A Basic Model of Ray-wing-type Propulsor for Future Underwater Vehicles

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Key Words: Bio-mimetic propulsor, Ray-wing, Underwater vehicles, Fluttering wing, Thrust measurement

1. INTRODUCTION

Ship propellers are simple and efficient propulsors but they have problems with vibration and noise radiation because they move at high speed in a non-uniform wake. These problems need to be reduced for ships that use acoustic apparatus, especially for underwater vehicles. One solution for this problem is bio-mimetic propulsor like fishes'.

Fig.1 Future underwater vehicle with ray-wing-type propulsor

Many theoretical and experimental studies about fish propulsors have been made. However, there are few studies about wing fluttering propulsion in water like manta’s; manta swims smoothly at good cruising speed by slowly fluttering its large wing. The authors are greatly interested in the manta’s propulsor because it has following advantages,\(^1\)

(1) Ray-wing-type propulsors generate less body swing in thrust generation than caudal fin (tail fin) propulsors.

(2) Ray-wing-type propulsors are potentially quieter than caudal fin propulsors because of the large actuating area and their position.

Figure 1 depicts a future underwater vehicle with ray-wing-type propulsor\(^1\). This paper discusses a basic model of just such a propulsor.

![Fig.2 Mechanism model of the propulsor](image)

2. MECHANISM MODEL OF THE PROPULSOR\(^2,3\)

Figure 2 shows the mechanism model made by the authors. It is designed to generate the flapping motion and feathering motion simultaneously by systematically stroking many linear actuators.

The model consists of two driving arms with 5 airfoil frames connected together. Each driving arm has 5 actuating units. One actuating unit has a couple of actuators and two half portions of bone (link) unit connected by a pin joint as seen in Fig.3.

![Fig.3 Actuating unit of driving arm](image)

The synchronized stretching \(\varepsilon\) of the coupled actuators varies the angle \(\theta\) between two bone units. The actuating units connected in a line form the driving arm bow (Fig.4). The bowing motion produces flapping elevation \(\xi\) of the arms. The difference in the bowing of the two arms generates the feathering angle on the airfoil frame.

The stretching \(\varepsilon_{ij}\) of each couple of actuators is governed by following rules for time \(t\), \(\tau\) is the period of the fluttering, \(\delta c\) and \(\delta s\) are the phase lags in the chord-wise and span-wise

\[\varepsilon_{1,j} = \varepsilon_0 F\left(\frac{2\pi}{\tau} t - (j - 1)\delta_s\right) ; \text{fore arm}\]

\[\varepsilon_{2,j} = \varepsilon_0 F\left(\frac{2\pi}{\tau} t - (j - 1)\delta_s - \delta_c\right) ; \text{aft arm}\]

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\* Technical Research and Development Institute, Japan Defense Agency
Received 25th September 2003
Read at the autumn meeting 13, 14th November 2003
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The shifting of the actuators' position, \( F(x) \) is an arbitrary periodic function of period \( 2\pi \) and magnitude 1.

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>( \tau = 25 \text{sec} )</td>
<td>( \delta = 5 \text{ mm} )</td>
</tr>
<tr>
<td>( \delta c = 8/\pi \times 180 )</td>
<td>( \delta s = 10/\pi \times 180 )</td>
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The model is tested in the air with a weight-canceling apparatus, with the parameters as in Table 1. The test demonstrates that the mechanism can make suitable fluttering motion for thrust generation.

3. PROPULSOR MODEL

Figure 5 illustrates the model ship (3.2 m long) equipped with the mechanism mentioned above (the span-wise length is reduced by one actuating unit). Coupled ray-wing-type propulsors are attached to the lower hull of the model ship. The wing surface is composed of rubber sponge and thin rubber film. A rigid rectangular wing is fitted on the tip end of each wing in order to generate thrust surely.

There are many technical hurdles for fluttering the ray-wing-type propulsor in the water. The most important issue is the weight cancellation in water. An actuator in each pair is replaced by a rigid dummy rod (except for the wing root) in order to decrease the weight.

4. PROPULSION TEST IN WATER

A test for measuring thrust was conducted for the ship model in various steady running speeds in a towing tank. The thrust is measured in various steady fluttering states by the load cell in the lower hull. The stretching parameters and \( F(x) \) are the same as Table 1, except for the period. Figure 6 is an example of recorded thrust and the fluttering motion at an advancing speed of 0. The records of the fluttering are estimated ones at the wing tip using digital data of the stretching of all actuators. Figure 7 is a chart of the measured mean thrust during one period at various ship speeds.

At the shorter fluttering period, the hydrodynamic load exceeds the capacity of stretching force of the linear actuators at the root of the wing. The maximum thrust is thus only about 1.2 N.

In the free-running test, the ship model is floated freely toward longitudinal direction and the heading course is restricted. The ship model runs at mean speed of 0.25 m/s in the fluttering conditions of Table 1.

5. CONCLUSION

(1) A ray-wing-type propulsor consist of many linear actuators has proven capable of generating appropriate fluttering motion to produce thrust quietly in the water.

(2) Thrust characteristics in various advancing speed are obtained. The maximum thrust is about 1.2 N for a fluttering period of 25 seconds.

Although the acquired thrust is small, the model has demonstrated that the ray-wing-type propulsor is a candidate for use as a propulsor for future ships. A stronger and smaller actuator is needed to develop a more practical propulsor.

Acknowledgments

The authors would like to express their gratitude to the members of TRDI for supporting this study. They also express their appreciation to Dr. Yuzo Kusaka of Akishima Laboratory (Mitsui Zosen) for his advice in fabricating the propulsor.

REFERENCES

