic were focused on the structural response of the superstructure, this work presents the effects on the lightship weight, the stability, resistance and the propulsion power requirements. Finally a simplified estimation of the fuel oil consumption reduction is performed.

Case study description

The vessel chosen for the study is PRINSESSE BENEDIKTE, operated by Scandlines between Rødby and Puttgarden. The upper part of the ship’s superstructure has been redesigned using composites materials according to the DNV Rules for Classification of Ships (2014) and DNV’s Rules for Classification of High Speed, Light Craft and Naval Surface Craft (2014). In detail, the passenger decks, the wheelhouse deck along with the masts, funnels and the wheelhouses have been considered for conversion (Fig. 1).

Fig. 1: PRINSESSE BENEDIKTE and the part of the superstructure considered for conversion

Since the original design requirements and constraints were unknown, it was decided to keep the exact same general arrangement for the new design. Glass fibers impregnated in epoxy resin were selected for the sandwich panels faces along with a PET core (P100) provid-
ed by DIAB. The core was selected based on its good performance in terms of fire, smoke and toxicity. The ply sequence for the structural elements for the conversion are presented in figure 2.

![Ply sequence of the structural elements of the superstructure](image)

### Weight reduction

Following the design of the new superstructure, weight calculations have been performed and compared to the calculated existing steel weight. The calculation of the steel weight has been performed based on available data from the ROPAX ferry PRINS RICHARD which is the sister ship of PRINSESS BENEDIKTE. At this point it is underlined that the calculated weight corresponds to the steel weight of the original superstructure excluding outfitting weights. Similarly the presented calculations for the composite cases solely consider the weight of the composite parts. Special considerations have been given to address structural and manufacturing details associated with composites such as pillar support areas, local reinforcement at openings/edges and the resin intake based on available data for the selected core type.

Comparing the composite superstructure to the original steel one, it can be seen that the structural weight reduction is significant being approximately 70% (Table 1). The result indicates that replacing part of the superstructure with sandwich materials leads to a reduction of the lightship of around 5%.

![Weight groups and center of gravity](image)

### Loading condition

To investigate how this weight reduction affects the performance of the ship, the average loading condition the vessel operates in is considered. This loading case was provided by Scandlines [C. Nicolajsen, personal communication]. Details about the deadweight in that loading condition are provided in figure 3. The duration of each trip is equal to 45 minutes out of which 17 minutes are needed for the acceleration and deceleration to (and from) a service speed of 15 kn. Approximately 15 minutes are needed for the embarkation and disembarkation of passengers and vehicles. The ship makes 8300 trips per year.

![Deadweight detail for the selected loading condition](image)

### Stability calculations

To calculate the stability for the retrofitted cases the calculation of the new center of gravity of the Lightship was necessary. This was done by assuming the outfitting weight (\(W_{OT}\)), the machinery weight (\(W_{M}\)) and the position of their center of gravity are unaffected by the conversion. This allows the decomposition of the Lightship in two groups namely the structural weight \(W_{ST}\) and the sum of \(W_{M} + W_{OT}\) (Eq. 1).

\[
Lightship = W_{ST} + W_{OT} + W_{M}
\]

Knowing from the existing data for PRINS RICHARD the center of gravity of the structural weight, the weight and center of gravity for the sum \(W_{M} + W_{OT}\) was calculated (Fig. 4). Additionally from the structural weight data for PRINS RICHARD the position and weight of the retrofitted parts were known. Replacing these weights with the ones estimated for the composite case allowed the calculation of the new Lightship weight and the new center of gravity. In all cases the center of gravity is measured from the Baseline of the vessel.
The new value of the displacement was calculated by adding the deadweight of the loading condition to the new Lightship. The draught and the other relevant hydrostatic data were taken from the ship’s hydrostatic tables which enabled the calculation of the metacentric height (GM) and of the righting arm (GZ) (Fig. 5). The dashed lines correspond to the existing steel case while the solid ones to the converted one.

Before calculating the resistance for the steel and the retrofitted case at the average loading condition it was decided to recreate the available resistance data using Harvald’s method (Guldhammer and Harvald, 1974). As expected some deviation was noted between the method’s prediction and the available results for the ship. To minimize this, it was decided to calibrate to match exactly the measured resistance from the model tests. The calibration was performed by changing the value of the appendages resistance coefficient at each speed. In reality this coefficient is to be kept constant as it is related to the vessel’s appendages which are independent of the vessel’s speed. The calibrated resistance estimation method was subsequently used to calculate the resistance of the vessel at the examined loading case. The draught for the original steel case is equal to 5.035m while for the converted case the draught is reduced to 4.87m. In addition, corrections for the added wind resistance and the effect of shallow water were taken into account considering a headwind speed of 6m/s and water depth of 18m. These values correspond to the average values for the area of operations of the vessel. As the draught decreases, the friction resistance is reduced. At the same time the area above the waterline increases which lead to an increase on the added resistance due to the wind. Typically for commercial ships air resistance represents about 2% of the total resistance (MAN, 2011). Nevertheless in ship types such as containerships, RORO and ferries the added wind resistance can be significant. The propulsion power at shallow waters as a function of the vessel’s speed is illustrated in figure 6 for the original case and after the conversion. Additionally the effect of the wind resistance to the propulsion power is illustrated by performing the calculations for both when the wind resistance is added and when it is ignored. Once again, the dashed lines correspond to the existing steel case while the solid ones to the converted one. For the derivation of the propulsion power, apart from the total propulsion coefficient an additional electrical/mechanical transmission efficiency factor was implemented to account for the efficiency of the electric motors. This factor’s value was taken equal to 0.9. Evaluating the results it appears that the reduction in resistance is practically negligible, ranging from 1.2% for low speeds to 0.8% for high speeds. This is caused by the fact that the draught change is not significant, resulting in a reduction of the wetted area by merely 67 m² (2.5%) and an increase of 5m² (<1%) of the projected area above the waterline needed for the calculation of the wind resistance.

**Resistance and propulsion power calculations**

The resistance estimation for PRINSESSE BENEDIKTE at a mean draught of 5.30 m was available.
The partial conversion of the vessel’s superstructure performed in combination with the decrease of the height of the center of gravity from the conversion led to a notable increase of the vessel’s overall stability, improving static, dynamic and the range of stability. This is of importance for large passenger ships where stability limitations might impose constraints to the number of decks these vessels are allowed to have. Regarding the resistance and propulsion power requirements, the draught change in the average loading condition does not significantly affect the resistance of the ship as the propulsion power reduction was around 1% for the service speed of 15 knots. This in turn led to a small fuel consumption decrease of about 1.5% per year which does not signify a potential source of cost saving for the ship-owner. This observation does not come as a surprise given that it was decided to keep the same general arrangement of the superstructure. It would be more profitable to increase the payload to displacement ratio by decreasing the lightship mass than to try to save on fuel by reducing the draught. It should be mentioned that the ship selected as the demonstration case does not encounter any challenges in reality that would necessitate such a conversion. Last but not least, it should be emphasized that the material acquisition and fuel consumption costs do not account for the total of the vessel’s life cycle cost and should not be regarded as the sole criteria for such options. On the contrary these tend to be misleading if all the associated costs are not well estimated and taken into consideration.

**Conclusions**

Evaluating the effects that the implementation of composite materials has had on the ship the following conclusions can be drawn. The design procedure can be performed by combining existing rules and regulations. The partial conversion of the vessel’s superstructure results to a reduction of the Lightship of about 5% for the selected materials. The Lightship reduction in combination with the decrease of the height of the center of gravity from the conversion led to a notable increase of the vessel’s overall stability, improving static, dynamic and the range of stability. This is of importance for large passenger ships where stability limitations might impose constraints to the number of decks these vessels are allowed to have. Regarding the resistance and propulsion power requirements, the draught change in the average loading condition does not significantly affect the resistance of the ship as the propulsion power reduction was around 1% for the service speed of 15 knots. This in turn led to a small fuel consumption decrease of about 1.5% per year which does not signify a potential source of cost saving for the ship-owner. This observation does not come as a surprise given that it was decided to keep the same general arrangement of the superstructure. It would be more profitable to increase the payload to displacement ratio by decreasing the lightship mass than to try to save on fuel by reducing the draught. It should be mentioned that the ship selected as the demonstration case does not encounter any challenges in reality that would necessitate such a conversion. Last but not least, it should be emphasized that the material acquisition and fuel consumption costs do not account for the total of the vessel’s life cycle cost and should not be regarded as the sole criteria for such options. On the contrary these tend to be misleading if all the associated costs are not well estimated and taken into consideration.

**References**


MAN Diesel & Turbo, (2011), Basic Principles of Ship Propulsion
Papanikolaou A. (2014), Ship Design Methodologies of Preliminary Design, Springer