

ZEUS and NOAH Projects of NMRI

Noriyuki Sasaki

National Maritime Research Institute (NMRI), Mitaka, Tokyo, Japan

ABSTRACT

ZEUS (Zero Emission Ultimate Ship) project and NOAH (No More Artistic Hull) project of NMRI (National Maritime Research Institute) are very challenging projects from the view point of utilized technologies. This paper will introduce some innovative ideas developed by these two projects. The objective of ZEUS project is to obtain the maximum energy efficiency by introducing a new idea such as a reaction pod system. It can be said that the project aims the final goal of ultimate ship hull form in the future. On the contrary, NOAH project is aiming to achieve the ideal ship space and arrangement from the purpose of transportation without excessive power increment. The shape of hull is almost a box like a NOAH's Ark. In order to improve EEDI for this type of vessels, several new ideas will be introduced. Here, "boundary layer suction" and "Gate Rudder" will be introduced.

Keywords

Reaction Pod, Boundary Layer Suction, Gate Rudder

1 INTRODUCTION

EEDI (Energy Efficiency Design Index) is a strong driving force to improve ship performance dramatically. ZEUS and NOAH projects have been executed from a view point of an image of bipolar ship design. The objective of ZEUS is to obtain the best performance ship neglecting cost.

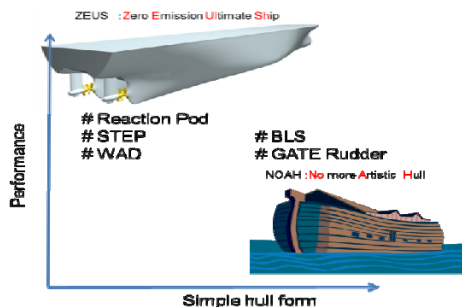


Figure 1 ZEUS and NPAH Projects of NMRI

The other end NOAH is aiming to obtain the most cost effective ship.

The performance of the vessels of NOAH is not so superior to the vessels of ZEUS however, the cost is much lower than those vessels. By considering these two extremal models, innovative ideas can be expected.

2 ZEUS PROJECT

Zero Emission Ultimate Ship (ZEUS) project has started from 2009 and the target of Phase 1 is to save 50% CO₂ emission from ship by 2020 using key technologies listed in Table 1;

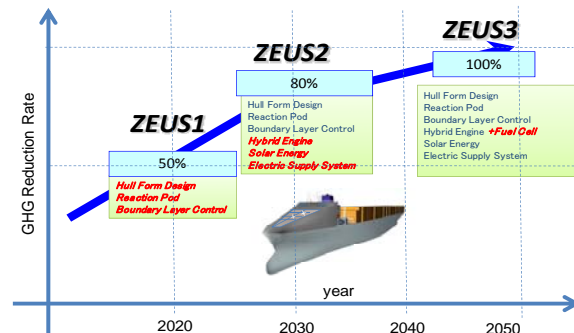


Figure 2 Mile Stones of ZEUS Project of NMRI

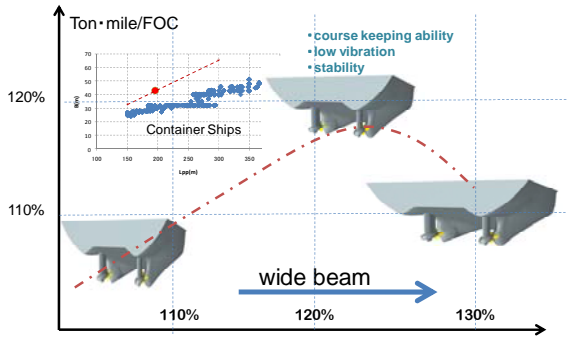
Table 1 Key Technologies of ZEUS 1

Key Tech.	Objective	Target %
Twin Skeg	DWT/Power	10
Reaction Pod	Propulsive Efficiency	20
STEP	Added wave Resist.	2
WAD	Propulsive Efficiency	8

By applying the above key technologies, about 35% of propulsion power can be reduced. Of course we can use very common countermeasures such as slow steaming, streamlined superstructure, low friction paint etc. for remaining 15%, taking cost effectiveness and interaction among devices into account.

2.1 Twin Skeg Hull with Wide Beam

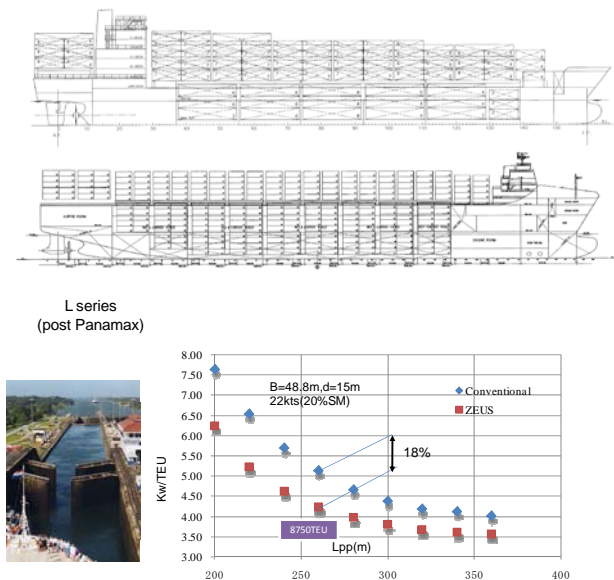
The beam of a vessel is the most flexible parameter compared with other main dimensions such as ship length, ship draft etc. because those parameters are strongly restricted from port limitations. The beam of the vessel also has upper limit from maneuverability and excessive wave resistance, due to the aft body bluntness and the fore body bluntness respectively. However, these limitations can be avoided by twin skeg hull form which has wider beam compared with conventional vessels. Therefore the maximum point of transportation efficiency



will move and show a higher value as shown in figure 3.

Figure 3 Optimum Beam of Twin Skeg Hull Form

By utilizing twin skeg hull and reaction pod concept mentioned in the next section 2.2, transportation efficiency of a container ship (kW/TEU) can be improved. Figure 4 shows the results of investigation for



the post panama containers ($B=48.8m, d=15m$).

Figure 4 Post Panamax Container Ships of ZEUS Concept

As shown in Figure 4, advantage of ZEUS concept varies from 14% ($L_{pp}=360m$) to 23% ($L_{pp}=200m$).

2.2 Reaction Pod

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 (called as tunnel), and descent flow for outside of skeg as illustrated by Figure 5, 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 5. 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.

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) blades¹⁾. 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.

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.

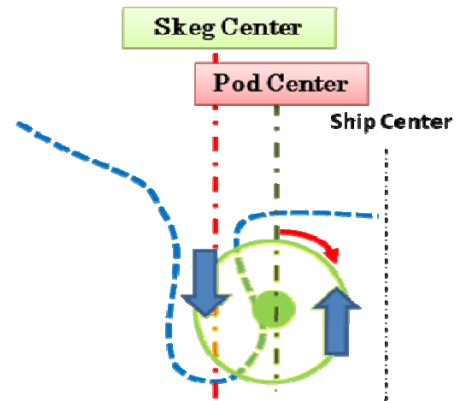


Figure 5 Counter-Rotating Flow of Twin Skeg Hull

2.3 Spray Tearing Plates (STEP)

Spray is a phenomena occurred on fast slender vessel around her stem and it increase not only frictional resistance and but also pressure resistance by increasing wetted surface area. Spray Tearing Plate (STEP) is a device to reduce the spray covering area and change a direction of spray pressure from normal to hull surface to upward or thrust direction (forward). Therefore STEP is very effective if the vessel has sharp stem and high speed enough to grow spray.

Figure 6 shows how the STEP works in the calm sea condition and STEP is effective even the position of STEP is higher than spray top observed at calm sea condition because the wave generation due to heavy weather lift the spray top as shown in Figure 7. The first STEP was installed on a first RO/RO vessel on Feb.2011 and the energy saving 2-3% (about 20% reduction of added wave resistance due to weather) was confirmed by comparing with a sister ship without STEP (see Figure 8)²⁾

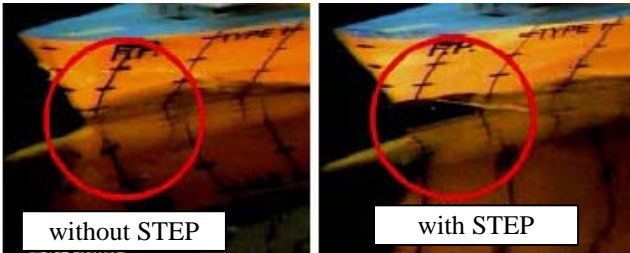


Figure 6 Effect of STEP (Calm Sea)



Figure 7 Effect of STEP (in Wave)

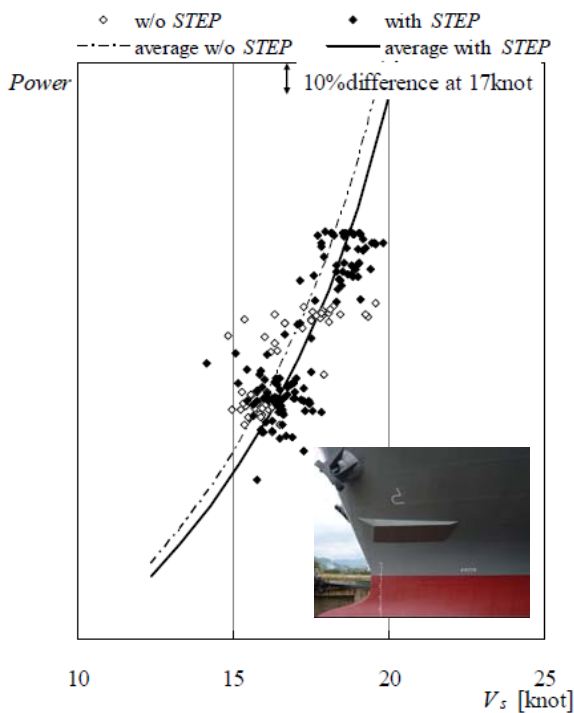


Figure 8 Comparison of Voyage Data of Two Ships (with and without STEP)²⁾

2.4 Weather Adapted Duct(WAD)

The ESD(energy saving devices) installed in front or behind of propeller is now days very common.³⁾ Among several energy saving devices, it seems that a duct system shows the superior performance to the others when the ship encounters in rough weather conditions because the thrust generated by the duct will increase propulsive efficiency. NMRI has been developing the special duct system which can be characterized by outstanding mutual interaction between a propeller and a duct. The system is composed of a propeller with special pitch distributions and a front duct placed very close to the propeller. The size of diameter of the duct is less than 45% of propeller diameter and the size is so small that harmful cavitation hardly occurs.

The distance between a propeller and a duct is less than 10% of propeller diameter which enable to amplify mutual interaction between two. The test set up of this system is seen from a Figure 9.



Figure 9 Test set up of WAD

Table 2: Ship Model and Propeller Models

Ship		Propeller	
Lpp(m)	6.20	Dia.(m)	0.189
B(m)	1.06	Pitch Ratio	0.77
d(m)	0.39	Exp.Area Ratio	0.38

The propulsion tests in regular waves were conducted with 6m model at 400m towing tank of NMRI. The purpose of this test is to investigate an actual navigation performance of a ship with WAD. The calculated wind resistance corresponding to Beaufort 6 to 7 was added to propeller loading condition during the test addition to generated regular waves. Table 2 shows the principal dimensions of a ship model and a propeller model. larger than calm sea condition as shown in Figure 10.

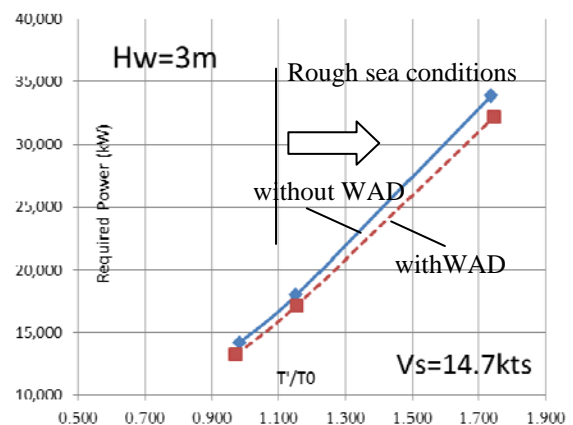


Figure 10 Performance of WAD at Sea

3 NOAH PROJECT

From 2012, the shipbuilding market is shrinking rapidly due to slow down of GDP growth in the world especially in China and Europe. The shipyards of Japan are suffering from getting new contracts to maintain their business. In this circumstance, the cost is the most important factor to survive by winning competitions among shipyards. As the capacity and operability are the first priority for the ship owners, it will be very evolutionary if we can design the ship with box shape within the allowable engine output (satisfy EEDI reference line).

Figure 11 shows the variation of required power for different C_b . From this figure we can easily notice that the critical C_b which exceeds EEDI reference line will appear around $C_b=0.86$ for a typical Panamax BC.

The project NOAH is looking for the countermeasures by which we can reduce the power at the range of extremely high C_b values where we need 20-30% reduction.

Table 3 Principal Dimensions of Studied Panamax BC

Loa = 225 m B=32.26 m d=14.45m Vs=14.75kts

CB	DWT	BHP	FOCR	EEDI
0.82	71,952	7,645	165	4.12
0.84	73,965	7,813	165	4.10
0.86	75,977	8,029	165	4.10
0.88	77,988	8,659	165	4.31
0.9	80,041	9,881	165	4.79
0.92	81,929	11,747	165	5.57

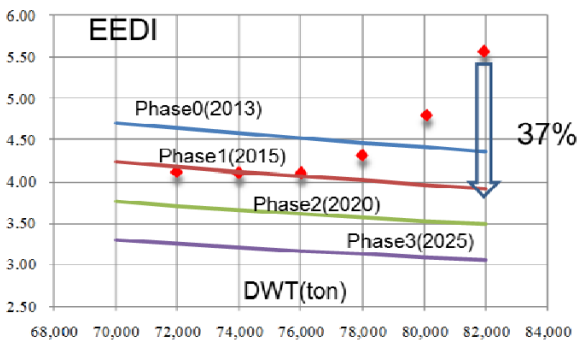


Figure 11 Effect of C_b on an attained EEDI

3.1 BOUNDARY LAYER SUCTION(BLS)

It can be said that this concept has many functions as shown in Figure 12, there are totally five functions⁴;

- (1) Main Engine Arrangement
- (2) Course keeping Ability
- (3) Cavitation Performance
- (4) Reduction of Resistance
- (5) Improve Propulsive Efficiency

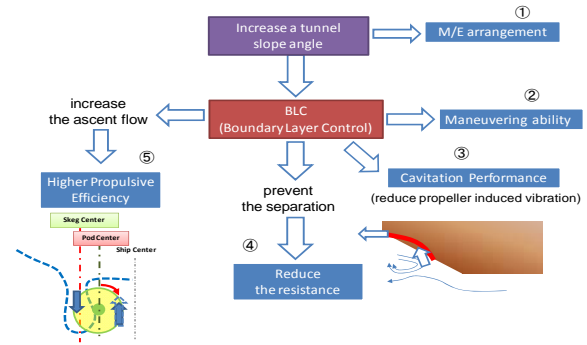


Figure 12 Multi Functions of BLS

3.1.1 Model test

In order to verify the aforementioned functions of BLS (Boundary Layer Suction), two model tests were conducted at 400m towing tank of NMRI.

Model test A

Model test A was conducted with a twin skeg hull of reaction pod concept. The ship was modified in order to have steep tunnel as shown in Figure 13. Where, modified line has a steep angle of 30 degree against to original angle 15 degree. The size of model was decided from the diameter of model propellers (0.226m) by which accurate data will be obtained.

Table 4: 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

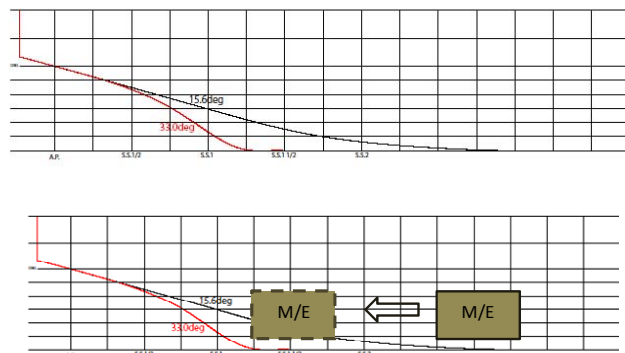


Figure 13 Modification of Tunnel Slope Angle for Efficient Engine Arrangement of Twin Skeg Hull

Model test B

The purpose of Model test B is to obtain physical explanation for energy savings by BLS. Therefore the model was manufactured as a box as possible. An acrylic model was used instead of wood or paraffin models commonly used for this kind of test. Table 5 shows the principal dimensions of the ship model.

Table 5 Ship and Propeller models for Model Test B

Ship Model		Propeller Model	
Lpp(m)	6.000	Dia.(m)	0.226
B(m)	1.300	Pitch Ratio	1.020
d(m)	0.2955	Exp.Area Ratio	0.35
CB	0.6564	Boss Ratio	0.18
LCB(%)	3.55	No. of Blades	3

Boundary layer suction concept is not a new idea. It has been applied to wings of an aero plane, a 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. The main difference between the water jet propulsion system and BLS is power ratio (P_{imp}/P_{main}) 1. Here P_{imp} and P_{main} are absorbed power of impellers and absorbed power of main propeller. P_{imp} is negligibly small compared with P_{main} .

3.1.2 Power Savings

Propeller loading test was conducted with the ship model and propellers shown in Table 4.

Propeller loading test is a propulsion test varying a propeller loading factor by changing a towing force (F_D).

By conducting this test, both resistance and propulsive performance can be evaluated at the same time. The results are shown in Figure 14. Where, P_{MAIN} means the output power of twin pod system and P_{IMP} is output power of impellers. If F_D is zero, the ship is propelled by only propellers (self-propelled condition). If ($P_{MAIN} + P_{IMP}$) is

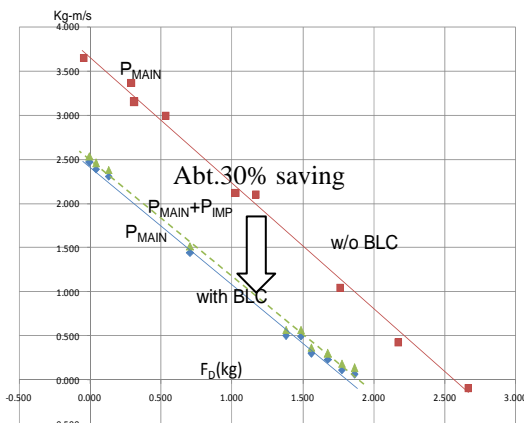


Figure 14 Power Saving of BLS

zero, this condition is very close to a resistance test.

The power of both pods and impellers were measured and compared between with BLS condition and without BLS condition.

As shown in Figure 14, effect of BLS on resistance is 27% (2.6kgf->1.9kgf). On the contrary, effect on power savings at model scale is 32%(3.7kgf m/sec->2.5kgf m/sec).The reason of difference can be explained by Figure 15 which shows the axial and tangential velocity distributions of behind two systems(with BLS and without). By adopting BLS, flow separation area(blue) can be completely eliminated and counter flow to blade rotation can be increased. It is very clear that these effects can improve propulsive efficiency.

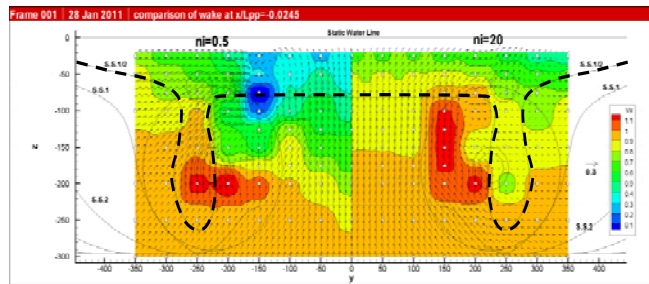


Figure 15 Flow Distributions behind Pod system (left: without BLS, right: with BLS)

3.1.3 Course Keeping Ability

As well known by ship design experts, it is not a simple task to improve a course keeping ability of a ship without changing her principal dimensions.

The simplest way is to increase the rudder area. However the larger area easily increase total resistance and then spoil her performance. It is generally recognized that the larger ruder area tends to spoil her propulsive performance. The index of N_b/Y_b is frequently used to evaluate the course keeping ability of a vessel because the index represents a center of effort of the vessel. Here N_b is a moment around the vertical axis of the ship center and Y_b is sway force acting on the vessels.

If the index was very large and far from the ship center, the ship can be categorized as unstable vessels.

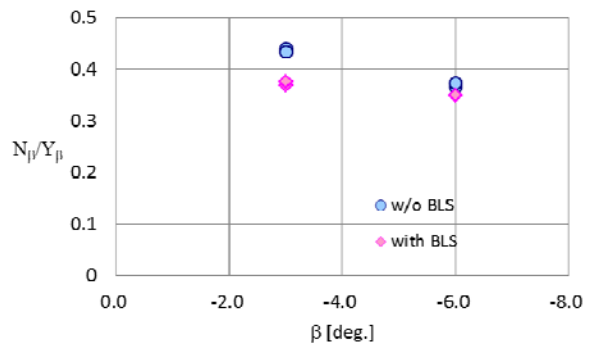


Figure 16 Effect of BLS on Course Keeping Ability

In order to obtain this index, the oblique motion test at yaw angle β was conducted with a ship equipped with a boundary layer suction system (BLS). The results are shown in Figure 16. By applying BLS, the index can be improved clearly. It can be expected that the more beamy ship can be designed if the system was applied.

3.1.4 Propeller exciting forces

Propeller exciting forces are dominant sources of ship vibration and noise in the stern. The simple criteria for the ship designers is to use maximum pressure fluctuations (ΔP) on the hull bottom just above a propeller tip at 12:00 o'clock. If the pressure fluctuations defined by this way was lower than 4kPa, normal ship vibration will be expected. However if the value exceeds 6kPa, the ship owner may ask the shipyard to reinforce the stern part.

Here, we will try to investigate the effect of BLS on propeller exciting forces by calculating based on an empirical method which was derived from full scale measurements.

Where, the pressure fluctuations can be obtained from following equations.

$$K_{PZ} = \sqrt{K_{P0}^2 + K_{PC}^2 + 2K_{P0}K_{PC} \cos(\pi - \varphi Z)}$$

K_{P0} and K_{PC} are non dimensional pressure fluctuations coefficients coming from non cavitating propeller and cavitating propeller respectively. Z is number of blades and φ is a blade angle where the maximum pressure fluctuation can be observed.

K_{P0} and K_{PC} can be obtained according to following empirical formulae.

$$K_{P0} = K_0 R_e^{-3}$$

$$K_0 = (0.0058 Z^2 - 0.0972 Z + 0.402) \frac{1}{2} K_Q$$

$$R_e = \sqrt{\frac{\xi^2 + \eta^2 + \zeta^2}{D}} - \frac{1}{2} (0.0117 Z^2 - 0.0684 Z + 0.72)$$

$$K_{PC} = K_{C0} R_{ec}^{-H} \quad Rec = \frac{d}{d_0}$$

$$K_{C0} = 0.0135 (\sigma_{cr} - \sigma_n)^{1.525} \quad \sigma_n \leq \sigma_{cr}$$

$$d_0 = 0.377 D \quad d = \sqrt{\xi^2 + (\eta - 0.201 D)^2 + (\zeta - 0.430 D)^2}$$

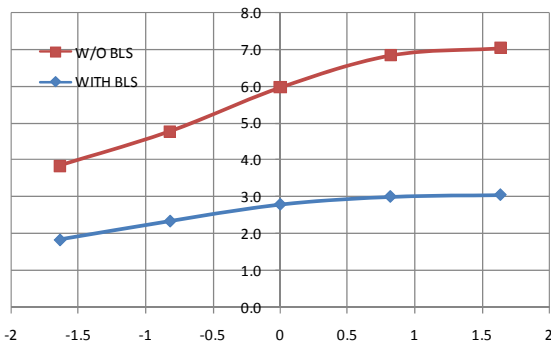


Figure 17 Comparison of Pressure Fluctuations

$$\sigma_{cr} = 2.0 + 5.2 \Delta W$$

Where, ΔW means difference between wake peak values at 90% radius of propeller and average wake for a propeller design. Figure 17 shows the results of calculations of pressure fluctuations (P) above the propeller for with BLS and without BLS.

3.2 GATE RUDDER

It is generally recognized that the best position of rudder is behind a propeller because of two reasons. The first reason is a rudder can obtain the better steering force due to propeller slip stream. The second reason is the rudder behind a propeller can reduce own resistance by propeller swirling flow by acting as a wing with attack angles. Therefore a rudder has been located behind a propeller from when a screw propeller was invented.

A gate rudder is the idea that two separated rudder are placed besides a propeller or in front of a propeller as shown in Figure 18.

Several advantages can be found from the model test of a ship with this new concept rudder. The remarkable effect on the ship performance is improvement of propulsive performance as shown in Figure 19 which were obtained from a model test with the ship and propeller model listed in Table 6. As shown in Figure 19 power saving by a gate rudder is more than 10%.

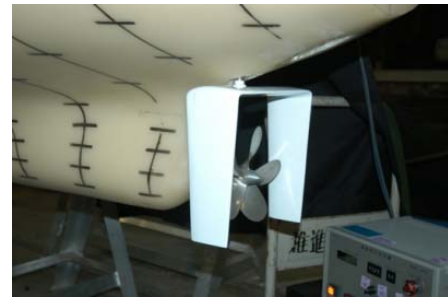


Figure 18 Gate Rudder of NOAH Project

Table 6 Ship and propeller models for Gate Rudder

Ship Model		Propeller Model	
Lpp(m)	6.000	Dia.(m)	0.226
B(m)	1.300	Pitch Ratio	1.020
d(m)	0.2955	Exp.Area Ratio	0.35
CB	0.6564	Boss Ratio	0.18
LCB(%)	3.55	No. of Blades	3

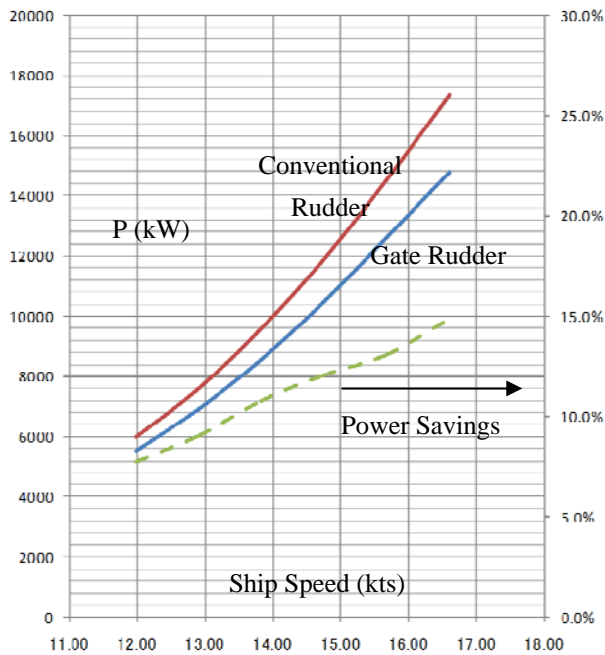


Figure 19 Power Curves of a Ship with Gate Rudder

As shown in Figure 19, the gate rudder has a clear tendency of better performance in high speed and this was brought by a smaller thrust reduction fraction. For example, (1-t) value of 16kts is about 0.90 instead of 0.83 which is a value of conventional rudder. It will be very important to investigate why the higher propulsive efficiency appears in a high speed range.

4 CONCLUSION

Two innovative projects ZEUS and NOAH are introduced. These projects have a quite opposite concept however, ideas developed in these projects are not far from reality. The ideas of NOAH will be utilized soon and the ideas of ZEUS will be realized in a near future. Main conclusions which were obtained here are as follows;

- By applying reaction pod concept, high propulsive efficiency of more than 90% can be obtained.
- BLS (Boundary Layer Suction) is a very effective solution to improve EEDI for the ship with the extremely steep tunnel for a twin skeg hull.
- Gate Rudder is a quite new idea and further investigation for the best stern configuration of stern (hull, propeller and rudder) shall be done..

ACKNOLEDGEMENT

The author would like to express great thanks to Mr.S. Kuribayashi ,Mr. M.Naito and Mr. M.Omote for supporting our projects “Gate Rudder and STEP” by giving us opportunities of full scale measurements.

REFERENCES

- 1) Sasaki N. “What is the best propeller for ZEUS” International Propeller Symposium ,April 2010, Okayama,Japan
- 2) Kuroda M. et.al. "Evaluation of STEP in actual seas by onboard measurements" Conference Proceedings of the Japan Society of Naval Architects and Ocean Engineers, Volume15, November 2012
- 3) Hollenbach U., Reinholz O., “Hydrodynamic Trends in Optimizing Propulsion” The 2nd International Symposium on Marine Propulsors 2011, Hamburg, Gemany
- 4) Sasaki N., “Boundary Layer Control of Twin Skeg Hull Form with Reaction Podded Propulsion”,The 2nd International Symposium on Marine Propulsors 2011, Hamburg, Gemany