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# Experimental study of the sweep-back angle on the aerodynamic performance of a flapping flexible wing

Mojtaba Ramezani Voloojerdi*[1], Hamzeh Eshraghi[1], Mahmoud Mani[2]

[1] PhD. Department of Aerospace Engineering, Amirkabir University of Technology, Tehran, Iran.
[2] Prof. Department of Aerospace Engineering, Amirkabir University of Technology, Tehran, Iran.

*Corresponding author: M_ramezani_v@aut.ac.ir

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## Abstract

The present study experimentally investigates the effect of flexible wing sweep-back angle on the aerodynamic characteristics and the thrust and lift coefficients. The experiments were conducted at Reynolds numbers of 42,000 to 170,000, which is the flight range for natural birds with dimensions close to pigeons. The model consists of two parts of rigid (at root) and flexible (at tip) and the oscillation is provided by an electro-mechanical system. The results show that increasing the speed at dimensionless frequencies less than 0.2 has caused a decrease in the wing lift. The thrust coefficient versus speed graph at angles of attack of zero to 6 degrees is completely different from angles of attack greater than 6 degrees; So that at an angle of attack of 3 degrees, the changes in speed were less than 10 percent; But at an angle of attack of 18 degrees, the thrust coefficient decreased by 50 percent as the speed increased from 5 to 20 meters per second. Also, the flexibility of the wing has caused the dynamic pressure difference of the flow to change the shape of the wing and ultimately reduce the lift coefficient of the wing. Likewise, the flow structure from an angle of attack of 9 degrees onwards is such that it is not capable of producing propulsive force.

**Keywords:** Flapping wing; Experimental test; Wind tunnel; Flexible wing; Sweep-back angle.

## 1. Introduction

The design of flying devices modeled after nature has attracted the attention of researchers, and the result of this research has been the design of numerous wing-beating models. The main difference between flapping wings and other flying devices is the generation of propulsive force by the flapping mechanism. The generation of propulsive force by the wing is the result of oscillating flow trails; The aforementioned tails cause a change in the pressure distribution, which results in the pressure distribution on the object producing propulsive force for the flying vehicle. The ratio of thrust required to weight for flapping wings is significantly lower than for fixed-wing and rotary-wing birds, it has also received much attention in the last two decades for numerous other reasons, such as low sound and radiation emissions and radar evasion. An important part of these activities is on the dynamics of the bird, as well as the aerodynamics of the oscillating wing and how the oscillating wing generates forces. Ramezani Volojerdi and Mani conducted an experimental study to investigate the effect of the angle of sweep angle in a flapping bird with a rigid wing, and investigated the effect of the type and angle of sweep back at different angles of attack and the Reynolds number range [1]. They also investigated the effect of the flapping wing of a bird model on the lift and thrust coefficients in a low-speed wind tunnel. By changing the flapping frequency and the angle of attack, it was shown that with increasing flapping frequency; the lift force increased by up to 100% and sometimes the drag force approached a negligible value, also leading to stall delay in the wing [2]. Ramezani et al. conducted an experimental study to investigate the aerodynamic performance of a flexible wing flapper with a geometry inspired by the pigeon wing. The mentioned wing was non-swept shape; by changing the flow components, flapping frequency, and angle of attack, the horizontal and vertical forces were investigated [3]. Eshraghi et al. conducted an experimental study to investigate the effect of wing flexibility on the aerodynamic behavior of a flapping wing [4]. Considering previous studies, the current study was conducted using experimental tools with the aim of identifying the effect of the sweep angle of a flexible wing in the face of free flow at different angles of attack and different flapping frequencies.

## 2. Methodology

In this research, inspired by the way birds fly; a mechanism has been designed and built to model flight. By being in the air flow and flapping its wings, the mechanism will model flight conditions at different angles of attack and different flapping frequencies. The implemented mechanism is presented in Figure 1.

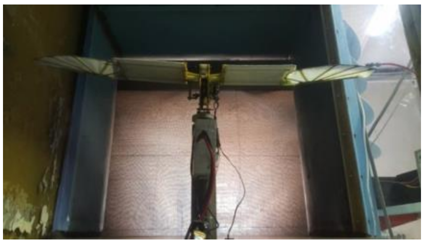
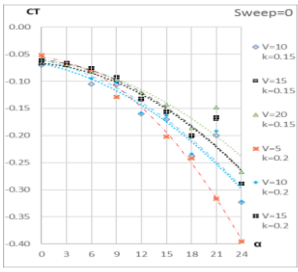


**Figure 1. The experimental setup**

To investigate the effect of the sweep angle on the aerodynamic characteristics, the wing sweep angle adjustment device was designed; the sweep angle of the shell wing is changed from 0 to 30 degrees in 10 degree increments.

## 3. Results and Discussion

Results of zero swept wing has been depicted in the figure 2.

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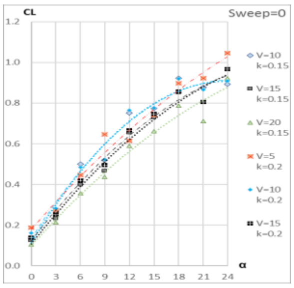


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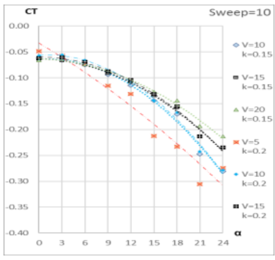
**Figure 2. Zero sweep wing results**

With increasing speed, the thrust coefficient increased, or in other words, the drag coefficient of the wing decreased. Of course, there was an exception to this conclusion; at angles of attack less than 9 degrees for a speed of 5 m/s, the highest thrust coefficient occurred, but from angles of attack from 9 to 24 degrees, the same general conclusion was observed. According to this figure, increasing the speed from 5 to 10 m/s increased the lift force of the wing, but increasing the speed from 10 to 20 m/s decreased the lift force of the wing.

Results of 10 degrees sweep back has been depicted in the figure 3. Up to an angle of attack of 9 degrees, the thrust decreases with increasing speed, but from an angle of 12 degrees, the trend of changes is reversed and with increasing speed, the thrust increases or the drag coefficient decreases. The trend of lift coefficient changes with speed for the wing with 10 degrees of sweep is more regular than for the wing without sweep, and the lift coefficient has always decreased with increasing speed. However, at angles of 21 and 24 degrees for a speed of 5 m/s, the drag coefficient has decreased significantly due to entering the dynamic stagnation range of the wing, and only at these two points has the general trend of lift decrease with increasing speed not been observed.

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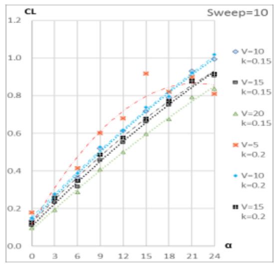


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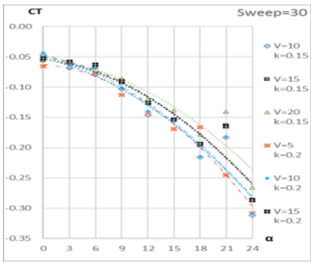
**Figure 3. 10º swept-back wing results**

Results of 30 degrees swept wing has been depicted in the figure 4.

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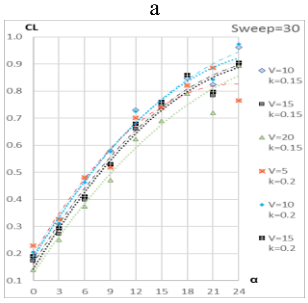


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**Figure 4. 30º swept-back wing results**

The thrust coefficient at a 30-degree sweep angle, as shown in Figure 4-a, has increased with increasing speed at all angles of attack, although this trend has fluctuated due to dynamic stalling at an angle of 18 degrees. The effect of speed on the lift force of a wing with a 30-degree sweep in terms of angle of attack as shown in Figure 4-b, the notable point is the conformity of the lift force coefficient up to an angle of attack of 12 degrees for two speeds of 5 and 10 m/s, although the lift coefficient has increased by 10 m/s from an angle of 15 degrees. It should be noted that the lift force coefficient has decreased as the speed increases from 10 to 20 m/s, similar to other sweep angles.

## 4. Conclusions

The results obtained from this section are summarized as follows:

- The behavior of lift force with respect to speed changes at speeds greater than 10 m/s was the same at angles of attack of 0 to 21 degrees, and increasing speed in this range reduced lift force by up to 30%.
- The behavior of the thrust and lift coefficients for the wing with sweep angles of 10 and 20 degrees was very similar at different speeds
- At a 30-degree swept-back, the thrust coefficient increased with increasing speed at all angles of attack, although this trend fluctuated due to dynamic stalling at an angle of 18 degrees.
- On a wing with a sweep angle of 30 degrees, the lift force was similar up to an angle of attack of 12 degrees for speeds of 5 and 10 meters per second, although the lift coefficient increased from an angle of 15 degrees to a speed of 10 meters per second.

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