Effects of Micro Spike Structure on Flow around Plate

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In recent years, biomimetics has been attracting attention. Biomimetics is research method to apply function principle of organism. Surface microstructure plays an effective role also in either case. On the other hand, dragonfly which is kind of flight insect has some microstructure on their wings. It is thought that these microstructure effective in flight of dragonfly. Among them, surface micro spikes are very unique structure. Therefore, in this study experiment and CFD analysis was performed, with the aim to clarify the effect of this microstructure. And we compared the result of CFD analysis with the experimental result to examine mechanism of them. As a result, we confirmed that the drag coefficient was reduced because the generation of a vortex on the plate behind was suppressed by the micro-spikes.

Keywords: biomimetic, dragonfly, micro fabrication, drag coefficient, CFD

1 Introduction

Recently, biomimetics has been attracting attention [1]. Biomimetics is research method to apply function principle of organism. There are numerous examples of biomimetic successes such as riblet structure of shark skin and surface structure of moth eyes [2] [3]. Surface microstructure is effective also in either case. On the other hand, dragonfly which is kind of flight insect has some microstructure on their wings [4]. It is thought that these microstructure effective in flight of dragonfly. Among them, surface micro spikes are very unique structure. As similar surface structure, it is reported in a field of aeronautical engineering that turbulence frictional resistance decreases by making groove called "riblet" structure [5]. Futhermore, “dimple” structure to be seen in golf balls promotes turbulence transition and reduces drag by suppressing exfoliation [6]. Same function can also be expected to micro structure of wings of dragonfly. However, researches on this microstructure have not been done at all. Therefore, in this study experiment and CFD analysis was performed, with the aim to clarify the effect of this microstructure. Moreover, we compared the result of CFD analysis with the experimental results for examining mechanism of them.

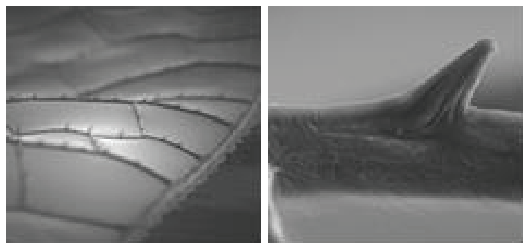
2 Micro spikes on dragonfly wing surface

The dragonfly has some micro structure in the surface of the wing. The structure that is the most characteristic in them is the micro-spikes. **Figure 1** shows the SEM image of the micro-spikes. The height of the spike is about 10~100μm, and the number of spikes on one side is about 3,000. In the airplane, it has been reported that turbulent frictional resistance decreases by riblets on the surface of wings. In the same way, the spikes on the wing of dragonfly affect the micro-flow and it is considered that spikes control the boundary layer flow. In this study, the effect of spikes is examined.

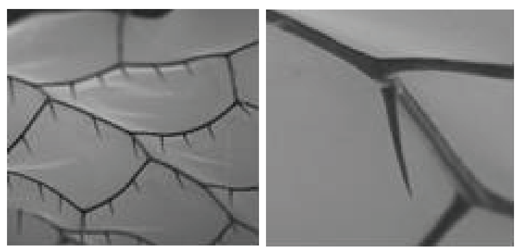
3 Measurement

3.1 Artificial wing

The artificial wing has spikes to confirm the effect of spikes experimentally. **Figure 2** shows Fabrication method of the artificial wing having spikes. First, Acrylic plate is processed into 40.0 x 10.0 x 0.3 mm (a). Next, heated tungsten wires are vertically inserted into the acrylic plate (b). Then, tip of tungsten wires are sharpened by electropolishing (c). Finally, excess tungsten wires are cut (d). **Figure 3** shows the plate having micro spikes fabricated by above method. Size



(a) Obverse side



(b) Reverse side

Fig. 1 SEM image of a dragonfly wing surface (Orthetrum albistylum speciosum)

of the plate is 10 mm in wing chord and 40 mm in wingspan (a/b = 4). Spike plate has 350 spikes on the surface, and the height of the spikes is about 500~700µm. Moreover, the diameter of tungsten wire is 30µm. We carried out each experiment with this spike plate.

3.2 Drag measurement

A drag force measurement is carried out to compare spike plate with flat plate. **Figure 4** shows a setup for a drag force measurement. The setup consists of a wind tunnel (0.3 x 0.3 x 0.85 m), load cell (Minebea Co., Ltd., UTA-100GR), and a test plate. The test plate was put in the wind tunnel and was connected to the load cell. Meanwhile, speed of wind was set under condition from 1 m/s to 10 m/s. In addition, for comparison with the numerical calculations, speed of wind in the neighborhood of 3m/s or 6m/s focuses and was measured 200 times. The experimental results are average value in 10 seconds. The drag coefficient C_D was calculated by Eq. (1);

$$C_D = \frac{2D}{\rho U^2 A} \tag{1}$$

D : Drag [N] ρ : Density of air [kg/m^3]
U : Velocity [m/s] A : Section area of wing [m^2]

4 CFD analysis

Table 1 shows properties of boundary condition. The computation grids are set with ANSYS Ver.14.5 software. The turbulence model used LES (large eddy simulation) model. It is better to direction and the movement vortices. The used of unstructured tetrahedral grid in the analysis. **Figure 5** shows a close-up illustration on the conformal hybrid mesh system employed to model the aerodynamic forces of artificial wings. In addition, calculate at 3m/s, 6m/s for comparison with the velocity of experimental result. In this study, as some posit infinite width in width direction (y) to the numerical calculation model (a/b=∞, a=Wingspan, b=Wing chord). The rectangular computation domain is composed length of 200 mm and width of 4mm.

The governing equations of LES are as follows.

$$\frac{D\overline{U_i}}{D_t} = -\frac{1}{\rho}\frac{\partial \overline{P}}{\partial x_i} + \frac{\partial}{\partial x_j}\left\{ \nu\left(\frac{\partial \overline{U_i}}{\partial x_j} + \frac{\partial \overline{U_j}}{\partial x_i}\right) - \tau_{ij} \right\} \tag{2}$$

$$\tau_{ij} = \overline{U_i U_j} - \overline{U_i}\,\overline{U_j} \tag{3}$$

$$\tau_{ij} - \frac{1}{3}\delta_{ij}\tau_{kk} = -2\nu_t \overline{S_{ij}} \tag{4}$$

$$\overline{S_{ij}} = \frac{1}{2}\left(\frac{\partial \overline{U_i}}{\partial x_j} + \frac{\partial \overline{U_j}}{\partial x_i}\right) \tag{5}$$

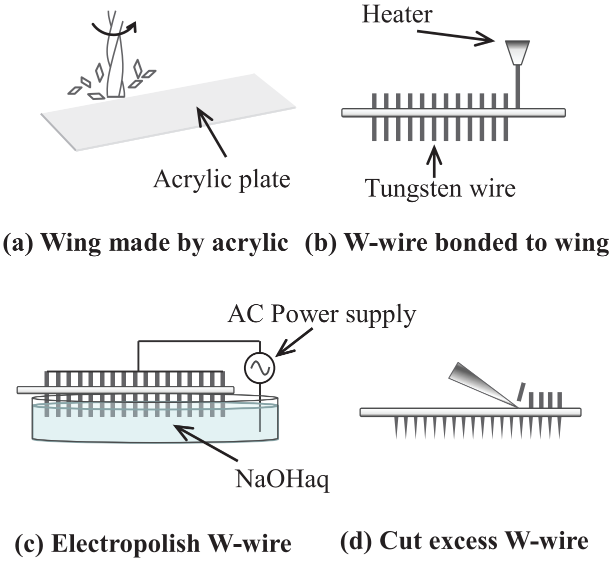


Fig. 2 Fabrication method of the artificial wing having spikes

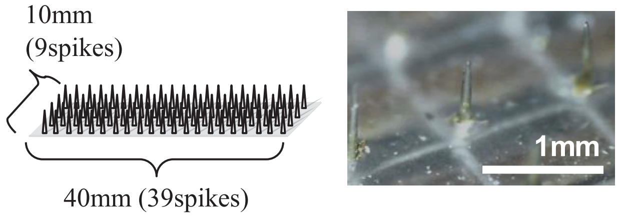


Fig. 3 Overview of artificial spike plate

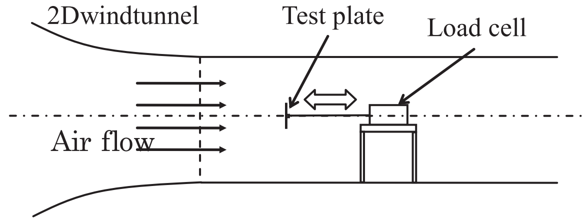


Fig. 4 Experimental set-up of drag force measurement

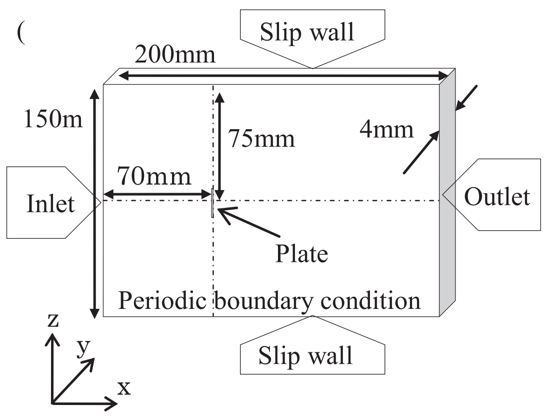


Fig. 5 Boundary condition for analysis

Table 1 Calculation condition

		Flat	Spike
Cells		864,490	1,735,739
Input condition	Inlet	3m/s , 6 m/s	
	Outlet	0 Pa	
	Side	Periodic boundary conditions	
Analytical area	Size of flow box	200 (20d)×4×150 (15d) mm	
	Size of wing	0.3×4.0×10.0 (d) mm	
	Wing position	X：7d,　Z：7.5d	
Calculation condition	Time step	About 5.0e-4	
	Iteration	About 100	

5 Results

5.1 Experimental result

Figure 6 shows the result of drag coefficient at each Reynolds number. Drag coefficient at each Reynolds number is remaining range-bound. The average values of drag coefficient of flat and spike plates are 1.151, 1.159, respectively. In general, the drag coefficient of flat plate is 1.19 in the case of a/b=4. However, drag coefficient of measurements were lower than the value. The measurement results were compared with analysis results under speed of wind of 3 m/s, 6m/s because there is no significant difference. **Figure 7** shows the drag coefficient of measurement that was measured 200 times. **Table 2** shows the average values of drag coefficient. In **Fig. 7**, the values of 6 m/s were no significant difference between measurement and analysis results. On the other hand, the average value of experiments of the spike plate was 3% lower than the value of flat plate at 3m/s as shown in **Table 2**. The reason obtained the result is to suppress the reduction of pressure behind the plate.

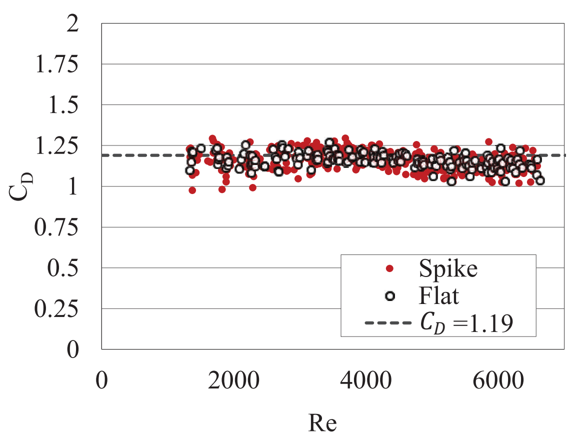
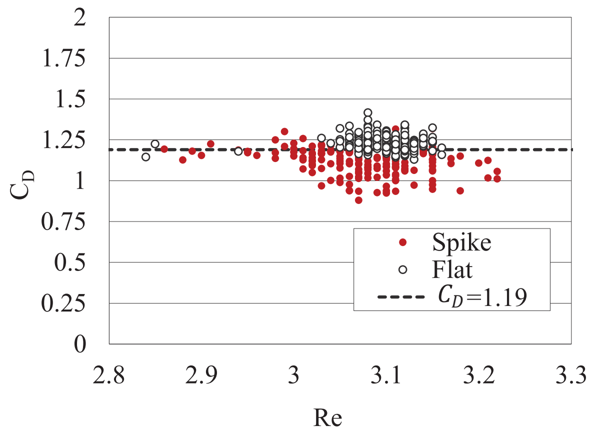
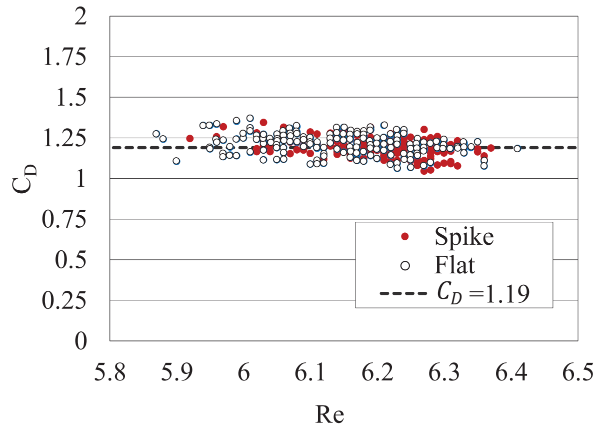


Fig. 6 Drag coefficient at each Reynolds number



(a) Around 3m/s (Re=1985)



(b) Around 6m/s (Re=3960)

Fig. 7 Drag coefficient at each velocity

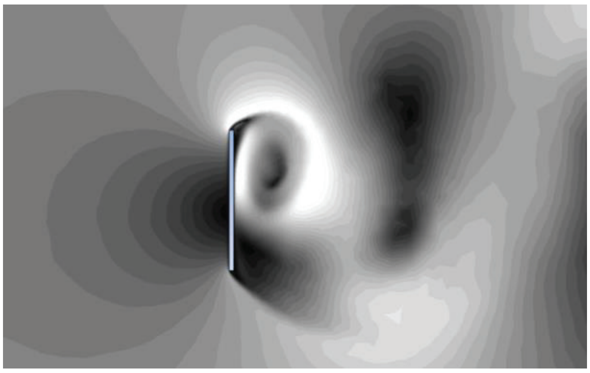
Table 2 Mean value of drag coefficient at each condition

		Flat	Spike
Exp.	3m/s	1.16	1.12
	6m/s	1.2	1.19
Cal.	3m/s	1.927	1.89
	6m/s	2.095	2.094

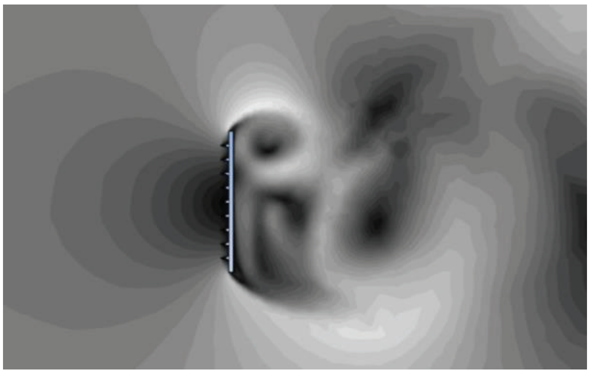
5.2 Calculation result

In this study, as some posit infinite width in width direction (y) to the numerical calculation model (a/b=∞). In general, drag coefficient of flat plate is 2.01 in the case of a/b=∞. Drag coefficient of flat plate obtained in this analysis showed a value close to 2.01. Meanwhile, drag coefficient of spike plate was in the same range in this numerical calculation model in the 6m/s. On the other hand, the value of 3m/s was down 2% age point from drag coefficient of flat plate.

Figure 8 shows the results of velocity distribution of 3m/s. These figure show a comparison of the moment in which the vortex on the plate behind is generated. As can be seen in this figure, the vortex can be observed in both results. The vortex in the case of spike plate is smaller than that of flat plate. Moreover, the velocity of vortex was also lower compared to result of flat plate. The reason for this behavior is probably to block the flow by the spikes. **Figure 9** shows the velocity vector

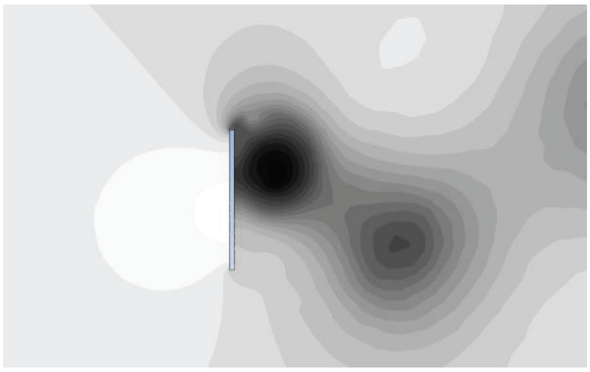


(a) Flat plate

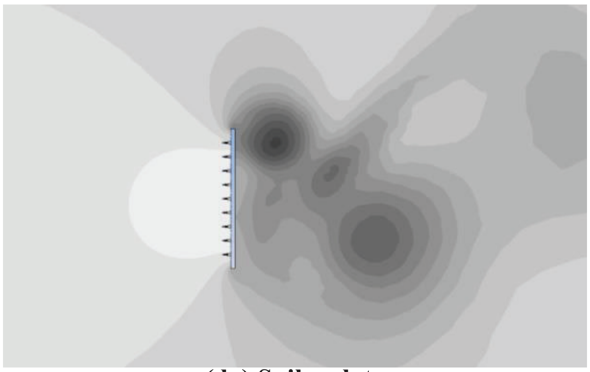


(b) Spike plate

Fig. 8 Velocity around plate (3m/s)



(a) Flat plate



(b) Spike plate

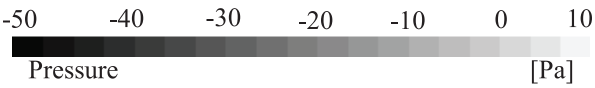
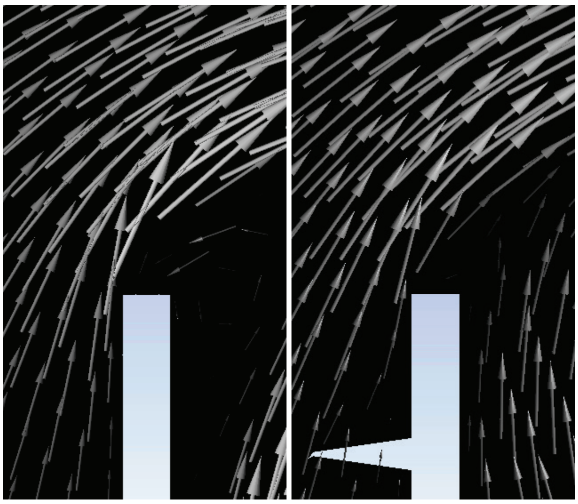


Fig. 9 Pressure around plate (3m/s)



(a) Flat plate **(b) Spike plate**

Fig. 9 Velocity vector around edge of plate (3m/s)

around the edge of plate. As can be seen in **Fig. 9**, the spike plate at edge of plate is reduced compared to that of flat plate.

Figure 10 shows the results of pressure distribution. Comparing these figures, the pressure of vortex of flat plate is lower than result of spike plate. The pressure difference around the plate affects the drag coefficient.

6 Conclusions

In this study, the effect of the micro spikes of dragonfly wings on drag coefficient was verified experimentally and theoretically. As a result, there was no significant difference between results of experiment and analysis at 6m/s. On the other hand, result of 3m/s shows that the drag coefficient of the spike plate was 3% lower than compared to the result of the flat plate. The velocity of spike plate at edge of plate was reduced compared to that of flat plate. Therefore, the drag coefficient was reduced because the generation of a vortex on the plate behind was suppressed by the micro-spikes.

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