Aerodynamic Optimization of a Morphing Winglet Design

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Abstract— **In the present study, a CFD is used to investigate the flow around an isolated wing equipped by a morphing winglet. In order to obtain initial estimates of lift and drag coefficients with flow velocity of 20 meters per second a various angles of attack, several cases of winglets were tested according to different dihedral angles. The model of k-ω SST turbulence is used for the investigation of the complex flow around the morphing winglet. The present results shown a good agreement with the literature data.**

Keywords—Morphing Winglet, Tip Vortex, Angle of Attack, Dihedral Angle, Numerical Analysis.

I. INTRODUCTION

Due to the high fuel consumption by airlines and their use of jet aircraft, researchers are working to find new ways to save energy, among them the control of the induced drag force resulting from the vortex [1] generated by the airflow around the finite span wing, which was explain by Prandtl in 1918 [2].

To optimize this problem, the research has several points of view; some worked on flexibility of the composite materials. A.Gatto et al [3] published in 2009 its works in the frame often bistable winglet and who made an experimental study to improve the capabilities of the wing in takeoff. And the other works on geometry as D.D.Smith in 2012 et al [4] has investigated many studies to optimize the morphing-wing system on passenger aircraft, the interested part of this study is focused on the objective of choosing the number of phase in flight to absorb this marginal vortex. The work of Klug in 1988 et al [5] allows the wing-winglet configuration to sweep action on the flight axis to follow the flight steps in order to reduce the induced drag. Experimental work of D.J.Smith in 2001 et al [6] who used multi-Winglet for induced drag reduction without increasing the wingspan of the aircraft and using a NACA0012 profile for the wing and flat plate for Winglet. A.Suleman in 2011 et al [7] presents a morphing wingtip mechanism based on a servo-actuated articulated winglet, able to rotate about two different axes: vertical axis (torsion angle) and aircraft's longitudinal axis (dihedral angle). S.K.Samal in 2013 et al [8] did simulated of the tip vortices for an unswepted and untwisted rectangular wing (NACA 0012) are carried out at a geometric angle of attack 10°. S.H.Ahn in 2016 et al [9] study the aerodynamic performance of a self-contained morphing winglet for an unmanned aerial vehicle (UAV), the results when the morphing winglet was actuated, the lift-to drag ratio increased by 5.8% compared with the flat wing geometry for angle of attack greater than 5°.And others, created algorithms such as M. Botez in 2016 et al [10] which worked in part1 on an 'in-house' genetic algorithm is described and applied to an optimization problem for improving the aerodynamic performances of an aircraft wing tip through upper surface morphing and part 2 Experimental validation .

It found that the geometric variation of the winglet angles reduce the tip vortex and for that I do a numerical analysis to optimize the configurations of D.D.Smith in 2014 et al [11] made an advanced numerical and experimental analysis was realized a wing of classic airplane with two morphing winglet and allowing the variation of the angles of torsion and dihedral.

In the present work, a CFD is used to investigate the flow around an isolated wing equipped by a morphing winglet. Several cases of winglets were tested according to different dihedral angles with flow velocity of 20 meters per second.

II. Numerical Analysis

The hypotheses to solve this problem are posed as follows: Turbulent and permanent flow, the fluid is incompressible and the physical properties of the fluid are constant. The Newtonian fluid flow equations describe the principles of conservation of mass (1), momentum (2) and energy (3).

$$\frac{\partial U_i}{\partial X_i} = 0 \qquad (1)$$

$$\frac{\partial U_i}{\partial t} + U_i \frac{\partial U_i}{\partial X_i} = -\frac{1}{\rho}\frac{\partial P}{\partial X_i} + \frac{\partial}{\partial X_i}\left[v \frac{\partial U_i}{\partial X_j} - \overline{U_i U_j}\right] + \frac{F_i}{\rho} \qquad (2)$$

$$\frac{\partial \emptyset}{\partial t} + U_i \frac{\partial \emptyset}{\partial X_j} = \frac{\partial}{\partial X_i}\left[\lambda \frac{\partial \emptyset}{\partial X_i} - \overline{U_i \varphi}\right] + S\emptyset \qquad (3)$$

These equations can be solved in the case of laminar flows and exact solutions can be obtained at this stage, it is not possible to solve these equations for the case of turbulent flows.

For resolve this type of problems. Fluent code is used it is based on the finite volume method and it allows to determine aerodynamic performance such as lift and drag forces. The K-ω SST turbulence model [12] is used to enable vortex modeling because coupling with two method, The advantage of the model K-ω SST with respect to the model K-ω SST resides in the taking into account of the effects due to the turbulence of the flows with low Reynolds number. It is usable for compressible flows and allows to take into account the parietal transfers.

As it shown in figure 1, SolidWorks CAD software was used for the graphical representation of an airplane with a Morphing winglet (Fig. 1) attached to the wingtips and composed of two equal positive dihedral panels representing the last third of the main wing with two joints form two variable angles in the order up to 90 ° (see Figure 2).

ICEM CFD allows the formation of a more refined tetrahedral (Fig.3) mesh with the boundary layer (Fig.4)

To ensure good analysis results you have to test the defrint quality of mesh .The mesh element used is the tetrahedral.The exact test value is 0.21

The angles of attack that studies to see the results, namely -5,…..,20 ° by 1 °. The angles of the dihedra which studies limited by 15, 30, 45, 60 and 90 °.

Calculations generate with boundary conditions corresponding to hovering conditions at a low flow velocity of 20m / s corresponding to Reynolds number Re = 2.6.106 of a viscous fluid compute the equations of the Navir-Stoks.

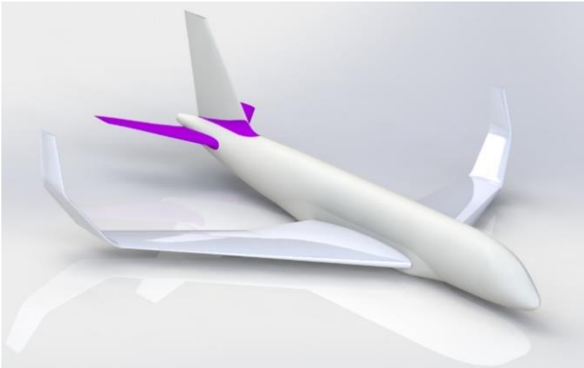

Fig. 1. Passenger airplane wing with Morphing Wing.

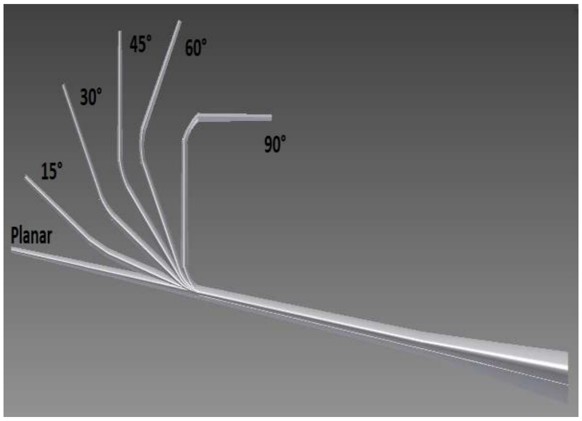

Fig. 2. Demonstration of the ranges of dihedral angle variation.

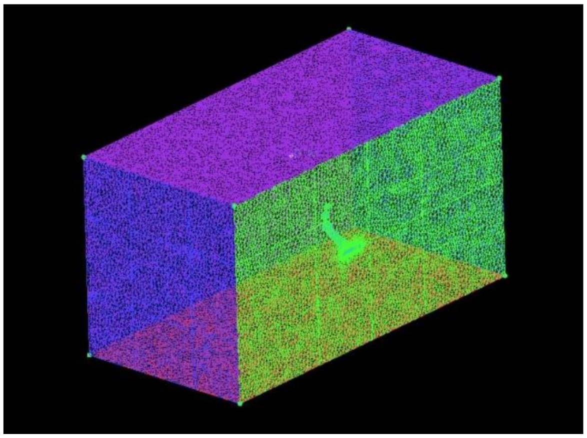

Fig. 3. Wing mesh with 45 °cofiguration Morphing Winglet.

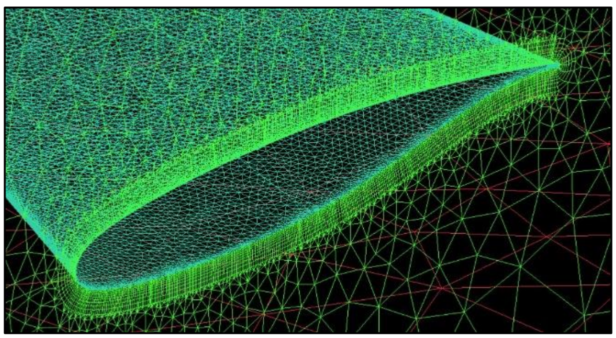

Fig. 4. Wing mesh with the boundary layer

TABLE I. MESH QUALITY

Mesh quality	Nodes	Element	Cd
0.2	30806	154970	0.019
0.21	30125	150750	0.020
0.22	29252	145553	0.021
0.23	28686	142191	0.025
0.24	28211	139283	0.025

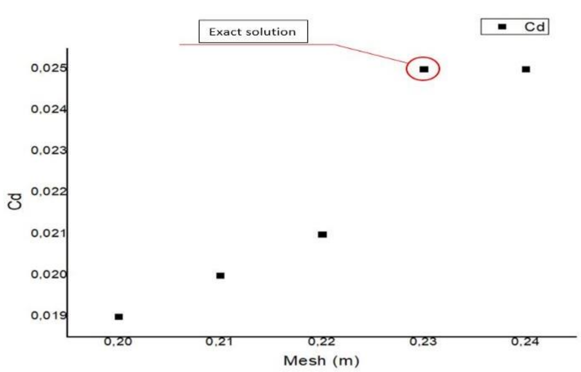

Fig. 5. Exact solution for mesh.

III. RESULT

The results of this nuimeric investigation are based on changes in aerodunamic performance for several cases studied. However, the lift and drag coefficients at several angles of attack are shown. The effect of winglet morphing on drag and lift is interesting. In addition, the effect of dihedral angles on the load is important because we can increase the weight of the wing, for each configuration of the wing cited in Figure 2. This represents the two angles of the dihedron at the same time.

The Fig.6 shows the slopes of the lift curves observed for each numerical analysis compare with the lift curve of the experimental study. We can notice that the different configuration influences the lift. As the dihedral angle decreases, the wing area decreases, which implies that the lift decreases. At 90° dihedral angle, the elevation of the lift force is decreased. For negative angles of attack the lift is negative. The lift in zero angle of attack is almost zero for the numerical analysis on the other hand it has a value in the experimental results.

The Fig.7 presents another appearing between the numerical and experimental results. For the drag curves of dihedral angles breakers. The experimental and numerical results trace a tendency to increase with a dihedral angle. although the experimental results for the minimum angular drag values of 45 ° and 60 ° compare very favorably to a plane wing. The minimum drag defined for experimental is the angle of -3 ° and in the numerical analysis is 1 °.

The drag induced is implicit in the global drag as we will demonstrate.

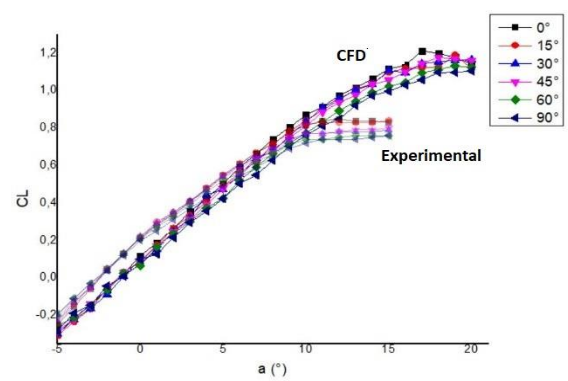

Fig. 6. Lift curves for comparing results to vary dihedral angles.

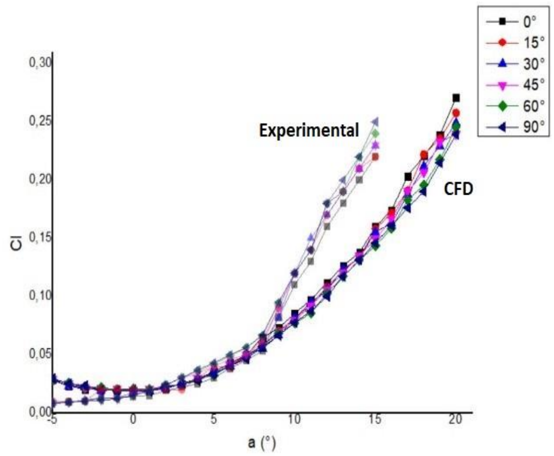

Fig. 7. Drag curves for comparing results to vary dihedral angles.

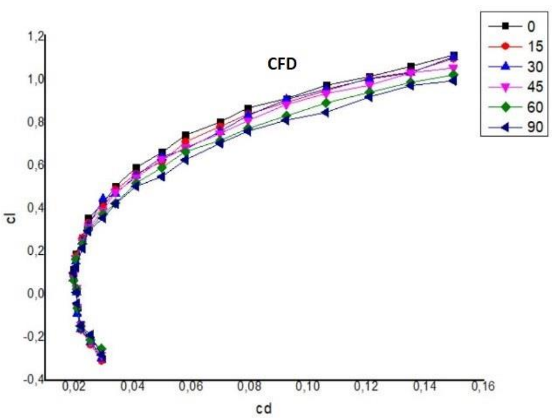

Fig. 8. Lift and drag comparison for the four solution methods to vary dihedral angles.

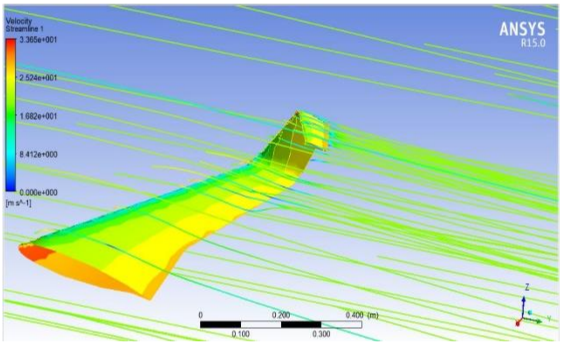

Fig. 9. Streamlines around a C-wing 90 °configuration at α= 10 °.

The figure 8 Shown the finesse curves for the configurations of the numerical analysis. We note for finesse that C = 0.15 and Cd = 0.02 great lift for a low drag.

The Figures 9 and 10 represent respectively the Streamlines and Path-lines for C-wing 90 °configuration at α= 10 °.

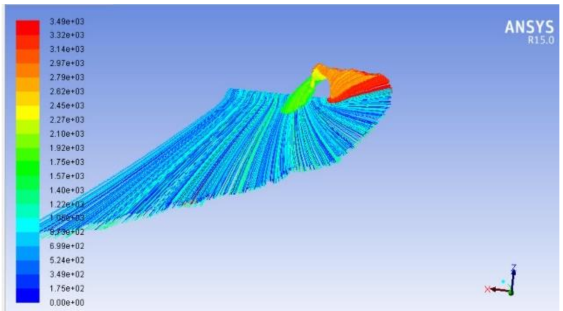

Fig. 10. Air Pathlines around a C-wing 90 °configuration at α= 10 °.

IV. CONCLUSION

The objective of the present study is to validate the aerodynamic and structural tendencies observed during the optimizations carried out with the Ansys code to maximize the ratio lift / drag by adopting a minimum of dihedron. The difference between the numerical and experimental results is based on the chosen calculation method and the mesh used. The numerical results are confirm the experimental results. As the wing configuration changes, the increased dihedral angles move the load inward, lose overall lift and potentially increase drag, but are able to counter this constraint with a reduced bending moment.

The results show that each configuration can offer good performance in terms of specific range, which indicates that one can search for and achieve an optimal number of points in any flight case.

The results, representing the take-off conditions, also indicate that the planar wing potentially offers the best specific airflow result, while the calculation results, modeled to resemble flight conditions, favor dihedral configurations.

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