Energy-Saving Principle of the IHIMU Semicircular Duct and Its Application to the Flow Field Around Full Scale Ships

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IHI Marine United Inc. (IHIMU) has already developed several energy-saving devices, such as their L.V. Fin (Low Viscous Fin), A.T. Fin (Additional Thrusting Fin), CRP (Contra-Rotating Propeller) and the IHIMU Semicircular Duct. The L.V. Fin, A.T. Fin and CRP have been employed in full-scale ships, and the energy savings expected have been confirmed. In order to employ the IHIMU Semicircular Duct in full scale ships, we verified the energy-saving principles of this device and optimized a full-scale shape for it, taking into account flow-field differences between the models and full-scale ships, through the use of CFD (Computational Fluid Dynamics) and PIV (Particle Image Velocimetry) techniques. This paper describes the energy-saving principles of this device and an outline of a design for its employment in full scale ships.

1. Introduction

In line with the international trend towards addressing global warming issues, the Ministry of Land, Infrastructure, Transport and Tourism of Japan is promoting as an environmental measure the "Support for Technology Development from Marine Vessels for Curtailing CO₂" project. The International Maritime Organization (IMO) is also working toward establishing regulations on CO₂ emission from ships by using the Energy Efficiency Design Index (EEDI), and toward a gradual and significant reduction in fuel consumption. To respond to the abovementioned environmental issues and to the steep rise in fuel oils, it is essential to improve hull forms, adopt high-efficiency plants, and further improve propulsion performance by employing energy-saving devices.

IHI Marine United Inc. (IHIMU) has developed energysaving devices, such as their Additional Thrusting Fin (A. T. Fin), ^{(1), (2)} Low Viscous Fin (L. V. Fin),⁽³⁾ and Contra-Rotating Propeller (CRP),⁽⁴⁾ and confirmed their energysaving effects in sea trials. The company has also developed a semicircular duct⁽⁵⁾ and confirmed its energy-saving effect in tank tests. In order to add the semicircular duct to the lineup of energy-saving devices applicable to full-scale ships, we verified its energy-saving principles by using new development tools, such as Computational Fluid Dynamics (CFD) and Particle Image Velocimetry (PIV) techniques, to examine its full-scale shape, which was designed for the flow field around full-scale ships. Through this study we acquired new knowledge about the operation principles of the semicircular duct, and so were able to optimize its fullscale shape, taking into account differences in flow fields between models and full-scale ships.

This paper reports the operation principles of the semicircular duct and the results of the examination of its full-scale shape.

2. Operation principles of the semicircular duct

We verified the operation principles (energy-saving principles) of the semicircular duct already developed and confirmed its energy-saving effect in tank tests to examine its full-scale shape and apply it to the flow field around full-scale ships. This chapter describes the energy-saving principles of the semicircular duct.

2.1 Energy-saving principles

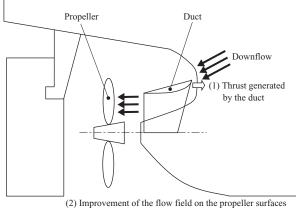
The semicircular duct installed just in front of a propeller has the following energy-saving principles. **Figure 1** shows the basic energy-saving principles.

(1) Generation of thrust by the duct

As shown in **Fig. 1**, there is a strong downflow along the stern hull. It is possible to make the duct generate thrust by using a suitable duct attack angle and blade shape.

(2) Increase in wake gain

The duct reduces the velocity of the flow behind it. It is possible to increase wake gain by guiding this slower flow to the propeller disc.



(2) improvement of the flow field on the propeller surfaces (increased wake gain)

(Note) (1) and (2) refer to the paragraph numbers of the description of the operation principles of the semicircular duct in Section 2.1.

Fig. 1 Basic energy-saving principles

The mechanism described in (1) had already been clarified⁽⁵⁾ but the mechanism described in (2) was still unclear, so we closely examined the flow field behind the duct by using CFD and PIV techniques.

2.2 Verification of energy-saving principles2.2.1 Verification method

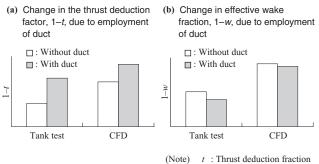
Using CFD, which is a technique that is actually used in design, and a new measurement technique, PIV,⁽⁶⁾ we analyzed and measured flows around hulls and ducts and studied flow fields in detail to verify the energy-saving principles. We also made CFD calculations for full-scale ships to examine the full-scale shape.

For CFD calculations, we used the NEPTUNE⁽⁷⁾ and SURF⁽⁸⁾ codes, which were developed by the National Maritime Research Institute and are used for design in many shipyards.

2.2.2 Estimated accuracy of CFD

We confirmed the estimated accuracy of CFD before using it for verification of the energy-saving effect of the duct. **Figure 2** gives a comparison of changes in self propulsion factor with or without the duct obtained in a tank test and in CFD analysis (SURF code).

Figure 2 shows that there are quantitative differences



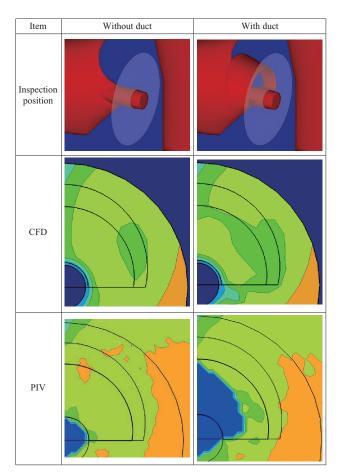
w : Effective wake fraction

Fig. 2 Comparison of changes in self propulsion factor due to employment of duct obtained in tank tests and CFD analysis between the values obtained in the tank test and in CFD analysis, but there are similar trends in the changes. Consequently, CFD analysis was considered useful for verification of the energy-saving effect of the duct.

2.2.3 Flow field where the duct operates

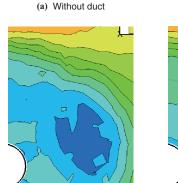
Figures 3 to **5** show the flow velocity distribution, pressure distribution, and vorticity distribution behind the duct, which were obtained by using CFD and PIV analysis.

Figure 3 shows that slower flow areas (green contours)



(Note) Green areas show slower flows, which make wake gains higher.

Fig. 3 Comparison of flow velocity distribution behind duct during propeller operation



(b) With duct

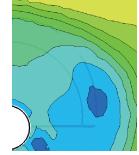
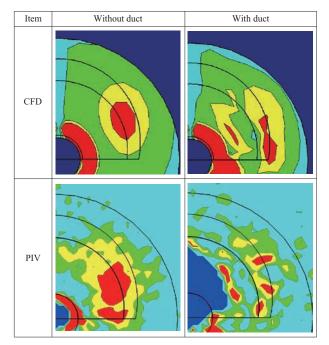


Fig. 4 Comparison of CFD estimates of pressure distribution behind duct during propeller operation



(Note) Red areas show higher vorticity, which makes the hull resistance higher.

Fig. 5 Comparison of vorticity distribution behind duct during propeller operation

become larger and wake gains become higher when the duct is employed. As can be seen in **Fig. 4**, pressure drops are reduced when the duct is employed and this effect is considered to cause the decrease in the flow velocity behind the duct. As can be seen in **Fig. 5**, the vortices around the stern hull (red contours) are separated and attenuated by the duct. This reduces pressure drops and thereby decreases the flow velocity behind the duct, resulting in a higher wake gain.

To verify how the separation of the vortices around the

stern hull influences the energy-saving effect of the duct, we conducted a series of tests with different duct diameters for the latest very-large crude carrier, which has a capacity of 300 000 tons. **Figure 6** shows the measured vorticities behind the duct. **Figure 7** shows the improvement in wake gain due to employment of the duct obtained in a tank test.

As can be seen in **Figs. 6** and **7**, the vortices around the stern hull are sufficiently attenuated and result in higher wake gains when the duct has a medium or large diameter that contains the center of the vortices. On the other hand, it was found that when the duct has a small diameter, the vortices around the stern hull are left behind the duct, and this results in a lower wake gain and a reduced energy-saving effect. For this reason, it is important to determine the duct diameter that contains the center of vortices around the stern hull and separates them.

2.2.4 Duct thrust

The energy-saving effect produced by duct thrust varies significantly depending on the attack angle at the duct leading edge. We conducted a series of tests on full ships with three hull forms and with large and small duct mount

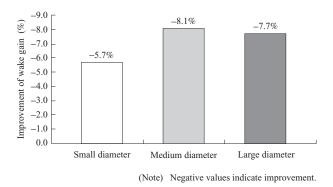
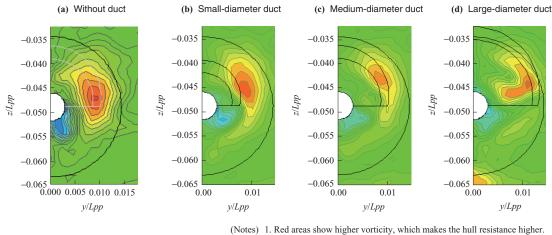


Fig. 7 Improvement of wake gain due to employment of the duct obtained in a tank test



Notes) 1. Red areas show higher vorticity, which makes the hull resistance higher
2. Symbols have the following meanings:

Lpp : Ship length

- y : Coordinate in the width direction
- *z* : Coordinate in the depth direction

Fig. 6 Comparison of PIV measurements of vorticity distribution behind the duct during propeller operation

angles, and then studied the correlation between the test results and the CFD estimated attack angles at positions along the duct leading edge. Figure 8 is a chart with the horizontal axis showing the position along the duct leading edge (from top to side) and the vertical axis showing the attack angle (CFD estimated values) in the series of tests with different duct mount angles. As can be seen in Fig. 8, the attack angles have constant values when the duct position is near the top and they decrease as the duct position changes from top to side. The tank test results indicate that the duct thrust produces a large energysaving effect at certain values of attack angle when the duct position is near the top. It is thus important to determine a duct mount angle that achieves such an attack angle near the top in order to produce a sufficient energy-saving effect from duct thrust.

2.3 Design concepts for the semicircular duct

The following is a summary of the design concepts for the duct shape and arrangement based on the above-mentioned energy-saving principles.

- Arrange the duct in a position where there is a strong downflow at a mount angle that generates a certain attack angle to enable the duct to generate a larger thrust. (Principle 1)
- Arrange the duct in a position where there are strong bilge vortices around the stern hull to separate vortices around the stern hull and reduce pressure drops. This results in a higher wake gain. (Principle 2)

3. Full-scale design of the semicircular duct

The correlation between the duct and the vortices around the stern hull and stern downflow has a great influence on the energy-saving effect. It is thus important to take into account the differences in the positions of the vortices around the stern hull and in the stern downflow between a full-scale ship and a model ship. For this reason, we studied the scale effect of the flow field where the duct operates.

3.1 Scale effect of the flow field where the duct operates

Figures 9 and 10 show CFD estimates of flow fields near the duct leading edge for a full-scale ship and a model ship. As can be seen in Fig. 9, vortices around the stern hull in the full-scale ship are stronger than those in the model ship and the center of the vortices comes closer to the center of hull. It is thus necessary to reduce the full-scale duct diameter in line with changes in the positions of the vortices around the stern hull. As can be seen in Fig. 10, the inflow angle near the top of the duct leading edge in the full-scale ship is smaller than that in the model ship. It is thus necessary to reduce the angle of aperture of the fullscale duct in line with changes in the inflow angle.

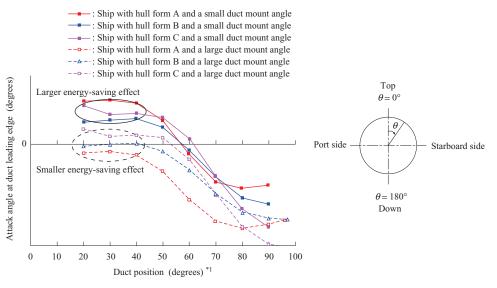
3.2 Shape of full-scale duct

Figure 11 shows the shape of the full-scale duct, which is designed based on the scale effect in the flow field where the duct operates as described in **Section 3.1**. The duct diameter is reduced as vortices around the stern hull tend to come closer to the center of the hull of a full-scale ship. The angle of aperture of duct is reduced to make the attack angle equivalent to that in the model ship, because the inflow angle at the duct leading edge is small.

It is considered possible to enable the duct in the full-scale ship to produce an energy-saving effect on the same level as that in the model ship by adjusting the correlation between the flow field and the duct to be equivalent to that in the model ship.

4. Conclusion

To meet the demand in society for the curtailment of greenhouse gases that cause global warming, we verified the energy-saving principles of an energy-saving semicircular duct that had already been developed at the model level to apply it to full-scale ships. As a result, we



(Note) *1:0 degrees corresponds to the top position.

Fig. 8 CFD estimates of attack angle at duct leading edge during propeller operation

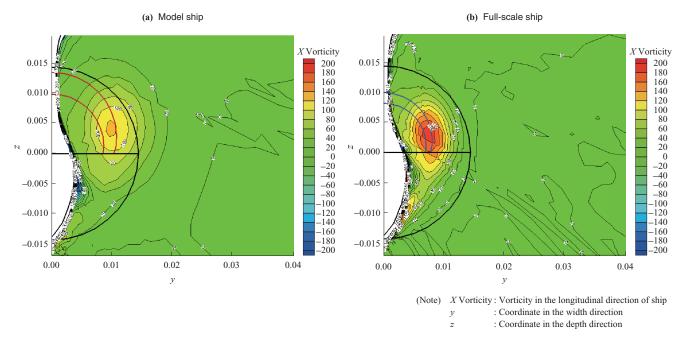
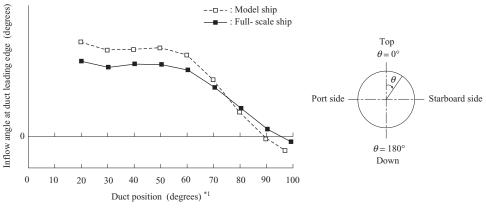


Fig. 9 CFD estimates of vorticity distribution at the front of the duct during propeller operation



(Note) *1:0 degrees corresponds to the top position.

Fig. 10 Comparison of CFD estimates of inflow angle at duct leading edge during propeller operation

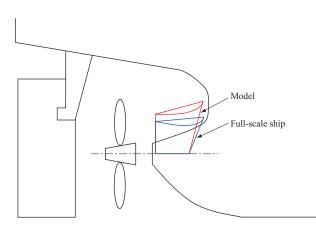


Fig. 11 Comparison of duct arrangement

acquired new knowledge about duct operation principles and used this to optimize the full-scale duct shape for the flow field around full-scale ships. We also verified the effectiveness of tools such as CFD and PIV, which has significance for future design work.

In the future, we aim to closely study the scale effect on the powering of ships as well as flow fields and further examine the energy-saving effect in full-scale ships.

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