Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2013
(ICMERE2013) 1 - 3 May 2014, Chittagong, Bangladesh

ICMERE2013-PI- 035

EFFECT OF SPOILER ANGLE ON AERODYNAMIC CHARACTERISTICS OF AN AIRFOIL

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Abstract- *The goal of this endeavor is to analyze the variation of flow physics of flow over an airfoil without spoiler and with spoiler at different angles. From this analysis how stall point are decreased with spoiler angle variation are to be found. For different values of spoiler angle, the variation of lift and drag component of force can be analyzed. The general-purpose CFD software FLUENT is used for this observation. At first the design of airfoil without spoiler and with spoiler at different angle is drawn in GAMBIT 2D simulation. The problem specifications are as follows- create geometry in GAMBIT, mesh geometry in GAMBIT, specify boundary types in GAMBIT, set up problem in FLUENT, solve the problem and analyze the results. This investigation led to a conclusion that lift is decreased and drag is increased which shows the common nature of spoiler.*

Keywords: Spoiler, Fluent and Gambit commercial tool, Airfoil design, K-epsilon model, Mesh generation.

1. Introduction

The cross-sectional shape obtained by the intersection of the wing of an airplane with the perpendicular plane is called an airfoil [1]. There is an aerodynamic force created by the pressure and shear stress distributions over the wing surface. This resultant aerodynamic force can be resolved into two forces, parallel and perpendicular to the relative wind. The direction of free stream velocity is defined as the relative wind. The two forces are called lift and drag force. The drag is always defined as the component of the aerodynamic force parallel to the relative wind. The lift is defined as the component of the aerodynamic force perpendicular to the relative wind.

In this project work, the commercial tool FLUENT is used. For mesh geometry the GAMBIT 2D simulation is used. The commercial package FLUENT is a powerful and flexible general-purpose CFD software developed by ANSYS, Inc. Thousands of companies throughout the world benefit from this engineering design and analysis tool, using FLUENT for a wide variety of multi physics applications.

At first the design of airfoil without spoiler and with spoiler at different angle is drawn in GAMBIT 2D simulation. The problem specifications are as follows- create geometry in GAMBIT, mesh geometry in GAMBIT, specify boundary types in GAMBIT, set up problem in FLUENT, solve the problem and analyze the results. For this experiment NACA 2415 airfoil was used with 1m chord length.

1.1 Spoiler

A spoiler, sometimes called a lift dumper is a device intended to reduce lift in an aircraft. Spoilers are plates on the top surface of a wing which can be extended upward into the airflow and spoil it. By doing so, the spoiler creates a carefully controlled stall over the portion of the wing behind it, greatly reducing the lift of that wing section. Spoilers are designed to reduce lift also making considerable increase in drag [2].

Spoilers are used by some older gliders to control their rate of descent and thus achieve a controlled landing at a desired spot. An increased rate of descent could also be achieved by lowering the nose of an aircraft, but this would result in an excessive landing speed. However spoilers enable the approach to be made at a safe speed for landing.

Airliners too are usually fitted with spoilers. Spoilers are sometimes used when descending from cruise altitudes to assist the aircraft in descending to lower altitudes without picking up speed. Their use is often limited, however, as turbulent airflow which develops behind them causes noticeable noise and vibration, which may cause discomfort to extra-sensitive passengers. The spoilers may also be differentially operated to provide roll control. Martin Aircraft was the first to develop spoilers to help with roll control in 1948. On landing, however, the spoilers are nearly always used at full effect to assist in slowing the aircraft. The increase in form drag created by the spoilers directly assists the braking effect. However, the real gain comes as the spoilers cause a considerable loss of lift and hence the weight of the aircraft is transferred from the wings to the undercarriage, allowing the wheels to be mechanically braked with much less chance of skidding [2].

Spoilers increase drag and reduce lift on the wing. If raised on only one wing, they aid roll control, causing that wing to drop. If the spoilers rise symmetrically in flight, the aircraft can either be slowed in level flight or can descend rapidly without an increase in airspeed. When the spoilers rise on the ground at high speeds, they reduce the wing's lift, which puts more of the aircraft's weight on the wheels. The flight spoilers are available both in flight and on the ground. However, the ground spoilers can only be raised when the weight of the aircraft is on the landing gear, usually activated by a sensor. When the spoilers deploy on the ground, they decrease lift and make the brakes more effective. In flight, a ground-sensing switch on the landing gear prevents deployment of the ground spoilers.

1.2 FLUENT And GAMBIT Commercial Tool

The commercial tool GAMBIT is used to create and mesh the solution domain and FLUENT is used to toward a converged solution and performs some simple file management. FLUENT is executed twice to enable solution on parallel processors. In the first Fluent session, the solution domain is divided into four partitions. For the second Fluent session, the parallel solver is invoked to iterate toward a solution.

To solve the problem NACA 2415 coordinate has been used in this problem.

To specify the airfoil geometry, a file containing a list of vertices along the surface is promoted and GAMBIT is used to join these vertices to create two edges, corresponding to the upper and lower surfaces of the airfoil. Then these edges are splited into 4 distinct edges to help us control the mesh size at the surface.

The file containing the vertices for the airfoil of NACA2415 has been used.

2. Theoretical Background

Lift: To overcome the weight force, airplanes generate an opposing force called lift. Lift is generated by the motion of the airplane through the air and is an aerodynamic force.aero stands for the air, and "dynamic" denotes motion. Lift is directed perpendicular to the flight direction. The magnitude of the coefficient depends on the shape of the body and its angle of attack [9].

Now, Lift force

$$L = 1/2\ \rho v^2 C_L$$

Where

- L is lift force
- ρ is air density
- v is velocity of air
- A is planform area and
- C_L is the lift coefficient at the desired angle of attack, Mach number and Reynolds number

Drag: As the airplane moves through the air, there is another aerodynamic force present. The air resists the motion of the aircraft and the resistance force is called drag. And coefficient of drag is also a unit less number, which indicates a body's ability to generate fluid resistance [6].

Now, Drag force

$D = 1/2\ \rho v^2 C_D$

Where

- D is Drag force
- ρ is air density
- v is velocity of air
- A is plan form area and
- C_D is the drag coefficient at the desired angle of attack, Mach number and Reynolds number.

2.1 How Spoiler Works?

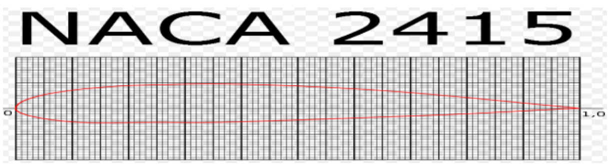
Spoilers are small, hinged plates on the top portion of wings. Spoilers can be used to slow an aircraft, or to make an aircraft descend. The main thing about spoilers is not the increase in C_D, but the decrease of C_L get more weight on the wheels. The L/D ratio goes to near zero from losing the lift and also increase drag to lose airspeed. Spoilers are intended to "spoil", that is reduced lift, and they do so via a shape which creates downward force from the air passing by the wing. That comes at the expense of drag, both from creation of the downward force as well as increased turbulence caused by the spoiler and its support structure. Spoilers reduce lift. Spoilers are found along the top of the wing. When they aren't being used, they fit into or flush with the wing's surface. When they are used, they protrude from the wing's surface into the airflow and destroy the laminar flow for a portion of the wing. The size of the spoiler varies according to how much lift is to be "spoiled". Different spoiler designs are found on different types of planes, but their function is the same, if they are deployed on both wings. Spoilers can also be used to generate a rolling motion for an aircraft, if they are deployed on only one wing. A single spoiler is used to bank the aircraft; to cause one wing tip to move up and the other wing tip to move down. The banking creates an unbalanced side force component of the large wing lift force which causes the aircraft's flight path to curve (Airplanes turn because of banking, not because of the force generated by the rudder).

The spoiler is a multifunctional flight control surface with three main functions:

- in-flight air braking for speed reduction;
- in-flight roll control (to augment the ailerons in turning); and
- Air braking on the ground, during lift dumping.

The latter dispels the remaining lift as an aircraft touches down on a runway. This increases the efficiency of the wheel brakes by applying the full weight of the aircraft on the wheels [10].

Spoilers are fitted in a fixed position on NACA 2415 airfoil for this experiment where only spoiler angles have been changed. As the chord length of the airfoil is considered to be 1m, the airfoil is designed with spoiler angles 2.5, 5, 7.5, 10, 12.5 degree at 0.05C.The spoiler is extended upward for 0.1 m for all those angles.



3. Mathematical Modeling

3.1 Two Equation Turbulence Models

By definition, two equation models include two extra transport equations to represent the turbulent properties of the flow. This allows a two equation model to account for history effects like convection and diffusion of turbulent energy [3].

The k-ε model introduces two new variables into the system of equations.
The continuity equation is then:

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_j}\left(\rho U_j\right)=0$$

And the momentum equation becomes:

$$\frac{\partial \rho U_i}{\partial t}+\frac{\partial}{\partial x_j}\left(\rho U_i U_j\right)=-\frac{\partial p'}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\mu_{eff}\left(\frac{\partial U_i}{\partial x_j}+\frac{\partial U_j}{\partial x_i}\right)\right]+S_M$$

Transport equations:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_j}(\rho k u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+P_k+P_b-\rho\epsilon-Y_M+S_k$$

$$\frac{\partial}{\partial t}(\rho\epsilon)+\frac{\partial}{\partial x_j}(\rho\epsilon u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial \epsilon}{\partial x_j}\right]+\rho C_1 S\epsilon-\rho C_2\frac{\epsilon^2}{k+\sqrt{\nu\epsilon}}+C_{1\epsilon}\frac{\epsilon}{k}C_{3\epsilon}P_b+S_\epsilon$$

Where,

$$C_1=\max\left[0.43,\frac{\eta}{\eta+5}\right],\quad \eta=S\frac{k}{\epsilon},\quad S=\sqrt{2S_{ij}S_{ij}}$$

In these equations, P_k represents the generation of turbulence kinetic energy due to the mean velocity gradients, calculated in same manner as standard k-epsilon model. P_b is the generation of turbulence kinetic energy due to buoyancy, calculated in same way as standard k-epsilon model.
Modeling Turbulent Viscosity

$$\mu_t=\rho C_\mu\frac{k^2}{\epsilon}$$

Where

$$C_\mu=\frac{1}{A_0+A_s\frac{kU^*}{\epsilon}}$$

$$U^*\equiv\sqrt{S_{ij}S_{ij}+\tilde{\Omega}_{ij}\tilde{\Omega}_{ij}}$$

$$\tilde{\Omega}_{ij}=\Omega_{ij}-2\epsilon_{ijk}\omega_k$$

$$\Omega_{ij}=\overline{\Omega_{ij}}-\epsilon_{ijk}\omega_k$$

Where $\overline{\Omega_{ij}}$ is the mean rate-of-rotation tensor viewed in a rotating reference frame with the angular velocity ω_k. The model constants A_0 and A_s are given by:

$$A_0=4.04,\quad A_s=\sqrt{6}\cos\phi$$

$$\phi=\frac{1}{3}\cos^{-1}(\sqrt{6}W),\ W=\frac{S_{ij}S_{jk}S_{ki}}{\tilde{S}^3},\ \tilde{S}=\sqrt{S_{ij}S_{ij}},\ S_{ij}=\frac{1}{2}\left(\frac{\partial u_j}{\partial x_i}+\frac{\partial u_i}{\partial x_j}\right)\quad (1)$$

Model Constants

$$C_{1\epsilon}=1.44,\ C_2=1.9,\ \sigma_k=1.0,\ \sigma_\epsilon=1.2\quad (2)$$

3.2 Boundary Conditions

In this experiment, at first an airfoil of NACA 2415 has been designed without spoiler. Then different spoiler angles have been used. For NACA 2415 airfoil, spoiler angle are 2.5^0, 5^0, 7.5^0, 10^0, 12.5^0 have been considered. The spoilers have been used at almost in the leading edge of 5 percent of the chord length. Position of spoiler is kept fixed for this analysis. The length of spoiler is 10 percent of chord length which is also fixed. The spoiler angle has been varied here. For different values of angle we have to design mesh files. Different mesh files have been read by FLUENT, from this our desired graphs and figures have been drawn out.

4. Results and Discussion

For without spoiler, a stall point has been got at α=15 which are given below:

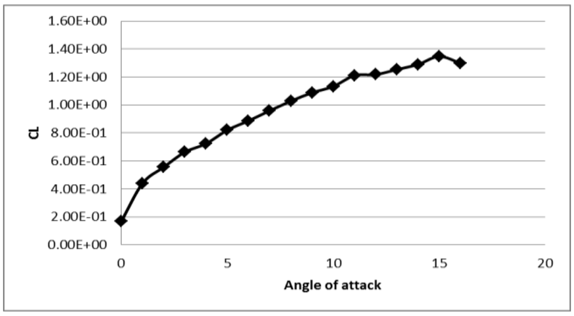


Fig.1: C_L Vs α for without spoiler

In case of drag component after plotting all the values of C_D for all values of α, a graph can be obtained which is given below:

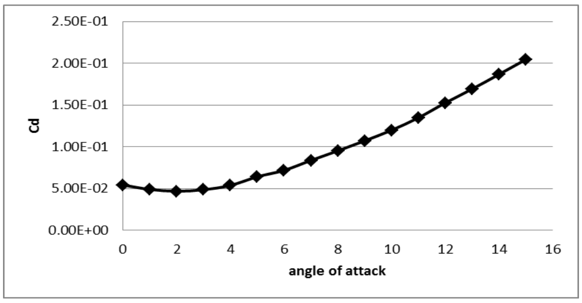


Fig.2: C_D Vs α for without spoiler

By plotting C_L/C_D Vs α for without spoiler also has been got,

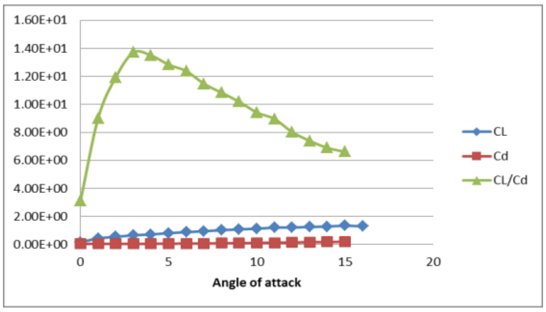


Fig.3: C_L/C_D Vs α for without spoiler

For spoiler angle = 7.5, a stall point has been got at α=13 which are given below:

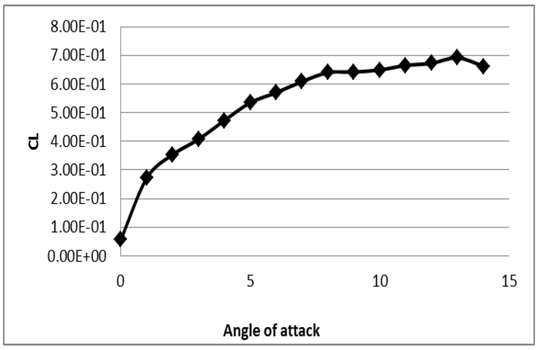


Fig.4: C_L Vs α with spoiler angle = 7.5

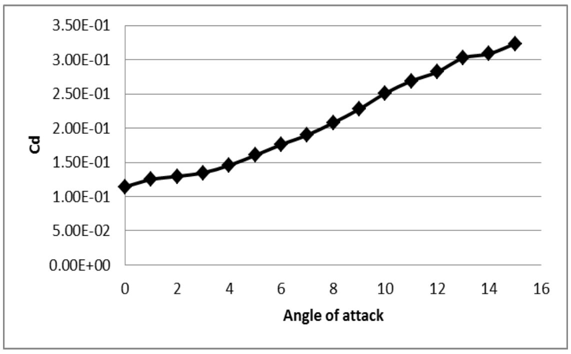


Fig.5: C_D Vs α with spoiler angle = 7.5

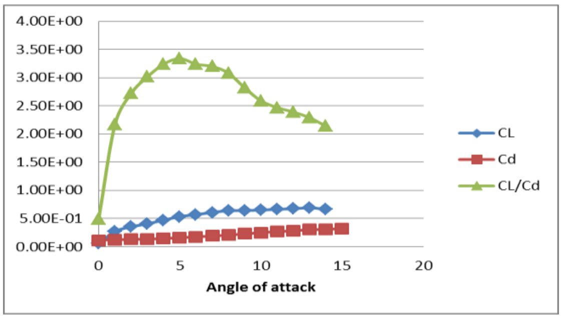


Fig.6: C_L/C_D Vs α with spoiler angle = 7.5

For spoiler angle = 10, a stall point has been got at α=11 which are given below:

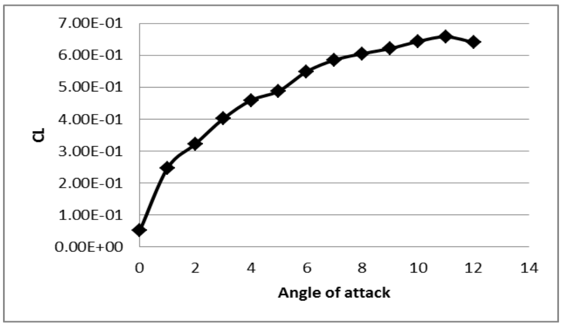


Fig.7: C_L Vs α with spoiler angle = 10

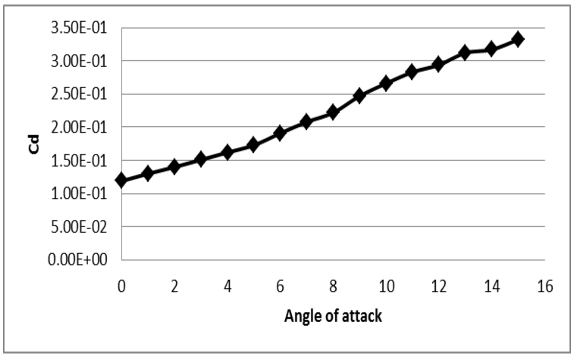


Fig.8: C_D Vs α with spoiler angle = 10

By plotting C_L/C_D Vs α with spoiler angle = 10 also has been got,

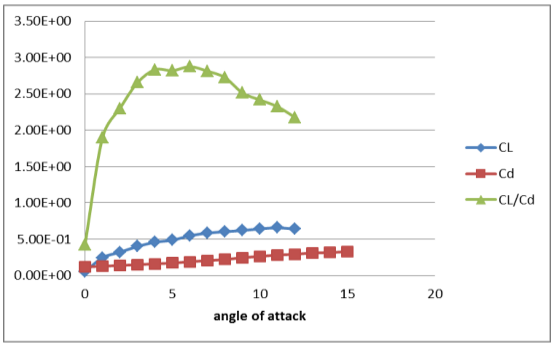


Fig.9: C_L/C_D Vs α with spoiler angle = 10

For spoiler angle = 12.5, a stall point has been got at α=14 which are given below:

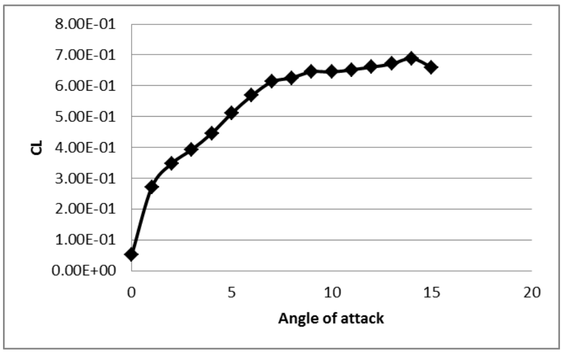


Fig.10: C_L Vs α with spoiler angle = 12.5

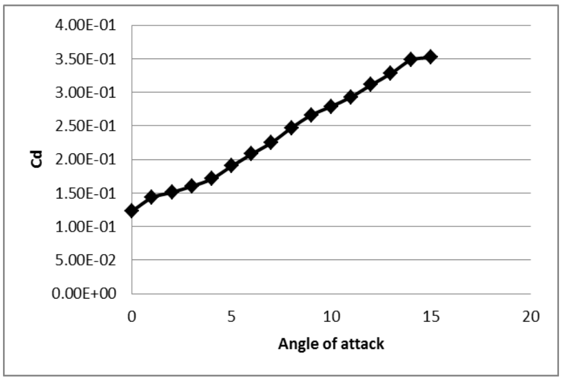


Fig.11: C_D Vs α with spoiler angle = 12.5

By plotting C_L/C_D Vs α with spoiler angle = 12.5 also has been got,

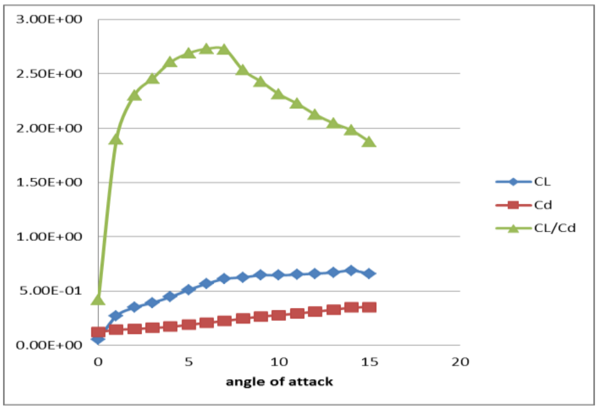


Fig.12: C_L/C_D Vs α with spoiler angle = 12.5

From the figure above we have for the airfoil having spoiler placed in any particular angle has a lift curve trending lower than the airfoil without any spoiler. Thus the effects of the spoiler for all the angles are demonstrated through the figure. A certain decrement of lift coefficient is obtained and it is quite reasonable. A spoiler is used to decrease the lift of the aircraft so as to descent the aircraft. For safe and smooth landing of the airplane spoiler plays an important role by decreasing the lift coefficient thus the lift is decreased with increasing angle of spoiler. From above graph it is understandable that by attaching a spoiler to the wing section or airfoil lift obtained is lower than that of the wing section without the spoiler attachment which is one of the main functions of spoiler. So the numerical result obtained is reliable [2].

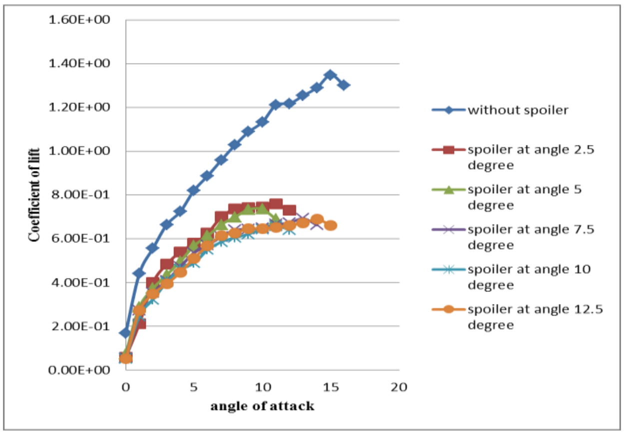


Fig.13: Comparison of the $C_L$vs. α curve for airfoil with spoiler and without spoiler

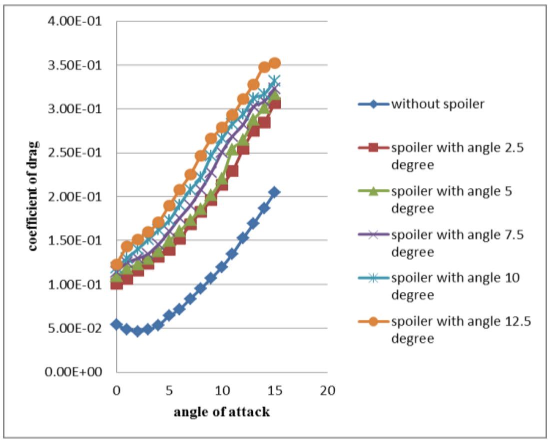


Fig.14: Comparison of the C_D vs. α curve for airfoil with spoiler and without spoiler

From the figure above we have for the airfoil having spoiler with different angles have a drag curve trending higher than that of the airfoil without any spoiler. Thus the effects of the spoiler for all angles are demonstrated through the figure. Increased drag coefficient is the indication of increase in drag force, thus the speed of the aircraft is decreased. Before landing on the desired destination speed of the aircraft must be slowed down for Safe landing. A spoiler acts as an arrangement which decreases lift by the cost of increase in drag force. From the above graph it is shown that the wing section or airfoil having spoiler attached at different angles increases drag coefficient thus the drag force than that of the airfoil having no spoiler. It is one of the principle characteristics of spoiler [12]. So the results obtained from numerical simulation are supporting the basic concepts of the spoiler.

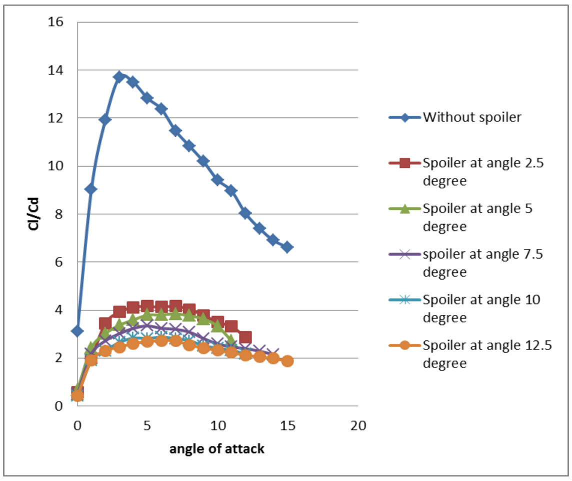


Fig.15: Comparison of the C_L /C_D vs. α curve for airfoil with spoiler and without spoiler

From the figure above we have for the airfoil having spoiler at different angles has a C_L/C_D curve trending lower than the airfoil without any spoiler. Thus the effects of the spoiler for all angles are demonstrated through the figure.

5. Conclusion

This problem is solved by a commercial software FLUENT. Spoiler is placed at 5 percent of chord and spoiler length is 10 percent of chord. Spoiler angles 2.5, 5, 7.5, 10, 12.5 degree are held in design.

This investigation led to a conclusion that lift is decreased and drag is increased which shows the common nature of spoiler. A spoiler, sometimes called a lift dumper is a device intended to reduce lift in an aircraft. Spoilers increase drag and reduce lift on the wing. From the results discussed above it can be concluded that the numerical experiment of the NACA 2415 airfoil having spoiler on five different angles have been identical to the main function of the spoiler.

6. NOMENCLATURE

Symbol	Meaning	Unit
C	chord length	m
V	velocity of air	m/s
L	Lift force	N
D	Drag force	N
C_D	drag coefficient	Dimension less
C_L	lift coefficient	---
α	Angle of attack	^{0}
k	turbulent kinetic energy	J
ε	turbulent dissipation	m^2/s^3
ω	specific dissipation	1/s.
P_b	generation of turbulence kinetic energy due to buoyancy	N
P_k	generation of turbulence kinetic energy due to the mean velocity gradients	N
ρ	density of the fluid	N/m^3
ω_k	angular velocity	rad./s
Ω_{ij}	mean rate of rotation	rad./s^2
μ_t	turbulence viscosity	Kg/s.m

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