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Aerodynamic Optimization of a Winglet Design

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Abstract. In the present study, an experimental study is presented for a flow around an isolated wing equipped by a winglet and profiled with Naca 0012. Several cases of winglets were tested according to the angle β: 0°, 55°, 65°and 75°. For all these cases at a velocity of 20, 30 and 40 meters per second, wind tunnel tests are performed and compared for different angles of incidence. It is observed that the aerodynamic performance of the winglet with β = 55° differ favorably for positive angle of incidence compared for other cases.

1 Introduction

When a wing produces lift, the pressure difference between the upper and lower generates a vortex. Near the ends of a wing, the high pressure air on the underside tends to slip off the ends and rounded to the side of low pressure forming a wing tip vortex. In the case of civil aviation, the intensity of this vortex is considered very dangerous for air traffic and its dissipation is estimated to average two minutes. This time interval is considered as an interval between two takeoffs or two landings. So this vortex is considered a significant factor in the design of airports. To distort the vortex in order to extract a portion of its energy, aerospace designers have designed aircraft with wings equipped with fins placed at the wing tips called winglets. Poincare defined as any object moving through air leaves behind a wake eddies or rather a more or less organized. So every flight leaves behind a turbulent wake consists mainly of two vortices. The first quantitative analysis of the induced drag for a three-dimensional hydrofoil was provided by Prandtl [2], he writes that the asymmetry of the airflow around the wing is equivalent to a vortex and he developed the theory of lifting line which applies, for low angles of incidence. Uberoi et al. [3] said that the vortex is characterized by extremely slow diffusion and persists for considerable distances downstream of the wing which gave it birth. With the arrival of the Boeing 747 airplane in the 70's the "Federal Aviation Administration" has established safe distances between aircraft based on their mass to limit the risk of incidents. These international standards define the minimum distance separation by class of aircraft, and these set a limit to the frequency of landings and takeoffs. Richard Whitcomb [4] has focused its research on the flow of air at the wing tip and found that the vortices can be broken in order to reduce induced drag by small devices without disrupting the mass and the backbone of the wing. This device called a winglet; it is a small vertical extension to the wing tip to improve its efficiency by increasing its effective length. By recovering some of the energy of vortices, the winglet increases the aerodynamic efficiency of the wing. The persistence of the vortex responsible for the drag-induced lift is estimated at over a third of the total drag of the aircraft and half for low-speed takeoff and landing [5]. Pascal et al. [6] determine that the reduction of drag of a wing is made by the management of marginal separation by attaching a thin piece of salmon trigger the detachment with a reduction in total drag of about 1 % is observed with an increase in the lift without the increase induced drag. Cosin et al. [7] Worked on a wing with multi winglets, three small fins attached to the salmon timing different for each winglet were used. This device increases the aerodynamic parameters, with a 7.3% gain in efficiency. The aerodynamic characteristics of the process indicated improvements in lift and reduced expression of induced drag, represented by a 32% increase of the efficiency factor of Oswald.

In the present study wind tunnel testing is conducted at 20, 30 and 40 meters per second and many various angles of incidence are used in order to obtain the effect of winglets on lift, drag, and power coefficient of isolated wing. For the purpose of this study, the National Advisory Committee for Aeronautics (NACA)0012 airfoil with winglet was used to simulate the real wing. This stalling point of this airfoil occurs when the angle of attack nears 18° [8]. As it shown in figure 1, several cases of winglets were tested according to the angle β: 55°, 65°, 75° and 180°. The case when β = 180° represents the baseline case of the wing (no winglet).

2 Experimental facility

The Wind Tunnel used is of an opened circuit, horizontal return type. The opened Circuit Wind Tunnel is of conventional design and has advantages over a similar open circuit design (see Fig. 2). These include; a higher maximum velocity, lower power consumption and lower noise level. It is driven by an A.C motor and axial flow fan that forces air around the circuit and produces a maximum velocity of 60 m/s. In order to conduct wind tunnel testing of the winglet, a many prototypes of winglets were designed from plans drawn in SolidWorks.

The experimental models are made in wood for a span of 25 cm corresponding to the half of maximum width of the test section of wind tunnel.

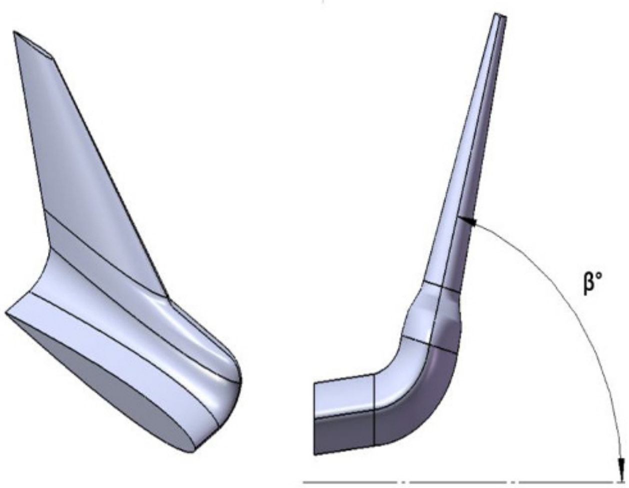

Fig.1. Winglet details

Fig.2. Experimental model

3 Results

Several measures were carried out for different angles of incidence to determine the lift and drag of isolated wing. Each case of winglet was carried out for different velocities: 20, 30 and 40 meters per second corresponding respectively for the Reynolds numbers Re: 2.35×10^5, 2.84×10^5 and 3.03×10^5. The angle of incidence extended from 0° to 20 degrees.

The evolution of the drag coefficient according to the angle of incidence is presented in figure 3 for β = 55° case and different Reynolds number effect on drag can be seen in this figure. It is a parabolic type tendency similar to those found on the literature. One notes that the evolution of the drag became constant according for different Reynolds numbers.

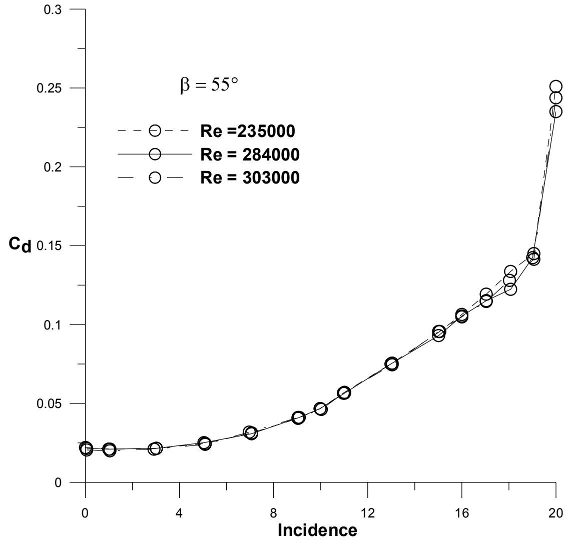

Fig. 3. Variation of drag coefficient against incidence for various Reynolds numbers.

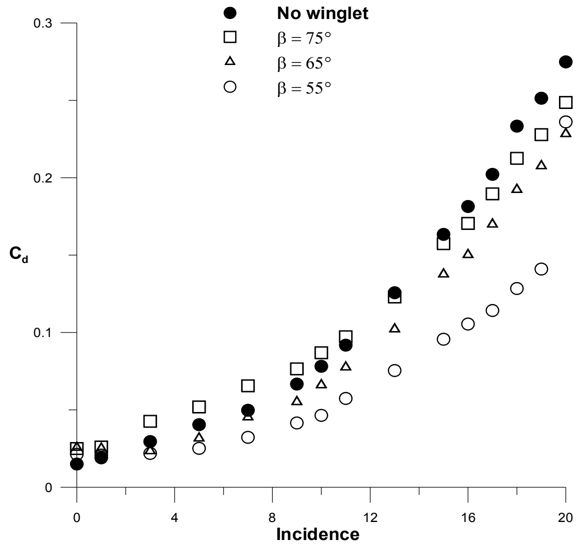

Fig. 4. Variation of lift coefficient against incidence

A winglet impact on drag coefficient characteristics is presented in Figure 4 and summarized in table 1, which indicates important impact on the aerodynamic performance of the wing. It's noticed that for zero incidence angle, there is a small difference between the drag coefficients for all configurations and when the incidence angle augments the variation increases. Clearly at the stall angle for β = 55°, 65° and 75° the decrease in the inductive drag is considered respectively about44 %, 20 % and 9 %.

Table 1. Drag coefficient C_d for V = 30 m/s

Winglet configuration	Incidence			
	0°	+5°	+10°	+19°
β = 55°	0.021312	0.025137	0.046448	0.1400
β = 65°	0.025683	0.031694	0.06612	0.20
β = 75°	0.025	0.051913	0.086885	0.2278
No winglet	0.0151	0.040437	0.078142	0.2513

Table 2. Lift coefficient C_l for V = 30 m/s

Winglet configuration	Incidence			
	0°	+5°	+10°	+19°
β = 55°	0.02	0.1770	0.50501	0.9910
β = 65°	0.04	0.22961	0.50241	0.9544
β = 75°	0.01	0.06203	0.36601	0.818
No winglet	0.01	0.1272	0.34100	0.7170

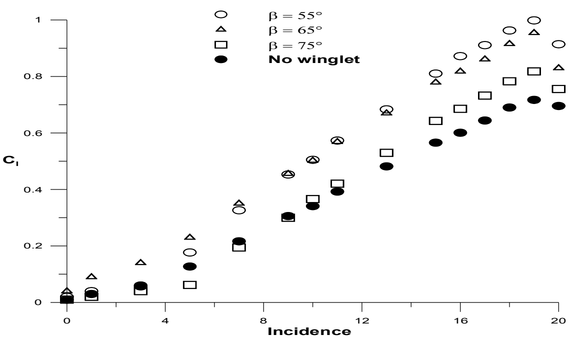

Fig. 5. Evolution of the lift coefficient

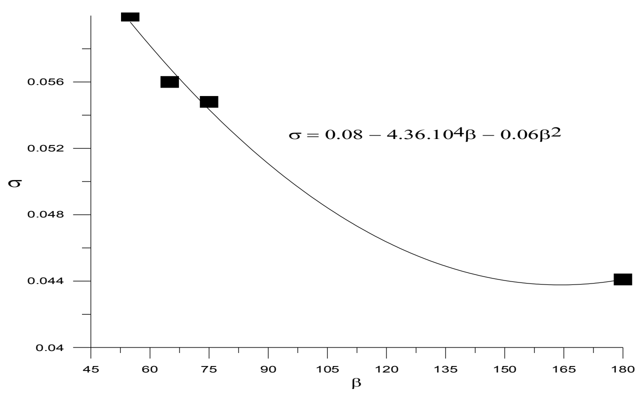

Fig. 6. Evolution of the linear lift slope

Figure 5 gives the lift curves for the different winglets. One notes that these curves are quasi- linear before the stall angle, probably this is due to the lower value of Reynolds number and they indicate that the winglets have a visible effect on the lift coefficient. The table 2 represents a summarize of the evolution of the lift coefficient, it's noticed that the impact of the winglet on the maximum lift coefficient was very clear: for β = 55°, 65° and 75° an increase in lift is considered respectively about38 %, 33 % and 14 %. However, one notes that the stall angle is not affected by β angle and almost all the versions of the winglets considered give an increase in lift, which is in agreement with the results of [8].

For different cases of winglets, the slope σ of the quasi linear part of the lift coefficient was calculated in table 3. In Figure 6, σ is plottedaccording to the β angle and it is observed that this parameter evolution is not linear and can be correlated by the following relation:

$$\sigma = 0.08 - 4.36.10^{4}.\beta - 0.06.\beta^{2}$$

Table 3. Slope of linear lift evolution

β°	55°	65°	75°	180° (no winglet)
Σ	0.060	0.056	0.0548	0.0441

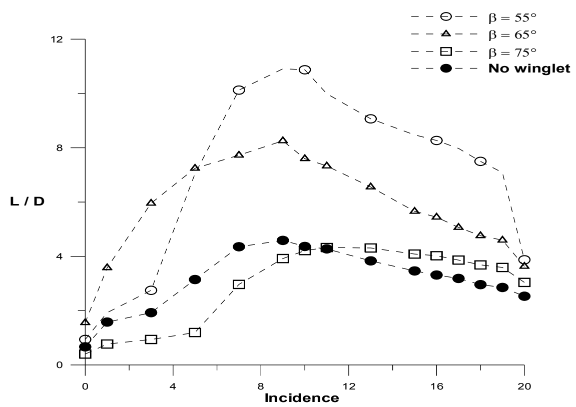

Fig. 7. Evolution of L/D

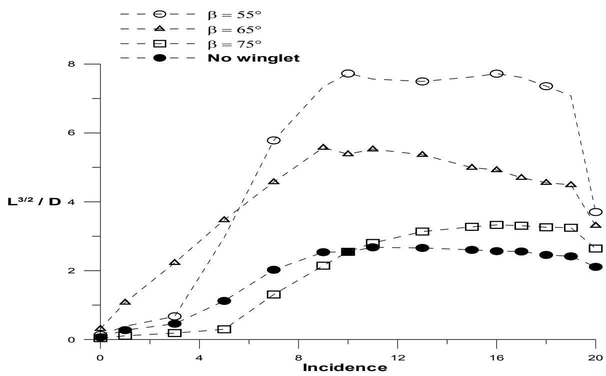

Fig. 8. Evolution of power coefficient

Figure 7, represents the L/D according to the incidence. It seems that the corresponding angle of incidence remainder the same one for all the configurations considered. For the case β = 55°, the L/D is maximum with a value of 10.4. It noticed that after an incidence angle of 6°, the L/D decreases when β increases. Figure 8 represents the variation of the power coefficient $L^{3/2}/D$ according to the incidence, one notices that the configuration β = 55° presents the maximum of power.

4 Conclusion

Experiments have been performed to examine the efficacy of winglets mounted at varying β angles to improve the performance of a wing in subsonic flow. It is shown that the winglets considered are placed upward at the tip of the wing to improve the wing efficiency by decreasing the induced drag and increasing the lift. In order to devote to the aerodynamic optimization of a wing with upward winglets, It is observed that the aerodynamic performance of the winglet with β = 55 ° differ favorably for positive angle of incidence compared to other cases.

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