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A Novel Power-Saving Device for Full-Form Vessels

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ABSTRACT

With the advent of today's volatile bunker prices, the reduction of fuel consumption has become a major concern for ship owners. From a propulsion point of view, one possibility lies in the use of so-called power-saving devices; these are stationary devices positioned near the propeller that improve the overall propulsion efficiency.

This paper introduces a novel approach, a Pre-Swirl Duct (PSD) which is marketed under the trademark "Mewis Duct"®. This power-saving device consists of a wake equalising duct combined with an integrated pre-swirl fin system positioned ahead of the propeller. By pre-correcting the flow into the propeller, the device essentially reduces the rotational losses in the resulting propeller slipstream and increases the flow velocity towards the inner radii of the propeller.

The PSD is suited to vessels with high block coefficient and speeds lower than 20 knots. This encompasses tankers and bulk carriers of every size, together with multi-purpose carriers and feeder type container vessels. The expected power reduction is in the range of 3 to 9%, depending on the propeller loading, and is virtually independent of ship draught and speed. A beneficial by-product of the PSD is a small improvement to the ship's yaw stability.

The PSD has been developed in cooperation with Becker Marine Systems, Hamburg (BMS).

Keywords
Propulsor, power-saving devices, power reduction, pre-swirl duct, Mewis Duct®,

1 INTRODUCTION

Power-saving devices are stationary flow-directing devices positioned near the propeller. These can be positioned either ahead of the propeller fixed to the ship's hull, or behind, fixed either to the rudder or the propeller itself.

Power-saving devices are designed to reduce flow losses around the working propeller. The main losses around a rotating propeller consist of:

- rotational losses in the propeller slipstream
- unequal ship wake inflow to the propeller with respect to the propeller rotation
- propeller hub and tip vortex losses

Power-saving devices that improve propulsion efficiency have been in use for over 100 years, for example Wagner (1929) reports on 25 year's experience with the contra-rotating propeller principle.

Well-known devices for reducing the wake losses are the WED (Wake Equalising Duct), see "(Schneekluth 1986)" and the SILD (Sumitomo Integrated Lammeren Duct) as detailed in "(Sasaki and Aono 1997)". Devices for reducing the rotation losses include the SVA fin system, "(Mewis and Peters 1986)", the Daewoo pre swirl fin system, "(Lee et al 1992)" and the Hyundai Thrust Fin system which is fitted to the rudder, see "(Hyundai 2005)". A well-known solution to reducing the losses in the propeller hub vortex is the PBCF (Propeller Boss Cap Fins), "(Ouchi et al 1990)". The Kappel propeller utilises a special tip fin integrated into the propeller blades to reduce the tip vortex losses, see "(Andersen et al 1992)".

It is clear that there are many existing power-saving devices on the market, each with extensive in-service and model testing experience. So it would appear to be impossible to develop an absolutely new solution to the problem. However by combining two or more components of already established principles new developments are possible. This approach offers even more possibilities by targeting a combination of flow loss types. The Pre-Swirl Duct described in this paper is such a combination.

2 DESIGN CONCEPT

The design goal of the PSD is to improve three components of the propeller flow, namely:

- Equalising the propeller inflow by positioning a duct ahead of the propeller. The duct axis is positioned vertically above the propeller shaft axis, with the duct diameter smaller than the propeller diameter. The duct is stabilising the fin effect.
- Reducing rotational losses in the slipstream by integrating a pre-swirl fin system within the duct. The chord length of the fin profiles is smaller that the duct chord length, with the fins positioned towards the aft end of the duct. The duct itself acts as a type of endplate to the fins, thus increasing their effectiveness.
- An additional improvement of the propulsion efficiency is obtained from higher loads generated at the inner radii of the propeller; this effect increases with increasing hub to propeller diameter ratio.

Figures (1) and (2) show a general arrangement of the PSD.

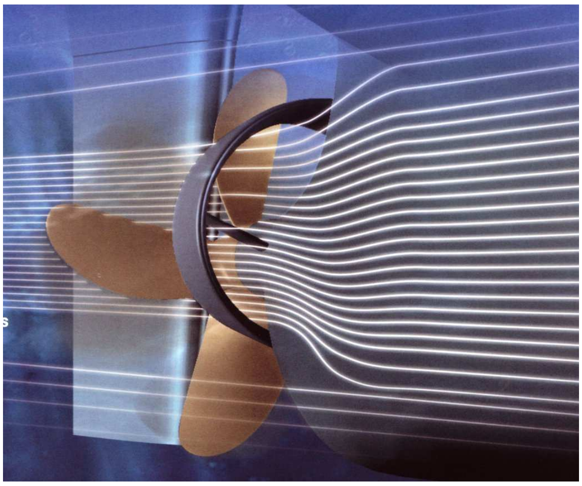

Figure 1 Pre-Swirl Duct, propeller right-handed turning, view diagonal from ahead/starboard, simplified picture

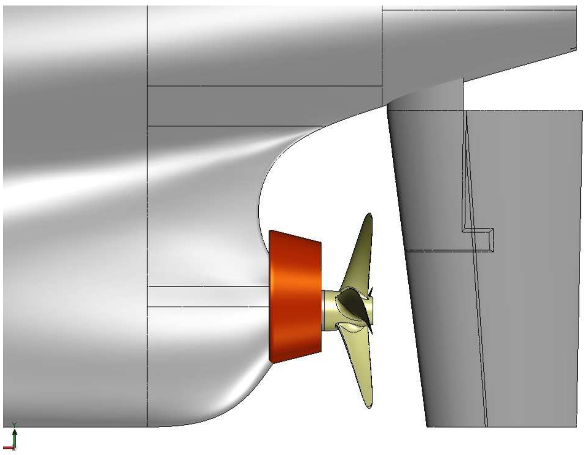

Figure 2 Pre-Swirl Duct, right-handed propeller, side view from port

The dimensions, location, fin and duct profiles, number of fins, circumferential location and individual pitch alignments were determined and optimised based knowledge of the ship's flow field via a combination of measurements (wake field), computational fluid dynamics, scale model tests of the duct assembly and experience.

It can be seen that the PSD is mounted offset vertically above the propeller shaft. The reasons for this are twofold:

- To distribute the wake equally in the upper region of the propeller plane
- To distribute the wake race of the duct through a wider range towards the propeller

In addition, the duct eliminates tip vortices from the fins, acting in a similar fashion to end-plates or wing fences.

The rotational asymmetrical arrangement of the rudder fins is due to the shape of the ship wake. The upward turning blades work mainly with the ship wake flow whereas the downward turning blades work against it. Therefore to achieve the desired pre-swirl flow correction more fins are required on the upward turning side of the propeller to redirect the flow against the direction of the propeller blades. It should be noted that the bilge vortices from the hull make the design especially complicated and have to be taken into consideration.

The optimisation of the whole device is therefore a complex non-linear task, involving sub-optimisation of various key features.

3 POWER SAVING - CONTRIBUTIONS AROUND THE ROTATING PROPELLER

The aft hull form, rotating propeller and rudder interact with each other to influence the overall propulsion performance. In particular, the propeller influences flow both ahead and astern of it, for example see the wake field images with and without the running propeller in figures (5) and (6).

There are three areas of influential losses around the rotating propeller: the inflow, the propeller itself and the resulting slipstream (propeller race. The following list gives an overview of improvable elements of the propeller flow and several possibilities for improving the propulsion efficiency, in other words improving the power saving.

3.1 Inflow

- Ship's wake: can be improved with better ship lines
- Asymmetrical inflow: can be improved by pre ducts, such as WED, SILD, PSD, as well as asymmetrical aft bodies
- Pre rotation: can be improved by SVA Fin System, Pre Swirl Fins, PSD and asymmetrical aft bodies

3.2 Propeller

- Blade friction losses: can be improved with smaller blades, lower roughness
- Tip vortices: can be improved by integrated fences at the blade tips – the Kappel propeller
- Hub vortex: can be reduced by PBCF, PSD

3.3 Slipstream

- Rudder: can reduce the rotational losses, asymmetrical (twisted) rudder
- Rudder fins: can reduce rotational losses

In summary, the new PSD reduces losses at the inflow to the propeller by equalising the inflow via the duct, reducing slipstream losses through the use of pre swirl fins and reducing hub vortex losses by increasing the propeller load at the inner radii.

The achievable power reductions depend on the ship speed and the propeller thrust coefficient C_{Th}:

$$C_{Th} = \frac{T}{\frac{1}{2}\rho \cdot V_A^2 \cdot D^2 \cdot \pi/4} \quad (1)$$

Where ρ is the water density, V_A the advance velocity, D the propeller diameter and T the propeller thrust.

The best possibilities for improvement occur where C_{Th} is high and the ship speed relatively low, see figure (3).

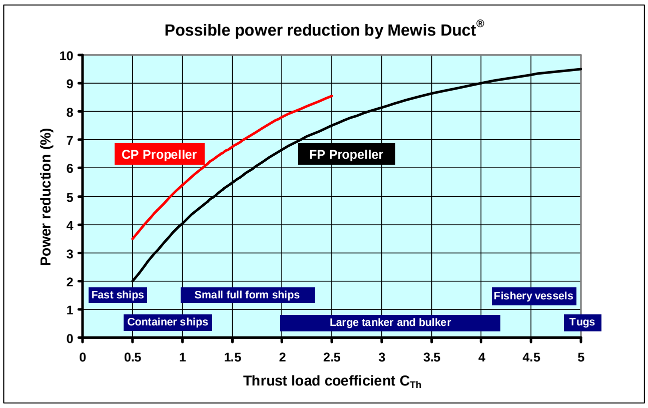

Figure 3 Possible power reductions by the PSD

The PSD is therefore well-suited for application to smaller container vessels, small vessels with high block coefficient, such as multi-purpose carriers, as well as bulk carriers and tankers of all sizes. Fishery vessels and tugs are typically equipped with Kort nozzles or Voith Schneider Propellers, so the installation of a PSD is generally precluded from these types. For all fast vessels including large container vessels the PSD is not appropriate at the present stage of development.

4 OPTIMISATION BY COMPUTATIONAL FLUID DYNAMICS (CFD) METHODS

CFD calculations are valuable in assisting the optimisation process of ship lines and propulsion devices. Whereas estimation of absolute power is still a difficult task for current CFD techniques given the available computer power, the calculation of changes of power due to changes in configuration is well within the capabilities of today's CFD technology. This approach was therefore used for initial optimisation of the PSD.

The flow around the aft body of a ship and its propulsion devices can be numerically estimated using Reynolds-Averaged Navier Stokes (RANS) methods, which take into account the viscosity effects of the working fluid. Nevertheless, given a suitably refined mesh and careful turbulence modelling RANS calculations give an excellent insight into the flow properties.

Like all CFD methods, the results are many and diverse, so it is a formidable task to manage the vast quantity of data that is produced. Successful use of CFD therefore requires understanding and experience in use of meshing, the calculation process, extracting and recognising the important results as well as their interpretation.

Following some preliminary CFD calculation iterations, the following results were selected as a basis for judgement at each design step:

- Computed wake, with and without a rotating propeller, evaluated at various planes and operating conditions
- Duct flow and associated forces
- Fin flow and associated forces
- Additional resistance of components
- Differences in delivered power

By means of example, figures (4) to (8) show the computed wake fields for five different operating conditions for one PSD design variant for a 300,000 DWT VLCC. Figure (4) corresponds to the computed wake field at the propeller plane for the naked hull without propeller, rudder or PSD. This wake field correlates well with the measured wake field from model tests.

Figures (5) to (8) show the wake at a plane positioned in front of the propeller and just behind the duct for various configurations. Of particular note are the differences in wake between the cases with and without the rotating propeller, see figures (5) and (6).

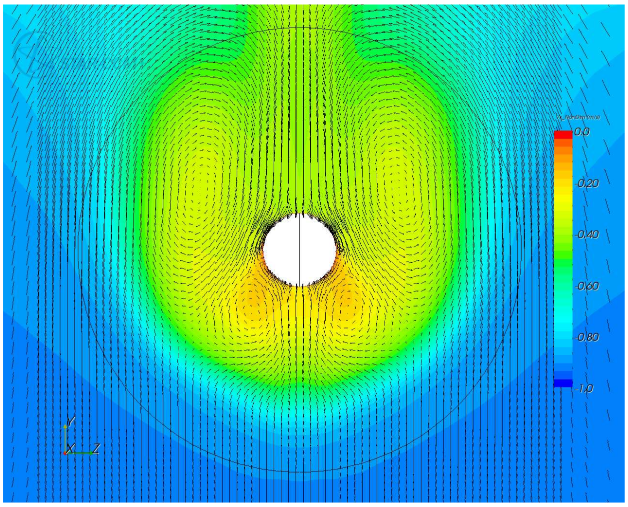

Figure 4 Wake field at propeller plane, hull only

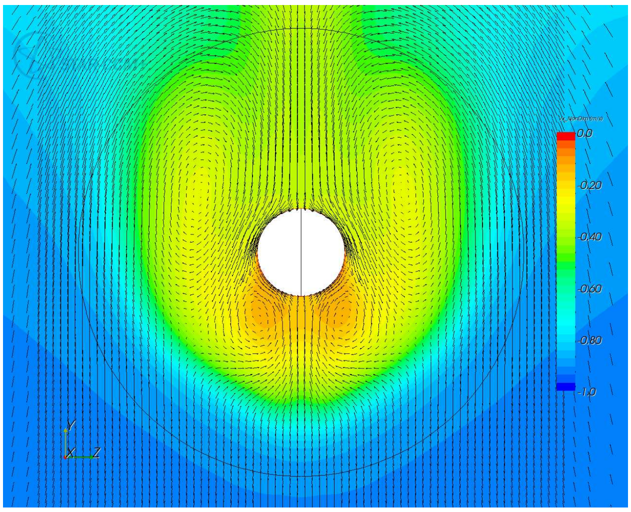

Figure 5 Wake field at plane directly behind duct (in front of propeller), hull only

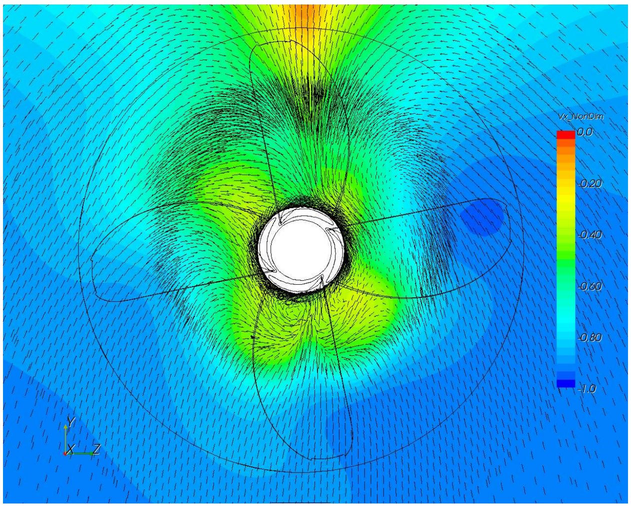

Figure 6 Wake field at plane directly behind duct with rudder & rotating propeller, hull only

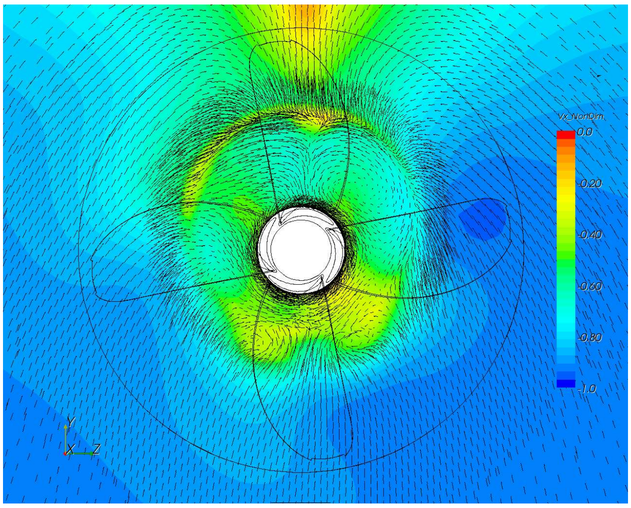

Figure 7 Wake field at plane directly behind duct with rudder, rotating propeller & PSD duct (without fins)

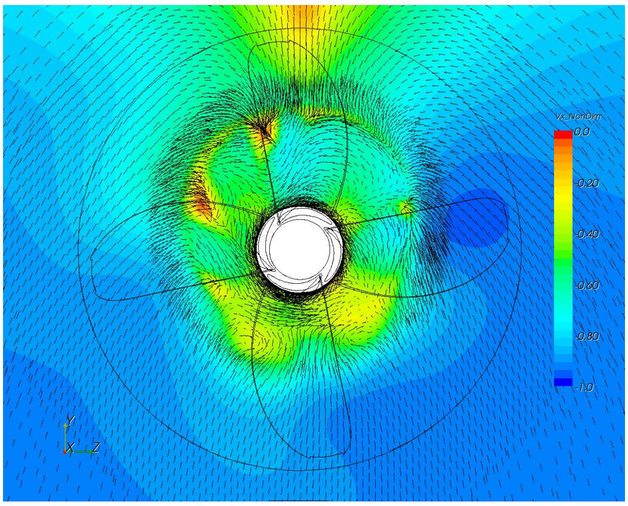

Figure 8 Wake field at plane directly behind duct with rudder, rotating propeller, full PSD duct with fins

The effectiveness of the device is clearly illustrated by considering the computed flow fields ahead and behind the rotating propeller. Figure (9) shows the tangential components over the propeller disk radii for four different cases. The reduction of rotational losses in the PSD slipstream correlates well with those observed behind the rotating propeller. The greatest improvement is also evident towards the propeller axis.

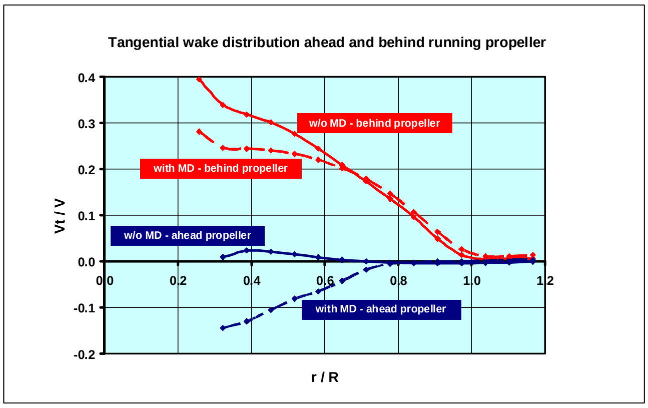

Figure 9 Tangential wake components ahead and astern of the running propeller, Multi-Purpose Bulker 12,000 DWT, CFD results

5 MODEL TEST RESULTS

Self propulsion tests are used to determine the required power and achievable ship speed, and are suitable for the validation of the CFD results. The optimisation of the individual fin pitch settings is particularly quick and easy; however optimisation of other elements of the duct is more difficult and expensive, due to the requirement that each design iteration would require an additional duct model to be manufactured and fitted.

During 2008 and 2009 three series of self-propulsion tests with the PSD were carried out at HSVA Hamburg and SVA Potsdam for three actual projects of differing hull types.

Figure (10) shows the installed PSD on a ship model (HSVA). Initial optimisation of the duct and fin alignment angles and section shapes was performed by CFD analysis. This configuration was used as a basis for the model test programme.

Figure 10 Bulk carrier ship model with installed PSD model, view diagonal from the back/port side, HSVA

The model test results are broadly in line with the CFD predictions, in terms of both power saving and optimal fin angles. Figure (11) also demonstrates that the degree of power saving is valid over a wide operational speed range.

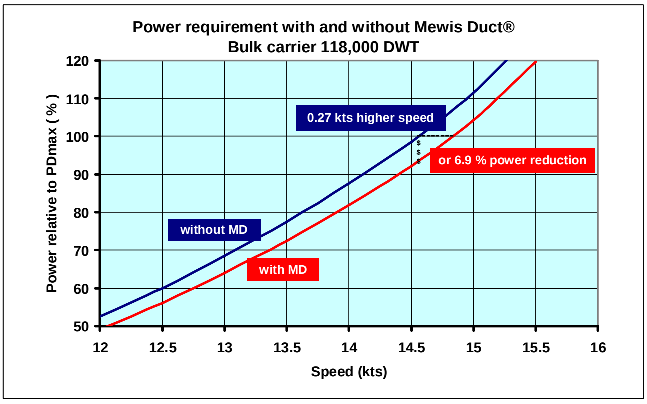

Figure 11 Power reduction of about 6.9 % by PSD in self propulsion test, 118,000 DWT Bulk Carrier, HSVA model test results

Table 1 Model test results with PSD to date (February 2009)

No.	Model basin	Ship type	Capacity	**Propeller type**	C_{Th}	Draught	Speed	**Power reduction**	**Speed increase**
			DWT		**-**	-	knots	**%**	**knots**
1	HSVA	Bulker	118,000	**FPP**	**1.9**	design	14.6	**6.9**	**0.27**
2.1	SVA	MP Bulker	12,000	**CPP**	**1.6**	design	15.2	**7.7**	**0.22**
2.2	-“-	-“-	-“-	**-“-**	**1.6**	ballast	15.9	**7.4**	**0.24**
3.1	HSVA	OH Bulker	45,000	**FPP**	**1.4**	design	15.4	**6.0**	**0.27**
3.2	-“-	-“-	-“-	**-“-**	**1.4**	light load	15.8	**5.4**	**0.24**

Table (1) shows all model tests results to date (February 2009). Notable is the very high power reduction by the PSD of the ship with a controllable pitch propeller fitted (high hub to propeller diameter ratio), as well as the virtual independence of the ship's draught to the performance of the PSD.

For all three projects the rpm reduction achieved by the PSD at constant power is less than 1%. In addition, the duct fitted alone without fins also resulted for all cases in a consistent reduction of delivered power.

6 CONCLUSIONES AND FUTURE DEVELOPMENTS

The Mewis Duct® (PSD) is suited to ships whose propeller load C_{Th} is typically greater than 1.0 and speed less than 20 knots. Generally speaking this encompasses small container vessels, small vessels with high block coefficient, multi-purpose carriers, all tankers and bulk carriers. Optimisation of the PSD is required on a ship-by-ship basis. Modern CFD techniques are used to assist in this process, and the results have been validated against model tests.

Future planned developments of the PSD involve extending the design and optimisation process to include vessels faster than 20 knots.

The first full-scale installation of a Mewis Duct® is scheduled for the second half of 2009.

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