Contra-rotating propellers

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Management Review
Contra Rotating propellers

Introduction

In the maritime shipping industries a solution for fuel consumption reduction is desirable. Present vessels use a large amount of fuel which is more expensive than four years ago. A small reduction of fuel consumption can make a huge difference economically and ecologically.

This Project contains a research of the possible application of contra-rotating propellers for large container vessels. Both desk- and field research has been done to find a solution to the main problem:

Fuel consumption in the commercial shipping industries is too high.

A high fuel consumption means a vast amount of emissions emitted into the air. The high fuel consumption also results in higher costs for the shipping companies.

Contra-rotating propellers can be applied in a variety of ways such as two contra-rotating propellers on a single shaft. This proved to be hard to apply and the money saved compared to the maintenance costs makes it a less profitable solution. The other way to apply contra-rotating propellers a regular fixed propeller with a pod propeller behind which rotates in the opposite direction.

The “modern” pod-propellers provide the opportunity to create a more durable application for the contra-rotating propellers.

The main question of this project is:

How can contra-rotating propellers reduce fuel consumption and increase efficiency of commercial shipping vessels.

The main question will be answered by answering the following sub questions:

- How does the concept of contra-rotating propellers work?
- What are the advantages/disadvantages of contra-rotating?
- To which criteria does the contra-rotating propeller system has to comply?
- What are the specifications and application of the contra-rotating pod-propeller system be?
- What are the fuel reduction be when equipped with contra-rotating propellers?

Summary

The concept of contra-rotating propeller consists out of placing a pod behind the main propeller. The pod is rotating in the opposite direction of the main propeller. This way of propelling the vessel comes along with a number of advantages and disadvantages.
If the current Tripple-E vessel will be equipped with Contra-rotating propeller a couple of advantages will be acquired. Including the wake factor which will increase, the vessels propulsion efficiency will increase, the overall fuel consumption will decrease, the maneuverability will increase and the vessel will have an emergency system in case of main engine failure.

However the Contra-rotating propeller comes along with a couple of disadvantages. Being the high investment which has to be made, a new power generating plant to control the pod and the maneuverability will decreased if the pod happens to shut down.

In order to generate the electrical energy to power the pod, several electrical generators has been taken into account. These systems are gas turbines, generators, steam turbine, shaft generator and the Thermal Efficiency System. These systems are compared to each other and the generator and Thermal Efficiency System came out as the most efficient way of generating electrical energy.

The system of Contra-rotating propellers (CRP) have a couple of specifications. Being the pod-main engine ratio, the recommended ratio for the Tripple-E vessel equipped with CRP is 30%-70%. The research also contains some options for the main engine and electrical power suppliers.

Finally the fuel reduction has been calculated and will be 1.14ton/h less than the current Tripple-E vessel. This is obtained through calculating the advantages of the CRP system into the propeller efficiency and hull efficiency.

Conclusion

The Triple-E vessels can reduce the fuel consumption and therefore reduce the emissions by applying the concept of Contra-Rotating propellers. When the vessel will be equipped with the suggested systems, the vessel can reduce her fuel consumption by 1.14ton/h. The vessel will also increase her propulsion efficiency due to the Contra-Rotating propeller system. With this increase of efficiency the vessel can sail at the same speed with less engine power. This results in a fuel consumption which is 8% less than the regular fuel consumption.

Our main recommendation is that there has to be further research regarding the financial aspects of the system to show whether this system will be profitable or not.

The recommendation for the ship owners is to apply the Contra-Rotating propeller system. The ship owners can add their own interpretation in choosing the main engine, pod and extra electrical power supply. The main engine power – pod power ratio is recommended as 70%-30% as explained in the application of the CRP system. The final specifications of the systems depend on the vessel's size and the demand of the ship owner.
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1. Introduction

In the maritime shipping industries a solution for fuel consumption reduction is desirable. Present vessels use a large amount of fuel which is more expensive than four years ago.\(^1\) A small reduction of fuel consumption can make a huge difference economically and ecologically.

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**Main question**

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- What are the fuel reduction be when equipped with contra-rotating propellers?

In this project a Tripple-E vessel form Maersk is used as an example for the concept of contra rotating propellers. In the second chapter the concept of contra-rotating propellers will be explained in general. In the third chapter the advantages and disadvantages are described. In the fourth chapter several different manners of generating electrical energy and will be compared to each other. The specifications and applications of the contra-rotating propellers on the Tripple-E vessel will be described in the fifth chapter. In the sixth chapter the fuel consumption of the Tripple-E vessel when equipped with contra-rotating propeller will be described. The conclusions and recommendations are presented in chapter seven. The field research with ABB will be shown in chapter 8. Finally the references are shown in chapter 9.

The subject has been issued by Mr. P.C. van Kluijven and has been guided by the project principal Mr. A. Hoorn. After the subject has been researched, project group 8 will present their findings and research results at the 2013 maritime symposium at the RMU.

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Figure 1

http://iliketowastemytime.com/sites/default/files/5471005041_d409043174_b.jpg

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2 http://iliketowastemytime.com/sites/default/files/5471005041_d409043174_b.jpg
1. How does the concept of contra-rotating propellers work?

This chapter describes the basic concept of the contra-rotating propeller (CRP). The concept of CRP is placing a pod propeller, behind the main fixed propeller, which is rotating in the opposite direction of the main fixed propeller.

In order to reduce the fuel consumption in the commercial shipping industry contra rotating propellers could be applied to vessels to increase the overall propulsion efficiency of the vessel. As shown in the formula below, by increasing the overall propulsion efficiency without altering the chemical energy in the fuel, the overall propulsion efficiency will increase and will result in less fuel consumption. A higher overall propulsion efficiency allows the propulsion plant to create less energy but maintain the same amount of effective propulsion power.

\[
\eta_p = \text{Ratio} = \frac{P_E}{Q_f}
\]

When a pod propeller will be placed behind the main fixed propeller. The pod propeller can take over a portion of the power required to sail the vessel. The article gives the benefits of contra-rotating propellers such as: efficiency of hybrid propulsion, hull resistance and propulsion efficiency and the other features of hybrid propulsion. These factors result in a higher overall propulsion efficiency which will reduce the fuel consumption.

When a pod propeller will be placed behind a normal fixed propeller the total thrust power will be divided among the two propellers with a certain ratio. This ratio, can be defined as:

\[
\frac{P_{\text{main propeller}}}{P_{\text{contra rotating propeller}}} = \text{Ratio}
\]

If the forces will be divided among the propellers, the propellers will sustain less heavy force which will extend the lifetime of the propeller and will reduce the fuel consumption.

In the past some vessels had contra rotating propellers on a single shaft. This caused a lot of mechanical problems. The inner shaft caused a lot of friction resulting in a lot of wear. The lubricating of the inner shaft is very hard to establish. At present date there are advanced pod propellers which will have the same effect but without the mechanical problems. An attached pod propeller as a secondary propeller can increase efficiency of the propeller up to 20%.

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3 ‘Hydrodynamic aspects of contra-rotating propellers’ by Jerzy Matusiak, Professor, Helsinki, University of Technology, Ship Laboratory 2004.
Single fixed propellers cause circulations in the water. When two different propellers are placed in front of each other the circulations will be neutralized. This will cause a bigger forward thrusting force and increase the propulsion efficiency. This effect can be notified by observing the water behind the vessel. When the two propellers are attached the water has substantial less backwater. (see figure 2)\(^4\)

The pod propeller also provides better maneuverability. The pod can be turned up to 360°. This way the vessel can steer much more efficiently compared to a fixed propeller-rudder combination. In case of main engine failure pod can also be used to reach the closest port for repairs. \(^3\)

2. What are the advantages and disadvantages of contra-rotating propellers?

Figure 3

The current Tripple-E vessel has two main propellers to propel the vessel\(^1\). In this chapter the advantages and disadvantages of the CRP system compared to the two main propellers.

**Advantages**

- **Increased propulsion efficiency**

  Every propeller creates two forces, one in the opposite direction of which the ship is sailing (thrust) and one sideways. This sideways force is called the wheel effect and decreases the effective energy used for propulsion of the vessel. This loss of energy can be reduced by mounting a pod propeller which rotates in the opposite direction behind the main fixed propeller (CRP). The propeller of the pod will cause the water to go into a horizontal direction (parallel to the thrust) as a result the energy loss caused by the wheel effect only occurs between the small distance between the two propellers.

- **Increased maneuverability**

  The pod propeller can rotate 360 degrees. This way the rudder can be turned 90 degrees to get the optimal steering angle. A normal ship with a single fixed propeller and a rudder, where the rudder angle has a maximum of 45 degrees. A ship equipped with a CRP system has a steering angle twice as much as the regular fixed – rudder system.\(^1\)

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- Emergency propulsion system in case of main engine failure

CRP has a certain main engine-pod ratio (this will be explained in chapter 4), if the ratio is 70%-30% the main engine will provide 70% of the necessary power while the pod propeller provides 30% of the necessary power. If the main engine happens to shut down for whatever reason. The pod can run on full power so that the vessel can still continue her voyage to the safest harbor, or even to the port of destination.

- Less need for tug assistance in ports

Because the pod propeller can be turned 360 degrees, maneuvering in the harbors will be easier. This will save a lot of money because the tug assistance in the ports is expensive.

- Less fuel consumption, less emissions

The increase of effective power produced means that the main engine has to provide less power, which means less fuel consumed by the engine, thus lowering the emissions of the vessel (see chapter 6).

- No need of stern thrusters and rudders

The increase of maneuverability by the stern, makes the use of stern thruster(s) no longer necessary.

The pod will also replace the main rudder, However the pod needs to have a rudder shaped design. If the pod happens to shut down the vessel can still maneuver quite well with the main engine. The picture shows the pod propeller which has a rudder shaped design.3

- Smaller main engine

Because the power is divided between the pod and the main engine as explained earlier, the power and dimensions of the new main engine can be scaled down.
Which results in more space in the engine room.

- Hull efficiency will increase

The current Mearsk Triple-E vessel has a two propeller design (or twin-skeg). This requires the hull to be adjusted to this propulsion method. A hull designed for two propellers has more resistance in the water compared to a regular hull which is designed for a single propeller. A CRP system will need a hull which has the same design as the hull for the single propeller, which is more efficient than an double propeller design (see table 3). 6,7

- Higher wake factor

A moving vessel will create a friction belt of water around the hull of the vessel, meaning a small layer of water will stick to the hull of the vessel. The velocity of the water in the water belt closest to the ship has the same velocity of the vessel. The velocity of the water reduces

6 ‘contra-rotating propellers part 1’ by A. Hoorn, STC Group 2010.
7 ‘Basic principles of ship propulsion’ MAN Diesel and Turbo.
the further away from the ship. The friction belt will have a limit where the vessels dimensions will no longer impact the water this is where the friction belt ends. The thickness of this friction belt is determined by the distance from the fore and aft of the vessel. The friction belt is also present in the aft end of the ship where the propellers are propelling the ship. The propellers are rotating a flow of water which has approximately the same speed as the ship.

The Triple-E ships have a twin-skeg propulsion which results in a lower wake factor which will decrease the hull efficiency. A vessel with a CRP has the same properties in hull design as a ship with a single propeller which gives the vessel a higher wake factor and results in a better hull efficiency in contrary to the twin-skeg design of the current Tripple-E vessel. 

**Disadvantages**

- **Higher costs**

  We won’t go into details with the costs, but the CRP system is a more expensive way of propelling the vessel. The maintenance will also cost a lot of money since it’s a very important part of the new propulsion. The CRP does increase the propulsion efficiency which will result in a fuel reduction thus saving money in the long run.

- **An advanced power supply system for propulsion and controlling the pod**

  The pod requires a vast amount of power to operate (19,2MW this is calculated in the next chapter), which means the vessel has to be equipped with a large power plant facility to provide the electric power needed for the pod, in addition to the existing power supply of the vessel.

- **The required systems requires the crew to have advanced knowledge**

  The crew onboard of the vessel need to have more knowledge about the new system on board, since not many vessels have the CRP few mechanics know a lot about the pods. Which results in more crew training and probably higher costs.

- **Retro fitting is almost impossible**

  Adapting CRP at vessels which don’t have them is really hard and expensive to do. The entire hull at the stern of the vessel has to be modified and the CRP requires to have new spaces in the vessel to store the power supply. This means that the CRP system will most likely only be applied to new vessels.
- **When the pod is malfunctioning maneuverability will decrease.**

If case of pod failure the maneuverability will decrease. The CRP is able to replace the stern thrusters, but the vessel has to have a propulsion system which controls the stern of the vessel whether these system are stern thrusters or a CRP system these systems are a must for maneuvering in harbors and in narrow sailing areas. This problem can be solved by giving the pod a rudder shaped design. This will not be as effective as a regular rudder but can bring the vessel safely into the harbor.

- **Complicated repairs of the pod**

It is hard to carry out maintenance in the small space inside the pod therefore making small maintenance a bit more complicated but possible.

Large maintenance/ replacements carried out on the pod has to be done in dock(see field research).

Table 1 gives a summary of the advantages and disadvantages of the CRP system compared to the twin-screw system the Tripple-E vessel currently has.

<table>
<thead>
<tr>
<th>3.</th>
<th>Current Twin-screw propulsion</th>
<th>Contra-rotating propeller propulsion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propulsion efficiency</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Maneuverability</td>
<td>+/-</td>
<td>++</td>
</tr>
<tr>
<td>Emergency propulsion system</td>
<td>N/A</td>
<td>+/-</td>
</tr>
<tr>
<td>Tug assistance</td>
<td>+/-</td>
<td>+</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>+/-</td>
<td>+</td>
</tr>
<tr>
<td>Stern thrusters</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Size main engine</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Hull efficiency</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Wake factor</td>
<td>+/-</td>
<td>+</td>
</tr>
<tr>
<td>Costs</td>
<td>+</td>
<td>--</td>
</tr>
<tr>
<td>Power generate supply space</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Retro-fitting</td>
<td>N/A</td>
<td>--</td>
</tr>
<tr>
<td>Maneuverability while malfunctioning</td>
<td>+/-</td>
<td>--</td>
</tr>
<tr>
<td>Maintenance/repairment</td>
<td>+/-</td>
<td>+/-</td>
</tr>
</tbody>
</table>

Table 1

++ = very good  + = good  +/- = average  - = bad  -- = worse

When studying table 1 the overall conclusion is that the CRP system has more advantages, compared to the Twin-screw propulsion system. But the disadvantages the CRP system has are less important than the advantages. The costs of the CRP system is a disadvantages that matters. The financial aspect of the system is not a part of our research, nevertheless it is a big disadvantage.

Not all the parts that are compared are equally important, the pus and the minus are just an indication.
4. To which criteria does the contra-rotating propeller system have to comply?

The CRP system that will be applied to the Triple-E vessel requires a high power source. We found several electrical generators to generate the power to drive the pod. To decide which electrical generator will be applied, several factors has to be taken into account. The factors are the fuel consumption, the emissions and generated power.

The table below shows the criteria the CRP system has to comply to.

<table>
<thead>
<tr>
<th>System</th>
<th>Fuel consumption</th>
<th>Emissions</th>
<th>Generated power</th>
</tr>
</thead>
<tbody>
<tr>
<td>TES (thermo efficiency system)</td>
<td>None (powered by exhaust gasses)</td>
<td>Very little due to extra load on main engine</td>
<td>3 MW (when applied to the 44.8 MW engine)</td>
</tr>
<tr>
<td>Steam turbine</td>
<td>Waste heat or regular fuel</td>
<td>Only if heated by regular fuel</td>
<td>Dependent of size boiler and fuel usage</td>
</tr>
<tr>
<td>Gas turbine</td>
<td>Gas (fuel efficient)</td>
<td>Regular emissions from using gas as fuel</td>
<td>Generates lots of power efficiently</td>
</tr>
<tr>
<td>Generator</td>
<td>Regular fuel (less fuel efficient)</td>
<td>Emissions of a regular generator</td>
<td>Wide range of available generators, power depends on power engine</td>
</tr>
<tr>
<td>Shaft generator</td>
<td>Powered by the main engine so the fuel consumption of the main engine will increase slightly</td>
<td>The emissions will indirect increase because of the increased fuel consumption</td>
<td>Depends on size and speed main engine. Size of shaft generator is also a factor</td>
</tr>
</tbody>
</table>

The TES system will be used. The TES uses exhaust gas flow and heat, to generate electrical power, which will otherwise be lost. This increases the fuel efficiency of the engine.

The steam turbine will not be used as a power source for the CRP system. The Tripple-E vessel is already using the steam turbine to provide the ship from electrical power.

A gas turbine will not be used as a power source for the CRP system. Gas turbines requires gas as fuel. The Tripple-E vessel does not come standard with gas tanks. This means extra tanks have to be installed in the vessel. And the tanks have to comply to strict regulations and rules. The extra space for the gas tanks result in less space for the containers.

Generators will be used to provide the CRP system from its power. Generators are a good solution because they create a lot of electrical power in a simple way if you compare it with the other options.
A shaft generator will not be used to provide the CRP system from its power. The current design of the Tripple-E vessel already has 2 shaft generators, each engine contains one shaft generator. In the new design only one main engine propels the ship so one shaft generator has already been removed.
5. What will the application of the contra-rotating pod-propeller system be?

During this project a Tripple-E ship will be theoretically equipped with a contra rotating propeller. The current Tripple-E vessels have a twin propeller propulsion meaning that the vessel also has two main engines. The total propulsion power from these main engines is 64MW. The power will be equally divided over the two propellers. So each main engine has a total power of 32MW. If the pod propeller system will be applied on the vessels only one main engine is required. This main engine will provide the required power for the main propeller. For the power of the pod propeller there are different options to generate the electrical power: a generator, a shaft-generator, TES and a gas turbine. This subject will be discussed in the last chapter.

The Triple-E vessels from Maersk have 64MW\(^8\) of propulsion power. When applying a pod propeller the power has to be divided to the pod propeller and the main propeller. Multiple researches give different ratio’s, these ratio’s differentiate from 25%-75%\(^8\) till 40%-60%\(^14\). During this research the ratio 30%-70%\(^16\) will be used.

Figure 5 shows a possible ideal power distribution which is 40%-60%. Though during this research the Tripple-E vessel use the 30%-70% ratio.

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\(^8\) ‘Combined diesel-electric and diesel-mechanical propulsion for a ropax vessel’ by Oskar Levander, 2001
The main propeller will have 70% of the power and the pod propeller will have 30% for the propulsion. This means 44.8 MW of the power will go to the main propeller and 19.2 MW will go to the pod propeller.

**Main engine**
The main propeller has to provide at least 44.8 MW, as example The Wärtsilä 8X92-70/R3²⁹ (this engine has 8 cylinders two-stroke crosshead engine, with a diameter of the piston of 920 mm. R3 is the amount of rating points) can be used as main-engine, this engine has sufficient power (45.2 MW) to power the main propeller and has a slightly lower fuel consumption which is 166 g/KWH, compared to the current main engine which has a fuel consumption of 168 g/KWH¹⁵.

**Pod**
Powering the pod however, is more complicated, the pod needs according to the 70%-30% ratio, 19.2 MW electrical power.

The pod that can be used for the CRP system is the ABB Azipod® XO2300¹⁰, this pod delivers 16-23 MW of propulsion power. The pod has to be able to produce enough power to produce the 19.2 MW. This pod is only a suggestion, there are several other possibility’s in choosing the pod.

**Electrical energy supply**
To generate the 19.2 MW of power needed, the vessel can be equipped with the Wärtsilä 8X72-66/R⁴¹¹ main engine which has a fuel consumption of 160 g/Kwh and generates 16.96 MW of power which can be converted (with a generator efficiency of 0.94) to 15.94 MW of electric power to power the pod. This main engine has been chosen because of its low fuel consumption, however this main engine is a two-stroke engine. This engine is also a suggestion, there are other and possibly better options of generating the electrical power.

To reach the required 19.2 MW we need another electrical source which will generate at least 3.26 MW. This electrical power can be achieved by applying a Thermo Efficiency system¹² on the Wärtsilä 8X92-70/R3. This Thermo Efficiency system will be described at the next chapter.

The total power needed to propel the ship, depends on a few different aspects. The main engine provides the vessel of the most power.

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Table 2

<table>
<thead>
<tr>
<th></th>
<th>Total Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Engine with CRP</td>
<td>45.200</td>
</tr>
<tr>
<td>Extra generator power</td>
<td>15.940</td>
</tr>
<tr>
<td>TES (Thermo efficiency system)</td>
<td>3.000</td>
</tr>
<tr>
<td></td>
<td><strong>64.140</strong></td>
</tr>
</tbody>
</table>

The suggestion of the two power suppliers will result in a lower fuel consumption and will deliver the same amount of power. Other benefits will be discussed in the next chapter, the detailed version of the reduced fuel consumption will also be shown in the next chapter.
6. What will the fuel reduction be when equipped with contra-rotating propellers?

The fuel efficiency of the main engine for a regular vessel is about 50\(^\circ\)\(^2\), the total propulsion efficiency of the vessel is about 30\% (See figure 8). This means that for every kilowatt of chemical energy that is stored in the fuel, only 30\% of it is actually used for the propulsion of the ship.

This loss of energy is caused by several factors such as: cooling, waste heat, friction of the engine parts (e.g. bearings etc.) and energy loss caused by the propeller.

Of course there are many other factors that affect the fuel efficiency of the vessel, but during this project the group will mainly focus on the overall fuel efficiency losses caused by the propeller.

A regular propeller has an efficiency of about 70\% (see figure 8) this means that 30\% of the energy is lost, using a contra-rotating propeller (CRP) the vessel’s total propeller efficiency can be increased by 12\%-17\%\(^1\). In figure 7 we applied this 15\% increase of the propeller efficiency to the total power which goes to the propeller, resulting in an overall propulsion efficiency of 41\%.

To reduce fuel consumption even more the pod that is part of the CRP system will be partially powered by the MAN Diesel & Turbo, Thermo Efficiency system\(^2\) (TES).

The MAN Diesel & Turbo TES is a system that consists of an exhaust gas fired boiler and steam turbine which uses a part of the exhaust gas flow to generate electricity.

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\(^{12}\) "Thermo Efficiency System for reduction of fuel consumption an CO\(_2\) emission" MAN Diesel & Turbo Aug. 2010.


\(^{14}\) "Novel propulsion machinery solutions for ferries " Oskar Levander, MSc (Nav. Arch.) Wärtsilä Corporation - Ship Power, Finland.
The amount of electricity produced depends on the power of the main engine (the amount of KW’s) and the number of turbines in the TES.

The TES comes in two versions, the single and the dual pressure system, the dual pressure which uses an exhaust gas turbine and a second lower pressure steam turbine to generate more electricity. A TES equipped on the main engine can generate about 3MW.

The main engine of the vessel has 45.2MW. To calculate the generated energy by the TES this has to be multiplied with 0.8512 which gives 38,42MW. The TES will generate 3MW of electrical power according to figure 7. This will result in 8%-10% less required power for the generators.

The current fuel consumption of a Mearsk Triple E vessel is 168g/Kwh15, the vessel uses a twin skeg design to house its two propellers.

Using this twin-skeg design the vessel’s hull efficiency will be reduced by 5%16 this 5% can be found in table 3. The vessel’s resistance will increase by 3%17 compared to a conventional single-skeg design.

With the CRP system the vessel will still be able to benefit from the dual propeller propulsion. However the CRP system is fitted on a hull which is designed for a single propeller. The overall hull efficiency will increase by 5% when equipped with a CRP. This increase is obtained by the switch from a twin-skeg design to a more efficient single-skeg design. The vessels resistance will be 3% lower.

On the whole there are many fuel reducing factors that make the CRP a fuel saving way of propelling the vessel.

The exact percentage of fuel reduction is yet to be determined because a large Triple-E sized vessel has not yet been equipped with a CRP, live tests should be conducted to prove this concept.

However a rough estimation can be made with the knowledge of the vessels that already successfully sail with a CRP system. We should be able to increase the propulsion efficiency by 8% (without altering the total propulsion power of the Tripple-E vessel).

This 8% (table 3) improvement of the vessel’s efficiency means that the main engine’s fuel consumption will be reduced by 8 % as well. In order to get the same amount of effective power, the vessel with CRP is able to use 8% less power. Which is an significant improvement both ecologically and economically.

Figure 8 contains an overview of the losses on a vessel with a Twin-screw propulsion and the losses on a vessel with Contra-rotating propellers. The first column gives the temperature losses in the main engine (see figure 6). The total mechanical losses on a modern vessel are 10%17. This 10% in mechanical losses are formed by the shaft losses and other remaining losses such as losses in lubrication, bearings etc. The shaft losses are 1%-4%7. The vessel with the Twin-screw has two times the shaft losses, since it has two shafts giving it a total shaft loss of 7%. The vessel with the Contra-

17 ‘scheepsdiesel motoren’ P. van Maanen, 2000
rotating propeller only has 3.5% since it has one main shaft. The final column contains the propeller losses. An average vessel has a propeller efficiency of 70% meaning a loss of 30%\textsuperscript{10}. A Contra-rotating propeller will increase the propeller efficiency by 15%\textsuperscript{14}. This results in a total propeller loss of 15%.
Ship's propulsion efficiency without CRP

[Diagram showing temperature losses/cooling and mechanical losses leading to propeller efficiency]

Ship's propulsion efficiency with CRP

[Diagram showing temperature losses/cooling and mechanical losses leading to propeller efficiency with a different total efficiency]
In order to explain the difference of fuel consumption between the Tripple-E vessel with CRP and the Tripple-E vessel without CRP, we have made some calculations according to the fuel consumption.

To compare the two hulls of the Triple-E vessel (twin-skeg and single-skeg) a table has been made to give summary of the total efficiency for both hulls. The difference between total efficiency is the increase of the overall propulsion efficiency, which is 8% (see table 3). If you compare the total efficiency from the twin-screw column and the CRP column the difference is 8% total efficiency. This 8% increase of overall propulsion efficiency has been implemented in the required power column for the Main Engine with CRP (see table 4).

Table 3 contains the advantages of the single-skeg hull design compared to the twin-skeg hull design. The single-skeg hull design does not have the disadvantages of the vessels resistance and the disadvantage of the hull efficiency. The 11% from the propeller efficiency can be found at figure 7 at the effective power of both matrix. The matrix without CRP has an effective power of 29.85%, while the CRP matrix has an effective power of 41.31% this gives a difference of 11% which is shown in table 3 at the row for propeller efficiency.

Table 3

<table>
<thead>
<tr>
<th></th>
<th>% change in power requirement for twin-screw propulsion plant</th>
<th>% change in power requirement for CRP propulsion plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel resistance</td>
<td>-3</td>
<td>0</td>
</tr>
<tr>
<td>Hull efficiency</td>
<td>-5</td>
<td>0</td>
</tr>
<tr>
<td>Propeller efficiency</td>
<td>+11</td>
<td>+11</td>
</tr>
<tr>
<td>Total efficiency</td>
<td>+3</td>
<td>+11</td>
</tr>
</tbody>
</table>

Table 4

<table>
<thead>
<tr>
<th></th>
<th>Fuel consumption (g/kWh)</th>
<th>Power (kW)</th>
<th>Fuel consumption (Ton/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Engine Current Design</td>
<td>168</td>
<td>64.000</td>
<td>10.752</td>
</tr>
<tr>
<td>Main Engine with CRP</td>
<td>166</td>
<td>41.584</td>
<td>6.902</td>
</tr>
<tr>
<td>Extra generator power</td>
<td>160</td>
<td>16.960</td>
<td>2.714</td>
</tr>
<tr>
<td></td>
<td>62.160</td>
<td>9.617</td>
<td></td>
</tr>
</tbody>
</table>

The table shows that the fuel consumption with the CRP system is about 1.14 ton/h less than the system without the CRP system. This result of 1.14 ton/h can be found in table 4 by if you take the fuel consumption of the Main Engine Current Design which is 10.752 ton/h and subtract the fuel consumption of the Tripple-vessel equipped with the contra rotating propeller system which is 9.617 this gives: 10.752 - 9.617 = 1.14 ton/h. This means that the CRP system reduces the fuel consumption, so a vessel needs less fuel on a voyage. On the long term the CRP system will compensate for the costs and the vessel will also emit less gasses.

The result of the reduced fuel consumption is an important improvement for the financial aspect, but the reduced fuel consumption will result in less emissions which is better for the environment, and because of the new regulations all the vessels have to comply with the lowering of the exhaust gasses.
Concludes, this research found the benefits of the CRP system to lower the fuel consumption. These advantages will result in a fuel reduction of 1.14 ton/h. This means that the change of the two main engines into a single main engine with a pod, will result in a lower fuel consumption of 1.14 ton/h. And also the vessel can sail with 8% less power while maintaining the proper speed.

This 8% fuel consumption reduction will save a vast amount of money on the long term when equipped with the CRP system, however during this project no research has been conducted on the profitability of the system.

Which means that the costs of the CRP system might exceed the money saved on the long term, and could render the concept useless.
7. Conclusion and recommendation

The Triple-E vessels can reduce the fuel consumption and therefore reduce the emissions by applying the concept of Contra-Rotating propellers. When the vessel will be equipped with the suggested systems, the vessel can reduce her fuel consumption by 1.14ton/h. The vessel will also increase her propulsion efficiency due to the Contra-Rotating propeller system. With this increase of efficiency the vessel can sail at the same speed with less engine power. This results in a fuel consumption which is 8% less than the regular fuel consumption.

Our main recommendation is that there has to be further research regarding the financial aspects of the system to show whether this system will be profitable or not.

The recommendation for the shipowners is to apply the Contra-Rotating propeller system. The ship owners can add their own interpretation in choosing the main engine, pod and extra electrical power supply. The main engines power – pod power ratio is recommended as 70%-30% as explained in the application of the CRP system. The final specifications of the systems depends on the vessel her size and the demand of the ship owner.
8. Field research

As part of this project there had to be determined if a podded CRP system large enough to fit a Triple-E sized vessel could actually be applied. Because the pod makes up a large part of the CRP system it was vital to gather more information about large pods. To gather such information a meeting was planned on the 14th of March with the company ABB (producer of electrical components) which builds, sells and maintains pods of various sizes. The meeting was planned with Sales manager, Marine & cranes process automation division BNL Hans Buiteman. Also attending at this meeting was Bart…., service engineer at ABB. During this meeting useful information was provided by Mr. H. Buiteman and Bart after asking several questions which are mentioned below as well as our summary of their response.

- **Who are you and what’s your function at ABB?**
  Hans Buiteman: Sales manager, Marine & cranes process automation division BNL.
  Bart ….: Service engineer ABB.

- **Are you familiar with the concept CRP?**
  Yes, ABB is currently conducting research on this subject.

- **Has ABB conducted any research about the concept of CRP, if so what were the results of this research?**
  Yes, we currently have a research running in cooperation with Jumbo Shipping. However because this research is still running we can’t make a statement.

- **Can a vessel’s pod be repaired while the vessel is still in the water, or does it have to enter dock to do so?**
  Yes, the new larger pods manufactured by ABB are designed with an small open space which can be accessed by a ladder.
  This small space inside the pod will provide the crew to carry out small maintenance, and repairs inside the pod.
  However, larger maintenance like the replacement of the water seals, electric engine and main bearings have to be carried out inside a dry dock.

- **Does the pod require more maintenance compared to the ‘regular’ methods of propulsion?**
  No, the pod does not require more maintenance.
  The maintenance can be done during the routine docking of the vessel.
- **Can the propeller of the pod be replaced?**
  Yes, Al pods manufactured by ABB are custom made to meet the clients demands. Also the propellers aren’t made by ABB.

- **Will the water flow caused by the main propeller increase the wear on the pod?**
  No, the water flow won’t cause any extra wear on the pod due to its robust design.

- **The pod for the CRP system has to provide 19,2MW of power, will the pod like the ABB XO2300 provide this amount of power efficiently?**
  Yes this is possible, however because ABB manufactures the pod according to the client’s given specifications ABB will be able to manufacture a pod that is designed to provide the 19,2MW needed exactly.

  After this meeting there could be concluded that a pod large enough to fit the Triple-E CRP system could be manufactured and that there is little to no increase in maintenance.

  However in this interview was mentioned that the costs of the pod would be high and might render the CRP system not to be durable on the long term. But since the costs and durability according to the plan of approach is not a part of this research no conclusion shall be based on this assumption.
9. References


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