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Combination of Pod, CLT and CRP Propulsion for Improving Ship Efficiency: the TRIPOD project

A. Sánchez-Caja[1], M. Pérez-Sobrino[2], R. Quereda[3], M. Nijland[4], T. Veikonheimo[5], J. González-Adalid[6], I. Saisto[1] and A. Auriarte[7]

[1]VTT Technical Research Center of Finland, [2]Universidad Politécnica de Madrid, [3]CEHIPAR, [4] A.P. Moller – Maersk, [5]ABB, [6]SISTEMAR, [7] CintraNaval-DefCar CND

ABSTRACT

Within EU Project TRIPOD, new ways of saving energy are being studied to improve ship operational costs. The main objective of the TRIPOD project is the development and validation of a new propulsion concept for improved energy efficiency of ships which is based on the combination of three existing propulsion technologies. In particular TRIPOD explores the feasibility of integrating podded propulsors and tip loaded endplate propellers into energy recovery systems based on counter rotating propeller (CRP) principle. A non-rotatable pod unit called Rudderpod is installed behind the ship main propeller. CRP units consisting of different combinations of CLT and conventional propellers are being analyzed in ballast and load conditions for a retrofit and a new building scenario. CFD tools and model tests are combined to facilitate the design process. A method for the extrapolation of model tests to full scale and another for the accurate estimation of effective wakes by CFD tools have been developed. TRIPOD includes the realization of an economical cost benefit analysis for the operation of a reference ship. The project will be completed this year.

Keywords
Pod propulsion, CLT, CRP, ship efficiency.

1. INTRODUCTION

During the last two decades integral electric-driven "pod propulsor" units have been applied in increasing number to different types of vessels. As stated by the ITTC Specialist Committee on Azimuthing Podded Propulsion (2008), "looking back on the past years, podded propulsors have been treated as the new-concept of marine outboard propulsive device, which has opened a new page on the history of marine propulsor." Conscious of the relevance of the matter, the EU has supported projects related to electric driven units, being "pod propulsion" considered as one of the most promising home grown technologies. Among others, projects like OPTIPOD, POD-in-Service, and FASTPOD were funded and completed during the past years within EU framework programmes, and their achievements have prepared the way to the next phase of R&D in podded propulsion. These projects have addressed issues dealing with noise reduction, efficiency increase, manoeuvrability improvement, and mechanical robustness among others. Some Far East countries have also been interested in the podded propulsion market. A fast Japanese ROPAX Ferry has been equipped for the first time with an ABB hybrid CRP-pod system and energy savings of 13 percent have been claimed by the Japanese, contributing to a reduction both of operating costs and of CO_2 emissions (Ueda et al., 2004).

In parallel the decade of the eighties witnessed a growing interest in unconventional propellers of tip loaded type. Blade tip loading (not allowed for conventional propellers without efficiency loss and high levels of noise) was made possible by placing an endplate at the blade outermost radial edge. After the first work of Gonzalo Perez on TVF propellers in the second half of the seventies, endplate propellers have evolved into CLT propellers during the eighties. Simultaneously other concepts of tip loaded propellers have appeared mainly in Europe and Japan promoted by several research groups. In the EU project Kapriccio a systematic study of Kappel propellers was made and three versions were manufactured, Andersen et al.

(2002, 2005). Recently the EU funded the LEADING EDGE project where scale effects on CLT propellers were numerically studied in fully turbulent flow using RANS solvers (Sánchez-Caja et al., 2006). The main interest has been in seeking more efficient ways of saving energy and additionally of developing environmentally-friendly propulsion systems by reducing propeller-radiated noise levels. As an example the super ferry Fortuny has been equipped with CLT propeller and a reduction of noise and improved efficiency has been reported (Perez Gomez et al., 2006).

In Finland the ENVIROPAX project, investigated the Hybrid CRP-Podded propulsor concept including various hydrodynamic issues like power split, propeller design, powering performance evaluation (Varis, 2005). One of the major outcomes of this programme was the realization of the first two Hybrid CRP-Podded propulsor driven Ropax ferries built in 2004.

In Japan, a domestic coast tanker of 4999GT, named "Shige Maru" was launched within the EcoShip project at Niigata Shipbuilding & Repair Corp. (NSR) in October 2007 (RINA, 2005). She has two sets of podded drive with contra-rotating propeller each of which absorbs 1250 kW. The Super EcoShip project was led by Ministry of Land, Infrastructure and Transport and National Maritime Research Institute from 2001.

An additional advantage of using pod propulsion for gas emission reduction can be explained as follows. Diesel engines are the main source of power in the vast majority of the world's ships. From an environmental point of view, however, these engines are not the friendliest. Fortunately pollution levels are not equal across the working range of the engine. In the optimum operating range, fuel efficiency is considerably higher and pollution lower than at low speeds. Therefore, the solution is to keep engines operating in this optimum range in all situations. With traditional mechanical transmission this is not possible, as engine speed is rigidly coupled to propeller speed. Using electric transmission (generators and motors connected by cables), this is no longer the case. Additionally, power reserves can be shared with the vessel's on-board service supply, decreasing the total power installed while raising reliability.

From the examples of the previous paragraphs it can be deduced that large energy savings and consequently, CO_2 emission reductions are expected by a rational combination of the proposed technologies.

The main aim of TRIPOD is to combine these technologies (podded propulsors, CRP and endplate CLT propellers) and explore the feasibility and potential benefits to be gained by the use of such an innovative propulsion system.

The viability of the new propulsion solutions is being check not only from a technical standpoint but also by performing economical cost benefit analysis for the operation of the reference ships. The real economic criteria applied by a market leader will be incorporated into the project. Elaborate procedures on how to determine yearly fuel savings and emission reductions based on the vessels operational profiles will be applied and then the cost-benefit will be assessed through a TCO (total cost of ownership) analysis.

The use of CFD tools and model tests are combined to facilitate the design activities and the assessment on ship performance.

2. STUDY CASES

An existing container ship of 351,081 meter length between perpendiculars, driven by a six bladed conventional propeller, with a displacement of 120000 tons has been selected for the study.

The way the project has been set up allows considering both energy optimization of existing ships and of new designs at full load and ballast condition. The optimization of existing ships is tackled in the first part of the project where a retrofitting of the propulsion unit is studied. In the second part a new building scenario is considered. The economic analysis made by the ship operator will determine the viability and the operational reliability of the propulsion conversion.

In order to make more feasible the retrofit scenario from the standpoint of the ship owner, i.e. reducing costs, the scenario will keep the original main propeller as it is, and will add a POD propeller working at a rate of revolutions proportional to the revolutions of the main propeller, thanks to a simple electrical driving system consisting of a generator coupled to the main engine that provide the main electrical energy to the pod propeller. This retrofit scenario includes all the studies carried out with the original hull form:

- Tests with original propeller (CONV1)
- Tests with a CLT propeller (CLT1) replacing the original CONV1
- Tests with a RudderPod unit replacing the original rudder, forming a CRP system, maintaining always the original CONV1 propeller, but testing two cases in the POD propeller:
    - CRP configuration: Main propeller CONV1 + POD propeller CONV3
    - CRP configuration: Main propeller CONV1 + POD propeller CLT3

The new ship scenario assumes that the after body of the ship would be slightly modified to install the new CRP-POD system maintaining all the main particulars of the ship. To obtain better comparison data two cases have been studied: with optimum conventional propellers and with CLT propellers. The following studies have been performed with the new hull:

- ❖ CRP configuration: Main propeller CONV2 + POD propeller CONV4
- ❖ CRP configuration: Main propeller CLT2 + POD propeller CLT4

3. DESIGN CRITERIA

Based on recorded data from the reference container ship, it was found that the ship currently operates most of the time with less than 50% of the installed propulsion power. Therefore, the design point for the operational scenarios was redefined and set to a ship speed of 22 knots. This means that in the case of the new building scenario the required power for the main engine will be noticeably smaller. This selection of 22 knots as design point was found not to compromise propeller efficiency at speeds of 18-20 knots, which are usual in the operational range of speed for this ship.

3.1 Pod unit design

A new pod unit geometry was developed during the project using 3D modeling techniques. The aim was to design a robust, hydrodynamically efficient and cost-attractive solution that can be applied to the reference container vessel and that can be used also for the more general segment of cargo vessels.

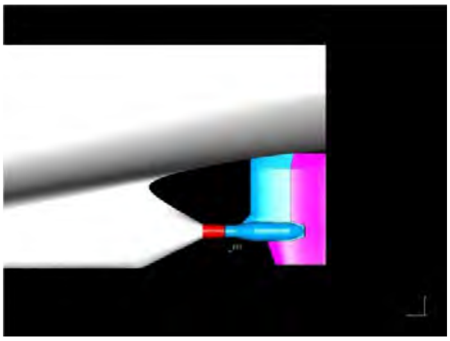

Fig. 3.1. Arrangement for self propulsion tests.

In order to keep the CRP pod unit cheap, compact and reliable, a CRP concept called RudderPod was further developed. It consists of a non-rotatable pod working as the aft-propeller of a CRP unit, being the ratio of main propeller to the pod propeller RPMs fixed. The after propeller is acting as a slave for the main propeller and follows the main propeller RPM. Steering is achieved by the use of flaps on the strut of the RudderPod.

After selecting the size of pod unit motor, the structure and shape of the torpedo around the motor, and the passive and active parts of the strut, the final shape of the unit was obtained. The efficiency of the propulsion system, the maneuvering characteristics and the structural strength of the pod unit were considered during the design phase. The hydrodynamic performance of the housing was verified by CFD methods at the final stages of the design. In particular the effect of different profile shapes of the strut on the pod unit drag was studied.

This new developed shape of the pod unit was then used in model tests at CEHIPAR (Fig. 3.1).

3.2 CRP design

The RPM ratio between the main propeller and pod propeller was fixed to 1:1.17 for the retrofit scenario throughout whole speed range. This fixed ratio is based on the shaft generator and RudderPod electric motor pole number ratio which is 14/12. For the new building scenario the RPM ratio between forward propeller and RudderPod propeller is 1:0.7143. This ratio is based on shaft generator and RudderPod electric motor pole number ratio of 10/14. The selection of RPM lower for the pod propeller than for the main one resulted in a significant improvement of the efficiency in the pod propeller. The maximum torque developed by the pod propeller was then a design constraint.

When the total propulsion power was considered, the mechanical losses were estimated in about one percent for the direct coupling of the main propeller. On the electric propulsion side the amount of power generation losses is estimated to be some 5 percent. This means that it is beneficial to keep the electric power share as low as possible in order to minimize the power generation losses. It has been estimated that in this kind of vessel power division of 80:20 is very close to the optimum when the gains in hydrodynamic side and overall losses are accounted for.

4. CFD ANALYSIS

During the project a new way of estimating accurately effective wakes has been developed, which seems especially useful for the design of CRP units.

The calculation of the effective wake within the CFD context is usually made by combining a potential flow method for modeling the propeller forces with a RANS equation solver for simulating the viscous flow around the hull and possible appendages. The different assumptions and/or simplifications made in the potential flow model relative to the viscous flow solver may result in significant errors in the prediction of the effective wake particularly for high loadings. This is especially troublesome for ships with full forms where large differences are expected between the nominal and effective wake, and for special propulsion applications such as contra-rotating units. Such errors are responsible within the hydrodynamic design problem for an unadjusted prediction of the propeller pitch, and within the hydrodynamic analysis problem for a deficient prediction of self-propulsion point.

An approach based on correction factors has been developed, which converts propeller induced velocities approximately estimated via potential flow theory into viscous induced velocities on the basis of a viscous flow RANS analysis. The correction factors are calculated for one reference advance number and work accurately in a neighboring region where the propeller loading may change about +/- 50 percent. This procedure allows calculating the effective wake precisely using simple potential flow methods for the representation of the propeller (Sánchez-Caja et al., 2013). Figures 4.1 and 4.2 show the total velocities and the effective wake respectively, estimated with the new method.

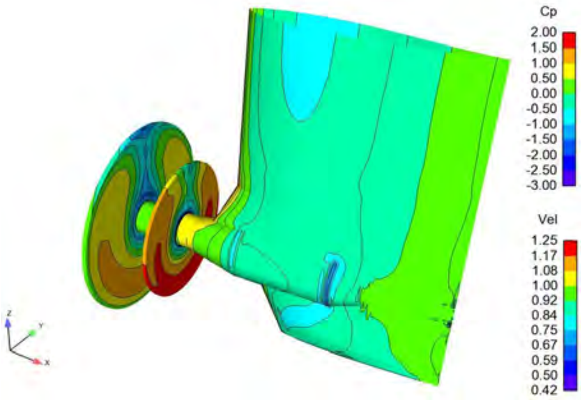

Figure 4.1. Total velocities at the propeller disks. The colors represent pressures on the pod surfaces and velocities on the propeller disks. Retrofit scenario.

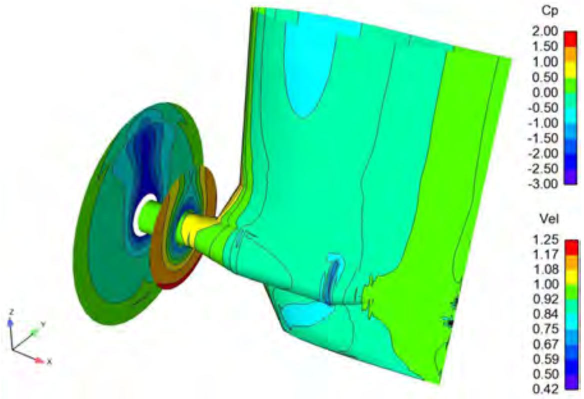

Figure 4.2. Effective wake at the propeller disks. The colors represent pressures on the pod surfaces and velocities on the propeller disks. Retrofit scenario.

RANS computations for the optimization of endplate propellers have been also made. Systematic variations of the endplate geometry were analyzed in order to assess the impact of different shapes on propeller performance. Several types of modifications including variations in plate contraction angle, in plate swept and flap angle are studied. A special procedure for the generation of the computational grids is implemented in order to minimize computational errors in the comparison of the alternative geometries. Comparisons are made at full scale. Scale effects on fully turbulent flow are also quantified (Sánchez-Caja et al., 2012).

As example, Figures 4.3 and 4.4 illustrate the change in pressure distributions for variations of plate contraction angle on the suction and pressure side of the blades, respectively. Variations in efficiency around 3 percent were found among the different endplate versions. The figures illustrate a possible way of cancelling tip vortices at the edge of the plate by endplate relocation or reshaping.

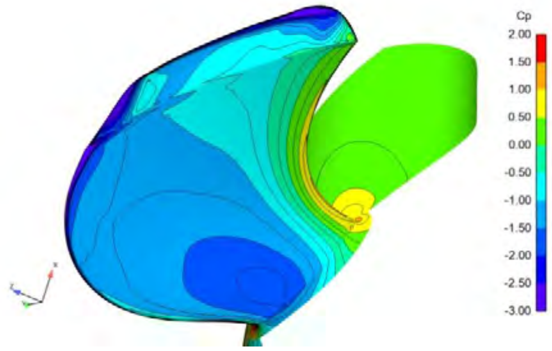

Figure 4.3. Pressure distributions on the suction side of the blade for large endplate contraction angles.

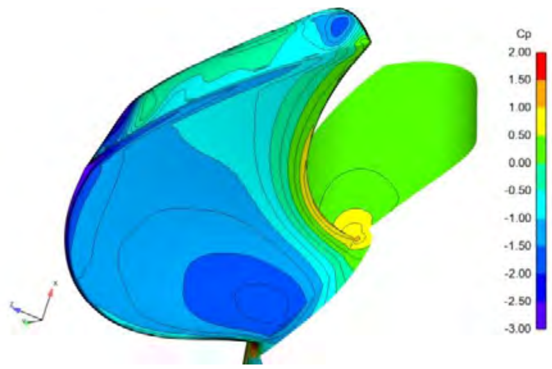

Figure 4.4. Pressure distributions on the suction side of the blade for low endplate contraction angles.

5. MODEL TESTS

5.1. Model test scaling procedure

A new procedure for the extrapolation of the results obtained with model tests was introduced for this new system consisting of a main propeller and a POD propeller in a CRP configuration. The method includes the procedure to perform model tests and is based on the ITTC-78 procedure and on its related ITTC procedures and recommendations.

Specific devices have been designed and manufactured to carry out the tests in the CEHIPAR calm water towing tank. Two independent dynamometers must be used to obtain all the needed measurements both in the open water and in the self-propulsion tests. The POD dynamometer has the possibility of measure the thrust of the propeller and the total force of the POD unit transmitted to the hull.

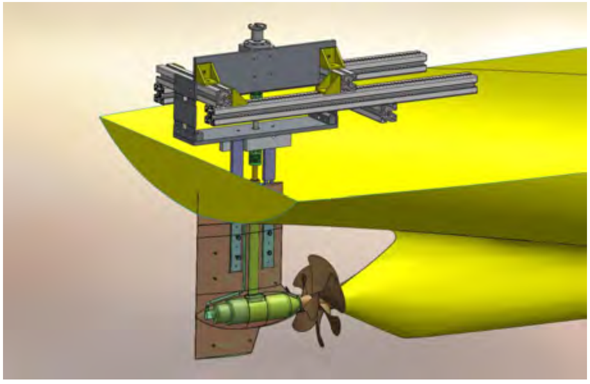

Fig. 5.1. Arrangement for self propulsion tests.

As this method has been explained in detail in Quereda et al. (2012), here below only the main assumptions and relevant findings will be exposed. The procedure for the extrapolation of model tests results is based on the following considerations:

- The propulsor is considered as a unit composed of the main propeller and the POD propeller arranged in Contra-Rotating configuration. That means that the POD drive support is considered part of the propulsor and therefore it is not included in the resistance test.

- The scaling of the Open Water tests of the propellers are carried out according to the standard ITTC-78 method in the case of conventional propellers and with some additional specific corrections in case of end plate CLT propellers.

- Open Water tests of the POD unit must be performed with the POD drive support, obtaining measurements of the pod propeller thrust, T^*_{m2}, and the total thrust of the POD UNIT, T^*_{mUNIT}, that is the thrust produced by the POD propeller minus the drag of the POD housing, R^*_{mPH}.

$$T^*_{mUNIT} = T^*_{m2} - R^*_{mPH}$$

- Hence the extrapolation of the POD UNIT Open Water tests includes a correction for the frictional scale effects of the drag of the POD housing R^*_{mPH}. Using the sub index 1 to refer to the main propeller and sub index 2 to refer to the POD propeller, in summary the extrapolation of the OW tests of the CRP-POD system corresponds to the following formulation:

Main propeller THRUST:

$$T_{S1} = (K_{Tm1} + \Delta K_{T1})\rho_S n_{S1}^2 D_{S1}^4$$

Where ΔK_{T1} is calculated according to ITTC'78 correction for main propellers.

POD unit THRUST:

$$T_{SUNIT} = (K_{TmUNIT} + \Delta K_{T2} + \Delta K_{TPH})\rho_S n_{S2}^2 D_{S2}^4$$

Where ΔK_{T2} is calculated according with ITTC'78 correction for conventional propellers, and

$$\Delta K_{TPH} = \frac{R_{mPH}}{\rho_m n_{m2}^2 D_{m2}^4}(1 - \frac{C_{FS}}{C_{Fm}})$$

THRUST coefficient of the CRP-POD system is:

$$K_{TS} = \frac{T_{S1} + T_{SUNIT}}{\rho_S n_{S1}^2 D_{S1}^4}$$

Main propeller TORQUE:

$$Q_{S1} = (K_{Qm1} + \Delta K_{Q1})\rho_S n_{S1}^2 D_{S1}^5$$

POD unit TORQUE:

$$Q_{S2} = (K_{Qm2} + \Delta K_{Q2})\rho_S n_{S2}^2 D_{S2}^5$$

Where ΔK_{Q1} and ΔK_{Q2} are the corresponding corrections of Main propeller and POD propeller, calculated for each one depending whether they are Conventional or end plate CLT. There is no new specific correction in Torque for the POD unit.

TORQUE coefficient of the CRP-POD system is:

$$K_{QS} = \frac{Q_{S1} n_{S1} + Q_{S2} n_{S2}}{\rho_S n_{S1}^3 D_{S1}^5}$$

Finally the open water curves of the propulsion system for the ship include parameters K_{TS} and K_{QS} represented in terms of the advance coefficient J_S:

$$J_S = \frac{V_S}{n_{S1} D_{S1}}$$

- In self-propulsion tests load variations are produced by varying the main propeller rpm, n_{m1}, and POD propeller rpm, n_{m2}. In this case the electrical drive of the POD propeller produces a fixed relation rate between n_{m1} and n_{m2}:

RR= RPM POD propeller / RPM Main propeller

Both independent dynamometers allows to measuring the rpm and torque on each propeller, Q_{m1} and Q_{m2}, at each model velocity. A minimum of three values of n_{m1} are used for each hull model speed to establish the load variation of the propellers. The self propulsion point is determined interpolating in the measured data of the load variation test. The frictional deductions due to hull model, F_{DHULL}, and pod housing, F_{DPH}, must be considered to calculate the total frictional deduction.

$$F_{Dm} = F_{DHULL} + F_{DPH}$$

$$F_{DHULL} = \frac{\rho_m S_m V_m^2}{2}\left[(1+k)(C_{Fm} - C_{Fs}) - \Delta C_F\right]$$

Where S_m is the hull model wetted surface. The deduction fraction on pod housing, F_{DPH}, is calculated.

$$F_{DPH} = R_{mPH}(1 - \frac{C_{Fs}}{C_{Fm}})$$

- The thrust deduction fraction t is considered to have the same value for model and full scale ship, t(model) = t(ship):

$$1 - t = \frac{R_m - (F_{DHULL} + F_{DPH})}{T_{m1} + T_{mUNIT}}$$

- The effective wake fraction for the ship, w_{TS}, based on thrust identity is extrapolated according to:

$$w_{TS} = t + (w_{Tm} - t)\frac{(1+k_S)C_{FS} + \Delta C_F}{(1+k_m)C_{Fm}}$$

- Once determined the J_{Tm} value, the non dimensional parameter K^{ow}_{Qm} is read off from the Open Water test curves of the propulsion system, and with K_{Qm} from self propulsion test, the rotative-relative coefficient could be determined:

$$\eta_R = \eta_{Rm} = \frac{K^{ow}_{Qm}}{K_{Qm}} = \eta_{RS}$$

as in the ITTC'78 method it is considered that no scale effect exists in the rotative-relative coefficient.

- The load of the full scale propeller is obtained

$$\frac{K_{TS}}{J_{TS}^2} = \frac{S_S}{2D_1^2}\frac{C_{TS}}{(1-t)(1-w_{TS})^2}$$

- With this K_{TS}/J^2_{TS} as input value the full scale advance coefficient J_{TS}, thrust coefficient K_{TS} and the torque coefficient K_{QTS} are read off from the full scale propeller characteristics and the following quantities are calculated:

$$n_{S1} = \frac{(1-w_{TS})V_S}{J_{TS} D_{S1}} \qquad \text{(rps)}$$

Thrust, T_S:

$$T_S = \frac{K_{TS}}{J_{TS}^2} J_{TS}^2 \rho_S n_{S1}^2 D_{S1}^4 \qquad \text{(N)}$$

The delivered power:

$$P_{DS} = 2\pi \rho_S n_{S1}^3 D_{S1}^5 \frac{K_{QS}}{\eta_R} 10^{-3} \qquad \text{(kW)}$$

The total propulsive efficiency:

$$\eta_D = \frac{P_E}{P_{DS}} = \frac{R_{TS} V_S}{P_{DS}}$$

- The share of power between both propellers is computed though the determination of the specific load and the OW curves of each propeller:

Load of full scale main propeller:

$$\frac{K_{TS1}}{J_{TS}^2} = \frac{S_S}{2D_1^2}\frac{C_{TS}\cdot\frac{T_{S1}}{(T_{S1}+T_{S-UNIT})}}{(1-t)(1-w_{TS})^2}$$

Predictions for Main propeller at full scale:

Rotation rate of Main propeller, rps

$$n_{S1} = \frac{(1-w_{TS})V_S}{J_{TS} D_{S1}}$$

THRUST of Main propeller, N:

$$T_{S1} = \left(\frac{K_{TS1}}{J_{TS}^2}\right) J_{TS}^2 \rho_S n_{S1}^2 D_{S1}^4$$

Delivered Power in Main propeller, kW:

$$P_{DS1} = 2\pi \rho_S n_{S1}^3 D_{S1}^5 \frac{K_{QS1}}{\eta_R} 10^{-3}$$

Load of full scale POD UNIT:

$$\frac{K_{TS-UNIT}}{J_{TS}^2} = \frac{S_S}{2D_2^2} \frac{C_{TS} \cdot \dfrac{T_{S-UNIT}}{(T_{S1} + T_{S-UNIT})}}{(1-t)(1-w_{TS})^2}$$

Predictions for POD propeller at full scale:

Rotation rate of POD propeller, rps

$$n_{S2} = RR \cdot n_{S1}$$

THRUST of POD propeller, N:

$$T_{S-UNIT} = \left(\frac{K_{TS-UNIT}}{J_{TS}^2}\right) J_{TS2}^2 \rho_S n_{S2}^2 D_{S2}^4$$

Delivered Power in POD UNIT, kW:

$$P_{DS2} = 2\pi \rho_S n_{S2}^3 D_{S2}^5 \frac{K_{QS2}}{\eta_R} 10^{-3}$$

Cavitation tests have been carried out at CEHIPAR cavitation tunnel:

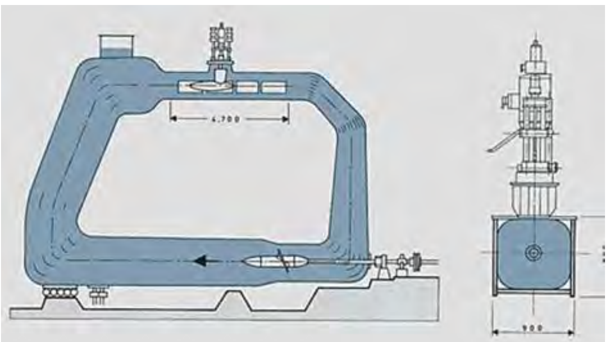

Fig. 5.2. Cavitation tests facilities at CEHIPAR.

A dummy model has been designed and manufactured to carry out the tests into the cavitation tunnel. The wake field on the forward propeller disc was reproduced with the aid of a mesh allocated at both sides of the model.

Holes to locate the pressure transducers on the stern of the dummy have been prepared.

A new Pod dynamometer was designed and manufactured to control the pod propeller parameters during cavitation observation test.

Fig. 5.3. Dummy model for cavitation tests with CRP-POD system.

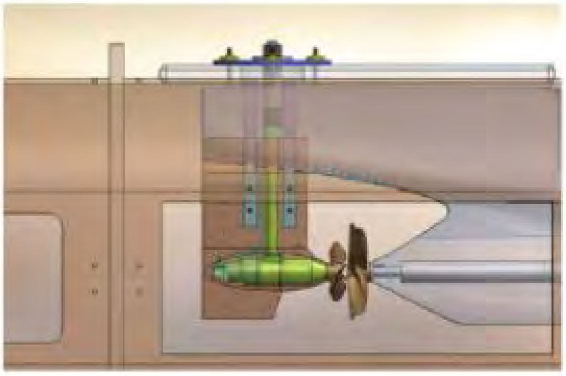

Fig. 5.4. Arrangement of cavitation tests with CRP-POD system.

To carry out the cavitation observation test in the tunnel, the K_T value is calculated for the main propeller performance at the selected ship navigation condition:

$$K_T = \frac{T_{S1}}{\rho_S n_{S1}^2 D_{S1}^4} = \frac{T_{m1}}{\rho_m n_{m1}^2 D_{m1}^4}$$

Thrust, T_{S1}, and rpm on the main propeller, n_{S1}, are selected from ship navigation condition. To carry out the tests the rpm of the main propeller model, n_{m1}, is selected and the corresponding thrust on the main propeller is obtained to attain the K_T value. The model pod propeller rpm must be adjusted to maintain the rpm ratio on both propellers.

The cavitation index is calculated according to the main propeller characteristics.

$$\sigma = \frac{P_{0S} - P_{SV}}{\frac{1}{2}\rho_S n_{S1}^2 D_{S1}^4}$$

The pressure pulses are measured during the cavitation observation tests at the same testing conditions. To extrapolate the pressure pulse amplitudes similar criteria than for conventional propeller were used.

$$K_P = \frac{P_{KS}}{\rho_S n_S^2 D_S^2} = \frac{P_{Km}}{\rho_m n_m^2 D_m^2}$$

Pressure pulse amplitudes are extrapolated for Main propeller according to:

$$P_{KS1} = P_{Km1} \frac{\rho_S}{\rho_m} \frac{n_{S1}^2 D_{S1}^2}{n_{m1}^2 D_{m1}^2}$$

and for POD propeller:

$$P_{KS2} = P_{Km2} \frac{\rho_S}{\rho_m} \frac{n_{S2}^2 D_{S2}^2}{n_{m2}^2 D_{m2}^2}$$

5.2.- Model test programs

Instead of using the tests programmes as a set of alternatives with different propulsors combinations, the tests have been oriented to obtain the best knowledge about the possible energy saving in two very realistic scenarios: in the case of retrofitting an existing ship and in the case of a new building ship.

In order to make more feasible the retrofit scenario from the standpoint of the ship owner, i.e. reducing costs, the scenario will keep the original main propeller as it is, and will add a pod propeller working at a rate of revolutions proportional to the revolutions of the main propeller, thanks to a simple and innovative electrical driving system consisting of a generator coupled to the main engine that provide the main electrical energy to the pod. To reinforce the ship owner confidence in the results, tests in ballast condition have been added in the case of new building scenario.

The main objectives of the model tests programs are:

1) Performing complete propulsion tests of the ship models for the cases of retrofitting and new hull design. The tests will allow evaluating the new propulsion concept from the point of view of energy saving.
2) Performing cavitation and pressure fluctuation tests to assess the impact of the new propulsion concept on the induced vibrations transmitted to the hull.
3) Finding the ship hull flow to the propeller both for the original hull and for the one optimized from the CRP-CLT-POD propulsion standpoint.
4) Additionally the test measurements will be used to validate CFD computations.

Five programs of tests have been scheduled according to Table I.

Each program of tests includes:

-Construction of required models: hull, propellers, pod housing.

-Resistance tests with and without pod housing.

-Open Water tests (propellers alone, pod+conventional propeller open water test, pod+CLT open water test, CRP open water test [main propeller+pod propeller]).

-Power split

-Propulsion tests

-Cavitation observation tests including pressure fluctuation measurements

Table I. Test programs

Scenarios in TRIPOD Project				
	Task	Main propeller	POD propeller	Ship condition
RETROFIT scenario	T4.1	CONV1	-	full load
	T4.2	CLT1	-	full load
	T4.3	CONV1	CONV3	full load
		CONV1	CLT3	full load
New Design scenario	T4.4	CONV2	CONV4	full load
		CONV2	CONV4	ballast
	T4.5	CLT2	CLT4	full load
		CLT2	CLT4	ballast

6. ECONOMIC ANALYSIS

The study of the viability of the new propulsion solutions will be made during the last term of the project by performing economical cost benefit analysis for the operation of the reference ship. The real economic criteria applied by the ship-owner will be incorporated into the project. Elaborate procedures on how to determine yearly fuel savings and emission reductions based on the vessels operational profiles will be applied. The cost-benefit will be assessed through a TCO (total cost of ownership) analysis.

Sensitivity studies will be made concerning the effects of changes in:

- fuel price
- ship speed
- geographical deployment in terms of speed or emission regulations
- etc.

The retrofitting scenario is especially demanding from an economical point of view due to the smaller acceptable payback time of the propulsion unit: it is very hard to predict when the vessels will be sold on, and therefore large investments in fuel saving equipment with long payback times are not acceptable.

7. CONCEPT VALIDATION

As stated in section 2, the tests have been oriented to obtain the best knowledge about the possible energy saving in two very realistic scenarios: retrofitting of the existing ship and a new building ship. Although the new concept CRP-POD-CLT propulsion system also has several advantages derived from the split of the power into two mechanically independent propellers, as for example the redundancy in propulsion, the main focus is the improvement of propulsive efficiency.

The speed of 22 knots has been selected to make comparisons, following the actual trend of lowering the operational speed of this kind of vessels. The reference value to compare different propulsion systems tested is the power needed to propel the ship with the CONV1 propeller. At the moment of writing this paper only preliminary results of the retrofit scenario are available, but they are significant enough to be presented from the point of view of the validation of the procedures developed in the Project.

At this speed of 22 knots the power needed in the two cases studied for CRP systems of retrofit scenario is:

% of Power vs. reference propeller CONV1 (100%)					
E-19048			E-19049		
CONV1	POD/CONV3	TOTAL	CONV1	POD/CLT3	TOTAL
78,4	19,5	97,9	79,7	16,3	96,0

Share of Power in each CRP system, %					
E-19048			E-19049		
CONV1	POD/CONV3	TOTAL	CONV1	POD/CLT3	TOTAL
80,1	19,9	100	83,0	17,0	100

So the CLT3 propeller have resulted slightly underpitched, being the design requirements 80% of the power to be absorbed by the main propeller (CONV1) and 20% of the power by the POD propeller (CONV3 or CLT3).

One of the most relevant innovations in the data obtained from model tests is related to the Open Water (OW) tests of CRP-POD system. Although the CRP-POD system is considered as one propulsion unit, it can be distinguished three parts: the main propeller, the POD propeller and the POD housing. In the tests measurements have been carried out for the individual component as well as for the whole system. To have a more detailed knowledge to validate the concept and the numerical calculations the OW tests have included in each case of CRP alternative the following tests:

⇒ OW test of the main propeller alone (standard test).

⇒ OW test of the POD propeller alone (standard test).

⇒ OW test of the POD housing+POD propeller (new POD dynamometer needed, measuring the POD propeller thrust, T^*_{m2}, and the total thrust of the POD UNIT, T^*_{mUNIT}, that is the thrust produced by the POD propeller minus the drag of the POD housing, R^*_{mPH}).

⇒ OW test of the whole CRP-POD system (two dynamometers are needed).

The value of the drag of the POD housing, R^*_{mPH} is different in the case of the OW test of the POD system and in the case of the whole CRP-POD system as it is shown in the next figure:

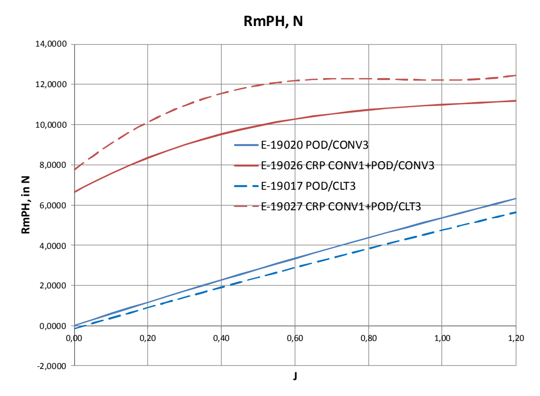

Figure 7.1. Drag versus advance coefficient.

The value of the drag of the POD housing, R^*_{mPH} is increasing with J values and is larger for the CRP system than in the case of the POD alone. The OW efficiency of the POD system is clearly influenced by the drag of the POD housing; for this reason this drag must be taken into account in the scaling procedure as it has been explained in the section 5 of this paper.

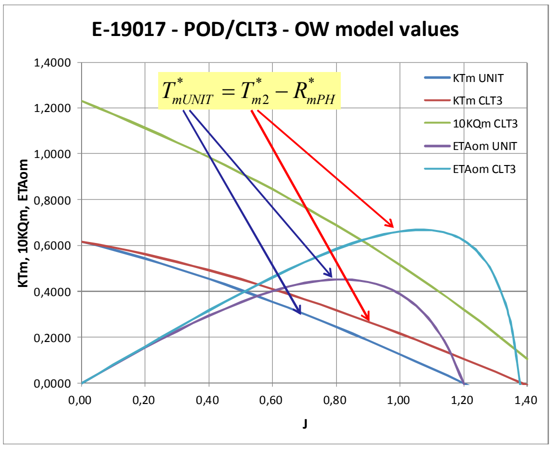

Figure 7.2. OW model values for CLT3.

This effect produces that the OW efficiency of the same propeller has different values depending of the configuration considered. For instance the CLT3 propeller, that is one of the propellers designed for the POD unit in the retrofit scenario, presents the following results at model scale:

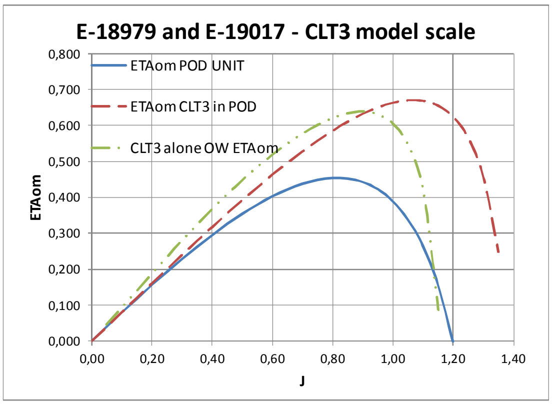

Figure 7.3. OW model scale efficiency for CLT3.

8. CONCLUSIONS

With the aim of improving ship operational costs new ways of saving energy are being studied within the EU project TRIPOD. A novel propulsion concept resulting from the integration of two promising technologies (podded propulsion and tip loaded endplate propellers) in combination with energy recovery based on counter rotating propeller (CRP) principle is considered.

In order to keep the CRP pod unit cheap, compact and reliable, a CRP concept called RudderPod was further developed. It consists of a non-rotatable pod working as the aft-propeller of a CRP unit, being the ratio of main propeller to the pod propeller RPMs fixed. The after propeller is acting as a slave for the main propeller and follows the main propeller RPM. Steering is achieved by the use of flaps on the strut of the RudderPod. Optimum efficiency was achieved for lower RPMs in the pod relative to the main propeller.

Two scenarios, retrofitting and new buildings, are analyzed for a 120000 tons container vessel. The retrofitting scenario is more demanding than the new building scenario due not only to less flexibility in fixing optimal design parameters from a technical standpoint but also to the smaller acceptable payback time from an economic standpoint: it is very hard to predict when the vessels will be sold on, and therefore large investments in fuel saving equipment with long payback times are not acceptable.

Within the TRIPOD project an extrapolation procedure of model test results for CRP units involving podded propulsion has been presented. At the moment of writing this paper only preliminary results of the retrofit scenario are available, but they are significant enough to be presented from the point of view of the validation of the procedures developed in the Project.

The TRIPOD project contributes to the advancement of CFD methods from both the theoretical and practical points of view. In particular, a method for prediction improvement of effective wakes has been proposed and the effect of end-plate shape on CLT propeller efficiency has been assessed.

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