supplementary files:

The cross-spring pivot fin rays with stronger stiffness variation are tested with the same controllable motion parameters. The results show the propulsive ability of the bionic cownose ray with the cross-spring pivot fin rays shows a similar trend to plastic sheets fin rays.

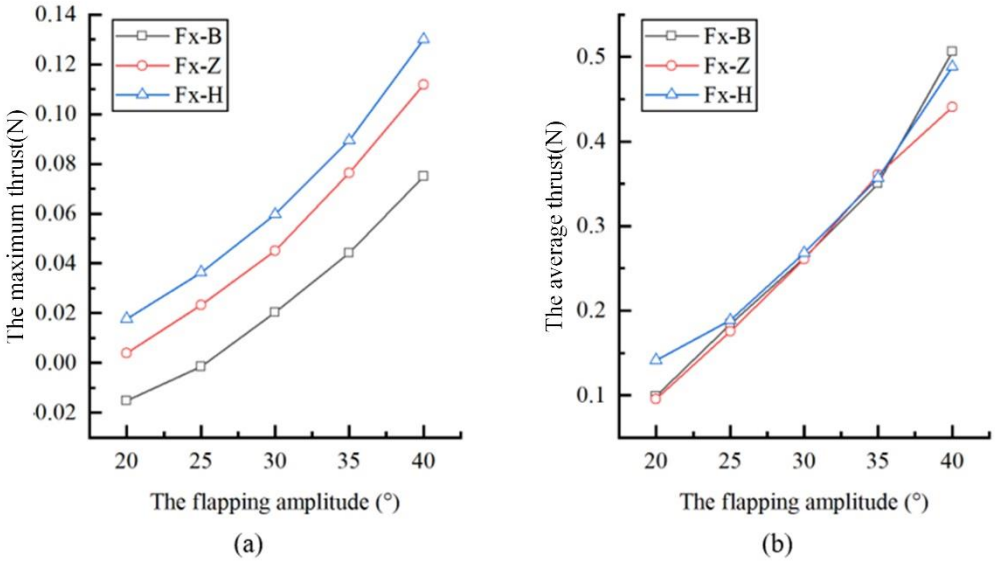

Figure S1 (a)the relationship between the maximum propulsion force and flapping amplitude（b）the relationship between the average propulsion force and flapping amplitude

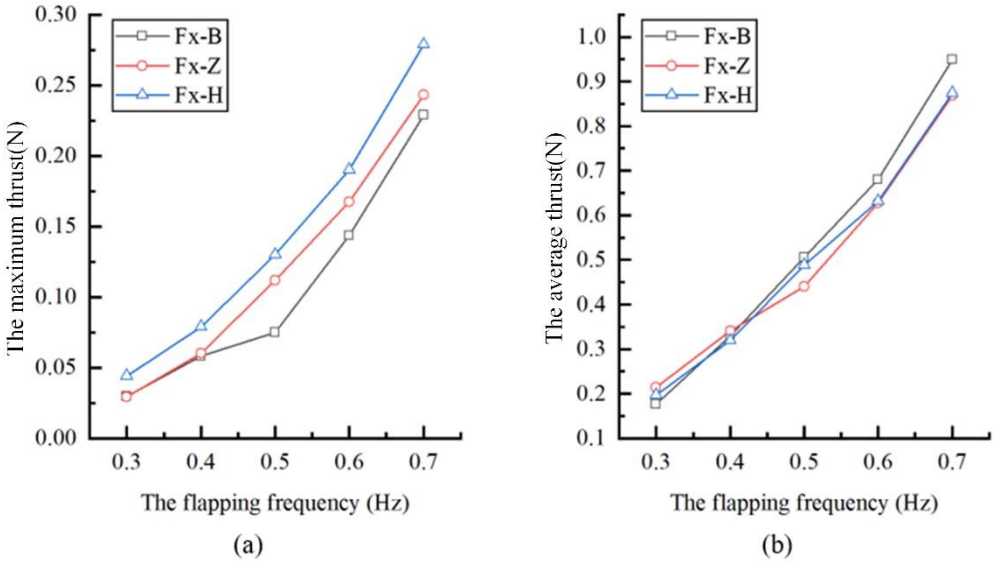

Figure S2 (a)the relationship between the maximum propulsion force and flapping frequency（b）the relationship between the average propulsion force and flapping frequency

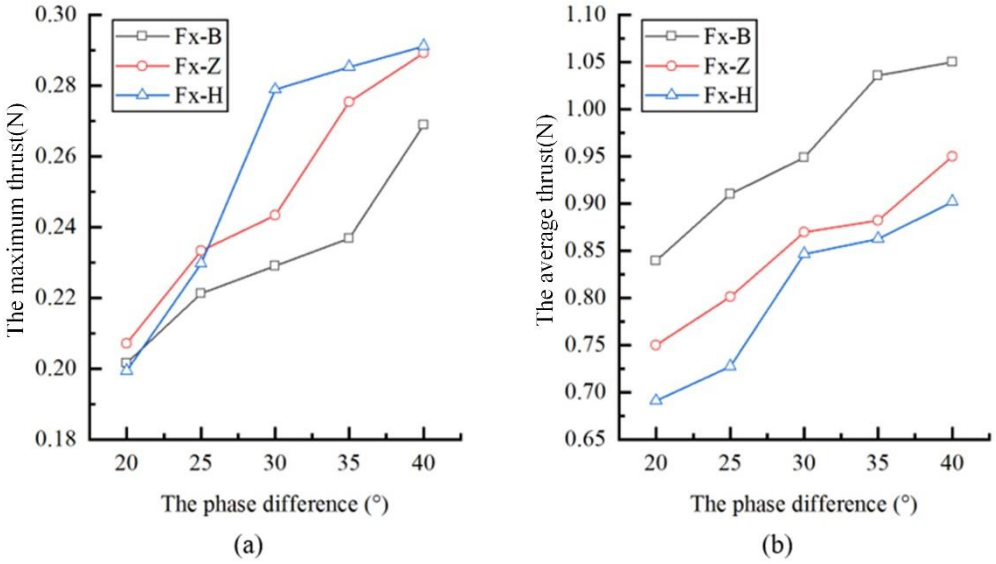

Figure S3 (a)the relationship between the maximum propulsion force and phase difference（b）the relationship between the average propulsion force and phase difference

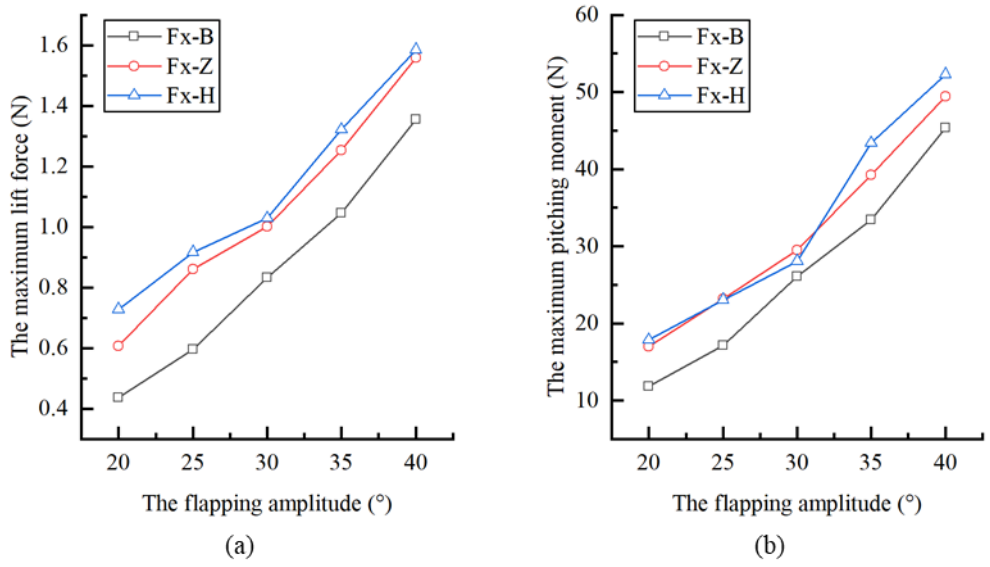

Figure S4 (a)the relationship between the maximum lift force and flapping amplitude（b）the relationship between the maximum pitching moment force and flapping amplitude

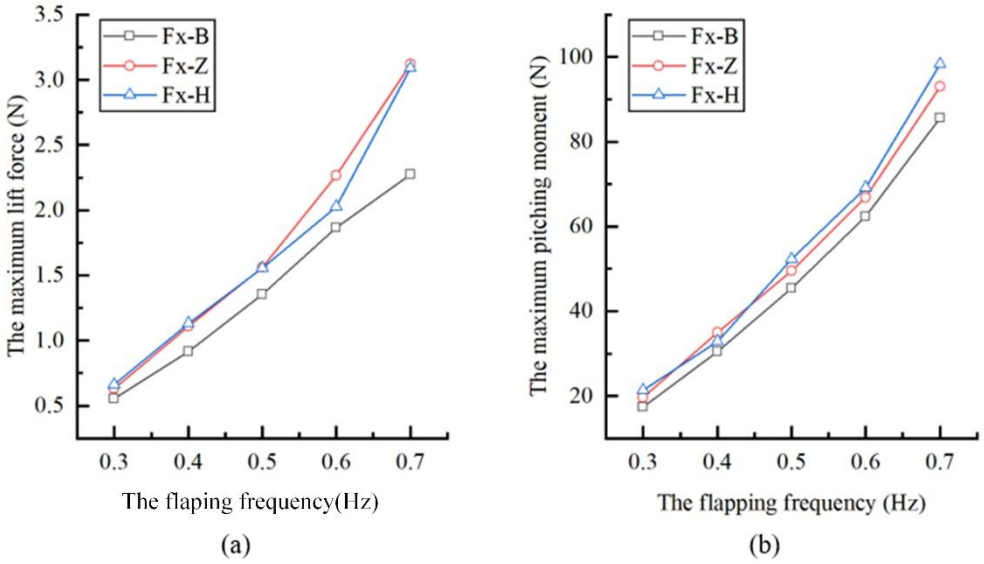

Figure S5 (a)the relationship between the maximum lift force and flapping frequency（b）the relationship between the maximum pitching moment force and flapping frequency

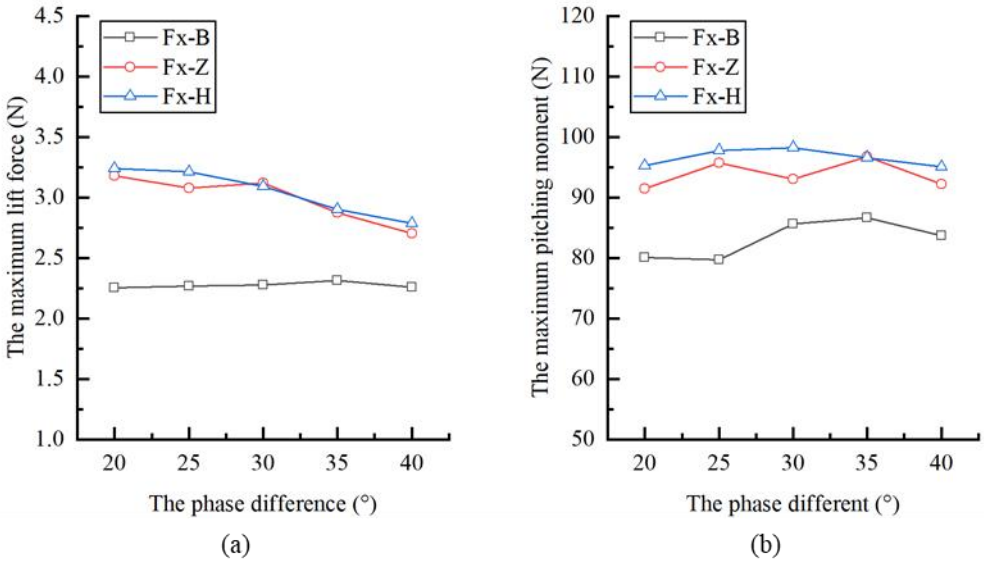

Figure S6 (a)the relationship between the maximum lift force and phase difference（b）the relationship between the maximum pitching moment force and phase difference