Experimental study of the transition between strokes in flapping flight

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The flight of birds has always been inspiring for engineers and has recently sparked the interest of researchers in the field of drone design[1 2]. However, flapping flight is difficult to study and replicate with an efficiency comparable to that of birds. One of the challenges lays in the large range of kinematic variations that the birds use in their flapping motion, both intra- and inter-species. In hovering, variations in the timing of the pitching of the wing at the transition between the strokes has a significant impact on the production of aerodynamic forces[3]. Here, we study if the same applies to forward flight. We thus assessed the aerodynamic effects of changes in the wing kinematics at stroke transition, using a mechanically actuated wing in a wind tunnel.

The experiments were performed using a robot[4], fitted with a rigid, 3D-printed wing. The wing has two degrees of freedom in flapping and pitching, and we varied the timing of the pitching motion that occurs between the strokes, and the mean elevation of the wing. The latter makes the wings interact either at the end of the upstroke or the downstroke, when the wing flaps in the upper or lower position, respectively.

We recorded the flow velocity in a plane behind the robotic flapper through PIV, and based our analysis on the velocity and calculated vorticity field, shown in Fig. 1. The results show that both the mean horizontal and vertical forces are affected by the changes, as shown in Fig. 2. The two parameters that we considered interact with each other.

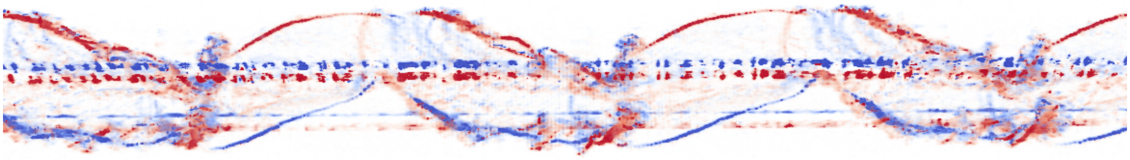

Figure 1: Volume rendering of the vorticity field recorded in an experiment

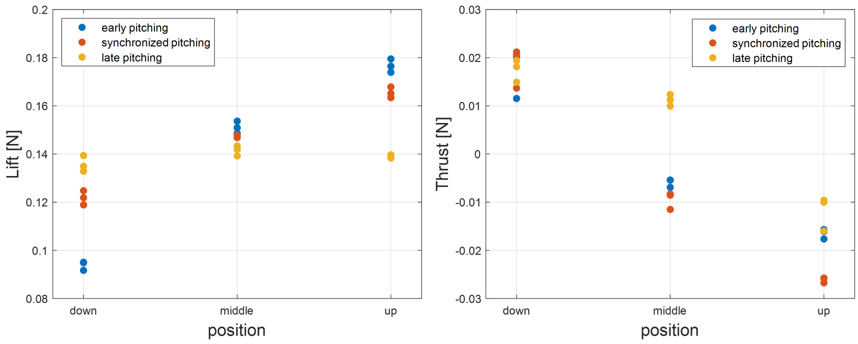

Figure 2: Mean forces computed for the various tested cases

Our results show that understudied kinematic strategies, such as the timing of pitch and the mean wing elevation, can be used to control the absolute and relative production of lift and thrust in flapping flight. Notably, since the tested parameters have different impacts on the horizontal and vertical forces, they could explain differences in flapping strategies observed in birds at different speeds and in different conditions. The results of this research can thus contribute to our understanding of birds, but also to the design and control of flapping drones.

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[1]Folkertsma et al., *IEEE Robotics & Automation Magazine* **24**, pp. 22-29 (2017)
[2]Phan and Floreano, *Science Robotics* **9**, p. eado3890 (2024)
[3]Dickinson et al., *Science* **284**, pp. 1954-1960 (1999)
[4]Ajanic et al., *Advanced Intelligent Systems* **5**, p. 2200148 (2023)