THE TRANSACTIONS OF THE ROYAL INSTITUTION OF NAVAL ARCHITECTS

TWIN-CRP-POD SYSTEM - A NEW IDEA TO INCREASE PROPULSION EFFICIENCY, REDUCE GHG EMISSIONS AND IMPROVE NAVIGATIONAL SAFETY FOR ULTRA LARGE CONTAINER SHIPS

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SUMMARY

This paper describes three-years project “twin-crp-pod ULCS”, that has been recently awarded with funding from National Centre for Research and Development within ERA-NET MarTERA call 2019. The international consortium is going to study the possibilities of improvements in ship propulsion efficiency and navigational safety for Ultra Large Container Ships (ULCS). The investigated idea combines twin screw arrangement, pod propulsors and contra-rotating propellers (shafts+pods).
Such propulsion system has not been installed on any of the existing vessels yet. Each of the particular solutions: twin screw arrangement, pod propulsion and contra-rotating propellers has an advantage of increased efficiency over the traditional single screw configuration. It is interesting however, how a combined system with all those solution would operate in actual conditions.
The aim of the project is to investigate the whole life cycle of an ULCS, whether from newbuilding or retrofitting starting point. The research analyses will include manoeuvring properties, general efficiency of the twin-crp-pod system and life cycle performance analyses from cradle to grave.
As a result, beside the economics and pure hydrodynamics, the influence of twin-crp-pod system on ship handling properties, thus safety of ship operation will be taken into account.
The research agenda includes initial design, feasibility studies, numerical simulations, towing tank experiment and manoeuvring/ship handling trials at model scale.

NOMENCLATURE

CFD	Computational Fluid Dynamic
IMO	International Maritime Organisation
ULCS	Ultra Large Container Ship

1. INTRODUCTION

MarTERA is an ERA-NET Cofund scheme of Horizon 2020 of the European Commission. The overall goal of the ERA-NET Cofund MarTERA is to strengthen the European Research Area (ERA) in maritime and marine technologies as well as Blue Growth. MarTERA consortium, consisting of 16 collaborating countries, organised and co-funded, together with the EU joint calls for transnational research projects on different thematic areas in years 2017, 2019 and 2020. Furthermore, joint activities that go beyond this co-funded calls are being planned, in order to contribute to the national priorities as well as to the Strategic Research Agenda of JPI Oceans and WATERBORNE. The focus of development in MarTERA is given to technologies (instead of sectors) due to their potentially large impact to a wide range of application fields. [Martera 2017].
In 2019 the mentioned funding opportunity was taken by a consortium consisting of Foundation for Safety of Navigation and Environment Protection, Gdańsk University of Technology, Seatech Engineering from Poland, Centre of Marine Technologies gGmbH, Otto Piening GmbH, Hamburgische Schiffbau-Versuchsanstalt GmbH from Germany and pilots organisation BRABO from Belgium.
Consortium partners took the challenge to minimise carbon footprint in maritime sector by applying to ultra large container ships three well-known ideas –twin screw arrangement, contra-rotating propellers and pod propulsion system.
All the ideas that will be developed and combined in the project are well known. Twin propeller configuration has been utilised since years for ships with draft restrictions, where the required power is too large to be consumed by one propeller with limited diameter. Podded propulsors are used especially on ships with high manoeuvrability requirements, like cruise ships, icebreakers or offshore vessels. Contra rotating propellers concept in classic form, i.e. two propellers on a shaft is also a known solution for reducing fuel consumption for containerships, bulk carriers or crude carriers.
There are designs that combine two of mentioned solutions, e.g. hybrid crp-pod, where single pod propulsor is placed behind a conventional propeller and works on contra rotation principle (ABB 2001), (Ammala 2004),

(Backlund, Kuuskoski 2000),(Sanchez-Caja et al. 2013). Such a configuration has been recently introduced to high speed vessels, like ro-pax (Jsmea 2003).
Design of such a complicated propulsion arrangement like crp-pod requires extensive research, due to complex character of existing hydrodynamic phenomena, that combine both conventional propeller-hull interactions and unusual shaft propeller to pod propulsor interactions. These interactions are key factors influencing both propulsion efficiency and manoeuvring characteristics and therefore should be deeply and reliably investigated and analysed.
“Twin-crp-pod ULCS” project has assembled a team of complementary partners contributing “cutting edge” expertise in all relevant areas affecting energy efficiency and safety of ships in service. The industrial partners in the project are represented by a designer and manufacturer of propulsion systems that provides products worldwide (Otto Piening), by renowned design office that delivers ideas and designs of various types of ships with perspectives on novel propulsion and steering systems (Seatech Engineering),by towing tank that provides a unique set of both numerical and experimental tools during design and development of new vessels (Hamburgische Schiffbau-Versuchsanstalt GmbH – HSVA) and by pilots from Antwerp (BRABO), that in their daily work operate such large ships as will be investigated in the project . Under the conditions of highly competitive market and continuously increasing demands put on the efficiency and environmental characteristics of vessels and safety of marine operations, it appears especially important that these companies are armed with the advanced, up-to-date methods and tools that allow for detailed evaluations of innovative design concepts and reliable analyses of existing solutions under various, also off-design conditions.
The non-industrial partners in the project are represented by a research institutes and a university. Centre for Maritime Technologies (CMT) possesses extensive expert knowledge in the field of assessing and registering new processes and design solutions and technical aspects of production. Foundations for Safety of Navigation and Environment Protection Ship Handling Research and Training Centre (SHRTC) is world-wide leading provider of ship handling courses on manned models. This method is evaluated as optimal solution for recognising manoeuvring and ship handling abilities of ships with different steering propulsion systems. Gdańsk University of Technology’s Faculty of Ocean Engineering and Ship Technology (GUT) specialises on one hand in hydromechanics, ship theory, naval architecture and on the other hand on application of composites, Manufacturing techniques, structural materials and their application, material problems and quality systems.

2. AIM AND SCOPE

The main goal of the entire project is to improve manoeuvrability, increase navigational safety and reduce fuel consumption of Ultra Large Container Ship by introducing above mentioned solutions: twin-screw arrangement, pod propulsion and contra-rotating propellers. All those solution has an advantage of increased efficiency over conventional arrangement, however, the interaction between them and influence on ship performance is unknown.
The specific objectives that need to be evaluated to answer the main research question include:

- recognition of propulsion efficiency for novel arrangement with use of numerical methods and experimental investigation including an assessment of the scale effect
- identification of the manoeuvring abilities of redesigned ULCS that includes the verification of compliment with IMO requirements
- definition of the technical and technological threats in the design, production and exploitation stage
- preparation of the ship masters and pilots for navigation and operation difficulties related to novel propulsion system.

To achieve project objectives the scope of the investigation will include initial design of the modified propulsion system, evaluation of the propulsive efficiency by means of model scale experiments in the towing tank and cavitation tunnel supported by numerical simulations, assessment of manoeuvring abilities based on manned model experiments carried out in the open-air facility.

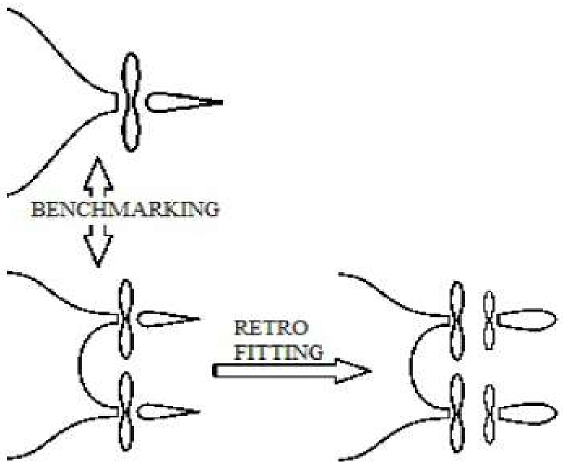

Figure 1 Research flow in the project

The investigations flow to explain planned activities with different types of steering-propulsion systems is shown in Figure 1.
At the same time the Life Cycle cost and environmental assessment will be done. Last element of the project will be preparation of the training programme for masters and pilots that aims to prepare ship crew for operating vessels on ships with twin-crp-pod propulsion system.
All the elements of the research agenda are described in details in Section 3 and Section 4.

3. RESEARCH PLAN

All the investigation will be based on the existing 396 m long 16000 TEU single-propeller container ship. The

manned model at 1:24 scale is already in use in Ship Training and Research Centre in Iława.
The very first step of the research will be creating the digital representation of the ship hull and carrying out experiment that will include IMO manoeuvring tests and propulsion test in the towing tank. Gathered data will be used as a benchmark for further study.

3.1 INITIAL DESIGN

The initial phase will be mainly done by the design office Seatech Engineering supported by Otto Piening, CMT and GUT. Multiple challenges related to design of the twin-propeller configuration will be analysed. The initial design study focuses on the design of twin-screw twin-rudder arrangement and twin-crp-pod system for the new ship as well as possibility to retrofit twin-screw ship into twin-crp-pod propulsion.
For twin-screw vessel the rudders will be designed according to the classification societies rules and current state of the art. Know-how of the consortium partners will be used to choose the proper distance between rudder and propeller.
For the novel solution the pod housing design will be supported by CFD simulations that take into account actual flow from the propeller. Also the proper position from the hydrodynamic point of view will be found. Propellers will be designed for both twin-propeller and twin-crp-pod arrangement.
Another aspect that will be considered is the preparation of new engine room arrangement and design of technical space from the propulsion and propulsion-related auxiliary machinery point of view. The machine room space will be later optimised to maximise the cargo capacity with special attention to the twin-crp-pod system as there is no experience in design of such arrangement.
The process of retrofit will be analysed, in particular taking into account the possible challenges and technological issues such as re-build of the construction, space for new systems, power balance and possible reduction of the cargo space. Fitting of the new system into existing construction is expected to be one of the main risks of retrofitting.
In principal, the expected outcome of this part of the project beside design of rudders, pod housing and propellers is feasibility study that points out advantages and disadvantages of twin-crp-pod arrangement and retrofit from the design and technological point of view . For the retrofit process the revision of investment cost will be included as well.

3.2 NUMERICAL SIMULATIONS

Important part of the project work will be the numerical simulations of the flow around the case study ship equipped with different types of propulsion system. This task will be mainly realised by GUT supported by the experience of the HSVA and SHRTC. Aim of this part of the research is to contribute to investigation into increase of propulsion efficiency for novel arrangement, support design process of pod housing and propellers and help to evaluate the scale effect in the towing tank test.
In the first part of the research as mentioned in Section 3.1 the numerical simulation will be used to assess the flow around the aft part of the ship. First, the result of the computations will help to design the shape of pod-housing and its' position. Multiple variants will be analysed and the best from the propulsion point of view will be chosen. Results of numerical simulation will also help to reduce the number of experimental test cases. What is more, the predicted wake filed will serve as one of the input data for propeller design process.
The powering prediction for benchmark hull, twin-screw twin-rudder and twin-crp-pod ships will be done. The results will be validated against the results of the towing tank experiments. Therefore, the propulsion efficiency of all arrangements will be evaluated by means of CFD simulations.
A significant knowledge gap that was found during the state of the art study was the scale effect in the towing tank experiment of the azipod thrusters. The crp-pod propulsion is a complex combination of two propellers and one passive pod structure. A part of the pod housing is in the accelerated propeller slipstream flow and other part in surrounding flow. The experiments at model scale need to be corrected due to scale effect that influences the flow around the pod structure. Numerical simulations are powerful tool that might help to assess the scale effect because they enable full scale and model scale computations at the same time. Together with theoretical studies and findings from the model tests the CFD method is supposed to strongly contribute in the assessment of the scale effect.

3.3 EXPERIMENTAL INVESTIGATION IN TOWING TANK AT MODEL SCALE

Experimental investigation at model scale will be done by HSVA with contribution from SHRTC, Otto Piening and GUT. Main aim of this part is the experimental assessment of the propulsion efficiency of the twin-crp-pod arrangement. This part is considered to be one of the most challenging in the entire project. Second objective is to evaluate the method of extrapolation the experimental results to full-scale for such complicated propulsion arrangement.
The first part of the research will be creating the benchmark data serving as the reference for further comparison. The powering prediction of single propeller single rudder ULCS will be performed in the towing tank. In the next step model will be modified to twin-propeller twin-rudder and twin-crp-pod arrangements. Both new configurations will be tested in the towing tank. The experiments will include also the wake field measurements at the propeller plane and assessing the open water propeller characteristics. In the first attempt the stock propeller will be used. The data from experiments will help to design the final shape of the propeller for which all the experiments will be repeated.
Except the powering prediction the cavitation tunnel HYKAT will be used for further investigation. Over the

last years HSVA has developed a new testing technique that allows comparative testing of different propulsion arrangements in HYKAT (Müller 2017a, 2017b). The big advantage of this technique over conventional towing tank testing is the high Reynolds Number that can be achieved in HYKAT, that helps to minimise undesired scale effects. Using the same experimental set-up cavitation behaviour as well as noise and pressure pulse generation can be investigated.
Based on the measurement in HYKAT, results of towing tank experiment and full scale CFD simulation the extrapolation procedure will be elaborated with special attention paid to assessment of the scale error.

3.4 EXPERIMENTAL INVESTIGATION IN SHIP HANDLING RESEARCH AND TRAINING CENTRE ON MANNED MODEL

Manoeuvring model tests will be carried out with the use of 1:24 manned model at an open air test station that belongs to the project coordinator – Ship Handling Research and Training Centre (SHRTC). All three ship steering-propulsion arrangements, i.e. single-screw and both twin-propeller arrangement – conventional twin-screw twin-rudder and twin-crp-pod will be investigated.

Figure 2 Manned model of ULCS

The model is presented in the Figure 2. In case of standard manoeuvres, the single-propeller single-rudder ship version will be a benchmark for further investigations on the twin-propeller twin-rudder and twin-crp-pod versions. Emergency manoeuvres will be carried out with the twin-propeller twin-rudder and twin-crp-pod ship versions and will cover most probable emergency situations to give an idea of the profitability of twin-crp-pod solution over the twin-propeller twin-rudder version:

- loss of one engine,
- loss of two engines,
- loss of one rudder/pod propulsor,
- loss of two rudders/two pod propulsors – berthing with the use of main engines and bow thruster.

Additionally investigations on interactions between shaft propellers and pod propulsors as vital for recognition of the hydrodynamic phenomena governing manoeuvring forces and behaviour of twin-crp-pod steering system will be carried out. The idea of current project is to check an extremely important part of the mathematical manoeuvring model, i.e. interactions between front propeller and pod propulsor in case of the twin-crp-pod arrangement. Manoeuvring forces and so called flow-straightening factor will be investigated to give a clue, what kind of quantity and magnitude of mentioned parameters to expect.
Taking into account that the novel twin-crp-pod solution combines hydrodynamic features of conventional and pod-driven ships, also the ship handling technique of developed ship might be different from both already-known. Therefore, besides recognising the manoeuvring abilities it is vital to validate and evaluate the ship handling procedures. Harbour manoeuvres that are planned to be carried out, in natural way introduce specific ship – berth and/or ship – seabed interactions. This will give an information on type and character of these interactions and will show how they influence the manoeuvrability of ships with so different steering-propulsion arrangements.
A specific programme for ship handling training will be elaborated with help of masters and pilots experienced in handling of ships of similar size. Furthermore eight high experienced seafarers will check the perspectives on handling of such a ship in different hydro-meteorological conditions, including wind, waves and current, both in unrestricted and restricted areas. The training will end up with an appraisal questionnaire on the difficulty of handling ship with novel twin-crp-pod propulsion-steering system. As masters and pilots are end users of the developed solution, their assessment will be of high importance during final evaluation of the quality and value of novel twin-crp-pod configuration.
Details on the harbour manoeuvres will be elaborated by masters and pilots employed by the project coordinator SHRTC, by the pilots from BRABO and the specialist from GUT.

4. LIFECYCLE PERFORMANCE ANALYSIS

The lifecycle performance analysis will be done by the Center of Maritime Technologies. The objective of this work is to determine the environmental impact and the economic benefits of the new twin-crp-pod concept in the Ultra Large Container Ship by performing the life cycle performance analysis. The observation of the environmental impact will be reflected into Global Warming potential from CO_2 and CH_4, Acidification Potential, Eutrophication Potential, Aerosol Formation Potential, and Cumulative Energy Demand value. Economic benefit assessment is based on the investment cost for the integration of twin-crp-pod in the ULCS, the operating cost, and the end of life cost.
The first stage will be the development of the modelling guidelines to provide a detailed definition on the Life Cycle Performance Analysis methodology and Key Performance Indicators which will be used to validate the twin-crp-pod on its economic feasibility and environment friendliness.
The second stage will be the definition of the ship model and the benchmark technology for the LCPA study. In this

stage, the list of detail assessment for each life cycle phase will be defined.
The third stage is to develop the scenarios which are addressing the future forecast of the key indicators such as fuel price, world gross domestic product, the market uptake, rules, and regulation. Besides that, the market uptake for the twin-crp-pod and ULCS need to be analysed to understand if the technology and the benefits are still relevant for the future market. Obtained methodology will be used to perform LCPA for both new build twin-crp-pod vessel as well as retrofitting.
The LCPA analysis will indicate the economic and the environmental potential from the newbuilding of ULCS with the twin-crp-pod propulsion system compared to the twin-rudder twin-propeller system. Once the design of the hull, the propellers, and the propulsion and manoeuvrability test are done, the necessary input values will be collected and the LCPA model will be created according to developed methodology and Key Performance Indicators.
Analogically, the economic and environmental potential of retrofitting process of the ULCS twin-rudder twin-propeller system into twin-crp-pod will be analysed. For the building process, the analysis will take into account the output from initial design stage to calculate the component of investment cost.

5. SUMMARY

This paper briefly described the three-years project "twin-crp-pod ULCS awarded with funding from National Centre for Research and Development within ERA-NET MarTERA. The project consortium consists of world-leading hydrodynamic institute, propeller designer, design office, ship handling operator, ship handling training provider and a university. By bringing together a wealth of knowledge on the propeller-hull interaction, structural integrity and manufacturing processes the consortium guarantees proper achievement of the project goals. Objective of the research is the investigation of the possibilities of improvements in ship propulsion efficiency and navigational safety for Ultra Large Container Ships (ULCS) by introducing unique twin-crp-pod propulsion arrangement. Project will consist of design stage, numerical and experimental investigation into propulsive efficiency, manoeuvring tests and lifecycle analysis. Expected outcome of the design stage are optimised propellers, proper shape of pod-housing and its position, reporting the technical challenges of newbuild and retrofitting to twin-crp-pod propulsion system.
The results of the investigation into propulsion efficiency are going to be assessment of the efficiency gain for such solution and proposition of extrapolation procedure for towing tank test. The outcome of the manoeuvring test will be report on IMO standard test, assessment of the emergency manoeuvres, preparation of the training program for ship masters and evaluation of the reports on handling capabilities of the twin-crp-pod ULCS. On the top of that the complete life-cycle analysis from the cradle to grave including economic and environmental cost of novel propulsion system will be delivered.
The twin-crp-pod consortium brings together the critical mass in human expertise and testing facilities to perform the proposed project in an efficient way. Authors of this paper are hoping to report soon their findings from the described scientific challenge.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

ABB. (2001). The CRP Azipod Propulsion Concept

Ammala P. (2004). CRP Azipod Propulsion Concept - Advanced Cost-Effective Solution, Journal of the Japan Marine Engineering Society. Vol.39. No.9

Backlund A., Kuuskoski J. (2000). The Contra Rotating Propeller (CRP) Concept with a Podded Drive. Motor Ship Conference. Amsterdam. The Netherlands

Jsmea - Japanese Marine Equipment Association. (2003). First Two CRP Azipod-Driven Hybrid Propulsion Plant High-Speed ROPAX Ferries, No. 87

Martera (2017). https://www.martera.eu. access: 23.03.2020

Müller J. (2017a). How much Can a Hub Cap Save?, HSVA newsletter NewsWave, issue 1-17, Hamburg, Germany

Müller J. (2017b). 'HYTES' - HYKAT Tested Energy Saving Devices, 5th Int. Conf. on Advanced Model Measurement Technology for the Maritime Industry (AMT'17), Oct. 2017, Glasgow, UK

Sanchez-Caja A., Pérez-Sobrino M., Quereda R., Nijland M., Veikonheimo T., González-Adalid J., Saisto I., Auriarte A. (2013). Combination of Pod, CLT and CRP Propulsion for Improving Ship Efficiency: the TRIPOD Project. Third International Symposium on Marine Propulsors – smp13, Launceston, Australia