Proposal and Fundamental Experiments on Unconventional Ducted Propulsor without Rotating Blades

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ABSTRACT
A conventional screw propeller has large rotating blades to get effective thrust force, and the respective blades advance in water as male screws. In the present study, an unconventional ducted propulsor having a shape of female screw is proposed. It has a duct, a rotating boss and vanes with screw surfaces installed on the duct inner surface. Viscous rotational flows caused by rotating motion of boss are curved by the vanes along the duct inner surface. According to this inner flow, suction flows at the front side and accelerated blowing flows at the rear side can be induced. In order to increase the rotational flow, protuberances or roughness should be adopted on the surface of boss. In the present paper, concepts of the new propulsor are proposed, and results of fundamental experiments carried out to investigate its basic hydrodynamic characteristics are reported.

Keywords
Unconventional propulsor, Ducted propulsor, Rotating blade, Flow visualization, Circulating water channel

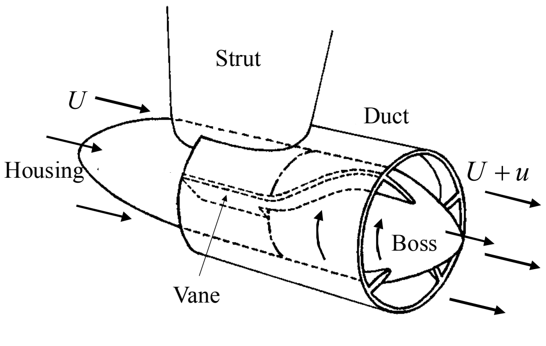

Figure 1: Image of new propulsor

1 INTRODUCTION
In this paper, the authors propose a new ducted propulsor without rotating blades. This propulsor has a duct, a rotating boss and vanes installed on the duct inner surface as shown in Figure 1, which is an image of the new propulsor illustrated by the first author. The vanes are arranged as screw surfaces along the duct inner surface and the duct with these vanes looks like a female screw. Viscous rotational flows caused by rotating motion of boss give the increase of flow momentum inside the duct and the rotational flows are curved by these vanes. The inner flows should be accelerated by the rotational flows. Due to this concept, suction flows at the front side and accelerated blowing flows at the rear side can be expected. If the accelerated flow is obtained by this concept, it can be expected to get the thrust force based on the momentum theory.

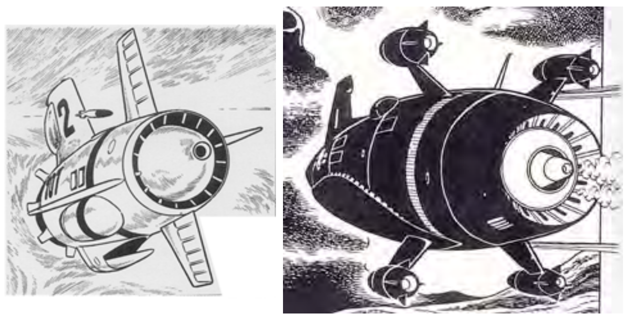

Figure 2: Unknown propulsors illustrated in SF comics; "Submarine 707" and "Blue submarine 6"

As introduced above, this new propulsor is based on the duct system having the shape of female screw, however, basic backgrounds and motivations to propose this new propulsor may be different from the usual sense. When the first author was an elementary and junior high school student, he preferred to enjoy SF comics (Japanese "manga") about submarines; "Submarine 707" and "Blue submarine 6" (Ozawa 1963, 1967) in which unknown propulsors were illustrated like Figure 2. Probably, a water jet (WJ) propulsion was assumed in these SF comics; however, he had no information about WJ in those days. Since then, he has been trying to imagine propulsion principles for these unknown propulsors. After summarizing ideas as the new unconventional ducted propulsor like Figure 1, he had applied the patent (Suzuki 2006). In the present paper, results of fundamental experiments on the new propulsor based on this patent application are reported.

2 FLOW VISUALIZATIONS AROUND PROPOSED NEW PROPULSOR

As the first fundamental experiments, both suction flows and blowing flows are visualized by using smoke for simple models based on the present new concept. Under the condition without uniform flow, suction and blowing flows can be visualized. For the purpose of the experiment of flow visualization around the new propulsor, simple models shown in Figure 2 with specifications in Table 1 are prepared. A small electric fan on the market is used and remodeled for the experimental purposes. In the experiments, low and high revolutions of the boss can be selected, tested vane angles are π/12 and π/6 rad., and relative positions of the duct and the boss can be changed.

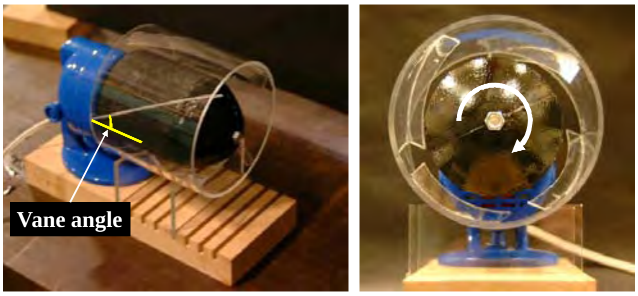

Figure 3: Simple model for flow visualization remodeled from small electric fan

Table 1: Specifications of tested models for flow visualization

Parts	Materials	Specifications
Motor	Electric small fan	Shaft length: 40 mm, Shaft diameter: 6 mm, High or low revolutions can be selected.
Duct	Acrylic pipe	Length: 100 mm, Inner radius: 54 mm, Outer radius: 60 mm
Vane	Polyethylen e sheet	Thickness: 1 mm, Height: 10 mm, Vane angle on duct inner surface: π/12 or π/6 rad.
Boss	Styrene foam	Total length: 110 mm, Radius: 40 mm, Length of circular cylinder part: 80mm

Examples of the flow visualization are shown in Figure 4, in which the vane angle π/6 rad. and the high revolutions are selected. Clearer blowing effects can be confirmed by video movie records. It can also be verified by the series experiments that the case of π/6 rad. vane angle is better than that of π/12 rad. According to increasing number of revolutions (case of high revolutions), blowing flow range can be extended, however, velocity distributions are not measured in the present fundamental experiments.

Since the boss surface of the present model is smooth, the viscous rotational flow caused by the boss is not enough to increase blowing flows at the rear side of duct. In order to increase the torque of boss and the rotational flows, ideas shown in Figure 5 can be proposed. In the following experiments, protuberances on the boss surface are introduced.

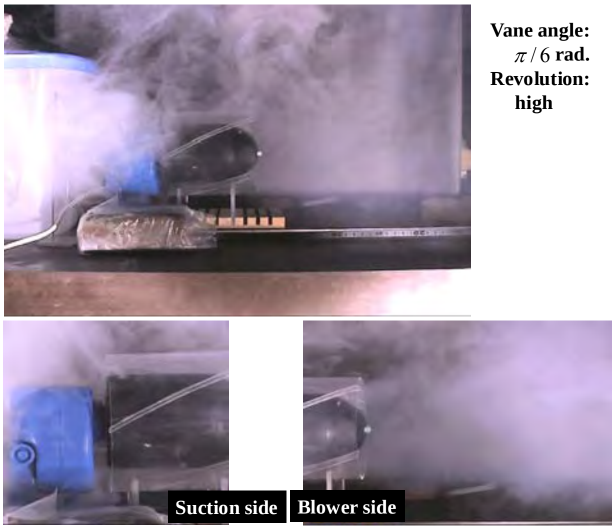

Figure 4: Example of flow visualization

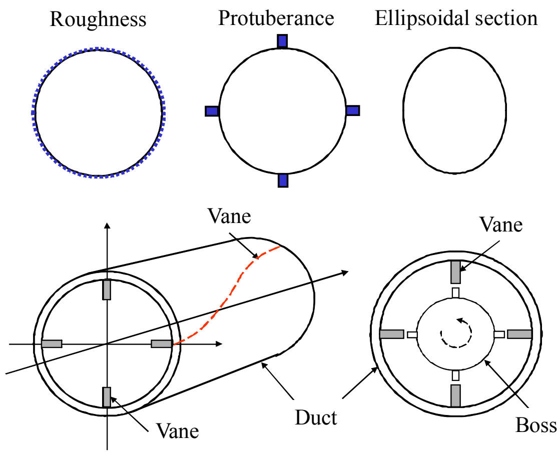

Figure 5: Ideas to increase torque of boss

3 EXPERIMENTS ON NEW PROPULSOR IN CIRCULATING WATER CHANNEL

More complicated propulsor models than the first one are used for experiments carried out in a circulating water channel. In these experiments, accelerated flow velocity distributions behind the model are measured to confirm momentum increments. Thrust forces and torques are not measured because of the basic models; however tendencies of the optimum parameters can be discussed.

3.1 Parameters Related to New Propulsor and Tested Models

Parameters related to this new propulsor are very complicated and important to discuss its practical applicability. As the basic parameters, radius ratios of boss to duct, number of protuberances on the boss surface, number of vanes and vane arrangements should be investigated. In the present experiments, however, radius ratios of boss to duct and vane arrangements are focused.

At first, an optimum radius ratio of boss to duct should be considered. If assuming Couette flow between the boss surface and the duct inner surface, the circular flow velocity is expressed as follows,

$$q_\theta = \frac{\omega\kappa^2 R}{1-\kappa^2}\left(\frac{R}{r}-\frac{r}{R}\right) \quad (1)$$

where, (r, θ) polar coordinate system is used on the duct section, ω is the angular velocity of boss, R is the radius of duct inner surface, and κR is the radius of boss ($0< \kappa <1$). According to the concepts of this new propulsor, it can be expected that the strength of blowing flows depends on the momentum of circular fluid motions in the duct. The momentum of circular fluid motions between the boss surface and the duct inner surface can be evaluated from the circular flow velocity in Equation (1) as follows,

$$\int_{\kappa R}^{R}\int_{0}^{2\pi} \rho r q_\theta dr d\theta = \frac{2\pi\rho\omega R^3}{3}\frac{\kappa^2}{1+\kappa}(2+\kappa)(1-\kappa) \quad (2)$$

where, ρ is the fluid density. The momentum based on Equation (2) becomes a maximum at $\kappa \approx 0.65$. The radius ratios of boss to duct can be selected by reference to this consideration. In the present experiments, κ = 0.45, 0.60, 0.75 are selected.

Table 2: Specifications of tested models in circulating water channel

Parts	Materials	Specifications
Motor	DC motor	BLF620A-A-3 (Oriental Motor Co.), Standard torque: 0.65 Nm, Start torque: 1.15 Nm, Maximum number of revolutions: 3000 rpm
Duct	Acrylic pipe	Length: 200 mm, Inner radius: 95 mm, Outer radius: 100 mm
Vane	Urethane rubber	Number of vanes: 4, Thickness: 5 mm, Height: See below, Vane angle on duct inner surface: π/6 or π/4 rad.
Boss	Chemica l wood	Total length: 200 mm, Radius: See below, Length of circular cylinder: See below
Protuberance	Wood	Number of protuberances: 4, Length: 129 mm, Height: 3 mm, Thickness: 3 mm

Radius of boss, length of circular cylinder part of boss and vane height:

κ	Boss radius	Boss length	Vane height
0.45	43 mm	157 mm	45 mm
0.60	57 mm	143 mm	31 mm
0.75	71 mm	129 mm	17 mm

Under the results of fundamental experiments reported in the previous chapter, tested vane angles are selected as π/6 and π/4 rad. However, in order to get blowing flow to advancing direction, vane angles are changed gradually to advancing direction near the end of duct. Specifications of tested models are shown in Table 2. The height of vanes changes due to the radius ratios of boss to duct. Number of vanes on the duct inner surface and protuberances on the boss surface are fixed as 4 for the simplicity of experiments. In future works, these numbers, the height of protuberances, shapes of boss and duct should be investigated.

An example of tested models setting in the circulating water channel is shown in Figure 6, and a schematic view of experimental setup is shown in Figure 7. Uniform flow velocities in the circulating water channel are selected as 0.2, 0.3 and 0.4 m/s. The number of revolutions of boss can be decreased by using a belt and pulleys as shown in Figure 7. As one of the experimental conditions, the number of revolutions of boss is fixed to 500 rpm for the experimental conveniences.

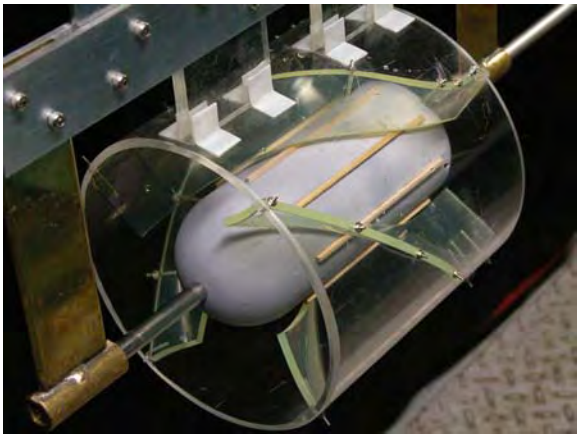

Figure 6: Tested model setting in circulating water channel

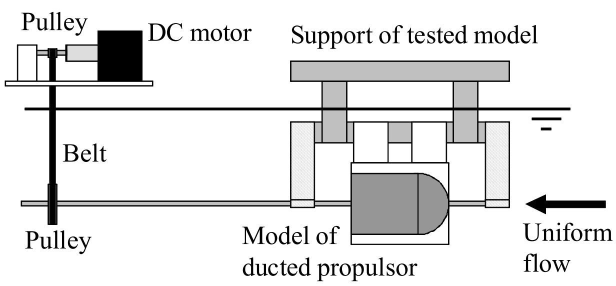

Figure 7: Schematic view of experimental setup

3.2 Experimental Results and Discussions

In the present experiments, velocity distributions behind the tested models are measured by using the small propeller type velocimeter. As shown in Figure 8, measured points are 20, 40~100 (10 mm pitch), 120, and 140 mm from the center of axis on the plane of 40 mm behind the end of duct. Because of the complicated experimental set up, thrust forces and torques cannot be measured.

Examples of measured velocity distributions are shown in Figure 9 and 10. Accelerated velocity distributions are observed near the duct radius, however, dead water zones are also observed behind the boss. According to the experimental results shown in Figure 9, the radius ratio of boss to duct κ = 0.75 is the best one among 3cases. The optimum radius ratio may be slightly higher than $\kappa \approx 0.65$ considered in the previous section, because the boss of tested models has protuberances. As shown in Figure 10, clear differences of velocity distributions are observed with respect to the vane angles. It can be verified that the case of $\pi/4$ rad. vane angle is better than that of $\pi/6$ rad. In the present experiments, however, the optimum angles cannot be discussed clearly, because only two cases of vane angles are tested.

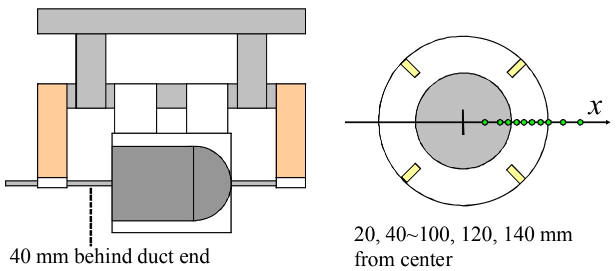

Figure 8: Measured points of velocity distribution

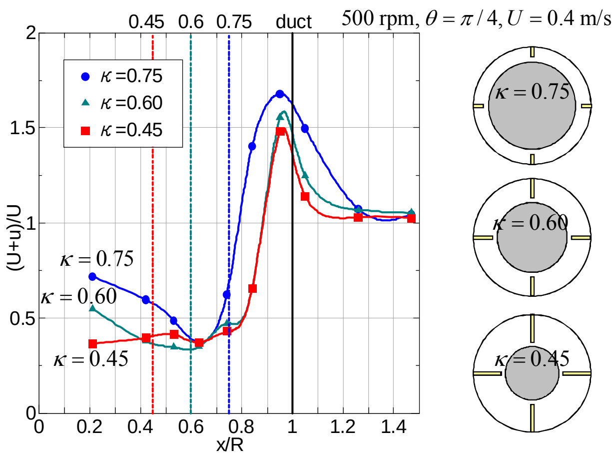

Figure 9: Comparison of measured velocity distributions

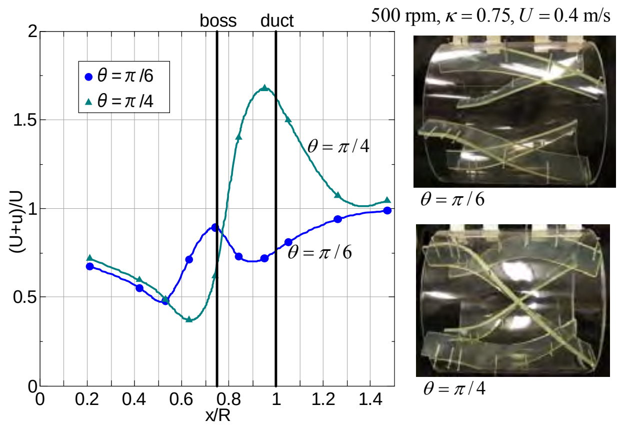

Figure 10: Comparison of measured velocity distributions

If axisymmetric velocity distributions are assumed, momentum on the plane to measure the velocity distributions can be estimated easily. The momentum of accelerated flow can be compared with that of uniform flow. In the present case, however, thrust cannot be estimated, because the velocity distributions are measured at the plane just after the end of duct. In this paper, the momentum increment can be defined as follows,

$$\frac{\rho \iint_S (U+u)^2 dS}{\rho S U^2} \tag{3}$$

where S is taken as the circular plane based on the measured points of velocity distributions. The momentum increments based on Equation (3) are compared in Figure 11. The increments of momentum in low speeds become better than those in high speeds. This unconventional propulsor may be efficient in low speeds. More detailed investigations are needed to confirm hydrodynamic characteristics in low and high speeds.

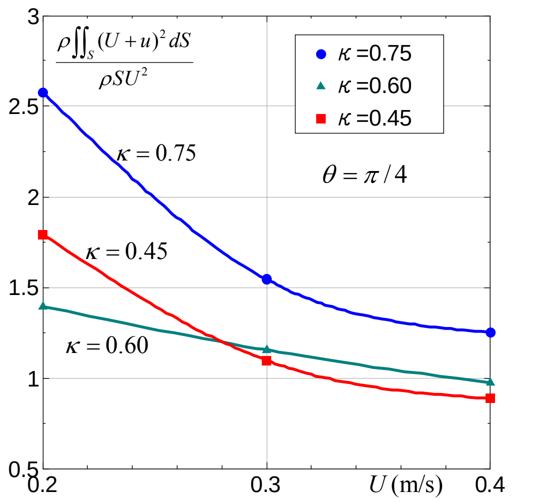

Figure 11: Comparison of momentum increments

For the purposes to verify practical applicability of this new unconventional propulsor, efficiency should be discussed. If the torque of boss and the thrust acting on duct with vanes are measured, the efficiency can be defined as that of the conventional screw propeller. In the present situation, however, it is not so easy because of the insufficient experimental data. In future works, more detailed experiments using practical models should be carried out to study the related parameters more clearly. The duct and boss shapes should also be optimized, especially; dead water zone behind the boss should be excluded. In order to avoid the energy losses by the swirl flow behind the propulsor, the shapes of duct and vanes should be investigated carefully.

4 CONCLUDING REMARKS

In the present paper, the authors propose a new unconventional ducted propulsor without rotating blades. The concepts of this new propulsor are based on the principle of female screws, which has a duct, a rotating boss and vanes installed on the duct inner surface. Two fundamental experiments are carried out to study the basic hydrodynamic characteristics of this new propulsor.

In the first part of this paper, flow visualizations are carried out for simple tested models by using smokes. Both suction flows at the front side and blowing flows at the rear side are observed.

As the next study, more complicated propulsor models than the first one are used for experiments carried out in the circulating water channel. In those experiments, accelerated flow velocity distributions behind the models are measured to confirm momentum increments. Basic information is obtained from the present fundamental experiments.

In future works, more detailed experiments using more practical models should be carried out. Thrust forces and torques should be measured, and the efficiencies of this new propulsor should be investigated. In addition to the studies on related parameters like the radius ratio of boss to duct and the vane angle, the other parametric studies and the shape optimizations of boss and duct should be tried.

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