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## **Contra-Rotating Propeller and Vessel efficiency**

*A study based on self-propulsion factors & CRP*

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### **ABSTRACT**

The economy of marine vessels is mainly recognized by the fuel efficiency as it account for the maximum portion of the overall efficiency of the vessel. To overcome the problem of scarce resources and fuel saving devices, one of the best solutions can be

Replacement of conventional propeller by Contra Rotating Propeller (CRP). It is an efficient energy saving device recovering the loss of rotational energy of forward propeller by aft propeller and thus improves the performance of the vessels. Apart from improving the vessel, CRP also makes the relevant transportation more effective and efficient after contributing to the growth of the national economy.

The paper states about the various benefits and features of Contra Rotating Propeller which plays an integral role in improving the overall performance of the vessel. It also describes the design methodology briefly. The paper also highlights the inferences of relevant research which have been done by different research scholars using experimental and theoretical data and describing the advantages in effective wake factor.

**Keywords:** Contra-rotating propeller, Energy saving device, effective wake factor, Design methodology ,role in transportation, hydrodynamics aspects, and cavitation.

## 1. INTRODUCTION

Energy is a subject of concern to everyone .Today we not only need varied sources of energy whereas we also need methods to save energy. Economic development of national has historically been linked with the use of energy, which is an essential element of such development. Thus, it is prudent, that the question of energy is understood and appreciated by those who are involved in marine industry. As a result, energy saving has become common objective of every professional in their respective field. The reason behind is very obvious i.e. scarce resources and more demand. The scenario shows the most common problem, rise in oil price.



Fig.1 a Contra Rotating Propeller

Thus the demands for energy efficient vessels have increased. For that in recent years many methods and devices have developed with the concept to increase the thrust and reduce the torque. Most the conventional propeller works under the condition where the flow is unsteady, non uniform, with the limitation of propeller diameter due to ship stern. The typical case arises when conventional propeller generates torque and to overcome this torque, asymmetric stern hull is designed. To avoid these problems Contra Rotating Propeller (shown in fig. no.1) can be best option which cancels the torque and hence improves the performance of the vessel.

## **2. LITERATURE REVIEW**

The concept of Contra Rotating Propeller (CRP) was originated more than hundred years before. The credit goes to Ericsson who invented it in 1836 for 45 feet ship .Then after many theories were revised with addition of appreciable new concepts. In 1909, Italian navy had experimented CRP for 46 feet steam ship .Later, US navy successfully experimented on a 70 feet steam ship. Theodorsen around 1944 developed a theoretical method based on Contra Rotating Propeller which was restricted to uniform flow only. Lerbs derived induction factor for single rotation propellers in 1952 and following in 1955 he developed first *Lifting Line Theory*. Based on Lerbs theory in 1960 Morgan introduced a detailed computational scheme for CR propeller design. He assumed that the interference due to the lifting surface effects between two propellers could be neglected. This design technique was different from others and widely accepted. *Rutundi made one of the first comparative tests between CRP and CP for 3500 tons naval training ship and has reported an 18 percent improvement in propulsive performance. Since then, the revolution of CRP began and it was readily used in torpedoes and small vessels.* Gunsteren developed a useful method for calculation of interaction effects between two propellers. The concept was based on momentum theory which gave the convenient method for calculation of mutually induced velocities and pressures.

Then Caster and Lafone developed a second generation lifting line design method. In 1975, Nelson developed a series of computer programs for designing CR propeller. A new lifting line program was developed by Cox and Reed who worked independently on it. But the program was based on Caster and Lafone method. Chen and Reed ,in 1988, developed a new lifting surface program for CR propellers based on the MIT lifting surface design program with hub effects .The advantage of this program was that it used to compute induced velocities one over the other automatically. The most recent lifting method was developed by Kerwin in 1986.It employed variation methods to solve the two coupled lifting line integro-differential equations simultaneously.

## **3. Design Concept of Contra Rotating Propeller (CRP)**

### **3.1 Design characteristics**

While designing CRP system, more characteristics are considered as compared to Conventional Propeller (CP) System .Some of them are as follow:

- Thrust distribution between the forward and the aft propellers.
- Rotational speed (RPM) of the forward and the aft propellers.
- Distance between two propellers (separation of two propellers).
- Diameters of two propellers.

- Slipstreams of the forward and the aft propellers.

### **3.2 Design Procedure**

Designing of a CRP system for a given specification of hull and engine are done in following steps:

- Propeller design in Uniform flow: Firstly, the design is planned with the aim that it should fulfill engine power requirement and its RPM.
- Modified Design for Non-uniform flow: At this stage the design is modified as per non-uniform flow condition such that it can provide better result in terms of propeller induced vibration, strength of blade for the propeller performance in non uniform flows and propeller cavitations.

There are commonly two methods used for designing of CRP in uniform flow. First is based on Lifting Surface Theory and the second one is based on the Systematic Series Data obtained from Open Water Tests. From the past reviews of CRP's report it has been observed that second method was preferred.

### **3.3 Hydrodynamics concepts for Designing.**

There are three fundamental principles namely momentum, mass conservation and circulation conservation which provides the pillar for CRP design. There are two types of drag, first is the drag of the bare body and second is the drag due to the propeller hull interaction. The net force generated by the CR propeller must be balanced by these two drags as per momentum conservation principle. Thrust deduction and wake fraction are two phenomena which contribute to the propeller hull interaction. The circulation distribution of the aft propeller is determined by mass conservation as per specified circulation distribution of forward propeller. At last circulation conservation determines the magnitude of the aft propeller circulation to ensure proper thrust and torque ratios. As well known, a rotational flow is generated behind the propeller when thrust is produced by a screw- propeller as shown in Fig.2. This rotational flow does not contribute to generation of thrust instead causes a loss of energy. The CRP system significantly improves the propulsion efficiency by recovering a part of the energy loss due to the rotation flow and hence could significantly reduce the fuel consumption.

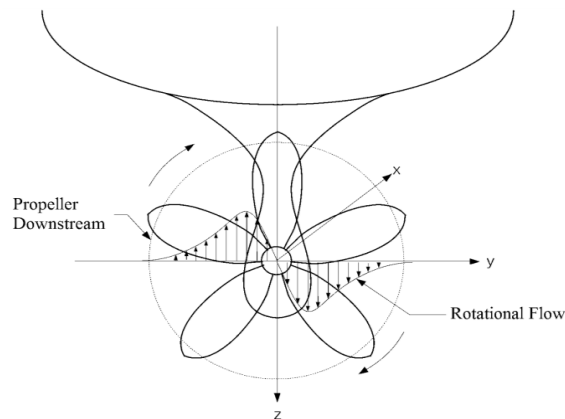


Fig.2 Tangential velocity distribution inside the slip stream for the propellers rotating in clockwise direction.

### 3.3.1. Ship Propulsion

To understand the basic relationship between ship power, shaft torque and fuel consumption we have to take the help of numerical methods which describes the mathematical relations among them.

**Torque:** Torque plays an important role in propulsion. The power generated by the engine is used to rotate the shaft connected between engine and propeller. Shaft horse power is converted in rotary force i.e. moment applied to the propeller. This rotary force necessary to turn the shaft is simply torque. It is sometimes denoted by  $Q$ . Torque of the propeller is given by

$$Q_s = K_Q T S \eta_R \rho D^5 n^2$$

$$K_Q = Q \rho n^2 D^5$$

Where  $\eta_R$  is relative rotative efficiency.

#### Relative rotative efficiency

The propeller in open water, with a uniform inflow velocity, at a speed of advance  $V_A$ , has an open water efficiency given by

$$\eta_0 = \frac{T V_A}{2 \pi n Q_0}$$

$Q_0$  is the torque measured in open water when the propeller is delivering thrust  $T$  at  $n$  revolutions.

**Thrust:** Thrust of the propeller is mathematically calculated by the relation given below:

$$T_s = K_r J^2 T S^2 \rho D^4 n^2 \quad ; \quad \text{advance ratio, } J = \frac{V_A}{n D} \quad ; \quad K_T = \frac{T}{\rho n^2 D^4}$$

And the thrust deduction is given by,  $T = 1 - R_T T$

#### Propulsive efficiency ( $\eta_D$ ) and hull efficiency ( $\eta_H$ )

$\eta_D = \frac{\text{effective power delivered}}{\text{power}} = \frac{P_{EPD}}{P}$  ;  $\eta_H = \frac{P_{EP}}{P_T} = \frac{R_T V_T}{V_A}$  ; wake factor,  $w_f = \frac{V - V_A}{V_A}$

Where T is the thrust, VA is speed in advance RT is the total resistance, PT is thrust power and PE is the effective power.

The gain in propulsive efficiency, together with the improved vibration characteristics of the smaller diameter screws and higher blade frequency, make the contra rotating propeller very lucrative from the hydrodynamics point of view.

•Cavitations

Cavitations occur when the local absolute pressure is less than local vapor pressure for the fluid medium. Cavitation number (inflow velocity) based is defined as :

$$\sigma_V = \frac{P - P_{vap}}{\rho A V_a^2}$$

Sometimes the propeller cavitation number is defined based on the propeller tip speed:

$$\sigma_{ND} = \frac{P - P_{vap}}{\rho n^2 d^2}$$

The Critical measurement for cavitation performance is the cavitation inception point which is the conditions (i.e. Cavitation number) for which cavitation is first observed anywhere on the propeller. Typically the Inception cavitation number as a function of Kt or J is plotted for a given

propeller which defines the cavitation free operation boundary. This boundary typically has a bucket shape which is referred to as the cavitation bucket. The given below fig.3 shows the phenomenon of cavitation. Morgan concluded that Lerbs' theory resulted in propellers with good torque balance and higher efficiencies than single propellers, and by giving more accurate values

of the inflow velocities to each section of the propeller blades gave better control over the cavitation performance of contra rotating propellers.



Fig.3 Cavitations.

3.3.2. Self Propulsion Test

The objective of self propulsion test is to confirm early ship power and speed requirements and to check the propulsor is able to absorb delivered. While designing a propeller for a ship the estimation of rough values of wake, thrust deduction fractions and relative rotative efficiency is very necessary as it helps in calculation of power. By far the most reliable values of these factors will be found from preliminary self-propelled model tests, in which a model of the new ship is propelled by a stock propeller chosen to have its principal characteristics as near as possible to the probable final design. These values will form a reliable basis for the design of the propeller, and if in the final model tests slight differences are found these can be allowed for in the manufacture of the ship propeller. The author has not done the self propulsion test rather he has collected data from research papers and had done study on contra rotating propeller regarding how it works and how it can be useful in energy saving.

As a part of the ongoing research and development process of the Steerprop propulsors, a series of model tests has been conducted at Krylov Shipbuilding Research Institute in St. Petersburg, Russia. The dual-end contra-rotating propulsor configuration was tested in both the towing tank (open water tests) and in the cavitation tank. The test series clearly showed the benefits of the dual-ended configuration and thus also proved the claims for high efficiency of CRP.

#### 4. Advantages

**Today CRP is regarded as energy saving device which recovers the loss of rotational energy of forward propeller by aft propeller and thus improving the performance of the vessel by 10 percent comparing conventional propeller (CP).** Apart from improving the vessel CRP also makes the relevant transportation more effective and significant after contributing the growth of national economy. Some the advantages are:

- It recovers the rotational energy that is lost in slipstream.
- It provides higher efficiency for a given disk area (smaller optimum diameter and lower loading per blade).
- Increased cavitations inception speeds through reduced blade loading for, blade surface cavitations and reduced circulation for tip vortex cavitations.
- Torque balance resulting and simpler machinery mounting system.

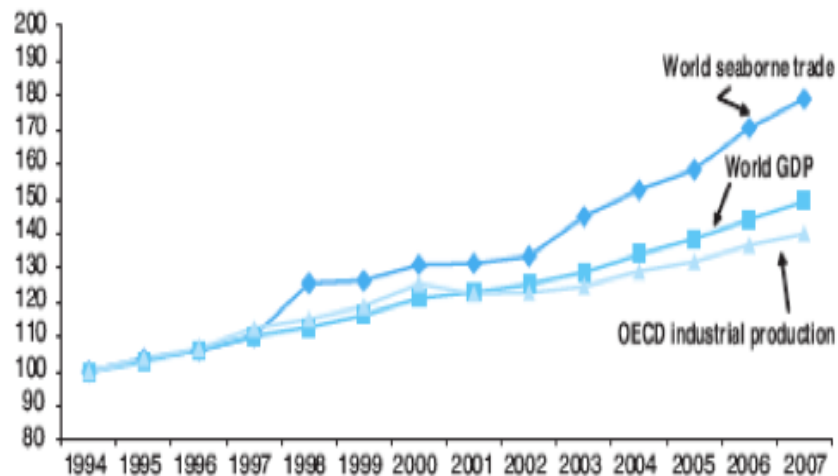
Nowadays several vessels equipped with CRP such as Bulk Carriers and very large crude carriers, are in service and a remarkable energy saving effect has been observed. Recently IHI MARINE UNITED INC. has successfully completed several diesel electric driven vessels equipped with CRP. The research work done by great scholars like Morgan in 1960 and Ishida in 1988 have proved that open water efficiency has been remarkably improved from conventional propeller. At the same other researchers reported that not only open water efficiency whereas as interaction between self propulsion factors like propeller, hull and rudder was drastically changed.

Meanwhile, it was reported that an effective wake fraction of CRP got often better than CP. The model test conducted by Fujino for bulk carrier observed higher effective wake fraction beyond 10 percent compared with conventional propeller (CP). As we know that effective wake factor is one of the major parameter to govern vessel's performance, the

CRP equipped vessels can satisfy our need. **Recently the CRP system developed by IHIMU has claimed to achieve 10 percent better propulsion efficiency compared to conventional diesel electric propulsion system, and is applicable to all vessels from small ships to large LNG carriers.** This efficiency improvements translates into significant fuel savings, thus enabling a short return in investment as well as reduced greenhouse gas emission .Research also shows that application of CRP system could be extended to include hybrid (mechanical driven and electric driven) propulsion system, and four stroke mechanical system at a future stage.

## 5. HOW IT HELPS IN TRANSPORTATION ECONOMY

*Maritime transport remains the backbone of international trade over 80 percent of world merchandise trade by volume being carried by sea.* What is the reason behind it? The answer is very simple. Seaborne transportation provides cheapest, safe, and convenient means of transportation. Shipping is essential to the functioning of the global economy and its dependence upon moving goods from production to consumption sites. World seaborne trade rises with economic growth. Shipping dominates world international cargo transport; passenger transport has met strong competition from air transport. The American market is the largest cruise market. The Mediterranean and Asian markets are developing fast, however. The major commodities in seaborne trade are crude oil, oil products, gas, chemicals, coal, iron ore, grain, phosphate, alumina, and intermediary and finished goods. The latter two are mainly carried in containers, whereas the first nine are moved in bulk. In addition, special shipping segments such as transportation of cars and of heavy cargoes plus offshore vessels supporting offshore oil production have emerged and grown into important segments in international shipping.



Source: UNCTAD secretariat on the basis of *OECD Main Economic Indicators*, April 2008; UNCTAD *Trade Development Report 2008* and UNCTAD *Review of Maritime Transport*, various issues.

Now, the importance of seaborne transportation is very clear where the need of energy efficient vessels plays a vital role. If we have methods to save energy in other words saving fuel we can make the transportation more economical and thus can enhance the growth of national economy. Therefore CRP is one of the best solutions for economical transportation as it provides improved propulsive efficiency and helps in saving the fuel indirectly money.

## **CONCLUSION**

In this paper we have discussed about an alternative propeller that is called Contra Rotating Propeller (CRP), its design methodology in brief, its literature review, advantages, its role in transportation, and finally we come to the conclusion that are numerated below :

- Propulsion efficiency is significantly improved by a CRP system, and hence, the same amount of fuel-saving could be achieved.

- It has been concluded by great scholars that almost all lost energy due to the rotational flow except the frictional loss can be recovered by the CRP system, if the system is properly designed.

- Torque balance resulting and simpler machinery mounting system.

- Increased cavitations inception speeds through reduced blade loading for, blade surface cavitations and reduced circulation for tip vortex cavitations.

Thus, the Contra Rotating Propeller has proved its great importance in building an energy efficient vessel for the economy of transportation and the nation both. Now, we need encourage this alternative propeller for efficiency improvements which translates into significant fuel savings, thus enabling a short return in investment as well as reduced greenhouse gas emission.

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