Artificial wings for flapping MAV imitating insect wings

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1 Introduction

A small-scale UAV (Unmanned Aerial Vehicle), which is called MAV (Micro Air Vehicle), has been attracting attention in recent years. However, developments of MAV are difficult for some reasons, such as the difference in the hydrodynamic characteristic due to the size changes. The knowledge from the developments of conventional UAVs cannot be directly applied to develop MAVs due to differences in hydrodynamic characteristics. Therefore, as a new approach, there is a high expectation for flapping MAV technology inspired by insects being small and highly maneuverable [1].

In insect flight, maneuverability, such as taking off, hovering, moving forward and backward, and changing direction, is achieved by flapping the wings. The wings that insects use for flapping have undulating veins called wing veins. The wing veins contribute to changes in the flexibility and stiffness of the wing and increased crack resistance [2]. The flexibility of the wings is supposed to contribute to flapping flight. Wing flexibility and flight performance have been studied mainly by numerical simulation, and only a few experiments were conducted in real space [3]. The effects of some parts of wing vein shapes on the deformation of a wing have been studied in some insects [4, 5]. More knowledge about the effects of wing veins could be used as a guideline for the design of MAVs.

In this study, we aim to experimentally clarify the relationship between wing vein structure and movement performance by using artificial wings made of industrial materials. For this purpose, we fabricated several types of artificial wings with different thicknesses of wing veins and leading edges and checked the movement performance produced by each artificial wing. This study is expected to improve the mobility performance and durability of MAVs by being used as one of the design guidelines for MAVs.

2 Method

2.1 Artificial wings

We built nine types of artificial wings that have three different wing veins, named model Insect, model M, and model E, and have three different thickness leading edges, 0.3 mm, 0.6 mm, and 0.8 mm. The wing vein in model Insect is based on the honey bee photograph attached to reference [6]. The wing vein in each model M and model E is simplified to only those running in the direction of the wing chord and the wingspan. Figure 1 shows the artificial wings which are model Insect, model M, and model E from the top.

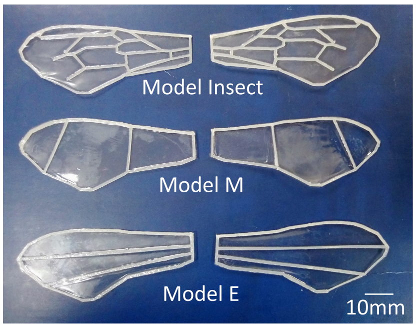

Figure 1: Artificial flapping wings

We used a polyoxymethylene (POM) sheet for the skeleton part and a polyvinylidene chloride sheet (Newkurewrap; Kureha Corporation) for the membrane part as the material of the artificial wings.

2.2 Measuring movement performance

We conducted experiments using a flapping device to investigate the movement performance of the artificial wings we fabricated. The frequency of the flapping produced by the flapping device was about 30 Hz. The reciprocating angle of the artificial wings was about 32 degrees. The flapping device was fixed on a rail (Figure 2), and the movement speed was measured by video recording how the wings moved on the rail. We used a high-speed camera (HAS-L1; DITECT Co., Ltd.) for recording. The artificial wings were fixed so that the wing surface was horizontal to the ground.

The terminal velocity of the flapping device on the rail installed horizontally was measured from the video taken. We estimated three forces acting on the flapping device: the force generated by the flapping of the wings f_{wing}, the dynamic frictional force f_{fric} received from the rail, and the air resistance $-kv$, where k is the coefficient of aerodynamic drag and v is the moving speed of the flapping device. The flapping force f_{wing} and the kinetic friction force f_{fric} from the rail are assumed to be constants that appear as integral values over one flapping cycle. Since the difference in the mass of the wing, which changes under each design condition, is considered to be sufficiently small to the mass m of the entire flapping device, the mass m is assumed to be the same under all design conditions. The dynamic friction force received from the rail is proportional to the mass m is

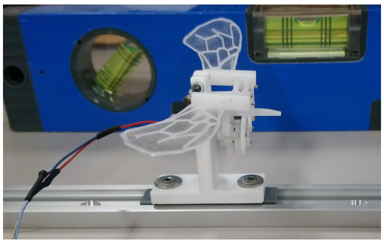

Figure 2: Conditions of the experiment on the rail

also assumed to be constant. When enough time has passed to consider $t \to \infty$, the speed would be constant, since f_{wing} and f_{fric} were assumed to be constants. Therefore, we evaluated the terminal velocity of the device as the movement performance. For each of the nine types of artificial wings, four sets of left and right wings were fabricated, and four samples of data were obtained.

3 Result

The experimental results are shown in Figure 3. The horizontal axis represents the wing vein type of the artificial wing and the vertical axis represents the terminal velocity of the flapping device. The mean of four samples is shown for each condition, and the standard error is shown as an error bar. Results are shown as circles for a wing vein leading edge thickness of 0.3 mm, cross-marks for a thickness of 0.6 mm, and triangles for a thickness of 0.8 mm.

Among the artificial wings fabricated in this study, the wings with a leading edge of 0.8 mm and wing veins of model M shown high mobility performance when used for MAVs. Artificial wings with wing veins of model Insect were relatively unaffected by changes in the leading edge.

4 Discussion

Focusing on the results of the wings that mimic insect wing veins, there was no significant difference in movement performance even when the thickness of the leading edge was different. One of the reasons seems that for the model Insect, the trailing edge is not easily displaced relative to the leading edge, regardless of the thickness of the leading edge. In contrast, for the wing with simplified wing veins, the thicker the leading edge of the wing, the higher the movement performance. The larger displacement of the trailing edge relative to the leading edge of the wing made more air pushed toward the trailing edge of the wing, and that may result in higher migration performance. Therefore, the wings having high bending stiffness in the leading edge and low bending stiffness in the trailing edge seem to achieve higher mobility performance.

The artificial wing that mimicked insect wing veins did not show superior mobility performance compared to the wing with simplified wing veins. This can be attributed to the difference between the material of the artificial wing used in this study and that of the insect organism, as well

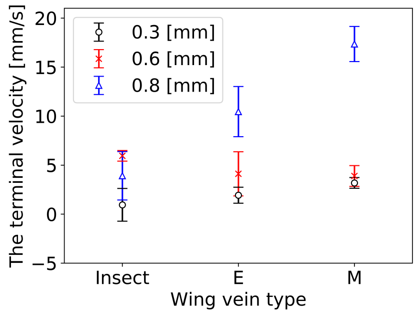

Figure 3: Results of experiments on movement performance

as to the difference in a structure that could not be reproduced due to technical problems. In actual insect wings, the wing veins have a hollow structure. However, the artificial wings in this study do not have a hollow structure. If the wings had a hollow structure, the bending stiffness values would be smaller and closer to the bending stiffness of a living organism. That would widen the difference in bending stiffness between the leading and trailing edges of the wing, which could lead to better mobility performance.

Another reason why the insect-like wing vein structure did not contribute positively to the movement performance was that the path of the wing flap in the experiment was different from that of the actual insect. While insects flap their wings three-dimensionally, the flapping mechanism in this experiment was a one-dimensional flapping in the same plane. As a future task, it is necessary to conduct experiments using wing-flapping paths more like those of insects.

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