# Latest experiences with Contracted and Loaded Tip (CLT) propellers

Juan Gonzalez Adalid
*SISTEMAR s.a, Madrid, Spain, sistemar@sistemar.com*

Giulio Gennaro
*SINM s.r.l., Genoa, Italy, sinm@sinm.it*

ABSTRACT: Since 1976 tip loaded concept has been evolved continuously. Presently SISTEMAR's CLT propellers are installed on about 280 vessels world wide. Despite this fact the use of CLT propellers has been curtailed due to the lack of specific knowledge of this type of propeller and due to the fact that CLT propellers need a different model-to-full-scale extrapolation methodology in respect with conventional propellers.
The conclusions that can be drawn from more than 30 years of model and full scale experiences are the following:

- CLT propellers are a fully developed technology;
- CLT propellers grant several significant advantages over conventional propellers, the most important being:
    - 5 to 8% higher efficiency over the entire operational range (i.e. 5 to 8% fuel saving and 5 to 8% reduced emissions);
    - lower induced noise and vibrations;
    - Improved ship maneuverability characteristics;
- CLT propellers are extremely indicated for new buildings and very attractive for ships in service.

## 1. INTRODUCTION

The first claims about the potential advantages of tip loaded propellers (TVF propellers, Tip Vortex Free propellers) were published in October 1976 in “Ingeniería Naval” [Ref.1].

Since 1976 tip loaded concept has been evolved continuously. After the first few years the design of tip loaded propellers was improved by accounting for the contraction of the fluid vein crossing the propeller disk. In this manner the new generation of SISTEMAR's tip loaded propellers was devised and, consequentially, it was named CLT propeller: Contracted and Loaded Tip Propeller.

Presently CLT propellers are the most efficient and widespread type of unconventional propeller, being currently installed on about 280 vessels worldwide.

In 1980 the “Lifting Line Theory” was generalized and the first designs were produced. From 1983 onward the use of folded tip propeller became systematic. Later on Prof. Gonzalo Perez Gomez and Juan González-Adalid completely revisited the screw propulsion theory; in 1993 they published the “New Momentum Theory”, which corrects the conventional “Momentum Theory”; in 1995 they published the “New Cascade Theory”, which takes into account the three dimensional cascade effects differentiating a propeller blade from an isolated wing profile.

From the beginning, the full scale experiences with CLT propellers showed remarkable agreement with the design calculation, while it became apparent the ITTC extrapolation procedures were not adequate for CLT propellers. This was, and it still is, a major obstacle for the installation of CLT propellers on new-buildings.

Figure 1. The striking difference between a CLT and a state-of-the-art high skew conventional propeller blade designed for the same Ro-Pax.

For this reason a series of R&D activities were carried out by SISTEMAR, in cooperation with CEHIPAR and NAVANTIA, between 1996 and 2006, in order to devise suitable model test procedures and extrapolations capable of predicting the full scale performance of CLT propellers with a similar level of confidence as in the case of conventional propellers.

Since 2007 SISTEMAR has been actively participating in different R&D projects of EU convocatories and has performed a very extensive R&D project with the A.P. Moeller Maersk Group.

## 2. GENERAL DESCRIPTION OF CLT PROPELLERS

CLT propellers are characterized by the following:

- The blade tip generates a substantial thrust.
- The pitch increases from the root to the tip of the blades.
- The chord at the tip is finite.
- End plates are fitted at the blade tips, toward pressure side; they are adapted to the fluid vein contraction to reduce as much as possible their viscous resistance.

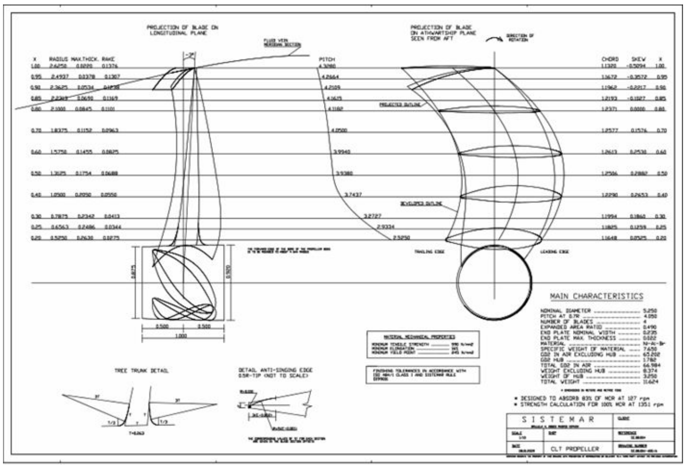


Figure 2. Typical drawing of a FP CLT propeller.

The end plates operate as a barriers, avoiding the communication of water between the pressure and the suction side of the blades, allowing to establish a finite load at the tip of the blades. At the same time the presence of longer chords at the tip determines the decrease of the local loading per square meter, thereby helping in controlling the cavitation.

The fundamental goal of the CLT propeller is to improve the propeller open water efficiency by reducing the hydrodynamic pitch angle through the reduction of the magnitudes of induced velocities at the propeller disk.

In the new momentum theory the parameter ε is defined; ε is the ratio between the suction in front of the propeller disk and the pressure jump across the propeller disk. In other words ε defines how the propeller thrust is obtained by combining the under-pressure existing at the suction side of the propeller blades:

$$(p_o - \varepsilon \Delta p)$$

with the over-pressure existing at the pressure side of the propeller blades:

$$(p_o + (1-\varepsilon)\Delta p).$$

In accordance with the new momentum theory, to reduce the magnitude of the induced velocities at the propeller disk it is necessary to reduce the value of ε, which means to reduce the suction for the same pressure jump across the propeller disk.

The non dimensional propeller specific load coefficient is defined as follows:

$$C_{TH} = T / (0.5\ \rho\ A\ V^2)$$

The ideal propeller efficiency can be expressed as a function of the non dimensional propeller specific load; according to the classic momentum theory the formulation is as follows:

$$\eta_0 = 2 / (1 + (1 + C_{TH})^{0.5})$$

The expression of the ideal propeller efficiency according to the New Momentum Theory is rather different:

$$\eta_0 = 1 / (1 + \varepsilon\ C_{TH})^{0.5}$$

In Figure 3 both formulations are plotted; the following comments can be made:

- According to the new momentum theory $\eta_0$ increases when ε decreases;
- The new momentum theory allows for greater ideal efficiency than classic momentum theory in case of ε parameter having a low value.

The ε coefficient depends on the type of propeller, its main characteristics (diameter, number of blades, blade area ratio, etc.) and on the radial load distribution.

For conventional propeller ε is in the range of 0.4, for a CLT propeller ε is in the range of 0.1.

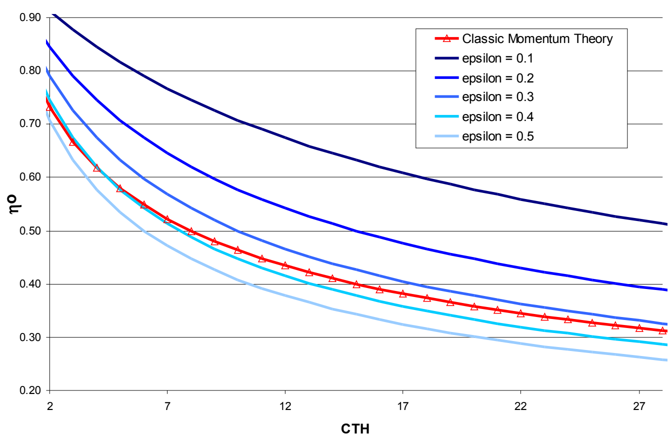


Figure 3. Ideal efficiency according to either the classic and the new momentum theory.

In the following table the full scale open water efficiency of recent CLT propellers is given in relation to their thrust loading coefficient.

| Case | $C_{Th}$ | $\eta_o$ |
|---|---|---|
| 1 | 3.077 | 0.596 |
| 2 | 2.973 | 0.576 |
| 3 | 1.249 | 0.726 |
| 4 | 1.090 | 0.709 |
| 5 | 0.712 | 0.729 |

Table 1. Open water efficiency vs thrust loading coefficient for some recent CLT propeller designs.

## 3. ADVANTAGES OF CLT PROPELLERS

Up to date CLT propellers, both of fix and controllable pitch type, have been successfully installed on more than 280 vessels, of very different types:

Tankers, Product carriers, Chemical carriers, Bulk carriers, Cement carriers, General cargoes, Container ships, Reefers, Ro–Ro, Ro–Pax, Fishing vessels, Trawlers, Catamarans, Hydrofoils, Patrol boat, Landing crafts, Oceanographic ships, Yachts.

The application range has been extremely wide:

- Up to 300,000 DWT
- Up to 22 MW per propeller
- Up to 36 knots.

The advantages of CLT propellers over conventional propellers resulting from full scale installations and from several comparative full scale trials and long term observation are the following:

- Higher efficiency (between 5 and 8%)
  - Fuel saving
  - Reduced emissions
  - Saving on MM/EE maintenance
  - Higher top speed
  - Greater range
- Inhibition of cavitation and of the tip vortex
  - Less noise
  - Less vibrations
  - Lower pressure pulses
  - Lower area ratio
- Greater thrust
  - Smaller propeller optimum diameter
  - Better maneuverability.

It should be remarked that the advantages offered by CLT propellers in terms of reduced emissions and fuel consumption add to what achieved by other means (e.g. hull form optimization, hull maintenance, slow steaming, exhaust gas treatment...).

The percentage of efficiency improvement over an alternative conventional propeller and hence the fuel saving achieved depends on the type of vessel, being higher for slow vessels with high block coefficient as tankers, bulk carriers, etc.

CLT propellers can be applied both for new-buildings and ships in service, either in FP or CP type. The boss for FP applications and the blade flange for CP are interchangeable with the ones of the alternative conventional propeller/blades and the inertia is almost the same, therefore the installation of CLT propeller/blades does not introduce any modification in the shaft line neither for new-buildings nor retrofittings.

Figure 4. FP CLT propellers installed on an hydrofoil.

In case of CP applications there are additional advantages for CLT blades operating in off-design conditions at constant rpm derived from its special radial pitch distribution. For conventional blades the radial pitch distribution at design pitch setting is unloaded at the blade tip with the aim to reduce the risk of high pressure pulses; such unloading becomes excessive in off-design low-pitch conditions so that the outer sections of the blades provide a negative thrust while the inner sections provide a positive thrust, as a consequence the propeller efficiency decreases while the level of pressure pulses increases because of the existence of a broad band spectra.

This is not the case for CLT blades because in off-design conditions the blade tip is a little bit unloaded but it still produces a positive thrust for a wide range of pitch settings and therefore the propeller efficiency is high also in off-design conditions and the broad band spectra of pressure pulses is not generated.

The effective reduction of pressure pulses, for CLT propellers, is due to both the higher clearances between propeller and stern post contour (thanks to the lower optimum diameter) and to the lower amplitude of higher orders harmonics (thanks to the more stable sheet cavitation developed on the suction side of the propeller). Model and full scale measurements demonstrated that the amplitude of the first harmonic may be similar to than the one of the alternative conventional propeller, or even higher in some case, but the higher order harmonics are much lower and therefore the total excitation for the CLT propeller is lower than for an alternative conventional propeller.

The amelioration in the maneuverability is due to the higher overpressure downstream of the CLT propeller and to the flow concentration produced by the end plates which can be roughly compared with the effect of a nozzle. Due to the higher pressure and the flow concentration acting on the rudder the action of the rudder is more effective in combination with a CLT propeller than with an equivalent conventional propeller. Significant reductions in tactical diameter and in the crash stop distance have been measured at full scale with different vessels alternatively fitted with conventional and CLT propellers.

## 4. PAST R&D PROJECTS ON CLT PROPELLERS

In the past the following R&D activities were carried out on CLT propellers.

1997 – 2000 "Optimization of ship propulsion by means of innovative solutions including tip plate propellers." CEHIPAR, NAVANTIA, SISTEMAR. This R&D project resulted in the development of an ad hoc extrapolation procedure for open water tests of CLT propeller. The extrapolation is based on the ITTC-78 method adapted for CLT propellers by considering the presence of the end plates and the scale effects on lift forces.

During 1999 a new type of mean lines has been developed by SISTEMAR with the aim to improve further the efficiency of CLT propellers by reducing the under-pressure on the suction side and increasing the overpressure on the pressure side. These mean lines are characterized by a higher slope at the trailing edge compared to standard NACA mean lines.

2001-2003 "Research on the cavitation performance of CLT propellers, on the influence of new types of propeller blades annular sections and the potential application to POD's" CEHIPAR, NAVANTIA, SISTEMAR. This R&D project resulted in the development of a new procedure for cavitation tests and pressure fluctuation measurements with CLT propeller at model scale.

2003 – 2005 "Research on the performance of high loaded propellers for high speed conventional ferries" CEHIPAR, NAVANTIA, SISTEMAR, TRASMEDITERRANEA, TSI. The aim of this research was the full scale application of CLT propeller blades to a large and modern conventional Ro-Pax and a complete full scale measurement campaign, aimed at comparing the CLT propeller blades with state-of-the-art high skew conventional propeller blades.


Figure 5. A CP CLT propeller installed in a modern Ro-Pax.

2005 – 2008 "SUPERPROP: Superior Life Time Operation of Ship Propeller" an EU sponsored R&D project aimed at studying the influence of different maintenance policies on the hydrodynamic performance of tugs and trawlers.

Within this project a CLT propeller was successfully retrofitted on a trawler.

## 5. ONGOING R&D PROJECTS ON CLT PROPELLERS

Several R&D projects on CLT propellers are currently being conducted.

In 2009 SISTEMAR has been invited by CEHIPAR and VTT to participate as subcontractor to the SILENV project implemented under the Seventh Framework Program of the EC, with the main objective of establishing a "green label" for vessels achieving low levels of noise and vibration on board as well as defining design guidelines to achieve said levels. CLT propellers will be analyzed by means of CFD calculations and model tests as one of the potential resources to decrease the noise and vibration levels on board.

The project "Triple Energy Saving by use of CRP, CLT and PODed propulsion" (TRIPOD) has been approved within the FP7 of the EU. The project has started on 1st November 2010 with the participation of A.P. Moeller Maersk, ABB, VTT, CEHIPAR, CINTRANAVAL DEFCAR and SISTEMAR. The main goal of this project is the development and validation of a new propulsion concept for improved energy efficiency of ships through the advance combination of three existing propulsion technologies: podded propulsion, CLT propellers and counter-rotating propeller (CRP) principle.

The ship selected for this R&D project is the 8.500 TEU's container vessel "Gudrun Maersk."

## 6. THE ROY MAERSK R&D PROJECT

In 2006 SISTEMAR entered into talks with A.P. Moeller Maersk who, at that time, was conducting an internal evaluation of energy saving devices. The CLT propellers were selected as the single most promising device and a joint R&D campaign was launched with the aim of conducting comparative model and full scale tests with CLT propellers.

CLT propellers were designed for a 2,500 TEU container vessel, a 35,000 DWT product tanker and a VLCC. Subsequently all three CLT propellers were tested at model scale at HSVA, Hamburg. The CLT propeller for the 35,000 DWT product tanker was also tested at CEHIPAR.

It was finally decided to proceed to a full scale on the 35,000 DWT product tanker Roy Maersk. At the end of October 2009 she was retrofitted with a CLT propeller.

Figure 6. 35,000 DWT product tanker “Roy Maersk”, new CLT propeller and pre-existing WED.

| | | |
|---|---|---|
| $L_{PP}$ | 162.0 | m |
| B | 27.40 | m |
| T | 9.75 | m |
| Δ | 35,300 | t |

Table 2. Main characteristics of M/V Roy Maersk

| | Conventional | CLT | |
|---|---|---|---|
| D | 5.65 | 5.25 | m |
| z | 4 | 4 | - |
| $a_E$ | 0.563 | 0.490 | - |
| P @ 0.7 r | 3.685 | 4.050 | m |

Table 3. Main characteristics of the propellers

A long measurement campaign has been conducted at full scale on the Roy Maersk, with two main goals:

- to compare the model scale extrapolations with the full scale measurements;
- to ascertain the advantages of the CLT propeller over the conventional propeller.

At the time of writing the present paper we were not yet authorized to disclose fully the results of the Roy Maersk R&D project, which will be the subject of a paper to be published in the near future.

In any case we can confirm that both goals were satisfactorily achieved:

- the full scale pressure pulses showed a good agreement with the ones measured at model scale;
- the cavitation patterns observed at full scale showed very good agreement with the ones observed in HSVA's HYCAT cavitation tunnel;
- the CLT propeller open water test extrapolation was checked by means of a KQ analysis which gave satisfactory results, uncertainties taken in due care;
- the gain in efficiency was comparable to the expected one, uncertainties taken in due care.

## 7. CLT PROPELLERS AND CFD

CFD technology has being applied to CLT propellers by several reputable institutions, such as as CEHIPAR and VTT, in order to try to gain insight to the scale effects peculiar of CLT propellers.

The results of these calculations have been contradictory, in general the CFD have confirmed the larger scale effects on KT, in comparison with conventional propellers, but they have been inconclusive in respect with the scale effects on KQ.

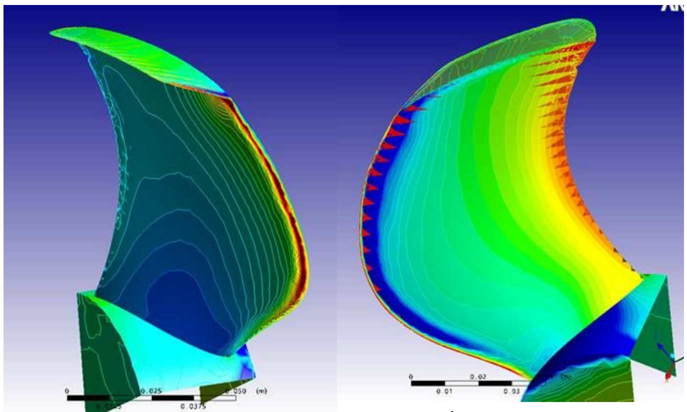

Figure 7. Pressure distribution on the pressures side (left) and on the suction side (right) of a CLT propeller blade computed by means of CFD.

In particular very large deviations have been observed between measurements and calculations performed at model scale, with errors up to about 6.5% on KT and 16.5% on KQ. This has so far prevented the use of CFD other than for qualitative purposes.

Lately CEHIPAR and the University of Genoa have reported very good agreement between measurements and CFD calculations of CLT propellers. In addition Lloyd Register has reported good agreement between observed and calculated cavitation patterns.

In conclusion it appears that today CFD is not yet sufficiently reliable for calculating CLT propellers but that it will be in a matter of years.

## 8. LATEST CLT PROPELLER INSTALLATIONS

In the last few years several noticeable CLT propeller installations have been completed.

In October 2009 the sea trials of the m/v Cantabria (Buque de Aprovisionamiento en Combate, BAC Class), the new replenishment vessel of the Spanish Navy, were carried out.

Figure 8. The replenishment vessel A15 Cantabria.

The m/v Cantabria is equipped with the largest and most powerful CP CLT propeller manufactured to date (single screw, 5 blades, diameter 5.7 meter, MCR 21.8 MW).

The full scale performance of the CLT propeller was in line with both design calculation and model test predictions.

The Spanish Navy has programmed a series of 14 corvettes (Buques de Acción Marítima, BAM class) to be built by NAVANTIA. All the units of the BAM class will be equipped with CP CLT propellers (twin screw, 4 blades, diameter 3.45 meter, MCR 2 x 4.5 MW).

All the 4 units of the first batch have been already launched and the sea trials of the lead unit were performed in March 2011 with satisfactory results.

The next batch of 5 units has been already announced by the Spanish Ministry of Defense and it is expected to be signed by summer 2011.

Figure 9. The launching of P41 Meteor, the lead unit of the BAM class

The Brazilian company EMPRESA DE NAVEGAÇAO ELCANO has signed a new building contract with ESTALEIROS ITAJAI shipyard for three 7,500 m³ LPGs to be chartered to PETROBRAS. The propulsion system will consist of a two stroke Diesel engine, MCR 4,400 kW, driving a 3.9 m CP CLT propeller. Model tests have been satisfactorily carried out at CEHIPAR, Madrid, in early 2011.

## 8. CONCLUSIONS

The technology for the design of CLT propellers is fully developed as well as the technology related with their model tests. This allows to estimate the performance of a CLT propeller at full scale with the same degree of accuracy of a conventional propeller.

The merits claimed for the CLT propeller (higher efficiency, lower noise an vibration levels and better maneuverability characteristics) have been demonstrated in more than 280 full scale applications for very different ship types.

The percentage of efficiency increase is in the range of 5 – 8 %, in general being higher for slow vessels with high block coefficient as tankers, bulk carriers, etc... Such increase in efficiency translates directly into comparable fuel saving and emission reduction.

SISTEMAR is currently involved in the application of CLT propellers to podded propulsors as well as in the application CFD codes to CLT propellers.

## REFERENCES


1. G. PEREZ GOMEZ. “Una innovación en el proyecto de hélices”. Ingeniería Naval, October 1976.
2. G. PEREZ GOMEZ; J. GONZALEZ-ADALID.

"Tip Loaded Propellers (CLT). Justification of their advantages over high skewed propellers using the New Momentum Theory". SNAME – New York Metropolitan Section, Fiftieth Anniversary 1942-1992, 11th February 1993 and also at International Shipbuilding Progress nº 429, 1995.
3. G. PEREZ GOMEZ; J. GONZALEZ-ADALID. "Optimisation of the propulsión system of a ship using the Generalised New Momentum Theory". WEMT Golden Metal Awards, 1997.
4. G. PEREZ GOMEZ; J. GONZALEZ-ADALID. "Detailed Design of Ship Propellers". Book edited by FEIN (Fondo Editorial de Ingeniería Naval), Madrid 1998.
5. G. PEREZ GOMEZ; J. GONZALEZ-ADALID. "Nuevo procedimiento para definir la geometría de las líneas medias de las secciones anulares de las palas de una hélice". Ingeniería Naval, September and December 1999.
6. M. PEREZ SOBRINO; J.A. ALAEZ ZAZURCA; A. GARCIA GOMEZ; G. PEREZ GOMEZ; J. GONZALEZ-ADALID. "Optimización de la propulsión de buques. Un proyecto español de I+D", XXXVI Technical Sessions of Ingeniería Naval. Cartagena, 25th and 26th of November 1999.
7. G. PEREZ GOMEZ; J. GONZALEZ-ADALID. "Scale effects in the performance of a CLT propeller". The Naval Architect, July/August 2000.
8. M. PEREZ SOBRINO; E. MINGUITO CARDEÑA; A. GARCIA GOMEZ; J. MASIP HIDALGO; R. QUEREDA LAVIÑA; L. PANGUSION CIDALES; G. PEREZ GOMEZ; J. GONZALEZ-ADALID. "Scale Effects in Model Tests with CLT Propellers". 27th Motor Ship Marine Propulsión Conference. Bilbao, Spain, 27th-28th January 2005.
9. "CLT: A Proven Propeller for Efficient Ships". Supplement of the Naval Architect, July/August 2005 issue.
10. G. PEREZ GOMEZ; J. GONZALEZ-ADALID; A. GARCIA GOMEZ; J. MASIP HIDALGO; R. QUEREDA LAVIÑA; L. PANGUSION, E. MINGUITO CARDEÑA, C. GALINDO, M. PEREZ SOBRINO; "Full scale comparison of a superferry performance fitted with both High Skew and CLT blades". WMTC Conference. London, U.K, 2006.
11. G. PEREZ GOMEZ; M. PEREZ SOBRINO; J. GONZALEZ-ADALID; A. GARCIA GOMEZ; J. MASIP HIDALGO; R. QUEREDA LAVIÑA; E. MINGUITO CÁRDENA; P. BELTRÁN PALOMO. "Un hito español en la propulsión naval: rentabilidad de un amplio programa de I+D+i". Ingeniería Naval, June 2006.
12. A. SANCHEZ CAJA, T. P. SIPILA, J.V. PYLKKANEN "Simulation of the Incompressible Viscous Flow around an Endplate Propeller Using a RANSE Solver" 26th Symposium on Naval Hydrodynamics Rome, Italy, 17-22 September 2006.
13. G. GENNARO; J.G. ADALID; R. FOLSO. "Contracted and loaded tip (CLT) propellers. Latest installations and experiences". 16th International Conference of Ship and Shipping Research, NAV 2009. Messina, Italy. November 2009.
14. B. CERUP.SIMONSEN; J.O. DE KAT; O.G. JAKOBSEN; L.R. PEDERSEN; J.B. PETERSEN; T. POSBORG. "An integrated approach towards cost-effective operation of ships with reduced GHG emissions". SNAME, 2010.
15. H. HAIMOV; J. VICARIO; J. DEL CORRAL. "Ranse Code Application for ducted and endplate propellers in open water". 2nd International Symposium on Marine Propulsors SMP'11, Hamburg, June 2011.

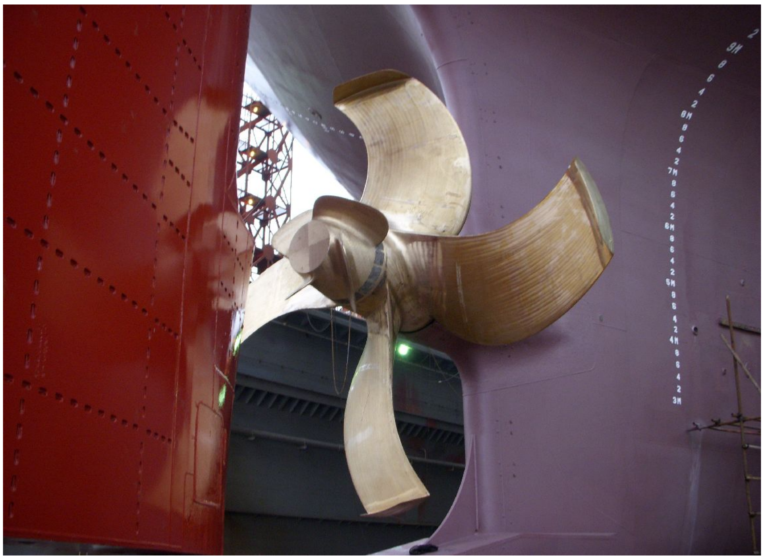

Figure 10. A FP CLT propeller installed on a bulk carrier, note the pre-existing PBCF and twisted rudder