Computational Investigation of Inviscid Flow over a Wing With Multiple Winglets

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***Abstract*-This effort is to examine the potential of multiple winglets to reduce the induced drag of the wing. The advantages of using multiple winglets include reduction of induced drag, increased L/D and improved performance of the wing. The models are computational in nature. The models are created using NACA 24012 airfoil section for untwisted, rectangular wing and flat plates for the winglets. The testing of configurations is done at Reynolds number of 290,000. FLUENT solver incorporated in ANSYS 13 is used for the numerical investigation of the steady flow over the wing. Solution is obtained via the Euler equations of motion. The wing has been tested with different combinations of dihedral angles of the winglets. The results show that certain multiple winglet configurations improved the L/D ratio by 15-20% compared with the baseline NACA 24012 Wing. A substantial improvement in lift curve slope occurs with dihedral spread of the winglets. The dihedral spread also distributes the tip vortices. These numerical results are well in agreement with the experimental results.**

Keywords - Induced Drag, Lift Curve Slope, Multiple Winglets.

1. INTRODUCTION

Flow Past a Finite Wing The flow over a finite wing is different from that of flow over an airfoil. This is because flow over an airfoil is two-dimensional. In contrast, finite wing is a three-dimensional body; that is, there is a component of flow in the span wise direction. The physical mechanism for generating lift on the wing is the existence of a high pressure on the bottom surface and a low pressure on the top surface. The net imbalance creates the lift on the wing. However, as a by-product of this pressure imbalance, the flow near the wing tips tends to curl around the tips, being forced from the high-pressure region just underneath the tips to the low-pressure region on the top. As a result, on the top surface of the wing, there is generally a span wise component of flow from the tip toward the root, causing the streamlines over the top surface to bend towards the root. Similarly, on the bottom surface, there is a span wise component of flow from root to the tip, causing the streamlines over the bottom surface to bend towards the tip. The tendency for the flow to leak around the wing tips establishes a circulatory motion that downstream of the wing; that is, a trailing vortex is created at each wing tip.

1.1 Induced Drag

The wing-tip vortices downstream of the wing induce a small downward component of air velocity in the neighborhood of the wing itself. These two vortices tend to drag the surrounding air around with them, and this secondary movement induces a small velocity component in the downward direction of the wing. This downward component is called downwash. In turn, the downwash combines with the free stream velocity V_∞.

1.2 Scope And Objective Of The Present Work

In the present work, first of all we have analyzed the effect of number of winglets to reduce the induced drag. We computed flow over the wing with different configurations of winglet angles. We took a benchmark test velocity as 25 m/s. The three configurations of models are wing (without winglets), wing with winglets with 5° decrement in dihedral angle (10º,5º,0º,-5º) and wing with winglets with 10° decrement in dihedral angle; that is, (20°, 10°, 0°, -10°). Flow parameters like lift and drag have been calculated for all angle of attack of the test cases. Numerical results have been compared to the experimentally reported results from the literatures.

2. LITERATURE REVIEW

In the 1970s, biologists began to look at the flying characteristics of soaring birds such as eagles, hawks, condors, vultures, and ospreys. Each of these birds has high lift wings with “pin” feathers at the ends that produce slotted wingtips. Biologists found that the pin feathers worked to reduce drag during gliding flight, as well as being used to provide roll control, in the same manner as ailerons on aircraft. These multi-winglets are quite often long and prominent, as in the case of the California condor.

Modern interest in winglets spans the last 25 years. Richard Whitcomb (9) of NASA Langley Research Center first looked at modern applications of winglets to transport aircraft in the 1970s. He used small, nearly vertical fins installed on a KC-135A and flight tested 1, 2 in 1979 and 1980. The winglet concept actually dates back to a patent in

1897, but not until Whitcomb investigated winglet aerodynamics did the concept mature. Whitcomb showed that winglets could increase an aircraft's range by as much as seven percent at cruise speeds. A NASA contract (5) in the 1980s assessed winglets and other drag-reduction devices, and they found that wingtip devices (winglets, feathers, sails, etc.) can improve drag due- to-lift efficiency by 10 to 15% if they are designed as an integral part of the wing. As add on devices, however, they have been shown to be detrimental to overall performance of the wing.

2.1 Flow Over Wing With Multiple Winglets

This effort examined the basic principles of multi-winglets. The multi-winglet design was evaluated to demonstrate its advanced performance potential over the baseline wing and an equivalent single winglet. A basic study of the flow-field physics surrounding the winglets and wing was performed with inexpensive models to guide selection of multi-winglet configurations. The number of winglets, their optimum shape, location and spacing, and their angles of attack, dihedral, and Sweep were the unknowns to be determined.

3. COMPUTATIONAL MODELING OF FLUID FLOW

Computational Fluid Dynamics is a computer-based mathematical modeling tool that incorporates the solution of the fundamental equations of fluid flow, the Euler equations, and other allied equations. CFD incorporates empirical models for modeling turbulence based on experimentation, as well as the solution of heat, mass and other transport and field equations. This technique is very powerful and spans a wide range of industrial and non-industrial applications.

4. WING AND WINGLETS CONFIGURATION

The wing configuration used for analysis is NACA 24012, the wing configurations are given as wing chord length 0.3048 m (12"), Wing span 1.2192 m (48"), Wing area 0.3716 m^2 and winglets configurations given as Winglet chord 0.0381 m (1.5"), Winglet span 0.3048 m (12"), Spacing between winglets 40.64 mm (1.6") and Number of winglets considered 4.

5. NUMERICAL RESULTS AND GRAPHS

In order to ensure that the numerical simulation of steady flow over a wing and wing with multiple winglets at different orientations using FLUENT are properly carried out, a few benchmark test cases for validation were simulated first.

Computational Test Case

- Inviscid flow over a wing, Re = 290,000
- Inviscid flow over a wing with multiple winglets (10º,5º,0º, -5º Dihedral) Re = 290,000
- Inviscid flow over a wing with multiple winglets (20º, 10º, 0º,-10º Dihedral) Re = 290,000

5.1 Inviscid Flow over a Wing

For the numerical simulation of flow over wing, a commercial package FLUENT incorporated in ANSYS 13.0 has been used to solve the basic governing equations for velocities and other quantities. The equations were discretized using the finite volume method on a collocated grid in fully implicit form. Second order upwind scheme is used for solving convective terms and central differencing scheme is adopted for solving diffusion terms. The second order implicit scheme was used for time integration of each equation. Semi-Implicit Method for Pressure-Linked (SIMPLE) algorithm was used for coupling the pressure and velocity terms. The convergence criterion for all the cases was taken to be 10^{-6}.

The Structured grid in Cartesian coordinates is chosen, where x-axis is along the free stream direction, y-axis is in the vertical direction, z-axis is in the span wise direction. Two grid arrangements of size 45,220 and 65,997 cells were tested for grid independency. Results are presented for the 45,220 grid size. The solution is started and allowed to converging and attains periodic nature. The flow over a wing for Reynolds number 290,000 is computed using FLUENT 6.0 incorporated in ANSYS 13.0 produced wing tip vortices. The values of the coefficient of lift and coefficient of drag obtained by the present computation are presented in the Table 1.

TABLE.1. Wing without Winglets

Angle of Attacks (degrees)	**Coefficient of lift (C_L)**	**Coefficient of drag (C_D)**
0	0.0347	0.00032
2	0.044	0.0007
4	0.0543	0.0012
6	0.066	0.0017
8	0.074	0.0022

5.2 Inviscid Flow Over A Wing with Multiple Winglets (10º, 5º, 0º,-5º Dihedral)

For the numerical simulation of inviscid flow over a wing with multiple winglets (10º, 5º, 0º, -5º dihedral) at Reynolds number (Re=290,000), the same schemes taken for the flow over a wing are given. The schematic representation of the computational domain is shown in Fig I. Structured grid in Cartesian coordinates is chosen, where x-axis is along the free stream direction, y-axis is in the vertical direction, z-axis is in the spanwise direction. A grid arrangement of size 46,604 and 68,250 was tested. Results obtained using this grid matched excellently with the existing numerical results computed by various researchers. The solution is started and allowed to converging and attains periodic nature.The values of the coefficient of lift and coefficient of drag obtained by the present computation are presented in the Table 2.

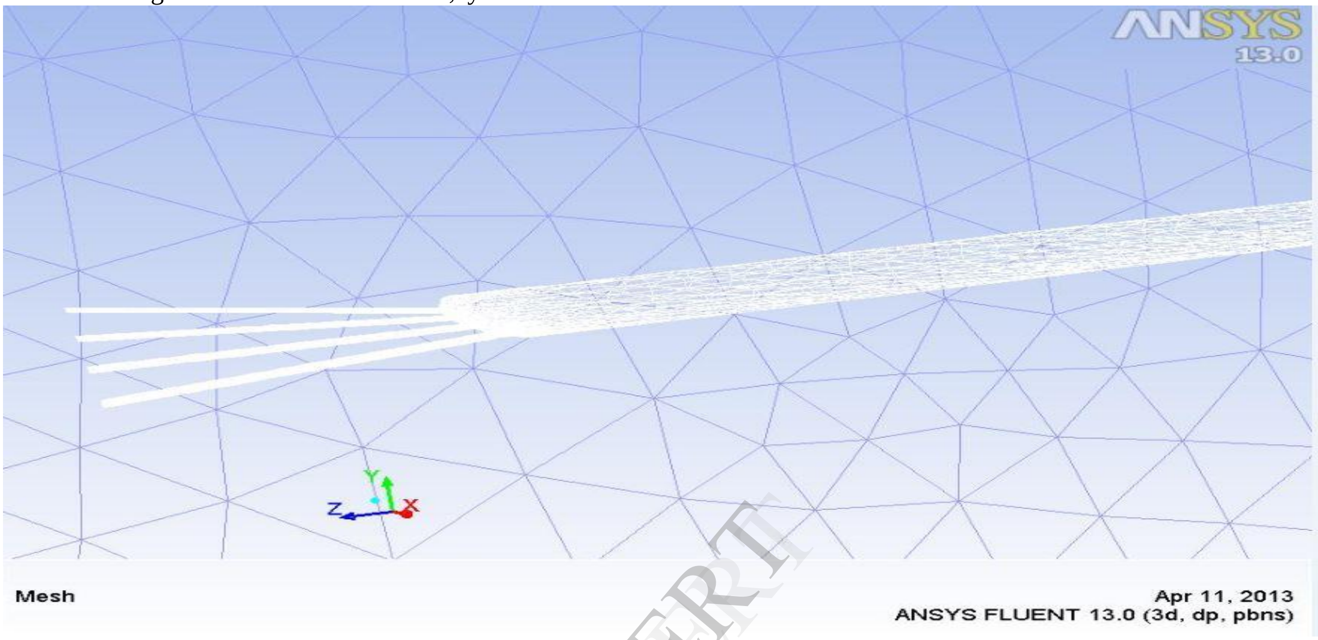

Fig.1. Computational mesh for flow over a wing with 4 winglets (10º, 5º, 0º,-5º Dihedral)

TABLE.2. Wing with 4 Winglets (10º, 5º,0º,-5º Dihedral)

Angle of Attacks (degrees)	**Coefficient of lift (C_L)**	**Coefficient of drag (C_D)**
0	0.031	0.0002
2	0.05	0.0005
4	0.069	0.0009
6	0.088	0.0014
8	0.098	0.002

5.3 Inviscid Flow Over A Wing With Multiple Winglets (20º, 10º,0º,-10º,-20º Dihedral)

For the numerical simulation of flow over a wing with multiple winglets (20º, 10º, 0º, -10ºDihedral) at Reynolds number (Re=290,000), the same schemes taken for the flow over a wing and wing with multiple winglets(20º, 10º, 0º, -10ºdihedral) are given.

The schematic representation of the computational domain is shown in Fig 2. Structured grid in Cartesian coordinates is chosen, where x-axis is along the free stream direction, y-axis is in the vertical direction, z-axis is in the span wise direction. A grid arrangement of size 45,763 and 67,970 was tested. Results obtained using this grid matched excellently with the existing numerical results computed by various researchers. The solution is started and allowed to converging and attains periodic nature.

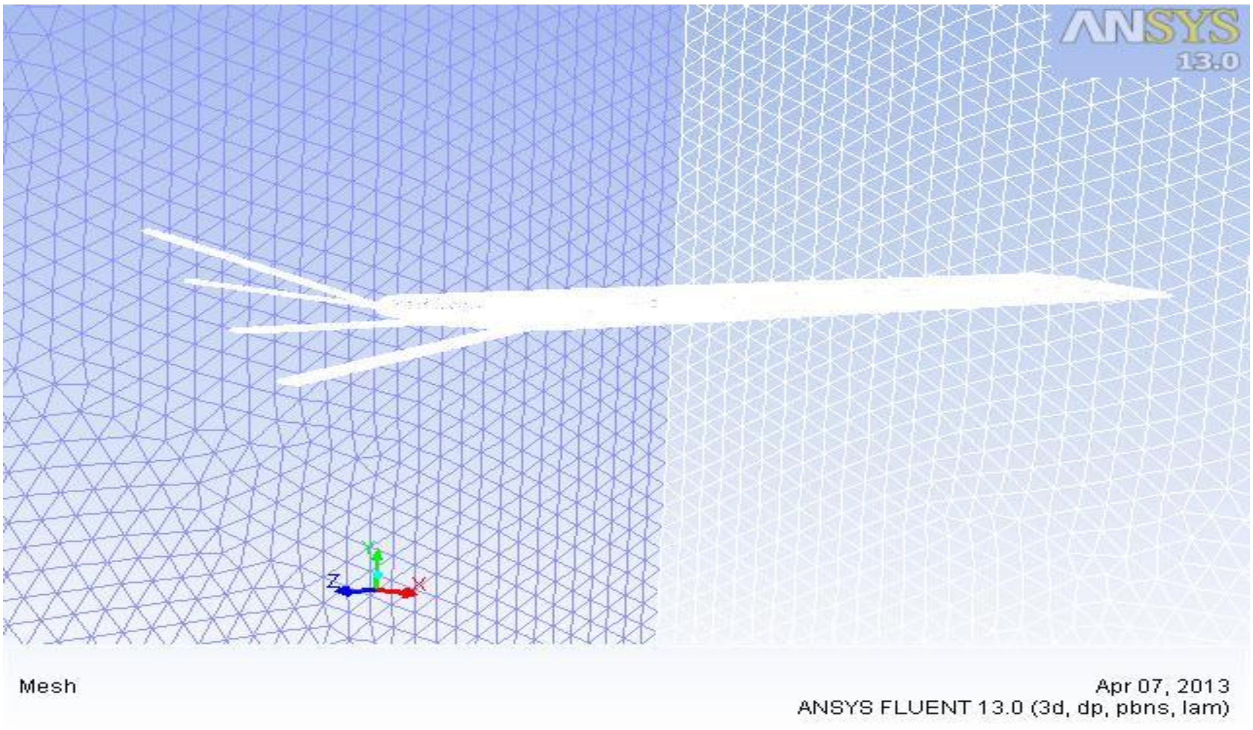

Fig.2. Computational mesh for flow over a wing with 4 winglets (20º, 10º, 0º, -10ºDihedral)

TABLE 3. Wing with 4 Winglets (20º, 10º, 0º, -10º Dihedral)

Angle of Attacks (degrees)	Coefficient of lift (C_L)	Coefficient of drag (C_D)
0	0.0581	0.0001
2	0.071	0.00015
4	0.08	0.0003
6	0.099	0.0007
8	0.114	0.0012
10	0.128	0.0017

The flow over a wing for Reynolds number 290,000 is computed using FLUENT solver incorporated in ANSYS 13 produced distributed wing tip vortices because of dihedral spread of winglets. The predicted results are plotted in Fig 3 to 5. The variation of lift coefficient Vs angle of attack shown in Fig. 3.as well as the variation of drag coefficient has shown Vs angle of attack shown in Fig 4.and C_L Vs C_D as shown in Fig 5. The values of the coefficient of lift, coefficient of drag and L/D obtained by the present computation are presented in the Table 4.

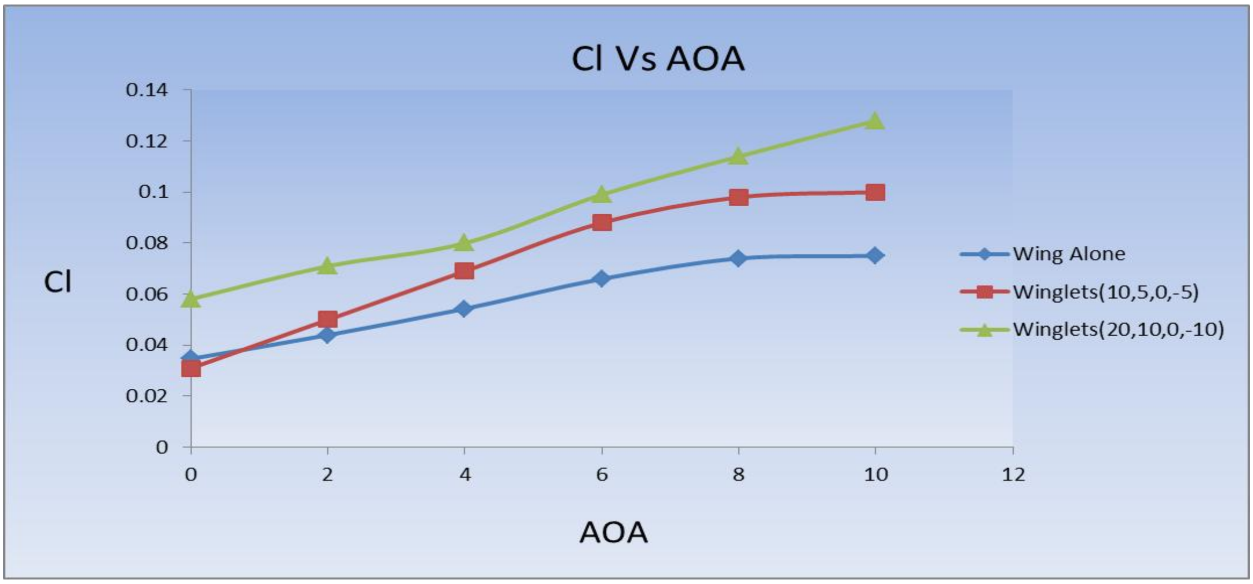

Fig.3. Coefficient of Lift (CL) Vs. Angle of attack (α in degrees)

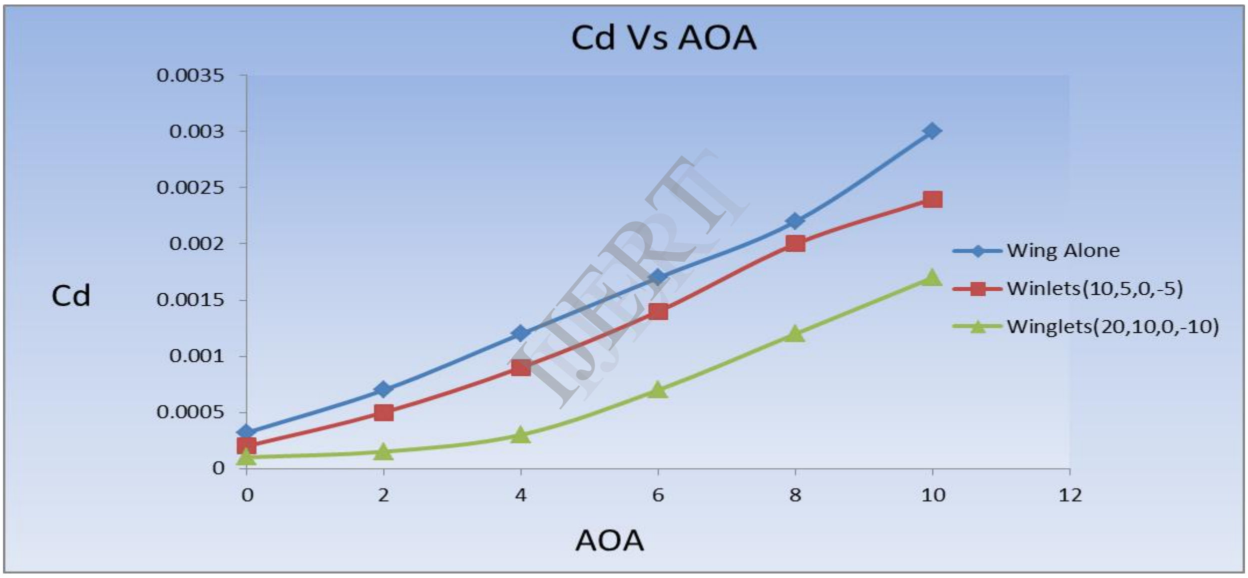

Fig.4. Coefficient of Drag (CD) Vs. Angle of attack (α in degrees)

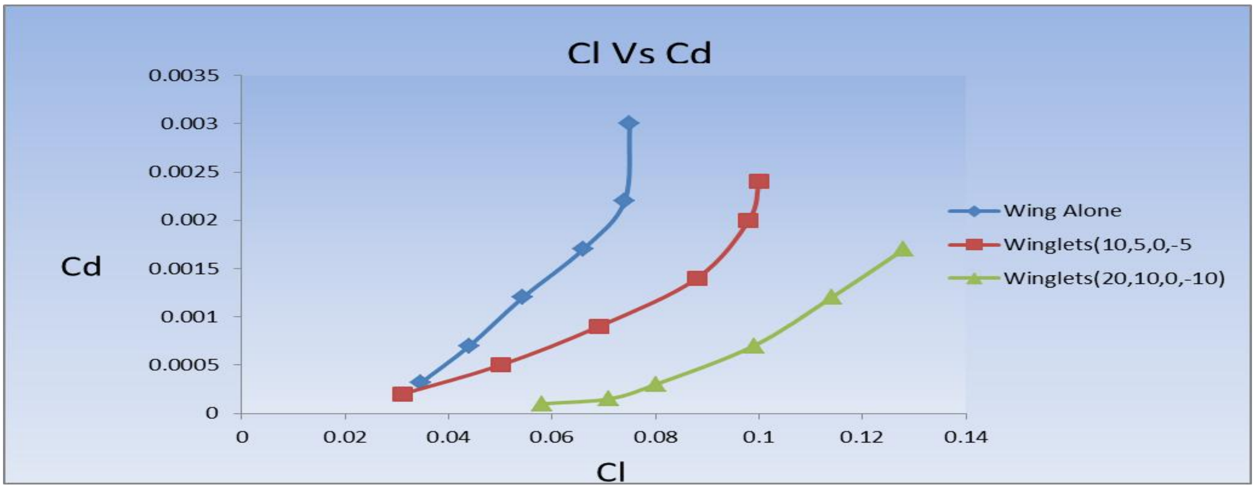

Fig.5. Coefficient of Lift (CL) Vs. Coefficient of Drag (CD)

TABLE.4. Comparison of CL & CD at 8 Degree Angle of attack (α)

Configuration	**Coefficient of lift (C_L)**	**Coefficient of drag (C_D)**
Wing without winglets	0.074	0.0022
Wing with winglets(10,5,0,-5)	0.098	0.002
Wing with winglets(20,10,0,-10)	0.114	0.0011

TABLE.5. Comparison of CL & CD for Symmetrical and Unsymmetrical airfoil at 0 Degree Angle of Attack (α)

Configuration	**Wing with winglets in symmetrical airfoil**	**Wing with winglets in cambered airfoil**
Coefficient of lift (C_L)	0.007	0.0581
Coefficient of drag (C_D)	0.019	0.0001

6. CONCLUSION

Computational investigations have been performed to examine the effectiveness of multiple winglets mounted at varying dihedrals to improve the performance of a wing in subsonic flow. Combining the Computational analysis measurement results with the experimental result, the following are presented for performance improvement due to multiple winglets:

- Multiple winglets configurations reduces the wing induced drag.
- Dihedral spread of the winglets improves lift by taking some of the winglets away from the wing plane, and redistributing the tip vortex into multiple vortices that do not merge in the near wake, thereby reducing the effective downwash at the wing plane.
- From the above two points it can be concluded that the wing with winglets at (20^0,10^0,0^0,-10^0) has better performance coefficients than the other two type of wings.
- From Table 5 we can conclude that the wing with winglets in cambered airfoil produces more lift and lesser drag than wing with winglets in symmetrical airfoil.

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