Wind tunnel study of column-type circular cylinder propulsion assistance system (C-PAS) for Ships

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ABSTRACT: Referring to the recent soared oil prices and the environmental requirements for saving energy, the requirement of ship energy saving has become a keen subject. Review of classical concepts of hydrodynamic principles such as Magnus effect, boundary layer control and so on. As a result, Column-type Circular Cylinder Propulsion Assistance System (C-PAS) was proposed for large vessels utilizing existing column structures of dodger support applying boundary layer control by air-suction. As a part of basic study, a preliminary design was made which is composed of a circular cylinder with a fin and air suction panel. Flow visualization by smoke test was conducted at a two dimensional wind-tunnel and the results showed the clear effect of air suction, permeability of suction panel. In this study, X-type hot-wire measurements was conducted to measure flow velocity and direction more in detail. The analyses and comparison with the results by a spherical probe indicated clearly the change of flow field around the circular body by air suction. The estimated lift by C-PAS implies a possibility of this system for assisting ship propulsion.

KEYWORDS: Wind energy, Ship propulsion, Boundary layer control, Hot wire measurement

1 INTRODUCTION

Oil prices have recently soared with the result that energy saving of ships is keenly required from the stand points of ship economy and environmental energy conservation. To date, improvements of ship performance have been made in propulsion devices and also in hull form refinement. It is a fact that there are some technologies which can save large amount of energy but few of them are justified economically or maintenance ability.

In order to provide a solution for this problem, review of classical concepts of hydrodynamic principles such as Magnus effect, boundary layer control and so on. As a result, Column-type Circular Cylinder Propulsion Assistance System (C-PAS) was proposed for large vessels. The concept of C-PAS is to utilize commonly equipped column structures of dodger support as a sail by applying boundary layer control using air-suction. Usage of fans for supplying air into engine room is in the scope of our development to minimize additional energy for the new device in order to increase the economical value.
A preliminary design of C-PAS was conducted to be composed of simple elements of a circular cylinder, a triangle tail fin. The column surface is partly provided with a punched metal to have permeability for air suction.

First study was made by the two dimensional wind tunnel at Akishima Laboratories of Mitsui Zosen Inc. to investigate the flow pattern by smoke, and velocity distribution by spherical probe hot wire. The results indicated that air suction controlled the boundary layer of the column and the column can exert lift. [1]. It is also found that detail flow around the cylinder is necessary to optimize the system since flow pattern measurement by smoke can not provide us with information near the surface nor separated area.

The second step, measurement using X-type hot wire was made to evaluate directly wind velocity and direction closer to the column surface. To cope with the wide variety of wind direction, 360 degree calibration was introduced. The analyzed velocity distribution is compared with those by spherical probe and flow patterns by smoke test. Basing on the results, evaluation of lift was made calculating circulation around the column.

The effect of boundary layer control by air suction is discussed about the flow velocity and direction. Lift force for propulsion assistance is also discussed by analyzing the circulation around the cylinder.

2. MODEL TESTS OF C-PAS

2.1 Model and test condition

Column models (Model A, B) were made of vinyl chloride pipe for two dimensional tests as shown in Table 1. Figure 1 shows the photo of Model B with punched metal surface. Air suction is made by using a vacuum cleaner through the mounting piece.

<table>
<thead>
<tr>
<th>Model</th>
<th>Diameter (mm)</th>
<th>Height (mm)</th>
<th>Flap Length (mm)</th>
<th>Hole dia. Permeability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>60</td>
<td>149</td>
<td>25</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>60</td>
<td>149</td>
<td>25</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 2. Test conditions

<table>
<thead>
<tr>
<th>Flow velocity U (m/s)</th>
<th>4.5 – 5.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attack angle (deg.)</td>
<td>0, 15, 30</td>
</tr>
<tr>
<td>Air volume (CQ=Q/LDU)(for4.5m/s)</td>
<td>0, 0.263, 0.390, 1.007</td>
</tr>
</tbody>
</table>

2.2 Hot wire measurements

The instruments are shown in Table 3. For X-type probe, calibration for 360 degrees was conducted and correction factors were used to derive the velocity components from wide range flow angle.

<table>
<thead>
<tr>
<th>Type</th>
<th>Manufacturer</th>
<th>Material</th>
<th>Diameter (mm)</th>
<th>Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spherical</td>
<td>Tonic</td>
<td>Aluminum</td>
<td>2.5</td>
<td>-</td>
</tr>
<tr>
<td>X-type</td>
<td>Kanomax</td>
<td>Tungsten</td>
<td>0.005</td>
<td>2.5</td>
</tr>
</tbody>
</table>
3. TEST RESULTS

3.1 Calibration results of X-type probe
The calibration of X-type probe was made in the uniform flow at the wind tunnel for the wind direction from 0 to 360 degrees with 15 degrees interval. By using this calibrated characteristics, correction factors for two probes were introduced to realize the wind velocity is constant for any angle.

3.2 Mean velocity distribution around the column
Test using X-type probe was made to confirm its applicability to the measurement around the column Model A without air suction condition. Figure 2 shows the mean velocity measured by X-type probe at $r/r_0=4/3$ ($r_0$: radius of cylinder) of Model B, comparing with the result by spherical probe and potential flow. This figure indicates that two methods are in good agreement in the potential range of forward half but also in the aft separated region. It implies that the correction factors introduced for the measurement is reasonable as far as mean velocity is concerned.

![Figure 2 Comparison of Velocity distributions($r/r_0=4/3$)](image)

3.3 Flow with air suction
The velocity measurements of Model B with air suction were made at several radiuses ratio $r/r_0$ from 3.2 to 7. Mean velocity components were calculated at the measuring points and flow vectors were derived. Smoke tests by using kerosene mist were also conducted for the same conditions.

Mean velocity vectors at attack angle 30 degrees with air suction of $C_Q=1.007$ is shown in Figure 3 comparing the smoke tests results. This shows that velocity vector is close to the flow line, although some discrepancy is found at upper half. This difference can be partly due to the correction method incorporated. From these results, it is clearly shown that air suction can accelerate the flow at lower half and generate the velocity differences with that at the upper half.
of the cylinder. The effect of tail fin is also found that the flow is divided into two preventing the roll up of flow and Karman vortexes in the down stream as shown in the smoke test.

![X-type probe & smoke test](image)

Basing on the measured flow velocity, circulation $G$ around the cylinder was calculated and the lift coefficient $C_L$ was estimated by the following equation.

$$C_L = \rho U \Gamma / (1/2 \rho DU^2)$$

(1)

where $\rho$=density; $U$=uniform velocity, $D$=cylinder diameter.

The maximum $C_L$ is estimated to be an order of 3.5 at 30 degrees attack angle with suction volume $C_Q=1.007$. This indicates that C-PAS can generate thrust for assisting ship propulsion.

4. CONCLUSIONS

The basic studies on C-PAS have indicated a possibility for an energy saving device for vessels. Following can be concluded:

1) Boundary layer control through suction panel can eliminate the separated zone in the aft half of the cylinder and flow is accelerated. Combining with proper attack angle, C-PAS can exert aerodynamic lift to be used for ship propulsion.

2) Velocity was measured by X-type probe, and the result was in good agreement with that by spherical probe. It implies that the correction method for probe supports is reasonable.

3) The estimated lift coefficient calculated from circulation around cylinder has an order of 3.5.

5. ACKNOWLEDGEMENT

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REFERENCE