Development of Design Methodology for Modular Passenger Ships for the Mediterranean
Razvoj metodologije osnivanja modularnih putničkih brodova za Mediteran

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Abstract

This paper deals with the novel design methodology of modular passenger ships aimed for operation in the Mediterranean Sea. It actually outlines aims and methods of an ongoing long-term competitive Installation research project funded by the Croatian Science Foundation (CSF) which is based on the modular concept enabling the change of the ship production paradigm from the classical all-in-one approach to a parallel manufacture of different components by highly specialized producers and a final assembly done by the local shipyard. The target vessel is considered as made of independent modules which can be combined together to achieve different characteristics in terms of ship dimensions, carrying capacity, operability, comfort, fuel consumption and energy efficiency. Within the project, an analysis of the market needs and of the corresponding ship requirements is being performed for different navigation regions in the Mediterranean Sea. Then, the preliminary concepts based on that analysis are being proposed, while the final concepts will be developed taking into account all important aspects of ship design: resistance and propulsion, seakeeping, structural aspects, ship habitability, simplified manufacturing processes as well as environmentally friendly energy solutions. Through this project several optimized modular passenger vessels will be proposed depending on the selected design criteria sets. In this sense it is expected that the project will result in a number of concepts fitting to the market needs with reduced production costs, higher level of comfort for crew and passengers, reduced fuel consumption as well as lower environmental impact.
Keywords: ship design, modular concept, hydrodynamic performance, ship habitability, energy efficiency, environmental protection

Sažetak

Ovaj rad vezan je za novu metodologiju projektiranja modularnih putničkih brodova namijenjenih za plovidbu na Mediteranu. Ukratko su prikazani ciljevi i metode dugoročnog kompetitivnog Uspostavnog istraživačkog projekta Hrvatske zaklade za znanost (HRZZ) koji je u tijeku i koji se temelji na modularnom konceptu omogućujući promjenu proizvodne paradigme od klasičnog „sve u jedan" pristupa do paralelne proizvodnje različitih komponenti od strane specijaliziranih proizvođača i njihova konačnog sklapanja u brodogradilištu. Ciljani brod sastoji se od nezavisnih modula koji se mogu kombinirati u cilju zadovoljavanja različitih značajki u vidu dimenzija, nosivosti, operabilnosti, komfora, potrošnje goriva, energetske učinkovitosti, itd. Prvi korak u provedbi projekta je analiza potreba tržišta i s njima vezanih projektnih zahtjeva za različite zone plovidbe na Mediteranu, nakon čega je potrebno predložiti projektna rješenja na konceptualnoj razini. Konačna projektna rješenja će se razviti uzimajući u obzir sve važnije aspekte osnivanja broda: otpor i propulzija, pomorstvenost, konstrukcijski aspekti, energetska učinkovitost, habitabilnost, jednostavnost proizvodnje, ekološki aspekti, itd. U okviru opisanog projekta biti će ponuđeno nekoliko optimalnih modularnih putničkih brodova ovisno o skupu odabranih projektnih kriterija. Očekuje se da će na taj način projekt rezultirati određenim brojem koncepata koji udovoljavaju potrebama tržišta s reduciranim troškovima proizvodnje, višom razinom komfora za posadu i putnike, smanjenom potrošnjom goriva i manjim utjecajem na okoliš.
Ključne riječi: osnivanje broda, modularni koncept, hidrodinamičke značajke, habitabilnost broda, energetska učinkovitost, zaštita okoliša

1. Introduction

Europe, and consequently Croatia is facing new competitive economy as well as social challenges. So European Commission presented new "Rethinking Education" strategy [5] which calls for a

fundamental shift in education, with more focus on 'learning outcomes' - the knowledge, skills and competences that students acquire. It points out the need for a much stronger focus on developing transversal skills and basic skills at all levels, especially for entrepreneurial and science, technology, engineering and mathematics (STEM) skills. It recognizes them as crucial in technology dependent society – for the development through scientific research, technology innovations, and as an important basis for lifelong learning. The strategy puts special focus on the need to use new technologies and a partnership approach. Unlike such strategies, in the current practice, the ship design is generally approached with the aim of keeping building-cost at the minimum, often forcing low-cost designs and low value-added market solutions. This is particularly true for small passengers vessels designed for short-sea shipping which are usually built by small shipyards which cannot sustain high costs of innovation and investments in education and research. In addition, unlike other transport modes, vessels are generally produced in small series and the investment cost has a strong impact on the initial vessel cost. Therefore, ships are often based on previous concepts and designs with essentially no modernization thus leading to poor energy efficiency improvements, high life-cycle vessel costs and significant environmental impact. The challenge behind „GReen Modular passenger vessel for Mediterranean – GRiMM“, an ongoing long-term competitive Installation research project funded by the Croatian Science Foundation (HRZZ), goes exactly the opposite way.

The conventional design and production paradigm can be changed by developing a new concept for a high efficient passenger vessel class which can alleviate the design process and reduce the initial cost of more technologically advanced vessels by spreading the innovation costs over a much larger series. Similarly, the modular concept is widely adopted in the automotive industry, especially during the commercial vehicle design, Figure 1, as it enables high level technology, flexibility, simplified design, reduced production costs and quicker delivery. Modular production processes are also characterized by flexibility to schedule parallel processes, better management of risks (delays, failures, etc.) and usually involve small specialized companies (SMEs) in the production cycle. This leads to a versatile production scheme, customizable to the end-user's needs, with most of the decision making process pushed towards the end of the production cycle. General idea of modularity is to divide large systems into smaller, self-sufficient parts. According to [6] there are several clear benefits from modularization: make complexity manageable, enable parallel work, and accommodate future uncertainty.

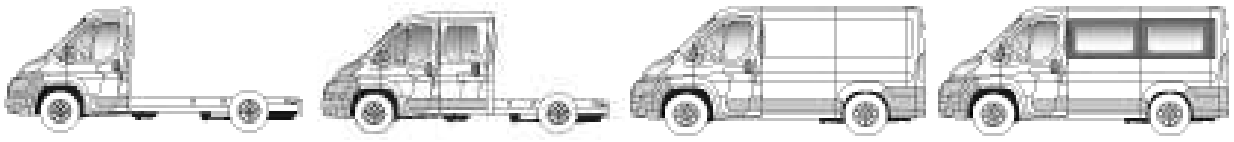

Fig. 45 Example of modular concept in the automotive industry
Slika 1. Primjer modularnog pristupa u automobilskoj industriji

The ship modularity idea is present for a certain time in the relevant literature. It seems that it has captured much more interest in the field of naval vessels [7], but due to the lack of publicly available information, it is very difficult to ensure smooth knowledge transfer to the merchant vessels. Therefore, the scientific literature on this challenging topic is rather weak [8]. To the best authors' knowledge, Jolliff [9] was the first who proposed a methodology for evaluation of ship modularity and module category definitions. In [10] the hull is similarly considered as divided into three main components, where one stern, two bows and two mid body components are considered. The two mid body components have the same profile of the aft section, but are characterized by a different bilge radius (i.e. loading capacity) and the two bows are designed to match the two different fore sections. Three different ship lengths are obtained by varying the length of the mid body component and thus a total of twelve combinations can be derived. Although the above solution goes in the direction of the hull modularity concept, there are some important limitations in the approach as the same bow

and stern are used while varying the ship length, which necessarily implies that the hydrodynamic design cannot be optimum for a variety of operating conditions.
GRiMM is committed to introduce a similar modular approach in the small passenger ships industry. With the modularity approach, the complexity is split into self-contained modules each one having system interfaces with others. In the shipbuilding field the modularity concepts have been mainly developed for the equipment and superstructures and mostly for military applications [11]. Such modularity approach was motivated by the needs that military ships are being frequently reconfigured for different missions; the modular adaptable technology enables a reduction of the costs and times for reconfiguration and allows the ship to remain operationally relevant for longer periods. Examples are MEKO (www.blohmvoss.com) or MOPCO (www.abeking.com) concepts [12]. The modularity concept has been also developed in passenger ships for cell cabin [13] or for cabin modules and other compartments [14]. In latter cases the motivations are not much related to the retrofitting aspects but mainly at delocalizing the modules production and optimizing their installation on the ship. Tvedt [15] dealt with modular approach to offshore vessel design and configuration, Figure 2. He focused on the development of a system that is able to efficiently develop and evaluate Offshore Support Vessel designs and alternative designs in conceptual and preliminary stages of design. Tvedt stated that the developed system seemed to efficiently develop design alternatives with good performance, but its applicability as a tool for use in the industry was not proved.

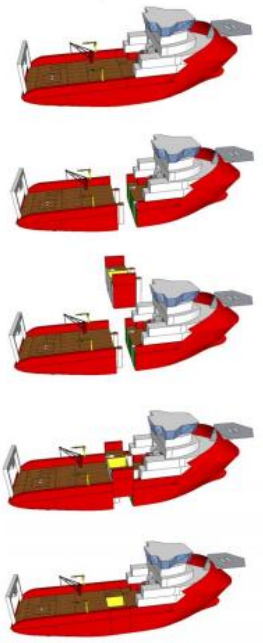

Fig. 46 Modular offshore vessel [15]
Slika 2. Modularni brod za opskrbu platformi [15]

In the context of modular approach in the building of passenger vessels it is necessary to mention recent series of modular ferries offered by the Damen Shipyard [16], where an entire ferry is configured out of container sized units, Figure 3. The units are called Damen Modular Barges and can be coupled together in the water with the specially designed coupling system, called the Damen Link. Also machinery, superstructure and deck equipment are mounted as modular units to the hull structure [16]. Furthermore, a ship can be (at least at the conceptual level) directly online configured through the appropriate interface, Figure 4, [17].

Fig. 47 Modular ferries [17]
Slika 3. Modularni trajekti [17]

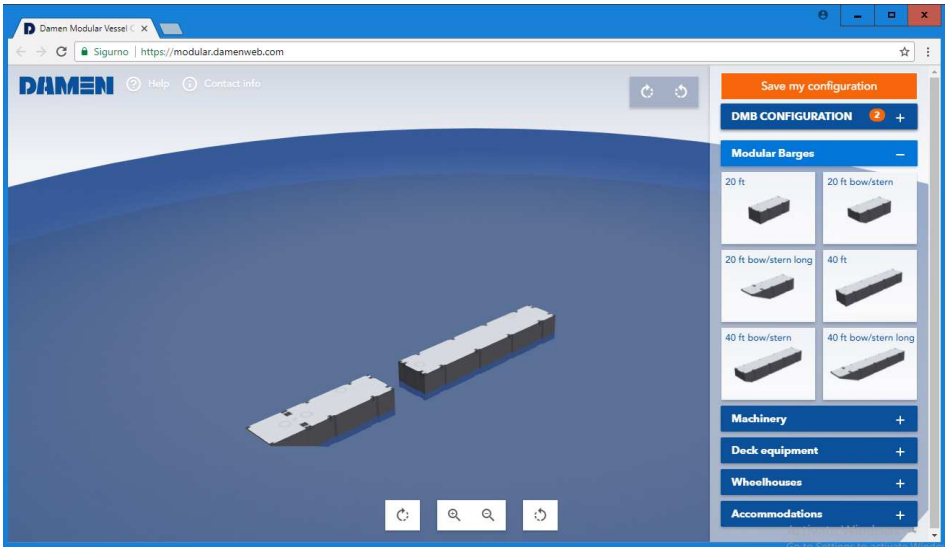

Fig. 48 Configuring of modular ship [17]
Slika 4. Konfiguriranje modularnog broda [17]

2. Objectives

The overall objective of GRiMM will lead to the development of a new concept of modular passenger ships designed for short-sea shipping based on interchangeable components which can be linked together to perform specific tasks or missions through a set of common standards and interfaces enabling easy joining and detachment. The modular system will be developed covering the needs of short-sea shipping, and it will specifically account for the different ship requirements. GRiMM is aimed at:

1. Reducing the environmental impact of the vessel as a result of the improved design which addresses all aspects of hydrodynamics, vibrations, energy management and adaptable configuration.
2. Increasing the comfort level for both passengers and crew.

3. Setting the base for a new business model for vessel production, which breaks the all-in-one approach, which is currently adopted in a parallel production where few, highly specialized, industries produce the different modules, leaving the final assembly to the local, small size shipyard.

To achieve the above goals, GRiMM will focus on the following main objectives:

1. Definition of ship concepts based on the modular design approach taking into account market requirements.
2. Calculation of hydrodynamic and propulsion characteristics of different concepts by applying advanced numerical procedures (CFD tools).
3. Definition of different superstructure comfort classes with various limiting values of noise and vibration. Performing analysis of noise and vibration characteristics of typical modules fitting to different class, as well as comparison of their production, installation and operation costs.
4. Performing Life Cycle Analysis (LCA) of different modules and concepts with emphasis on emissions from ship to air, including CO_2, NO_X, SO_X and PM emissions.

3. Methodology

The project activities in GRiMM are split into 8 work packages (WPs); 7 technical and 1 for management, Figure 5. The project can be divided into 3 main steps.

The first step concerns the definition of the small passenger ship concept. First, an analysis will be performed within WP1 using both available databases and questioners for the shipbuilding market participants (ship-owners and shipyards) in order to identify the market needs. After that, the main features of the modular vessels concept will be defined through a synthesis of the available data in order to be in line with the market requirements.

The second step concerns the development of the concept. A number of preliminary modular concepts will be proposed within WP2 based on the market requirements analysis. These concepts will be assessed by hydrodynamic calculations using OpenFOAM software within WP3 in order to define more precisely the hull module. The output of WP3 will be used to determine the power demand on the power system module. In WP4 power system modules will be proposed and evaluated according to their power and ecological characteristics. Results of WP2, WP3 and WP4 will be used to determine the superstructure module within WP5. Vibration calculations will be performed by the Finite Element Method (FEM), while for the noise assessments hybrid Statistical Energy Analysis (SEA) is at disposal. Technical aspects related to the organization of the industrial production with the introduction of the modular concept will be also addressed.

The third step concerns the energy efficiency and environmental impact analysis using "GaBi Academy". Based on the results from the analysis a number of concepts fitting to the market needs with reduced production costs, higher level of comfort for crew and passengers, reduced fuel consumption as well as lower environmental impact will be identified.

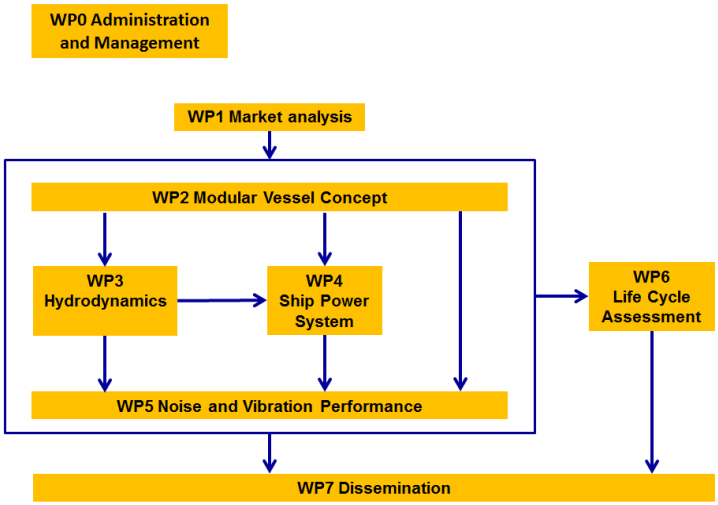

Fig. 49 GRiMM work packages
Slika 5. Radni paketi projekta GRiMM

4. Activities and expected results

WP1 aims at gathering pertinent information about the potential markets for the passenger ships engaged in short-sea shipping. Besides the potential market, also the data concerning the ship main particulars, e.g. length, capacity (number of passengers and/or cabins), design and operational speed, typical sailing routes, manoeuvring abilities, equipment and outfit, will be also collected. This will be done by analysing the available data about ship orders and deliveries in the last 10 years and by preparing questionnaires to be sent to all involved parties in ship production and operations (shipyards, ship-owners, classification societies, port authorities, etc.) in the Mediterranean.

WP2 will formulate the specifications for the modular vessel concept. Starting from the data collected in WP1, the scope of WP2 is to define the basic characteristics of the preliminary modular concepts. Thanks to the different combinations allowed by the modularity, they should enable to embrace the widest potential market in terms of ship characteristics and application. A special attention in this preliminary phase will be paid to the hull form definition.

Starting from the parameters provided by WP2, WP3 will develop the hull module defining the mid body component, bow and aft hull part and deal with testing of hydrodynamic performances of different module combinations. Calm water resistance tests, added resistance in waves and seakeeping characteristics will be analysed by means of worldwide recognized OpenFOAM software module called NavalHydro Pack [14-16]. The module was developed by project participants V. Vukcevic and I. Gatin, under the supervision of Professor Hrvoje Jasak, and is continuously being improved by his team. Therefore, the most advanced tools for hydrodynamic computations will be ensured. Bearing in mind the modularity concept, the mid body will be modified only for some limited aspects, whereas the bow and the aft part will be designed to achieve favourable hydrodynamic and seakeeping performances and uniform inflow at the propeller plane. This will allow achieving the optimum hydrodynamic performances (in terms of both resistance and seakeeping) for all configurations and for the assigned operating conditions, thus achieving a significant improvement in the vessel efficiency (reduced fuel consumption) and consequently a reduction of the environmental impact. WP3 will also deal with the selection of appropriate propeller for different modular configurations of ship hull. Existing propeller series will be tested in scenario-based operative regimes and consequently, most appropriate solution for each scenario will be offered. Of course, for each tested combination ship hydrostatics will be checked.

In WP4 a set of power system configurations will be identified on the basis of the power demand for different combinations of the modules, as provided by WP3, and applications, according to the outcomes from WP2. The adequate energy generation and distribution architecture will be studied and assessed for the different configurations, and finally, the energy efficiency and management

strategies will be developed and implemented. The outcomes of the WP4 will represent power system modules which can be used in small passenger ships concepts.
The main objective of WP5 is to offer modular superstructure solutions for different comfort class. Both engine and propeller induced vibration and noise will be considered for different superstructure topologies (leading to different global stiffness) and various insulation combinations. For each selected modular combination three levels of comfort packages will be offered (low-cost, moderate, high-class). Noise sensitivity analyses of different modules with respect to different materials, insulation types and thicknesses, etc. will be performed. Results from WP2, WP3 and WP4 will be used as initial inputs for WP5.
The activities in WP6 are aimed at assessing the energy efficiency and environmental impact of the proposed concepts. The proposed concepts will be adopted and customized for the specific application. Input will be available from other WPs; WP2 for the design options, WP3 for the hull module, WP4 for the power system module and WP5 for the superstructure module. In this WP the focus will be on the ship emissions to air.
The activities in WP7 are aimed at planning dissemination and exploitation strategies in order to maximize the impact of the project. The project outcomes will be disseminated through papers in leading scientific journals and at specialized conferences and exhibitions worldwide. So far a dedicated website is developed (www.grimm-project.com), where project advances are communicated in a timely fashion. During the third year of the project, a workshop will be organized where intermediate project results will be shown. Also, one final project conference in last year of the project is planned, where representatives of all interested parties at international level will be invited. Invited lectures given by leading experts from academia and industry, and publication of dedicated conference proceedings are planned.
Conclusion
The idea behind GRiMM, i.e. the modular vessel concept, is a ground-breaking innovation step, inspired by the automotive industry, and especially that of commercial vehicles, which provides the market with a fairly wide spectrum of solutions, fitting essentially all needs for the sector. Several solutions are provided in terms of size, payload, installed power, fuel and use, e.g. cargo, transport, hybrid or bare vehicles for customized applications. The customers can easily browse through the catalogue and make their choice. But this does not stop the technological progress of the products. Indeed, the large market represents a strong motivation and the offer is dynamically evolving catching any new needs and desires in terms of application, innovative technological solutions, ICT, comfort and so forth.

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