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# On flapping flight mechanisms and their applications to wind and marine energy harvesting

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In this paper, we present a short review on some of significative results on insect flapping flight. In particular, we focus on the time varying shape mechanisms observed during the flapping cycle that are used by insects to enhance the production of aerodynamic force. We then discuss a few examples on how these mechanisms are adapted to energy harvesters in engineered applications.

## I. INTRODUCTION

The mechanics of flight and in particular insect flight is an archetype of an efficient energy conversion process. Insects produce mechanical work through muscles actuation that converts into useful aerodynamic capabilities to produce lift and thrust [1]. In more details, the conversion mechanisms are based on complex dynamics involving fluid/structure interactions aiming at optimizing in time the production of aerodynamic force. For insects, this optimization is obtained by adapting instantaneously the position of the wing with respect to the surrounding flow. This can be achieved through muscle-based active control such as pitching, rowing or yawing [2] but also by using the passive reconfiguration faculty of the wings themselves [3, 4]. These mechanisms have inspired the biomimetic community for animal locomotion understanding and innovative engineered air vehicles.

This idea can also be reversed by considering the conversion process the other way around. In that case, the input/output conversion is not made from an imposed rate of mechanical work to fluid force production but conversely from a fluid forcing to a structural excitation. This approach is interesting for energy harvesting purposes by using proper mechanical vibrations to electrical potential transducers [5, 6]. In any case, both approaches share the same physical mechanisms (illustrated in Fig. 1); the basic idea consisting here in seeking for the best "shape" (of a wing, blade, etc..) in order to maximise the production of force.

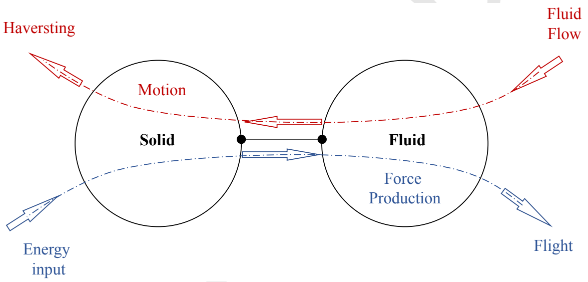

FIG. 1. Schematic diagram illustrating the solid/fluid interactions leading to flight (blue) and the reversed fluid/solid interaction leading to energy harvesting.

In this short review, we revisit recent works using this optimization approach for energy conversion. In particular, we show how the search for optimizing energy consumption of bio-inspired artificial insect flight can lead to wind energy harvesting.

## II. TIME-VARYING WING SHAPE AND FLIGHT PERFORMANCE

In order to sustain weight, produce motion and keep stability, everything at the same time, the shape of the wing is continuously changing in time during the stroke cycle. This complex flapping wing dynamics is obtained by a combination of an active control (i.e. a control of the kinematic and wing shape through muscle actions) and passive deformations of the soft materials constituting the membrane of the wing. Each of these passive or active controls of the wing contribute to improve the overall flight performance. We give here two examples illustrating these important mechanisms taken from significative works in that field.

Fig. 2 (a) shows a computational reconstitution of a desert locust (*Schistocerca gregaria*) flapping cycle [7]. The columns A, B and C represents the results of computed surface pressure maps obtained using full-fidelity kinematics from real insects (A), same kinematics removing artificially the camber (B) and removing the twist (C), respectively. As can be seen, regions of low and high pressure are drastically different when removing some of the features of the time varying wing shape. In their study, the authors demonstrated the crucial contributions of time-changing camber and twist to the global flight performance (both in terms of thrust and lift enhancement and of required power). Those observations have been further confirmed for other species in more recent studies [8–11]. The link between time-varying shape and flight performance has also been straighfor-