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Boundary Layer Control of Twin Skeg Hull Form with Reaction Podded Propulsion

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ABSTRACT

The ZEUS (Zero Emission Ultimate Ship) project of the NMRI (National Maritime Research Institute) is very challenging and is unique from the view point of utilized technologies. This paper will introduce some innovative ideas, which are "reaction pod" and "jet-assist motor propulsion". Reaction pod is a concept which can increase propulsive efficiency by using off-centered podded propulsors of twin skeg hull form. By putting the pods at the optimum position in the stern, a propeller can act as a contra-rotating propeller. Jet assist motor propulsion can be used for several objectives, such as prevention of flow separation, reducing stern vibration, improving course keeping ability, etc. This paper will explain these two new ideas by introducing model test data which were obtained from NMRI towing tank.

Keywords

Reaction Pod, Boundary Layer Control, Zero Emission

1 INTRODUCTION

The author believes that we still have a lot of innovative hull form design technologies to reduce fuel consumption, in contradiction to the tremendous pessimism throughout the world. It is true that we don't have enough room to improve ship performance based on a simple solution, such as reduction of resistance or improvement of propeller efficiency. However, we should know that the energy balance among ship propulsion mechanism is not fully understood even now. Flow field of a ship stern is the most difficult area to understand and we may chance upon a new phenomenon. The technologies which will be introduced here are those of such discoveries.

2 ZEUS PROJECT

The total amount of CO_2 emission from ships is estimated to be around 3% of emission from the entire globe, and this figure corresponds to emission amount from the country of Germany. UNFCCC (United Nations Framework Convention on Climate Change) has requested IMO to increase the reduction of GHG (Green House Gas) emitted from ocean going vessels. In order to contribute to this push, NMRI started the ZEUS project in the beginning of 2009 and the following mile stones were decided:

ZEUS 1: Reduction of 50% by Hull Form Design, Reaction Pod and Boundary Layer Control

ZEUS 2: Reduction of 80% by Hybrid Engine, Solar Energy and Electric Supply System addition to ZEUS1

ZEUS 3: Reduction of 100% by Fuel Cell addition to ZEUS 2

As shown in Figure 1, hydrodynamic technology will play the main role until 2020. After ZEUS 1, it will be required to introduce Hybrid Engine technology. As the final goal, we expect Fuel Cell to be a viable energy supply system for ocean going vessels.

The Zero Emission Ultimate Ship (ZEUS) concept has several key technologies, as shown in Table 1.

Table 1 : Key Technologies of ZEUS 1

Key technologies	Objective	Target values
Twin skeg hull with wide beam	Increase dead weight /power	10%
Reaction pod	Increase propulsive efficiency	20%(10%*)
Spray Tearing Plates (STEP)	Reduce added wave resistance	20% of added wave resistance
Boundary layer control(JAMP)	Reduce viscous resistance Increase propulsive efficiency and maneuverability	20%

* taking electric conversion loss into account

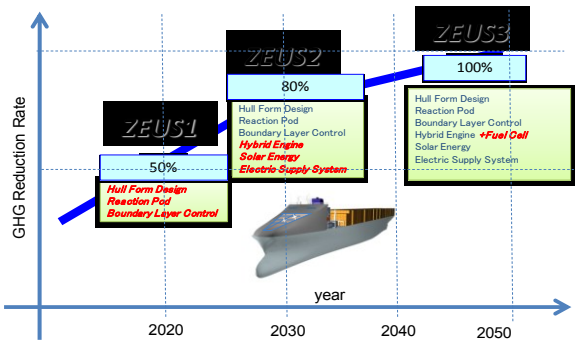


Figure 1: Mile Stones of ZEUS Project of NMRI

2.1 Twin Skeg Hull with Wide Beam

$$EEDI = \frac{CO_2(g)}{Capacity \cdot Vs} \qquad (1)$$

There are three ways to improve EEDI represented by Equation(1). The first way is to increase capacity as shown in Figure 2 and this can be achieved by twin skeg hull form under the limitations of ship length and draft. The second way is to reduce CO_2 by increasing propulsive efficiency by applying reaction pod and boundary layer control. The last way is to increase ship speed without any additional power. There are two countermeasures for this. One is to increase efficiency of cargo handling/loading and the other one is to have better sea keeping ability.

Twin skeg hull form itself is not a new idea and a few vessels of this type have been built. The main difference between ZEUS and existing twin skeg vessels is an application of podded propulsion system. By adopting podded propulsion system, design capabilities of the vessel can be much improved. The most important point is that ZEUS requires no shafts and requires an engine room inside of skegs. This means that the designer can optimize stern part only taking the optimum propulsive efficiency into account.

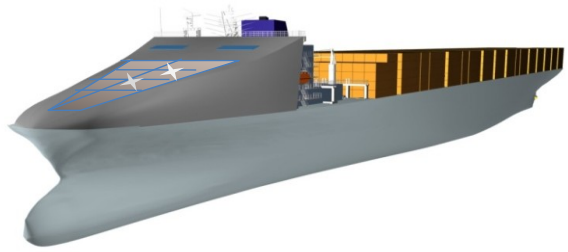


Figure 2: 4000TEU Container Ship with 200m Length and 44m Beam

Generally speaking, the beam of a vessel is the most flexible parameter compared to other main dimensions, such as ship length, ship draft, etc. because those parameters are strongly restricted from port limitations. The beam of a vessel normally has upper limit from the aspect of maneuverability and this weak point can be solved easily by applying twin skeg hull form. By increasing beam until the transportation efficiency reaches the maximum, the capacity (DWT: Deadweight) can be increased without sizing up of her length and draft. The maneuverability is not a big concern because the twin skeg hull form has a superior course keeping ability from the very start.

Effect of beam on a parameter DWT/BHP can be seen from Fig. 3, which was computed by the program, Hull Optimization Program for Economy "HOPE", developed by NMRI. HOPE has many functions, not only powering of twin skeg hull form, but also prediction of calculation of fuel consumption at actual sea (in wave and wind) and EEDI based on a predicted DWT. By using the program HOPE, the optimum point where the minimum EEDI exists can be found.

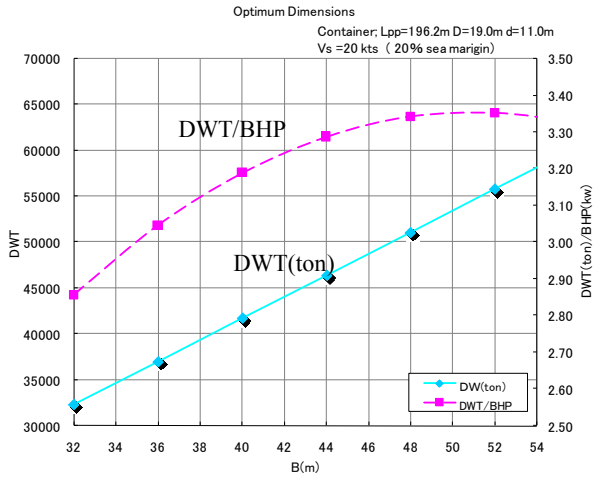


Figure 3: Optimum Beam(B) Simulated by "HOPE"

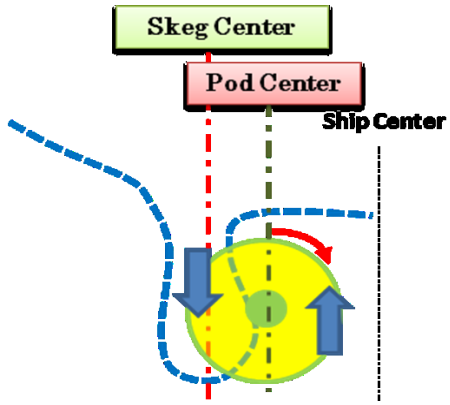


Figure 4: Counter-Rotating Flow of Twin Skeg Hull

2.2 Reaction Pods

Reaction pod is quite a new idea for podded propulsion system and it means the optimum pod arrangement for the twin skeg hull form. Because a typical ship wake of twin skeg hull form has two remarkable characteristics, i.e., ascent flow for inside of skeg, and descent flow for outside of skeg, as illustrated by Figure 4, the optimum pod position is rather inside of center line of skeg from an aspect of the best propulsive efficiency in order to obtain both counter flow and viscous flow as shown in Figure 4. The left hand side of propeller disc exists behind a skeg center line and right hand side of propeller disc exists in the up going main flow in the tunnel.

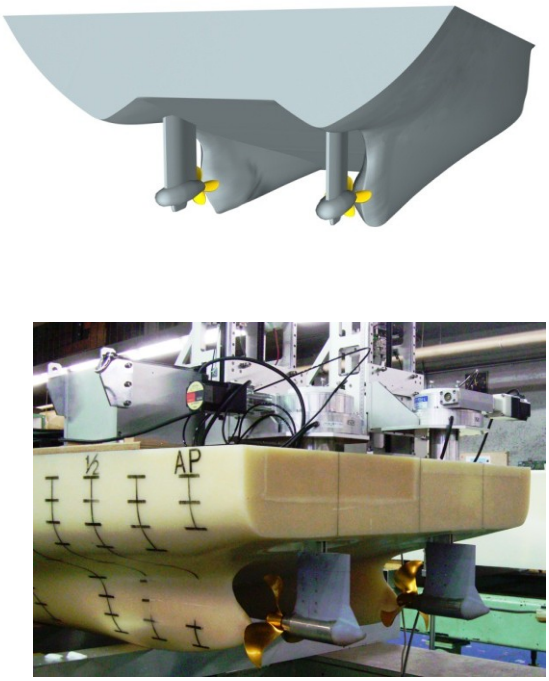


Figure 5: Reaction Pods Concept and Ship Model with Pod Traverser

Figure 6 shows the result of propulsion test of the container ship model of Figure 5 and it can be seen that the propulsive factors varies with the pod position. By shifting the propeller center to aside, strong wake peak generated by the skeg, which may provoke harmful cavitation on ship vibration, can be avoided and it allows smaller number of blades such as three (3) blades. Moreover, the clearance between propeller tip and hull bottom plate can also be reduced. These advantages have a strong potential to obtain much higher propulsive efficiency by increasing the propeller diameter.

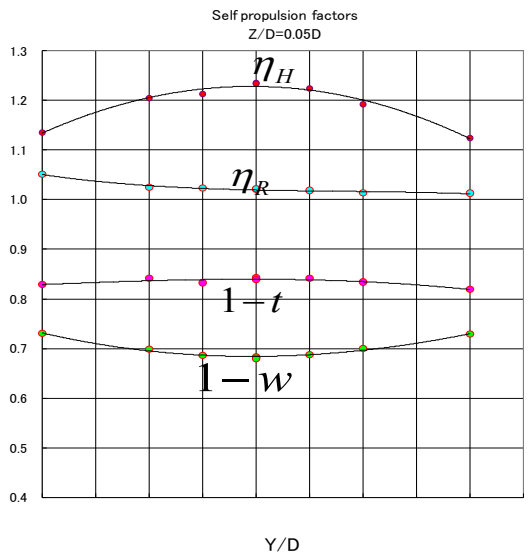


Figure 6: Self propulsive factors of Reaction Pod Propulsion

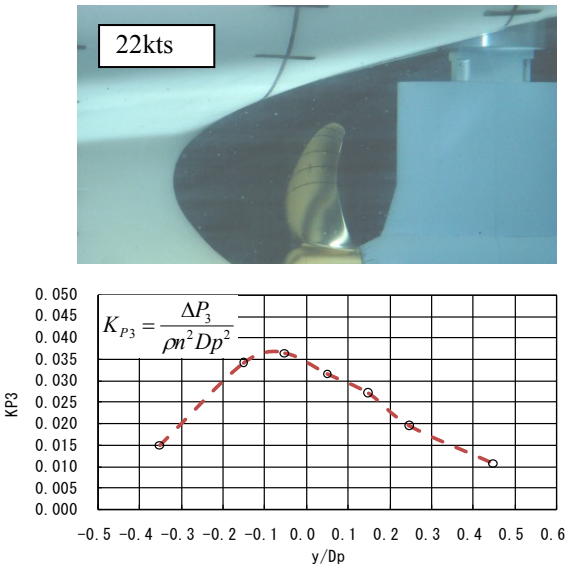


Figure 7: Cavitation Patterns and Measured Pressure Fluctuations Obtained From Cavitation Test(22kts)

Figure 7 shows the results of cavitation test obtained from the same vessel of Figure 5. It is very obvious that the cavitation extent and propeller induced ship vibration can be minimized by adopting a reaction pod concept.

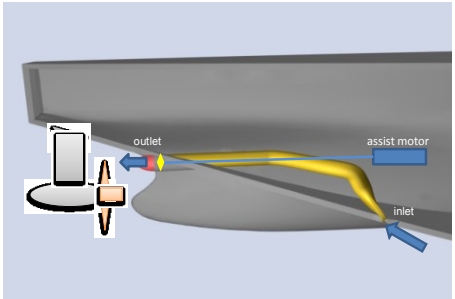
2.3 Propulsive Efficiency of Reaction Pod

Owing to extremely high hull efficiency and three-bladed large diameter propellers, the propulsive efficiency of reaction pod system is over 90%, while a conventional propulsion system is around 75%. The improvement is (90-75)/75=20% and this value can be used directly to the full scale power reduction.

3 BOUNDARY LAYER CONTROL

As explained in the previous section, the reaction pod concept brings several advantages, not only propulsive efficiency but also cavitation performance, and these advantages show synergetic effects on propulsive efficiency. Same as the reaction pod concept, BLC (boundary layer control) has several functions. It can be said this concept has more functions than reaction pod concept. BLC mentioned here is the system as shown in Figure 8 and named JAMP (Jet Assisted Motor Propulsion).

The system has an inlet near the tunnel starting point and



JAMP(Jet Assist Motor Propulsion)

Figure 8: JAMP (Jet Assisted Motor Propulsion)

two outlets near the skeg top under the water surface. The inlet and the outlets are connected by simple tubes and small impellers are located very close to the outlets.

Figure 9 shows how the BLC concept works.

As shown in the figure, there are totally five (5) functions.

3.1 Main Engine Arrangement (Function 1)

The idea of twin skeg hull is very old and has been studied from the aspect of ship performance viewpoints. As a result of the studies, it was concluded that the following two disadvantages are the most difficult things to apply, except when a ship has been specially designed as result of particular requirements, such as an extremely shallow shaft:

Disadvantage I: Cost of propulsion system

Disadvantage II: Difficulty of engine arrangement

Owing to the higher oil banker price, Disadvantage I is not as important as before; however, Disadvantage II is very serious for the ship owner because they may lose big capacity due to inconvenient engine room arrangement. In order to move the engine room afterward, a tunnel slope angle must be increased. However, this means that the designer loses the energy savings obtained from twin skeg hull form and this means losing both capital and interest.

BLC concept can solve this problem without any disadvantage, as will be explained later.

3.2 Maneuvering Ability (Function 2)

Increment of tunnel slope angle can trigger poor course keeping ability of twin skeg hull by shortening the skeg length, which contributes control surface of maneuvering. By applying BLC, stability forces can be increased and the course keeping ability of the vessel will reintegrate into the normal position.

3.3 Cavitation Performance (Function 3)

It is very obvious that the jet flow by BLC can change retarded flow into smooth flow and clear the cavitation away from propeller blade surface near the top position which may induce harmful vibration on the vessel.

3.4 Reduction of Resistance (Function 4)

The most important function of BLC is to prevent the flow separation on the tunnel wall where the two-dimensional flow separation easily occurs. By putting two outlets on the top positions of two skegs, three-dimensional and strong ascent flow can be generated. The image of this flow pattern is illustrated in Figure 10. In the figure, effectiveness of the inlet and outlets can be seen.

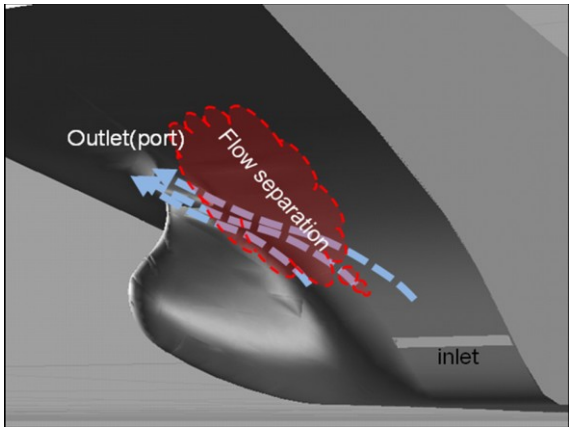


Figure 10: Flow Pattern Image of BLC Effect

3.5 Improve Propulsive Efficiency (Function 5)

By eliminating the separation zone of tunnel flow as shown in Figure 10, ascent flow of tunnel between two skegs can be increased and result in high propulsive efficiency by strengthened contra-rotating flow.

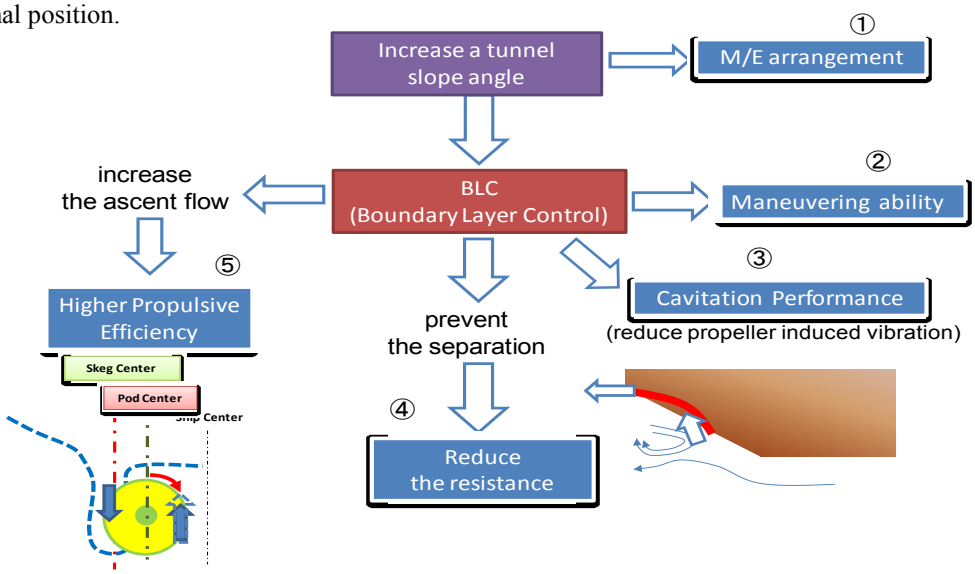


Figure 9: Multi Functions of JAMP System Utilizing Boundary Layer Control (BLC)

4 MODEL TEST

In order to verify the aforementioned functions of JAMP system utilizing BLC (Boundary Layer Control) for reaction pod concept, model test listed in Table 2 was conducted at NMRI towing tanks and NMRI cavitation tunnel. Regarding the cavitation test, only the result of an original hull will be shown because the data is not ready in time. The test with JAMP system will be conducted soon and the result will be submitted.

4.1 Ship Model, Propeller Models

Model tests were conducted with 5.418 m paraffin model and twin podded propulsion system at a towing tank of the National Maritime Research Institute. Table 3 shows principal dimensions of ship model and propeller models.

Table 2: Ship Model and Propeller Model

Kind of model test	Conditions
Propeller Loading Test	with BLC & w/o BLC
Flow Measurement	with BLC & w/o BLC
Oblique Going Test	with BLC & w/o BLC
Cavitation Test	Original hull

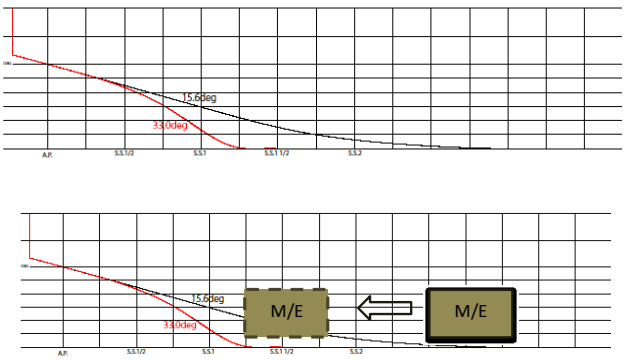


Figure 11: Modification of a Tunnel Slope Angle for Efficient Engine Arrangement of Twin Skeg Hull

4.2 Modification of Tunnel Slope Angle

The most effective utilization of JAMP system is to modify a tunnel slope angle, as shown in Figure 11.

Based on the program "HOPE", the form factors (k) of two configurations are estimated 0.30 and 0.52, respectively.

4.3 Propeller Loading Test

Boundary layer suction concept is not a new idea for a wing applied to an aero plane, wing cascade of pump or turbine, etc. However, the application to a ship is quite new and only an investigation into the effect of performance of water jet propulsion can be found. Not only is the difference between the water jet propulsion system and JAMP studied, but power ratio (Pimp/Pmain) is studied as well. Here Pimp and Pmain are absorbed power of impellers and absorbed power of main propeller. Because the objective of JAMP is to control the boundary layer near the stern, power ratio is far from that of water jet propulsion as below:

Table 3: Ship Model and Propeller Models

Ship		Propellers & Impellers		
Lpp(m)	5.418	Dia.(m)	0.226	0.04
B(m)	1.182	Pitch Ratio	1.020	0.70
D(m)	0.2955	Exp.Area Ratio	0.35	0.40
CB	0.6564	Boss Ratio	0.18	0.18
LCB(%)	3.55	No. of Blades	3	4

$$(P_{IMP} / P_{MAIN}) \quad < \quad 0.01 - 0.10 \qquad (2)$$

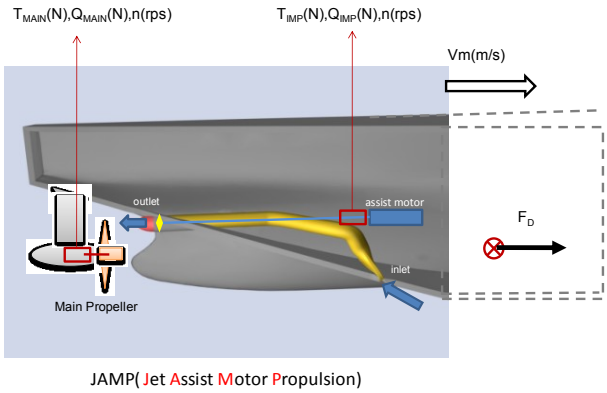


Figure 12: Measuring System of Propeller Loading Test

Model test was conducted varying both main propeller loading and impeller loading, as illustrated by Figure 12.

The typical example of propeller loading test is shown in Table 4.

The effectiveness of JAMP system is very clear from Figure 13 and Table 4, where we can see resistance and propulsive performance at the same time. In Table 4, T is total thrust as described:

$$T = T_{MAIN} + T_{IMP} \qquad (3)$$

Table 4: Obtained Data from Propeller Loading Test
(Vm=1.0m/s, unit=kg)

F_D	T_{MAIN}	T_{IMP}	F_D+T	remark
2.55	0	0	2.55	w/o BLC
1.80	0	0.11	1.91	with BLC
0	3.30	0	3.36	w/o BLC
0	2.32	0.09	2.41	with BLC

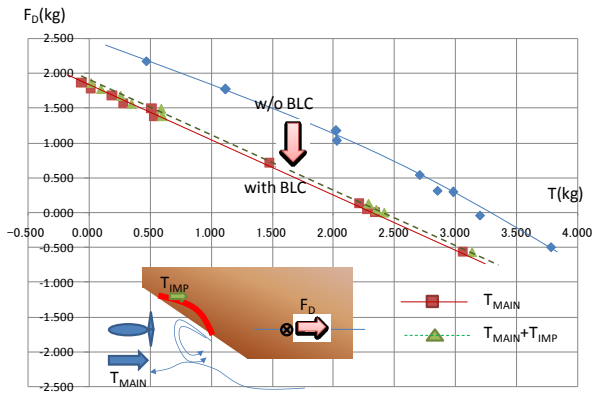


Figure 13: Result of Propeller Loading Test

The amplification factor f_{AT} of JAMP system base on thrust can be represented as follows:

$$f_{AT} = \{ (F_D + T)_{W/O} - (F_D + T)_{WITH} \} / T_{IMP} \quad (4)$$

Where, with and w/o means with BLC and w/o BLC. From Table 4, f_{AT} of JAMP system is 6(towing)-10(model point) and it is very feasible to estimate 7-8 for ship point which can be figured out after full scale power prediction. It is also possible to define the amplification factor f_{AP} of JAMP based on power.

$$f_{AP} = \{ (P_{MAIN})_{W/O} - (P_{MAIN} + P_{IMP})_{WITH} \} / (P_{MAIN})_{W/O} \quad (5)$$

From the measurement of torque of main propellers and impellers, amplification factor f_{AP} is concluded as 17, which is incredibly high.

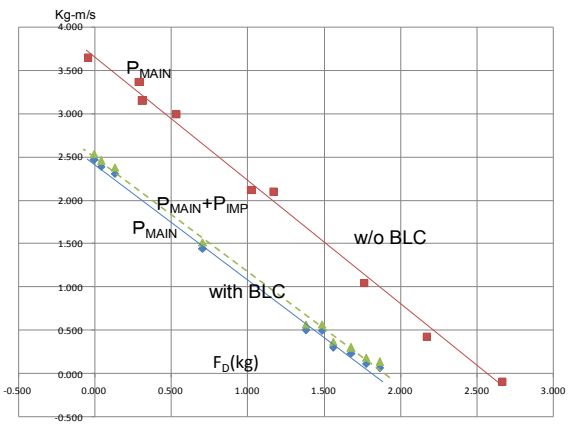


Figure 14: Comparison of Power between with BCL and without BLC

5 CONSIDERATIONS

The reason for extremely high performance of JAMP system was investigated by conducting flow measurement of the position behind the ship stern with rotating propellers. Two conditions of with BLC and without BLC were compared in the Figure 15. The flow field of these two conditions is quite different and clearly explains the reason of the high performance of BLC system. The resistance due to momentum loss of two conditions are calculated and compared with Figure 13. The obtained result from calculation is abt. 0.8kg, while the difference of Fd(kg) in Figure 13 is 0.9kg. Therefore, it can be concluded that main reason of the high performance of JAMP system is a contribution of Function 4 (reduction of resistance due to separation).

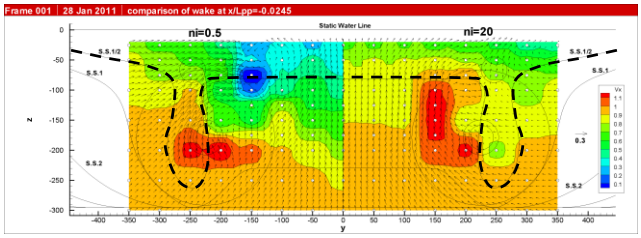


Figure 15: Flow Measurement behind the Ship with Podded Propellers (left w/o BLC, right with BLC)

6 CONCLUSIONS

The key technologies of the Zero Emission Ultimate Ship (ZEUS) concept are reviewed from the model test data. From the studies, it is very clear that the concept of ZEUS is very promising and effective. Main conclusions which were obtained here are as follows:

- By combination of a twin skeg hull form and twin pods, high propulsive efficiency of more than 90% can be obtained.
- JAMP (Jet Assisted Motor Propulsion) system utilizing BLC (Boundary Layer Control) is a very effective solution to solve the disadvantage of an engine room arrangement of twin skeg hull.
- Amplification Factor 17 (obtained power reduction /input power) of JAMP was obtained from the tank test, while verification is still underway.

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