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PATH OPTIMIZATION OF THRUST PRODUCING FLAPPING AIRFOILS USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

Based on observations on flying birds, insects, and swimming fish, it appears that flapping wings may be favorable for flights of very small scale vehicles, so-called micro-air vehicles (MAVs) with wing spans of $15\ cm$ or less. Flow characteristics of flapping wings are currently investigated experimentally and numerically to shed some light on the lift, drag and propulsive power considerations for a MAV flight[1,2]. It should be noted that in order to maximize the thrust and/or the propulsive efficiency of flapping airfoils the kinematic parameters, such as the flapping path, the frequency and the amplitude of the flapping motion, need to be optimized.

The present authors recently employed a gradient based optimization of sinusoidal and nonsinusoidal flapping motion parameters in flapping airfoils[3,4]. In the study, unsteady flow fields needed for the evaluation of the gradient vector are computed in a parallel computed environment. In a nonsinusoidal flapping motion, the flapping path is defined by a parametric 3^{rd} degree Non-Uniform Rational B-Splines (NURBS) (Figures 1,2). The optimization studies with a limited number of optimization variables show that the thrust generation and efficiency of flapping airfoils may be increased significantly. However, the gradient based global optimization process becomes computationally expensive as the number of optimization variables increases in the nonsinusoidal flapping motion definition.

Response surface methodology (RSM) is mainly employed for the construction of global approximations to a function based on its values computed at various points[5]. The method may also be employed for the optimization of a function when the objective function is expensive in terms of computational resources[5,6,7]. In the present study, the thrust generation of a flapping airfoil in a combined nonsinusoidal pitching and plunging motion is globally approximated using RSM. The constructed approximations are based on viscous flow solutions obtained in a parallel computing environment. Various NURBS based nonsinusoidal flapping motions are considered in the design of experiment (DOE) required by RSM.

In a preliminary study, RSM for 3 optimization variables is assessed and compared to the gradient based optimization method in terms of the optimization performance and the accuracy. Two optimization cases are considered as given in Table 1, where the optimization variables are denoted by V. The performances of the RSM and the gradient based steepest ascent method are given in Figures 3 and 4 in terms of the number of unsteady flow computations. It is shown that the parallel optimization process with RSM is about one order of magnitude more efficient and robust in comparison to the gradient based optimization process. In the full paper, the optimization variables defining the nonsinusoidal flapping motion will be increased, and the efficient, thrust producing flapping motions will be studied in detail.

Table 1: Optimization cases

Case	k	h_0	$P_{1\alpha}$	$P_{2\alpha}$	P_{0h}	P_{1h}	P_{2h}	$P_{0\alpha}$	α_0	ϕ
1	1.0	0.5	1.0	1.0	V	V	V	0.0	10^o	90^o
2	1.0	0.5	1.0	1.0	0.0	1.0	1.0	V	V	V

Table 2: Optimization results

Case 1	P_{oh}	P_{1h}	P_{2h}	C_t
RSM	0.9	5.0	5.0	**0.59**
Steepest Ascent	0.9	5.0	5.0	**0.58**

Case 2	$\alpha_o(^o)$	$\phi(^o)$	$P_{0\alpha}$	C_t
RSM	9.3	90.6	0.03	**0.17**
Steepest Ascent	9.2	90.7	-0.01	**0.15**

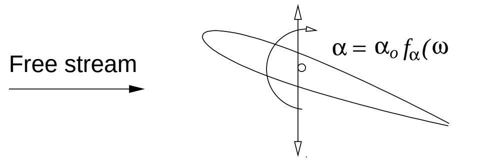

Figure 1: Flapping motion of an airfoil

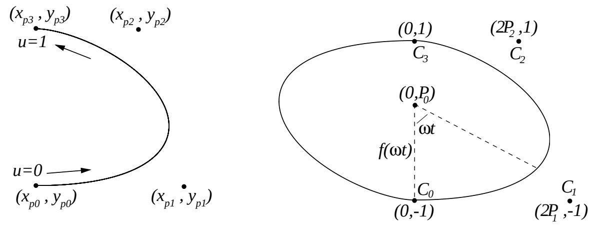

Figure 2: Flapping path defined by a 3^{rd} degree NURBS

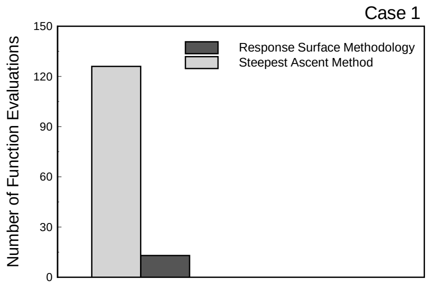

Figure 3: Function evaluations for Case 1

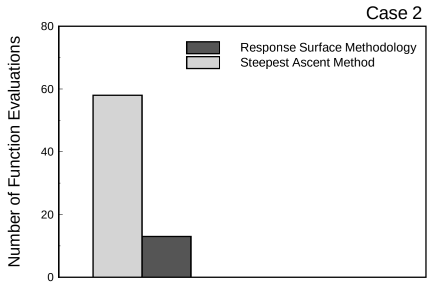

Figure 4: Function evaluations for Case 2

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