ISME2013-904

Design and simulation of an efficient winglet to enhance aerodynamic performance of a MAV

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Abstract

The purpose of this paper is designing an efficient winglet in wings of Micro Aerial Vehicles (MAV) for low speed Reynolds. Winglets are designed to reduce induced drag generated by downwash and to reduce the strength of tip vortices. The wing is made of FX60100 aerofoil for the MAV studied. A comparison is made between the aerodynamics characteristics of the wing with and without winglets. Different types of winglet are examined. The designed winglet has enhanced almost 20 percent on lift to drag ratio.

Keywords: Winglet, CFD, Micro Aerial Vehicles, Aerodynamics, Drag Coefficient.

Introduction

One of the common works done to improve the efficiency of airfoils is to attach a small device named Winglet to them. Winglets were broadly used on large dimensional airfoils. Winglet is a small wing like structures at the end of a wing. It has been used in many different kinds of airfoil to increase the performance of Aircrafts, Unmanned Air Vehicles and Micro Aerial Vehicles, Fig.1.

Figure 1: Winglet in practical use

Since theoretical tools for the design of winglets for low-speed aircraft were initially of limited value, and other experimental works all are too timely and an expensive, an appropriate method like computational simulation was used to design winglets. Many works have been done to design an efficient type of winglet in Macro dimensional size. In one of such works, designing an efficient winglet was described by Maughmer [1]; in this study, theoretical tools in low-speed aircrafts were used to design an effective winglet. Maughmehr et al. [2] also applied their theoretical approach on specific airfoil to get high performance design for sailplane. Weierman [3] also developed a method to design and optimize an efficient winglet for UAV platforms; this research was compared with an experimental study to examine the overall procedure. One of the most interesting aspects of designing winglet was considered by Kuo and Boller [4]. They designed and analyzed multiple adaptive winglets by inspiration of bird's wing during flight. They simulated their special winglet with CFD techniques. In a similar work, Hossain et al. [5] also did some experimental work on NACA airfoils with and without winglet by inspiration of bird feather like as the winglet. The experimental results of this work show 25-30 percent reduction in drag coefficient and 10-20 percent increase in lift coefficient. In another work, Azlin et al. [6] compared Elliptical winglet with semicircular winglet by just computational simulation for low subsonic flow. They chose $NACA65_3218$ airfoil and simulated all tests by FLUENT solver.

Although many works have been done to design winglet, most of these works were related to experimental studies that improved the efficiency of large dimensional airfoils. The goal of this paper was using winglet to get the highest performance of the appropriate airfoil for Micro Aerial Vehicles. We based our work on [7]; in this work, Barnhart et al. conducted an experimental research on MAV's airfoils. Among some commonly used airfoil in MAVs, it was shown that FX60100 is the best choice for implementing in MAVs. Thus, in this paper, we tried to design an efficient winglet for FX60100. It could accentuate the efficiency of this airfoil to get high performance function. So we did numerous tests to design this new efficient winglet.

This paper is organized as follows. After the introduction, a short review on Winglet's design is given which is followed by methodology and Numerical simulation of our work. To design an efficient winglet for FX60100, we collect the results and discuss the effect of changing each feather of winglet. Finally, the paper closes with some conclusions.

Methodology

In this work, we simulated a special airfoil with a broad type of winglet and calculated the coefficient of drag and lift for each of them.

Coefficient of lift is defined as

$$C_L = \frac{L}{\frac{1}{2}\rho_\infty V_\infty^2 S} \quad (1)$$

and coefficient of drag is defined as

$$C_D = \frac{D}{\frac{1}{2}\rho_\infty V_\infty^2 S} \quad (2)$$

To design the study efficiently, we estimated C_L / C_D for each test.

As shown in Fig.2, we have different parameters to change in the procedure of designing winglets. Length of winglet and two angles in each surface are changeable factors but due to recent works, it can be shown that an efficient length is for 10 percent of full length and it can get the most effective result. Thus, we choose it as the best winglet's length and change other characteristics of winglets to get the highest performance design.

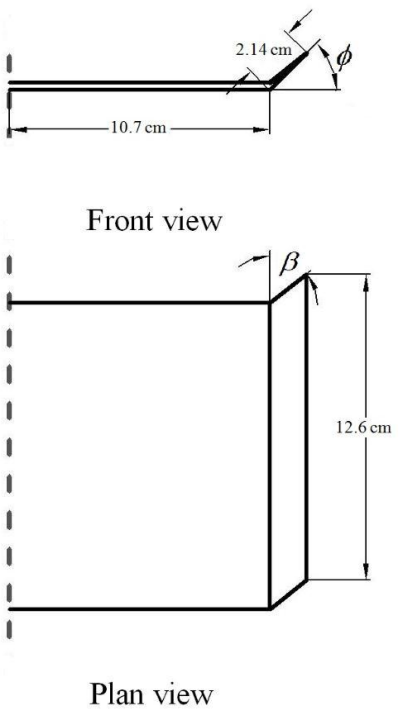

Figure 2: Designing factors

Numerical Simulation

The main part of our works was to simulate each airfoil with the attached winglet and compare each of them by calculation of lift and drag forces in the whole area of each airfoil. Thus, we first created the required 3-dimensional geometry with GAMBIT software and then meshed our domain. Also, the 3-dimensional unstructured tetrahedral mesh was utilized for computing flow around the model. To enhance resolution of our calculation and obtain considerable level of calculation, as shown in Fig.3, we decreased the size of mesh around airfoil and smoothly increased the size with size function ability of GAMBIT. It is noteworthy to mention that our domain set in all our airfoils was as much as it could make a confident domain.

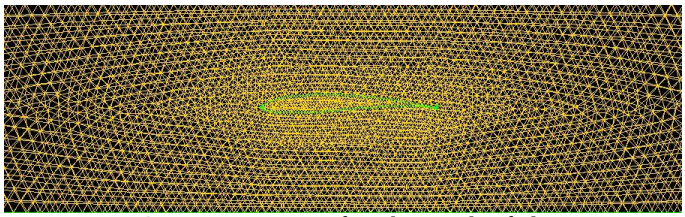

Figure 3: Decreasing size of mesh around airfoil

The next part of simulation was aided by FLUENT solver. Computational simulation uses Finite Volume approach. We simulated air flow around an airfoil with the designed winglet and the solver formulation, boundary condition, solution control parameter and material properties were defined. We ran numerous cases to examine all feathers.

Verification and Validation of Numerical Simulation

Since this part is an important part of every numerical problem, we did it carefully to ensure the accuracy of our simulations. As represented before, we chose FX60100 airfoil shown in [7] that is a suitable airfoil for Micro-Aerial Vehicle. In [7], coefficient of drag and lift were reported from experimental studies for this airfoil without winglet. Thus, we implemented the same study with computational simulation.

Thus we have very reliable results in this study and so, we can see that our results for this airfoil have good fitness with experimental test.

Table 1: Comparing result of experimental work with numerical simulation

velocity	result	Coefficient at 0° angle of attack	
		C_D	C_L
7 m/s	Experimental work	0.02	0.16
	Numerical simulation	0.0221	0.153

Results and Discussion

In this part, we compared different wings by changing characteristics of attached winglet on FX60100 airfoil. We simulated 3-dimensional wing and to decrease time of solution, we used symmetric boundary in the middle of airfoil. So we consider just half of the wing with and without winglet for simulations. As mentioned before, we have two angles which we can be changed for the purpose of our study. First, with 10 percent winglet that was attached to airfoil FX60100, we changed the angle of ϕ to get the best angle for designing airfoil. After that, we changed another angle, β, to the highest performance winglet for FX60100. The simulations were carried out in a wide range of angles of attack and velocity that could provide low speed regime of fluid. So our study was based on the simulation between 0 to 12 angles of attack at 7m/s, 10.5m/s, 13.9m/s velocity, respectively. These velocities have been chosen to provide low speed Reynolds.

1. Results for optimizing angle of ϕ

In this part, we changed angles of ϕ from 0 to 60 degree for every 15. We simulated every design by changing velocity and angles of attack one by one.

A) Lift coefficient, C_L

Table 2: Lift Coefficients

Number	Velocity	Lift Coefficient, C_L				
		0°	3°	6°	9°	12°
Winglet 0°angle	7	0.210	0.369	0.528	0.695	0.844
	10.5	0.491	0.844	1.206	1.583	1.917
	13.9	0.879	1.499	2.134	2.792	3.381
Winglet 15°angle	7	0.213	0.374	0.536	0.701	0.840
	10.5	0.499	0.863	1.223	1.594	1.908
	13.9	0.892	1.532	2.165	2.811	3.366
Winglet 30°angle	7	0.215	0.372	0.532	0.692	0.829
	10.5	0.503	0.859	1.218	1.572	1.887
	13.9	0.897	1.525	2.155	2.772	3.325
Winglet 45°angle	7	0.211	0.366	0.519	0.675	0.807
	10.5	0.494	0.842	1.189	1.533	1.836
	13.9	0.882	1.493	2.103	2.702	3.233
Winglet 60°angle	7	0.204	0.356	0.498	0.648	0.776
	10.5	0.477	0.817	1.143	1.475	1.767
	13.9	0.853	1.448	2.023	2.601	3.117

B) Drag coefficient, C_D :

Table 3: Drag Coefficients

Number	Velocity	Drag Coefficient, C_D				
		0°	3°	6°	9°	12°
Winglet 0°angle	7	0.029	0.042	0.063	0.092	0.129
	10.5	0.057	0.086	0.132	0.201	0.284
	13.9	0.092	0.142	0.223	0.345	0.492
Winglet 15°angle	7	0.029	0.041	0.063	0.093	0.133
	10.5	0.057	0.086	0.133	0.202	0.295
	13.9	0.093	0.143	0.226	0.348	0.514
Winglet 30°angle	7	0.029	0.041	0.062	0.092	0.131
	10.5	0.057	0.085	0.132	0.199	0.290
	13.9	0.092	0.142	0.224	0.342	0.503
Winglet 45°angle	7	0.029	0.041	0.060	0.089	0.127
	10.5	0.057	0.083	0.128	0.193	0.281
	13.9	0.091	0.139	0.218	0.332	0.486
Winglet 60°angle	7	0.028	0.040	0.058	0.086	0.122
	10.5	0.055	0.081	0.123	0.186	0.269
	13.9	0.088	0.135	0.209	0.318	0.466

C) Lift to Drag ratio, C_L/C_D

Table 4: Lift to drag ratio

Number	Velocity	Drag Coefficient, C_L/C_D				
		0°	3°	6°	9°	12°
Winglet 0°angle	7	7.337	8.785	8.439	7.533	6.563
	10.5	8.665	9.859	9.108	7.886	6.753
	13.9	9.541	10.56	8.081	7.975	6.877
Winglet 15°angle	7	7.373	9.046	8.476	7.516	6.293
	10.5	8.711	10.08	9.168	7.878	6.471
	13.9	9.593	10.71	9.581	8.076	6.553
Winglet 30°angle	7	7.472	9.049	8.619	7.536	6.329
	10.5	8.814	10.10	9.256	7.910	6.510
	13.9	9.703	10.74	9.621	8.115	6.614
Winglet 45°angle	7	7.414	9.017	8.610	7.543	6.361
	10.5	8.772	10.08	9.265	7.929	6.543
	13.9	9.673	10.74	9.641	8.144	6.658
Winglet 60°angle	7	7.331	8.969	8.599	7.548	6.370
	10.5	8.715	10.06	9.280	7.947	6.564
	13.9	9.639	10.73	9.672	8.170	6.689

2. Results for optimizing angle of β at ϕ = 30°

After getting the most efficient angle of ϕ. We followed our work to get the highest performance by changing other angle, which is β, on airfoil with optimized angle of ϕ. The changeable interval for angle of β due to design problems is not wide as the angle of ϕ. Also it can be considered in front and back respect to airfoil line. So we changed angles of β from 82 to 98 degree for every 4 degrees.

D) Lift coefficient, C_L

Table 5: Lift Coefficients

Number	Velocity	Lift Coefficient, C_L				
		0°	3°	6°	9°	12°
β =82° angle	7	0.214	0.376	0.533	0.689	0.834
	10.5	0.499	0.865	1.217	1.568	1.900
	13.9	0.893	1.532	2.153	2.766	3.353
β =86° angle	7	0.216	0.374	0.533	0.692	0.830
	10.5	0.503	0.862	1.221	1.577	1.885
	13.9	0.899	1.53	2.159	2.780	3.321
β =90° angle	7	0.215	0.372	0.532	0.692	0.829
	10.5	0.503	0.859	1.218	1.572	1.887
	13.9	0.897	1.525	2.155	2.772	3.325
β =94° angle	7	0.215	0.372	0.533	0.693	0.827
	10.5	0.501	0.858	1.220	1.575	1.882
	13.9	0.896	1.523	2.158	2.778	3.322
β =98° angle	7	0.213	0.371	0.531	0.691	0.835
	10.5	0.499	0.857	1.218	1.573	1.898
	13.9	0.892	1.521	2.155	2.774	3.346

E) Drag coefficient, C_D

Table 6: Drag Coefficients

Number	Velocity	Drag Coefficient, C_D				
		0°	3°	6°	9°	12°
β=82° angle	7	0.029	0.041	0.063	0.091	0.132
	10.5	0.057	0.085	0.132	0.198	0.292
	13.9	0.093	0.142	0.224	0.341	0.507
β=86° angle	7	0.029	0.041	0.062	0.092	0.132
	10.5	0.057	0.085	0.132	0.200	0.290
	13.9	0.093	0.142	0.225	0.344	0.503
β=90° angle	7	0.029	0.041	0.062	0.092	0.131
	10.5	0.057	0.085	0.132	0.199	0.290
	13.9	0.092	0.142	0.224	0.342	0.503
β=94° angle	7	0.029	0.041	0.062	0.092	0.131
	10.5	0.057	0.085	0.132	0.199	0.289
	13.9	0.092	0.142	0.224	0.343	0.502
β=98° angle	7	0.029	0.041	0.062	0.092	0.132
	10.5	0.057	0.085	0.132	0.199	0.289
	13.9	0.092	0.142	0.224	0.342	0.501

F) Lift to Drag ratio, C_L/C_D

Table 7: Lift to drag ratio

Number	Velocity	Drag Coefficient, C_L/C_D				
		0°	3°	6°	9°	12°
β=82° angle	7	7.423	9.075	8.532	7.545	6.330
	10.5	8.754	10.11	9.213	7.914	6.514
	13.9	9.635	10.75	9.613	8.116	6.614
β=86° angle	7	7.459	9.057	8.609	7.513	6.306
	10.5	8.791	10.10	9.245	7.878	6.492
	13.9	9.674	10.74	9.609	8.081	6.599
β=90° angle	7	7.472	9.049	8.619	7.536	6.329
	10.5	8.841	10.10	9.256	7.910	6.510
	13.9	9.703	10.74	9.621	8.115	6.614
β=94° angle	7	7.463	9.043	8.614	7.526	6.335
	10.5	8.808	10.09	9.251	7.899	6.514
	13.9	9.670	10.73	9.615	8.104	6.620
β=98° angle	7	7.418	9.041	8.616	7.534	6.383
	10.5	8.764	10.09	9.253	7.902	6.566
	13.9	9.653	10.73	9.616	8.108	6.684

3. Comparing designed model with simple FX60100

In this section, we put result of our simulation in same situations for FX60100 with and without optimized design's winglet. We can see difference between using winglets in this airfoil for low speed regime of flow.

Table 8: Comparing result of the most efficient airfoil with simple FX60100

Number	Velocity	Drag Coefficient, C_L/C_D				
		0°	3°	6°	9°	12°
Without winglet	7	6.92	7.920	7.706	6.719	5.921
	10.5	7.564	8.882	8.310	7.251	6.108
	13.9	8.366	9.494	8.668	7.455	6.221
With designed winglet	7	7.459	9.057	8.609	7.513	6.306
	10.5	8.791	10.10	9.245	7.878	6.492
	13.9	9.674	10.74	9.609	8.081	6.599

Conclusions

In this paper, we designed an efficient winglet for MAVs wings with FX60100 airfoil sections. The effects of two main factors of designing winglets are studied. Numerical simulations were conducted to determine the effects of each factor on performance of the MAV. It is shown that almost 20 percent is increased in lift to drag ratio. Furthermore, it is concluded that the overall high efficient airfoil comes with $\phi = 30$ and $\beta = 86$.

Acknowledgment

Authors would like to thank the CFD group of Isfahan University of Technology for assisting in simulations.

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