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Experimental investigation of strip theory validity for flapping wings aerodynamic load prediction

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Flapping Micro Air Vehicles (FMAVs) have gained considerable attention due to their inherent potentials in providing energy efficient, highly manoeuvrable and hover-capable flight performance. However, much of these potential benefits emanate out of their complex flapping aerodynamic behaviour whose accurate modelling and prediction is yet a challenging task. Despite numerous exotic numerical and experimental studies, still many researchers like to utilize simpler approximate strip theory based (STB) aerodynamic models in the process of FMAVs design cycle. However, no-span wise-flow assumption used in STB models could affect the results by a great deal. Thus, from an engineering point of view one would like to know the accuracy level achieved by these relatively simpler STB analytical aerodynamic models. To this aim, the current study was set to experimentally investigate the validity range of strip theory and its key no-span wise-flow assumption. In this regard, an experimental 3DOF flapping mechanism was designed and constructed that allows for plunging, root flapping and pitching motions of an FMAV with independently adjustable amplitudes and frequencies. A set of experiments were carried out using a 10 cm root-flapping, pitching and plunging rigid wing in the wind tunnel and the results were compared with two well-known analytical aerodynamic models. The result demonstrate that despite the flow complexities, strip theory assumptions are not restricting for acceptable aerodynamic load prediction of a rigid wing undergoing pure plunging and/or combined pitching-plunging motions. However, in case of a root-flapping wing it was shown that analytical STB models significantly underestimate aerodynamic loads for large flapping angles. In particular, the results indicate that for low-amplitude flapping angles around 35 degrees, FMAV aerodynamics is sufficiently predicted via STB models utilizing a series of plunging strips with no-span wise-flow assumption. Nonetheless, by increasing the flapping amplitude beyond 40 degree, the span wise flow intensifies and the STB models can no longer properly predict the aerodynamic loading of flapping wings. The results of this study helps to identify the validity range of strip theory for flapping systems and is effective for further development of analytical models.

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