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# Aerodynamic optimization and mechanism design of flexible variable camber trailing-edge flap

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**Abstract** Trailing-edge flap is traditionally used to improve the takeoff and landing aerodynamic performance of aircraft. In order to improve flight efficiency during takeoff, cruise and landing states, the flexible variable camber trailing-edge flap is introduced, capable of changing its shape smoothly from 50% flap chord to the rear of the flap. Using a numerical simulation method for the case of the GA (W)-2 airfoil, the multi-objective optimization of the overlap, gap, deflection angle, and bending angle of the flap under takeoff and landing configurations is studied. The optimization results show that under takeoff configuration, the variable camber trailing-edge flap can increase lift coefficient by about 8% and lift-to-drag ratio by about 7% compared with the traditional flap at a takeoff angle of 8°. Under landing configuration, the flap can improve the lift coefficient at a stall angle of attack about 1.3%. Under cruise state, the flap helps to improve the lift-to-drag ratio over a wide range of lift coefficients, and the maximum increment is about 30%. Finally, a corrugated structure–eccentric beam combination bending mechanism is introduced in this paper to bend the flap by rotating the eccentric beam.





## 1. Introduction

Aircraft wing design generally takes the efficiency of the cruise flight and the high-lift performance at takeoff and landing into consideration. In the actual flight, the flight condition is ever-changing, but the shape of the wing is almost unchanged. In order to improve the efficiency of the mission profile of the flight, a mission-adaptive wing would be ideal. At present, one feasible method for improving mission efficiency is to install a flexible variable camber trailing-edge flap on the wing. Such a device, combined with the large aircraft high-lift device concept and structure-deformation technology, has great application prospects in aircraft wing design.

Trailing-edge high-lift devices have been widely used on many kinds of aircraft previously. The structure-deformation technology has also been regarded as promising in the field of aircraft design. Traditional high-lift devices have a precedent of using the concept of deformation, which is mainly

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applied to the rear of wing, in order to improve the performance of takeoff and landing. Among such devices, the "Smart High-Lift Devices for Next Generation Wings (SADE)" cooperative research project among Airbus, the German Aerospace Center (DLR), and 11 other European institutions, is most representative of studies taking place outside of China. Smart leading edge (SLE) and smart single slotted flap (SSSF) are studied respectively in the project, and stress analyses of flexible variable camber mechanisms and skins are carried out, but there are less aerodynamic data available for these two kinds of flexible variable camber device.[1–8] Aeroelastic analyses have been carried out by Li et al.[9] using the SADE concept. The "Variable Camber Continuous Trailing Edge Flap (VCCTEF)"[10–13]project launched by NASA is another representative study related to deformation technology and aircraft high-lift devices. Preliminary results show that the VCCTEF can increase the lift-to-drag ratio by about 4.85%. Analyses of the mechanism behind VCCTEF and the rigidity and aeroelasticity of the material have been carried out by Eric Ting and Sonia Lebofsky respectively.[14–18]

In addition, Yokozeki et al.[19,20] designed the variable camber morphing airfoil using corrugated structure to change the trailing-edge camber of a wing. Similarly, the variable-camber compliant wing is being studied by Joo et al.[21,22]

In China, Yin[23] and Chen et al.[24] have carried out similar research, mainly focusing on the aerodynamic performance of the trailing edge of variable camber airfoils.

Based on the existing research concerning high-lift devices and structure-deformation technology, the optimization of flap position parameters and the bending angle of the flexible variable camber flap of the GA(W)-2 airfoil at takeoff and landing is studied in this paper. The aerodynamic characteristics of the variable camber flap in cruise configuration are investigated. Finally, a corrugated structure and eccentric beam combination bending mechanism is designed in this paper, capable of bending the flap by rotating the eccentric beam.

## 2. Model design

In this paper, the GA (W)-2 airfoil is selected as an analytical model; this is an advanced airfoil for general aviation with a maximum thickness of about 13% of its chord $c$.[25]

The baseline configuration of the takeoff and landing configuration[25] is shown in Fig. 1, and $\delta_f$ is the deflection angle of the flap, $x_p$ is the translation amount in the horizontal direction and $z_p$ is the translation amount in the vertical direction, which are refer to Ref. 25. In this paper, the geometry of the variable camber trailing-edge flap is shown in Fig. 2. The trailing edge of the flap bends flexibly starting at 50%. Here, $\delta_{angle}$ is the bending angle of the flap, $c_{flap}$ is its chord length, and $O/L$ is the overlap between the main wing and the flap; gap refers to the width of seam, and $\delta$ is the deflection angle of the flap.

In order to find the appropriate bending angle and flap position parameters (overlap, gap, and $\delta$), the takeoff and landing configurations are optimized separately in the iSIGHT optimization platform, as shown in Fig. 3. The optimization objective[26,27] of the takeoff configuration is the lift coefficient $C_{L8}$, and the lift-to-drag ratio, $C_{L8}/C_{D8}$, is at an attack angle of 8°. The optimization objectives of the landing configuration are the lift coefficients $C_{L8}$ and $C_{L12}$ at attack angles of 8° and 12°, respectively. As shown in Fig. 4[28], $\alpha$ is the attack angle, $C_L$ is lift coefficient and $C_{L0}$ is lift coefficient at attack angle of 0°. For most of the general aircraft, 8° is the normal attack angle for aircraft takeoff and landing, and 12° is near the stall angle of attack. The multi-island genetic algorithm is selected for optimization, and the optimization variables and objectives are shown in Table 1.

A certain type of general aviation aircraft is chosen to verify the 2D results, and the main parameters of this aircraft are shown in Fig. 5 and listed in Table 2. The GA (W)-2 airfoil is selected as the wing cross-section and maintains equal proportions upon stretching into three dimensions. Here, the flap chord accounted for 25% of the local wing chord and the flap was stretched to 70% of the span.

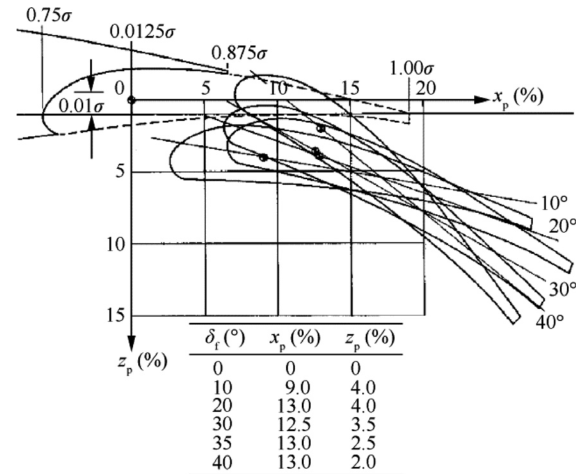


**Fig. 1** Baseline configurations from Ref. 25.

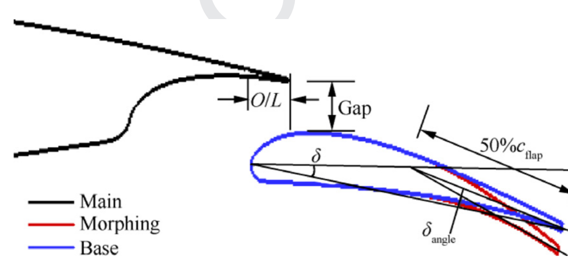


**Fig. 2** Geometry of variable camber trailing-edge flap.

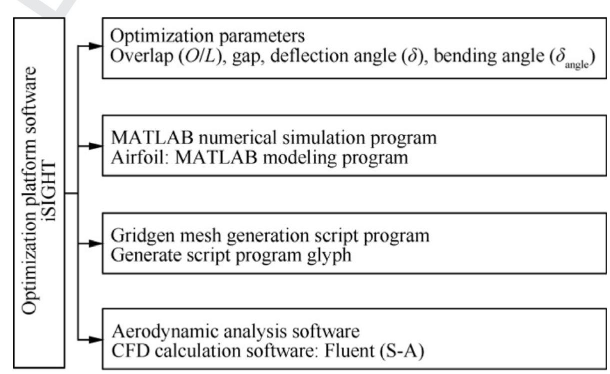


**Fig. 3** CFD optimization platform architecture based on iSIGHT.