Propulsion of Offshore Support Vessels

Contents:

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Abstract

This paper describes how the design process works at MAN B&W Diesel when engineering propulsion packages. The company's strategy is to further develop its role as a single source supplier of propulsion systems for offshore support vessels – like for numerous other marine propulsion segments, which have been continously developed since 1904. The recent technological progress done in the offshore propulsion field is presented in this paper. Making optimal custom-designed propulsion solutions involves many parties such as owners, shipyards, consultants/ship designers and suppliers. The best solution for the customer requires close cooperation and coordination between all parties. With the application of CFD (Computational Fluid Dynamics) as a propulsion optimisation tool, MAN B&W Diesel has developed an improved propeller nozzle design for various applications. The most interesting results of the latest development supplemented by model test results will be presented.

Introduction

The development of the offshore propulsion business at MAN B&W Diesel dates back to the early 1970s, and has since then not only been focused on supplying complete propulsion systems but has also been concentrated on the associated know-how and technology.

The demand for system engineering and package responsibility has grown in recent years. One reason is the reduced technical staff at most shipyards in combination with outsourcing of technical work to consultants and partners.

A general and common experience is that the engineering of a propulsion package not only requires engine, gear, propeller and control expertise. A number of integration tools and skills are necessary as well. Not even the best engine specialist in cooperation with the best gear specialist, the best propeller specialist and the best control specialist are capable of engineering and attaining an overall optimisation of a genuine propulsion package without these integration tools and disciplines.

Propulsion plant engineering as well as single element engineering are vital for the creation of genuine complete propulsion packages which cover the shipowners' need for reliable ship propulsion.

MAN B&W Diesel takes responsibility in the entire plant life cycle by supplying and servicing propulsion systems and equipment.

The typical standard OSV (Offshore Supply Vessel), designed for maximum bollard pull, is a twin screw vessel with CP propellers operating in nozzles.

To ensure that a certain bollard pull is attained, different approaches can be taken into use. Most of them are methods that directly lead to the required power to be installed and are based on thumb rule figures. Precise optimisation of an OSV for bollard pull, requires a more detailed analysis of parameters like engine power, propeller diameter, nozzle design and propeller hull interaction.

Limiting ourselves to twin screw vessels and their propulsion systems, the following describes a design procedure that will ensure an optimum solution with respect to attaining a certain bollard pull. As it is customary with most projects, this procedure is divided into a project stage where the main parameters are fixed and subsequently an order stage where attention is paid to the details.

Project Stage

Thumb rules

Within the industry it is common practice to apply a simple thumb rule for a given propulsion power to obtain a first estimation of the bollard pull. One rule for instance states that the bollard pull is in the order of 1.36 metric tons per 100 bhp. A more scientific formulation using the non-dimensional propeller characteristics – Kt and Kq – specifies the bollard pull to be calculated from ((Kt/π)^(3/2))/Kq. The former has proven too simple to apply for a wide spectrum of propulsion configurations whereas the latter is too complicated in daily use.

Refined approach

Apart from the engine power, the propeller diameter is the second most important factor in determining a more correct bollard pull. Based on a theoretical study of model tank test results, correlated with full scale measurements, a new refined formulation has been made. Input is now not only the engine power but also the propeller diameter being combined into the power density given by:

$$\frac{P_D}{\frac{\pi}{4} D_P^2}$$

where P_D [kW] is the delivered power at the propeller (engine power minus transmission and shaft losses) and D_P [m] is the propeller diameter.

Displaying the specific bollard pull as a function of the power density gives a universal coherence as shown in Fig. 1.

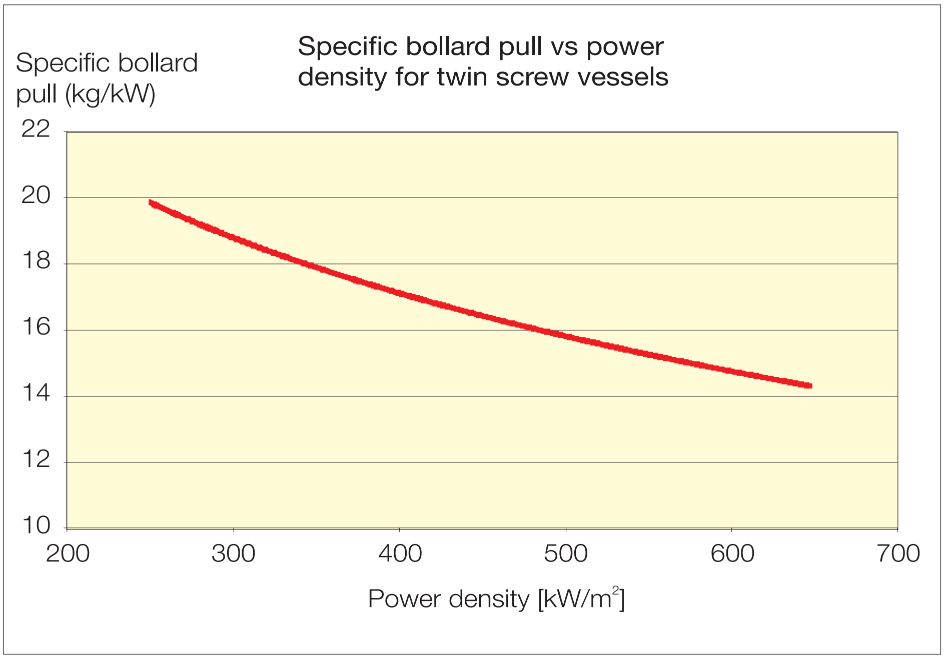

Fig. 1: Specific bollard pull vs. power density

Converting from specific bollard pull to an absolute bollard pull in kg is done by multiplying with the delivered propeller power. As can be seen from Fig. 1, the obtainable bollard pull depends on the power density. To achieve the highest bollard pull for a vessel with a given power, a low power density should be chosen. As a consequence, the propeller diameter should be as big as the hull can accommodate, and still secure a full immersion of the propeller in ballast draft. It is presumed that the propeller speed is optimised for the given power and propeller diameter.

Example

In order to obtain a bollard pull of 90 tons, several combinations of engine power and propeller diameter exist. The MAN B&W Diesel standard propulsion programme for the L27/38 engine type can be used to illustrate a number of possibilities for obtaining a 90 tons bollard pull. Possible twin screw plant combinations with ducted propellers are listed in the following table.

Engine		Gearbox		Propeller		Bollard pull for a twin screw OSV [tons]
Type [-]	Power [kW]	Series	Type	Speed [Rpm]	Diameter [mm]	
6L27/38	2040	AMG28EV	60VO28	134	3650	90.0
7L27/38	2380	AMG28EV	45VO30	177	3200	91.2
8L27/38	2720	AMG28EV	36VO30	224	2850	91.8
9L27/38	3060	AMG28EV	29VO30	274	2550	91.2

The example clearly reflects the influence of the power density on the bollard pull. A 6L27/38 propulsion plant with a power of 2x2040 kW delivers a bollard pull similar to a 9L27/38 with a power of 2x3060 kW. The cost comparison of the different propulsion configurations given in Fig. 2 further highlights the advantage of a low power density.

The power for maintaining a vessel service speed of 12 knots as given in Fig. 3 again favours the lower power density given by the 6L27/38 propulsion plant. From both an initial investment and operating cost point of view, the lowest power density configuration is indeed preferable.

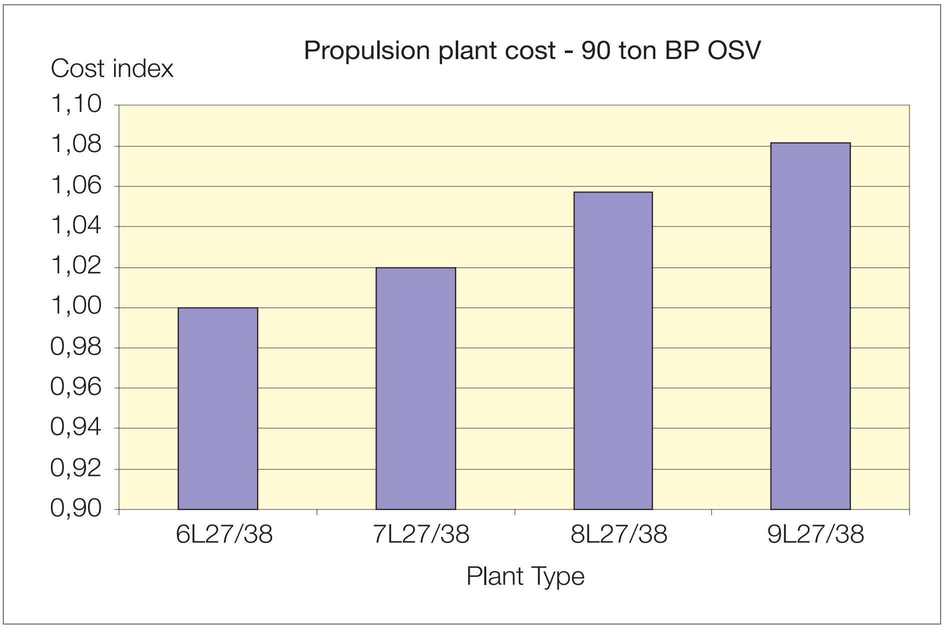

Fig. 2: Propulsion plant cost index

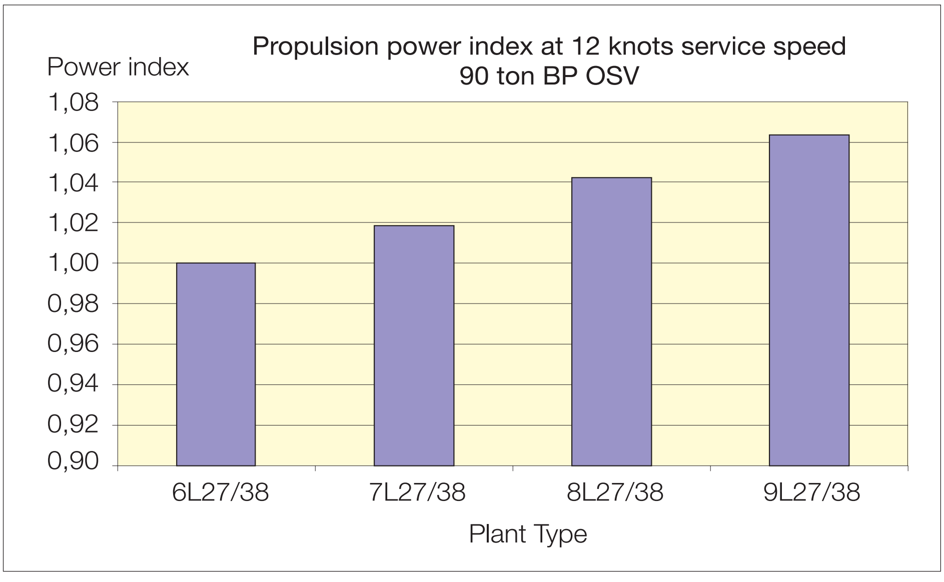

Fig. 3: Propulsion power index

Order Stage

Further refinements

The previously described optimisation deals with the project phase. However a fully customised propulsion solution requires that attention is paid to the details of not only the individual propulsion components but also to the interaction with hull, struts, nozzle supports, rudders, etc. Some of the more important details are:

a. **Aft ship design :** The bollard pull depends not only on the delivered propeller thrust, but also on the propulsion components' interaction with the ship hull. When comparing the thrust of a propeller operating in an open water condition – without the obstruction of the ship hull – to a "behind condition", a loss in thrust will be experienced. This is mainly due to the propeller thrust being counteracted by the suction of the propeller on the ship hull. Typical values for this reduction in thrust are in the range of 3-5% in a bollard pull condition. In some cases, MAN B&W Diesel has experienced much higher values, which can be ascribed to a too steep slope of the buttock lines of the aft ship as well as a non optimum design of the nozzle support to the hull. Thrust deduction values of up to 13% have been experienced. It is important to note that for a 100 tons bollard pull vessel a 10% thrust deduction instead of 5% leads to 5 tons less bollard pull!

b. **Nozzle design:** For years it has been common practice to design and optimise the propeller blades for each individual project, but using more or less standard nozzle types. Since the early 1970s, the 19A and 37 type nozzles have been applied universally for all sorts of purposes. The 19A originates from model tests carried out by

MARIN (previously Wageningen) and is a simplified version of the 19 type nozzle in order to make it more production-friendly. The 37 type nozzle has, due to its more rounded trailing edge, a better astern performance though at the expense of its forward thrust. Recently, new nozzle types have appeared on the market claiming a higher performance based on a CFD shape optimisation. At MAN B&W Diesel a new nozzle type called Alpha High Thrust (AHT) has been developed to increase the performance compared to earlier types. The AHT nozzle is not a standardised design but customised according to its application. As an example, an Anchor Handling Tug Supply (AHTS) vessel could be optimised for maximum bollard pull, whereas a purse seiner could be optimised for service speed. The two nozzle designs will differ significantly not only in its appearance, but also in performance when compared to a standard off-the-shelf nozzle design. The development of the AHT nozzle design will be described in a subsequent part of this paper.

c. **Shaft strut design :** A prerequisite for obtaining a good and uniform inflow to the propeller is a proper flow alignment of the struts. Up till now, the traditional way of achieving this has been paint or tuft tests during model experiments. However, the emergence of numerical tools as CFD, including viscous effects, now makes it possible to optimise the orientation of the struts at an earlier stage.

Other areas of optimisation are the rudder shape and the rudder positioning. Nozzle positioning and tilting are also very important areas that should be addressed. As many of these items are not only related to the propulsion system but also adjacent areas like hull and rudder design, it requires that a close cooperation is established between the involved parties.

Developing the AHT nozzle design series

The need for investigating more complex flow phenomena has led MAN B&W Diesel to introduce and implement CFD software. Among those areas which have benefited from this are nozzle designs and their interaction with the propellers. Viscous effects, that play an important role in this respect, are dealt with by using CFD as it relies on solving the full Navier-Stokes equations. By systematically designing various nozzle geometries and subsequently performing CFD calculations on each individual parameter, an optimised solution has been established. Calculations have been performed for various conditions including bollard pull, astern and ahead.

An iterative process was used in the development of the AHT nozzle series for an OSV type including the following steps:

1. Calculations based on several design proposals were used to determine whether a bollard pull improvement compared to the 19A nozzle was present. The AHT design was improved successively finally leading to an optimum solution for bollard pull.

An optimum geometry is characterised by a uniform pressure distribution at the nozzle inlet followed by an even conversion of the high velocity flow into thrust. A comparison between the 19A type nozzle and the AHT design shows improvement of both the relative pressure and the velocity distribution, see Fig. 4. The pictures on the left side show the 19A type nozzle while the AHT type is to the right.

The higher velocity at the leading edge of the AHT nozzle design results in a lower pressure which generates more forward thrust. It is also shown that the diffusion angle results in a larger pressure at the trailing edge. This pressure difference contributes to a larger bollard pull. The calculations for this particular case were performed in model scale. The influence going from model scale to full scale showed a tendency towards a better full scale performance.

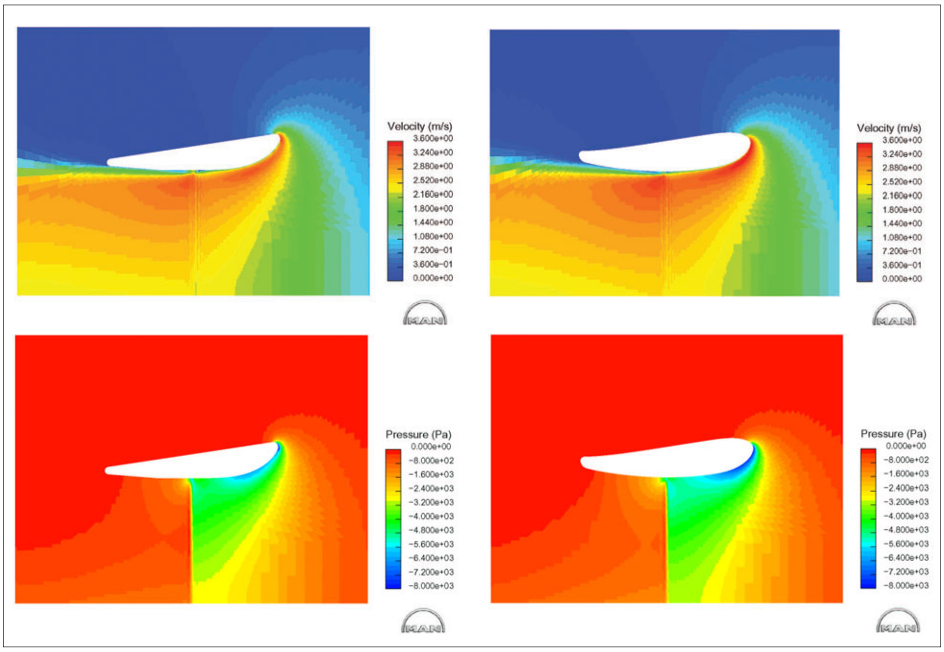

Fig. 4: Pressure and velocity distribution – 19A left and AHT right

2. After reaching an optimum design using the 2D model, a more detailed 3D model consisting of nozzle, propeller blades and hub is calculated in order to verify the bollard pull improvement from the 2D model calculation. If further improvement is needed, the ability to study flow details such as propeller tip circulation, flow separation and similar phenomena all associated with viscous effects is an advantage when using CFD. Nozzle, propeller and hub are presented for the AHT type nozzle calculation.

   Fig. 5 shows the relative pressure distribution in the propeller/nozzle area. A low pressure is generated in the vicinity of the propeller tip. Fig. 6 is an axial slice through the nozzle and one of the propeller blades showing the longitudinal pressure distribution on the AHT nozzle. As mentioned before, the low pressure at the leading edge generates pull for the vessel.

   Other parameters which have been subjected to investigation are listed below:

a. **Length/diameter (L/D) ratio:** It is a fact that longer nozzles provide a better thrust at lower ship speed than shorter ones. Nozzles with smaller L/D ratios than the original L/D=0.5 were introduced for vessels where free sailing plays an important role in combination with a pull condition. Furthermore, smaller nozzles require less installation space which can be beneficial in connection with fitting to an existing vessel with limited space available. In bollard pull condition the CFD studies confirmed a better performance for the higher L/D nozzle types, which can be observed from Fig. 7.

   It is obvious that especially in bollard pull condition the nozzle thrust is significantly higher for the longer nozzle type. In this case, the nozzle thrust increases about 8% giving a total thrust gain of around 4% for the combined propeller/nozzle system.

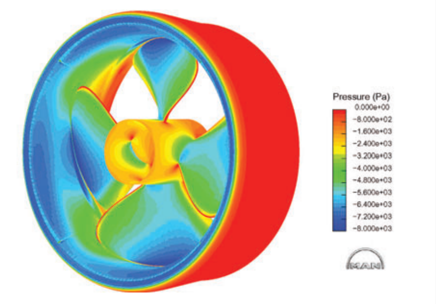

Fig. 5: The relative pressure distribution in the propeller nozzle area

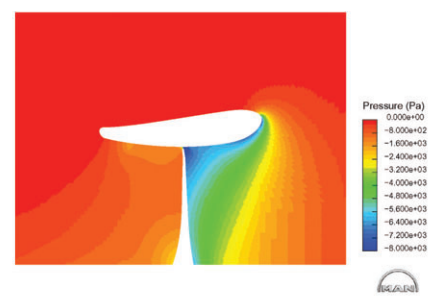

Fig. 6: Longitudinal pressure distribution on the AHT nozzle

b. **Outlet diffuser angle:** In order to generate as much thrust as possible, a non-viscous solution would predict a very high exit angle. Taking viscous effects into account, a too high exit angle will lead to flow separation at the exit of the nozzle, reducing the thrust significantly. Consequently, these two factors have to be balanced in order to reach an optimum. This optimum is not universal for all types of nozzle applications and for that reason each individual project should include an analysis of the propeller and nozzle interaction in the operating modes. During the design process, several design proposals showed flow seperation which required a lower outlet diffuser angle to be used.

c. **Axial location of propeller in nozzle:** For the nozzle types tested so far the optimum location of the propeller is found to be in the center of the nozzle.

At MAN B&W Diesel, CFD is introduced in order to perform relative studies of design proposals, aiming at capturing the same tendencies as experienced during tank test. Correctly applied, this method will ensure an optimum design before tank testing is initiated.

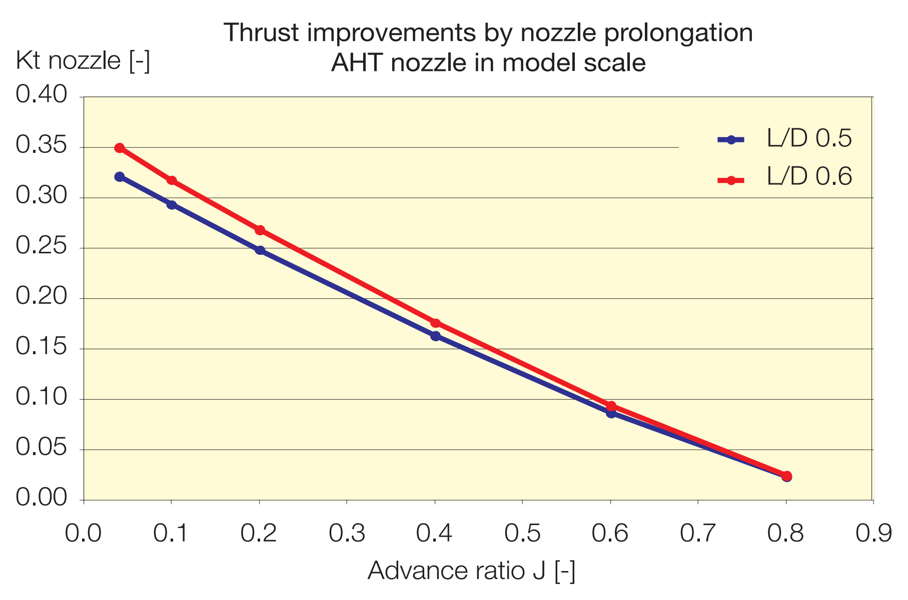

Fig. 7: Thrust improvements by nozzle prolongation

Example

The design procedure described above has been applied for an ocean-going tug boat having a bollard pull requirement of 210 tons. The vessel is designed with a propeller diameter as big as the draft of the vessel allows, thus leading to a relatively small clearance between the hull and the nozzle. Among several considered nozzle supports the chosen one was finally selected to be of the head box type. In order to avoid vibration, a relatively wide head box is needed to keep a sufficiently high natural frequency. The negative influence of the head box on the performance of the nozzle is however limited due to its location in the hull boundary layer. This is also confirmed by a relatively small thrust deduction in the order of 5-6%.

A thorough investigation of several propeller and nozzle combinations was carried out, supplemented by intensive CFD optimisation. As a basis, the 19A type nozzle and a corresponding propeller design were used for benchmarking. Based on various CFD optimisation studies, a customised AHT nozzle and propeller blade design finally emerged showing a nozzle thrust improvement in bollard pull condition of almost 8%. In order to make a comparison with subsequent model tank test results, all calculations were carried out in model scale. An example of propeller grid and a 3D propeller/nozzle system for the AHT nozzle is presented in Fig. 8. The cutting plane illustrates the velocity distribution, Fig. 9.

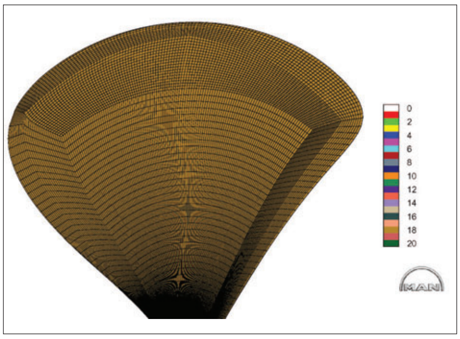

Fig. 8: Propeller grid

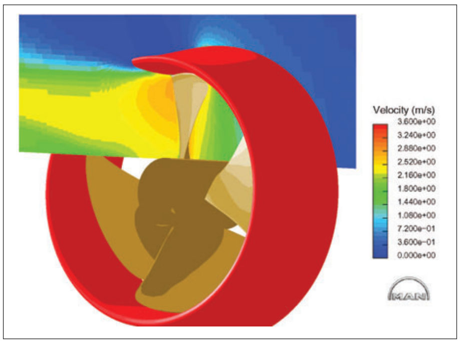

Fig. 9: Velocity distribution

Concluding Remarks

To obtain an optimum propulsion solution for an OSV, the importance of paying attention to not only the individual components but also to their interaction has been demonstrated. It has been shown that bollard pull is not only a matter of engine power. Bollard pull depends particularly on the propeller and nozzle design and the environment in which they operate. The ability to analyse and optimise the design using CFD opens new possibilities to improve the performance of OSV vessels by analysing different alternative design proposals.

From an economical point of view, an optimised solution results in not only a lower initial cost of the propulsion plant but also contributes to a lower operating cost leading to the lowest overall life-cycle-cost.

Only a strong and genuine propulsion plant supplier is able to secure that optimum solutions are accomplished, which leads to the most favourable economical yield.

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