

Flow Manipulation Over A Symmetric Airfoil using DBD-Actuators

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering in Aeronautical Engineering

by

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**DEPARTMENT OF AERONAUTICAL ENGINEERING
SCHOOL OF MECHANICAL ENGINEERING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

**Accredited with Grade “A” by NAAC | 12B Status by UGC | Approved by AICTE
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119**

April - 2021



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DEPARTMENT OF AERONAUTICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of
S. Nikita (37260027) , Pulkit Bhardwaj (37260031) who carried out the project
entitled “Flow Manipulation Over A Symmetric Airfoil Using DBD-Actuators” under my
supervision from December 2020 to April 2021.

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DECLARATION

I, S.Nikita (37260027) hereby declare that the Project Report entitled “Flow Manipulation Over A Symmetric Airfoil Using DBD-Actuators” done by me under the guidance of Mr.Gokulnath, is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering in Aeronautical Engineering.

DATE:14/04/21

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SIGNATURE OF THE CANDIDATE

ACKNOWLEDGEMENT

I am pleased to acknowledge my sincere thanks to the Board of Management of SATHYABAMA for their kind encouragement in doing this project and for completing it successfully. I am grateful to them.

I convey my thanks to Dr.S. Prakash, M.E., Ph.D., Dean, School of Mechanical Engineering and Dr.Boomadevi , M.E., Ph.D., Head of the Department, Dept. of Aeronautical Engineering for providing me necessary support and details at the right time during the progressive reviews.

I would like to express my sincere and deep sense of gratitude to my Project Guide Mr.GOKULNATH, M.E., (Ph.D.) for his valuable guidance, suggestions, and constant encouragement that paved way for the successful completion of my project work.

I wish to express my thanks to all Teaching and Non-teaching staff members of the Department of Aeronautical Engineering who were helpful in many ways for the completion of the project.

ABSTRACT

Plasma actuators are a type of actuator which are currently being developed for aerodynamic flow control and various other purposes in the aeronautical industry. These actuators work on the basis of low temperature plasma formed between two electrodes arranged in an asymmetric manner by the application of AC-high voltage across the electrodes. Hence the air particle(s) and molecule(s) around the electrodes get ionized. These ionized air particle(s) are accelerated through the electric field.

Single-dielectric-barrier-discharge (SDBD) actuators have been studied and examined for almost a decade now. SDBD's in particular possesses mechanisms and properties for use in air at atmospheric pressure. These actuators produce a body-force vector field when used, this force interacts with the external flow which can be used for active flow control. These actuators and their effect can be readily introduced into flow solvers to determine their placement and performance can be configured. They have a scope of application in external and internal flow. However it was considered they are only valuable at low speeds. After a few years of research and examinations it was seen plasma actuators are also useful in and have various applications in high subsonic, transonic, and supersonic Mach numbers. Plasma can be used to manipulate the flow over the airfoil for which can alter the aerodynamic characteristics. This actuation by plasma can encourage the flow over the airfoil by making it laminar. This aid may increase the stall angle for the airfoil by increasing the lift coefficient at high angle of attack. Basically the body-force generated by plasma is transferred to external flow air particles by collision(s), which in turn increases the velocity of the flow keeping the boundary layer intact to the airfoil.

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LIST OF SYMBOLS AND ABBREVIATIONS

DBD	Dielectric Barrier Discharge
EHD	Electrohydrodynamic
kV	kiloVolts
λ_d	Debye Length
AC	Alternating Current
mSec	milliSecond
SDBD	Single Dielectric Barrier Discharge
c	chord length of airfoil
x/c	length to chord ratio of airfoil
NACA	National Advisory Committee for Aeronautics
m/s	meter per second
kHz	kiloHertz
L/D	Lift to Drag ratio
V	Volts
A	Ampere
mA	milliAmpere
mm	milliMeter
cm	centimeter
kg	Kilogram
kg/m ³	kilogram per meter cube
RPM	Rotation per minute
(°)	degree
C _L	Lift Coefficient
C _D	Drag Coefficient

CHAPTER-1

INTRODUCTION

Typically, engineers have always relied on the laws of physics to obtain a preferable effect for humankind. Even in the area of aerodynamics it is similar. Engineers are ceaselessly searching for a means to control the flow in all possible styles and configurations.

Flow Control is gradually evolving in the field of fluid dynamics. It infers a small change in portion of a configuration serves an ideally large engineering benefit, like drag reduction, lift increase and noise reduction. There are two methods for Flow control :

1) *Passive Flow Control*

2) *Active Flow Control*

When the flow control is achieved without using any auxiliary power and no control-loop it is known as Passive flow control. Examples of passive flow control are : application of zig-zag tapes, dimples on surfaces. Active flow control requires some energy expenditure or some amount of energy input. Furthermore Active flow control can be achieved by two types of devices ,either Predetermined or Reactive Flow Control devices. Predetermined Flow Control consists of the usefulness of either steady or unsteady energy input without considering the state of the flow control. Which implies control-loop is open. While Reactive flow control includes a closed-loop section in which control action keeps changing due to the flow variables. Feedforward and Feedback control are two types of reactive flow control. The calculated and monitored variables are different in Feedforward control. In feedback management, a controlled variable is calculated and compared to a reference value, resulting in the control unit being adjusted. The description of flow control systems is seen in Figure 1.1. In the last few years, Active flow control has gained popularity among the flow control techniques. Dielectric-Barrier Discharge (DBD) plasma actuator is the most favourable device used for active flow control . Here on it is named as plasma actuator . The plasma actuator

has some intriguing properties like : Low weight, low energy consumption, no moving parts, and a wide range of applications. It is a Predetermined or a Reactive flow control device. The plasma actuator belongs to the category of flow control methods that use momentum injection in the near-wall field.

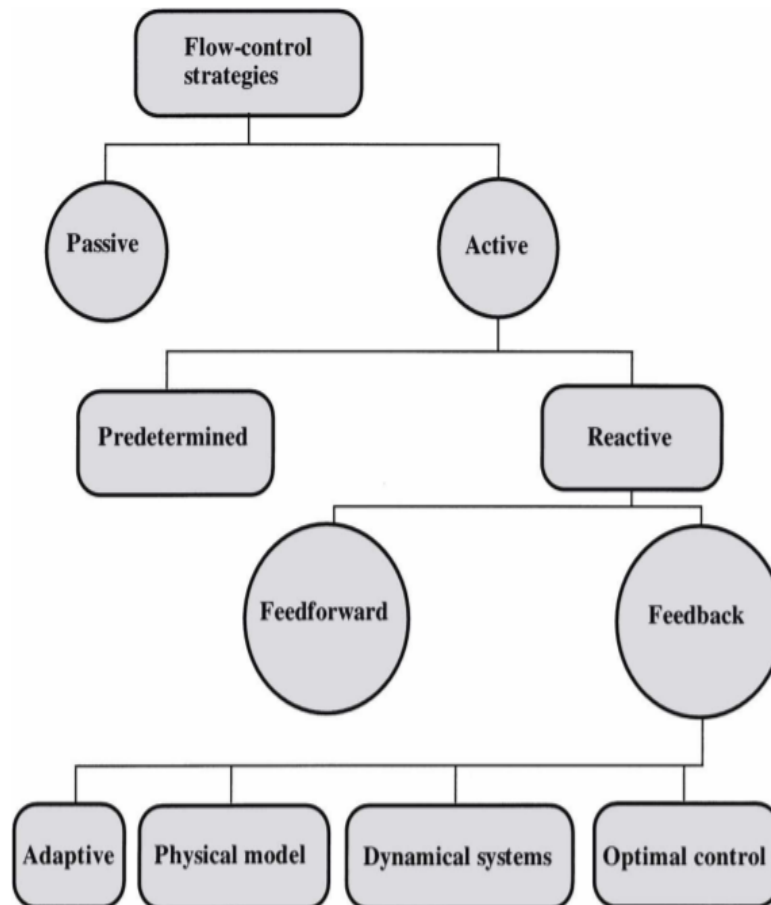


Fig 1.1 Flow Chart for Flow Control.

To control a free airflow, three major areas of flow control can be investigated :

- 1) The point where flow separation takes place*
- 2) Flow transition from laminar to turbulent*
- 3) Turbulence*

1.1) ELECTROHYDRODYNAMICS :

Electro-hydro-dynamics (EHD) is also identified as Electro-fluid-dynamics (EFD) or electrokinetics, is the analysis of the movements of ionised particles or molecules, as well as their encounters with electric fields and the surrounding fluid. The discharge which is created on the exposed electrode in the plasma actuator have many application in the field of aerodynamics. The force generated by the ionized particles is called as EHD force which accelerates the external air particles by transferring the momentum. The force acting on fluid is given by the formula:

$$F=Id/k$$

Here , F: resulting force ,measured in newtons.

I : current ,measured in amperes

d : distance between electrodes

k : ion mobility coefficient of the dielectric fluid

1.2) DESIGN AND SCIENCE OF DBD PLASMA ACTUATOR :

1.2.1) INTRODUCTION TO PLASMA :

Plasma is one of the four fundamental states of matter, it was described by chemist Irving Langmuir in the 1920s. Plasma is basically made of gas of ionized particles and free electrons. Peculiar definition of plasma as stated in the Literature is given below :

A plasma is a quasi-neutral gas of charged and neutral particles which exhibits collective behavior.

Heating a neutral gas or exposing it to a strong electromagnetic field to the point where an ionised gaseous substance becomes increasingly electrically conductive can be used to create plasma. The ionized particle can be either electrons , positive ions or negative ions. The phrase quasi-neutral mentioned in the

definition tells us that the plasma has the property of being electrically neutral which implies that intensity of ions and electrons remain the same. It also poses a continuum behaviour. Another property of plasma is that it can either be hot or *cold*. In hot plasma nearly all the particles are ionized. On the other hand in cold plasma a part of gas is ionized. Usually cold plasma is used for industrial applications.

1.2.2) PLASMA ACTUATOR CONSTRUCTION :

There are hundreds of various plasma actuator models in the mentioned literature and references. The most fundamental, standard and broadly used configuration is the asymmetric SDBD's (Single Dielectric-Barrier-Discharge) plasma actuator. A typical SDBD contains two electrodes separated by dielectric material. The electrodes are made of conducting material like copper, aluminium etc. One of the two electrodes is enclosed under the dielectric material and the second electrode is exposed in air, this electrode is known as *Active Electrode*. These electrodes have an asymmetric orientation for continuous generation of plasma. There are different ways of giving asymmetry to the electrodes. At last these electrodes are connected to a High Voltage AC power supply. A schematic of a single DBD is shown in Fig 1.2.

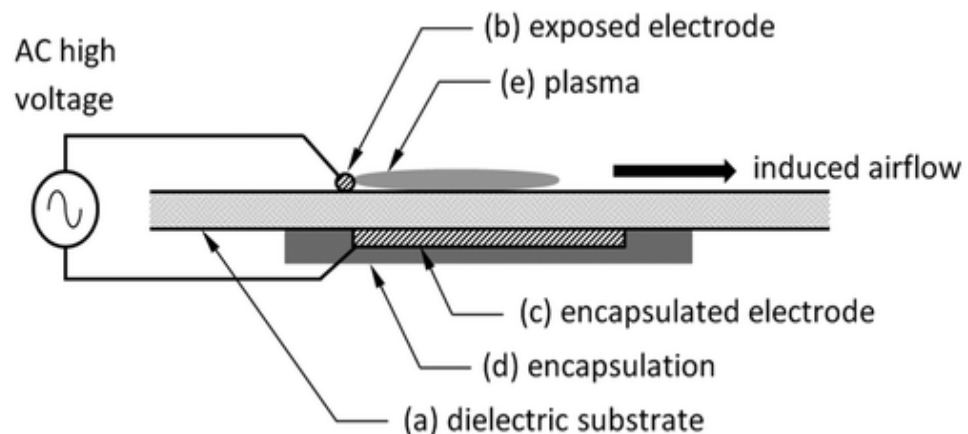


Fig 1.2 : Schematic of plasma actuator

A voltage range of 5kv-20kv is required , this high voltage is applied to the electrodes which in turn generate plasma.The plasma generated is cold plasma and can be observed over the covered electrode.This plasma passes the momentum to the oncoming airflow. This feature can be used for flow control application ,example : separation control.

1.2.3) Debye Shielding :

A brief analogy will be the easiest way to illustrate this idea. Assume we have a volume of plasma (a combination of ions and electrons) into which we position two electrodes.One electrode will be charged positively, and the other will be charged negatively. Species with the opposite charge would be attracted to the electrodes.As a result, a cloud of electrons and a cloud of positive ions will form around the positive electrode and the negative electrode, respectively. We'll presume that the voltage source is powerful enough to maintain potential on both electrodes through the clouds of opposite charge that surround them. At a certain distance 'l' measured from the electrode some certain particle which is at the edge of the cloud will be able to elude the attractive force from the electrode due to the counterbalance surrounding the cloud.This length is called as Debye Length represented by λ_d .

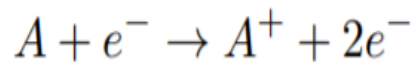
According to literature Debye Length is given by :

$$\lambda_d = \left(\frac{\epsilon_0 k T_e}{n_0 e^2} + \frac{\epsilon_0 k T_i}{n_0 e^2} \right)^{1/2}$$

in which n_0 is the background plasma density, k the Boltzmann constant, ϵ_0 is the permittivity of free space and T_i and T_e are respectively the temperature of the ion and electron species.

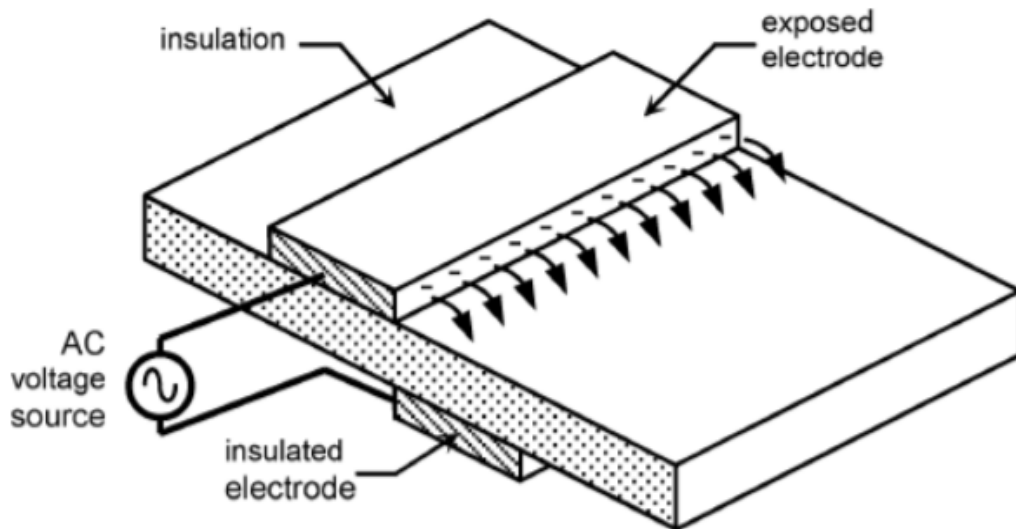
1.2.4) FUNCTIONING OF THE ACTUATOR :

In a single DBD actuator AC high voltage power supply is used and it consists of two cycles. When the first half cycle takes place the uncovered electrode acts like anode while the covered electrode acts as cathode. Ionization takes place which extracts electrons from neutral particles in the region between the two electrodes. Gas is ionized as the collision takes place between neutral particles and electrons which are accelerated towards the anode under the action of electric field.

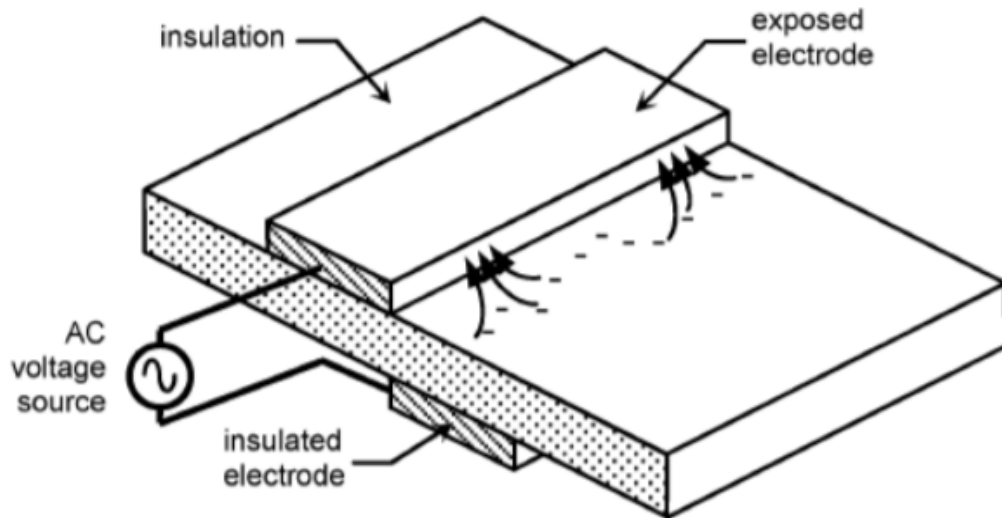


Here A is a neutral particle and A⁺ is a positive ion. Clearly it can be observed that one electron collision with neutral particles provides an ion and two electrons. Furthermore these two electrons will collide with other two neutral particles to generate two charged particles and four electrons and this process will keep going on like a chain reaction. As a result of the continued multiplication of electrons as they drift from the cathode to the anode, this creates discharge current. Momentum is pumped into the flow. Since electrons have low mass compared to the mass of ions their contribution to momentum transfer is less. During the first half-cycle, electrons drift from the uncovered electrode (cathode) to buried electrode and congregate on the dielectric surface. In the consequent half-cycle the accumulated electrodes return to the covered electrode (now anode). The plasma generates pulsed velocity which is equal to the frequency of AC voltage.

Plasma actuator poses a self limiting effect , which helps to nullify the creation of an undesirable arc-discharge. This arc-discharge is capable of making the plasma actuator unstable.



a)



b)

Fig 1.3 : Schematic drawing of the charge build-up on the dielectric material surface a) buried electrode acting like anode b) exposed acting like anode

1.2.5)TIME SCALES :

In the process of a SDBD there are three time scales related to it. The origin of micro-discharges through the plasma actuator gap, which leads to charge redistribution, is the first and fastest time scale. This happens in a matter of nanoseconds. The function of the dielectric barrier discharge itself is the subject of a second time scale. The length of a single loop of alternating current discharge describes it. This time scale is on the order of 0.1 msec, and it is mostly used in the actuator body force simulation. The flow of the neutral fluid in response to the plasma actuator is controlled by a third time scale. The time scale used here is on the order of 10 milliseconds.

CHAPTER-2

LITERATURE SURVEY

Dmitriy M. Orlov Et al. - For flow control practices aerodynamic plasma actuators have shown great assurance in various applications. In previous published journals the lumped-circuit model accurately explains the behaviour of aerodynamic plasma actuators. In this study of the same the model is updated to provide the spatial distribution of the discharge inside the plasma so that it can be incorporated into the Navier-Stokes solver. To reflect the characteristics of a single dielectric barrier discharge the plasma actuator was modeled as a grid of N subcircuit ,each representing a finite domain of the whole electric circuit. These subcircuits included air capacitor, dielectric capacitor, plasma resistive element, and diodes. The simulation results were related to the experimental data collected with the help photomultiplier tube. The comparison between the simulation data and experimental data obtained was similar.

Thomas C. Corke Et al. - The paper focused on the design and physics of the plasma actuators and its effect on the flow over the airfoil. The NACA 0009 model was selected as an airfoil model and the plasma actuator was located at $x/c=0.72$. The flow was studied with actuator on and off condition. The voltage applied ranged from 3-5kv having a frequency of 1-3kHz. Two freestream velocities 15.2 and 30.4 m/s were used. The tests were conducted in a subsonic wind tunnel. The results show a small increment in lift coefficient. Similarly there was an increment in drag too , the drag increment was not linear.

Voikov Vladimir Et al. - Weakly ionized plasma actuators and its application over airfoil was simulated numerically. The flow fields near the NACA 0015 airfoil with plasma actuators mounted on the suction surface in two separate arrangements: one at the leading edge and the other at the trailing edge, were measured using the NASA Langley CFL3D unsteady thin layer Navier-Stokes solver. Navier-Stokes-Equation was used to show the body force produced by the plasma. The solution to the resulting electrostatic

problem yielded the body force. Previous work on separation control is considered for analysing the effectiveness and the results were used for the separation control over the airfoil. At Reynold Number=217000 and Mach Number=0.1 computation was done and the observations were compared with existing experimental data for validation.

C. L. Enloe Et al. - A single DBD was manufactured and its mechanism ,responses and geometric effect were observed. The first thing taken into consideration is electrode geometry and its effectiveness. By the experiment it was observed that plasma expansion is limited upto an extent ,which implies plasma can only stretch upto few millimeters downstream. Although the dimensional prospects of the exposed electrode have a little effect on plasma but it does have a evidentiary effect on momentum transfer . Next, the electric forces on the actuator are examined. Asymmetric orientation of electrodes is used to define the electric potential and electric field. Presence of an electric field implies that there will be force on plasma.

Nicolas Benard Et al. - This research examines the physical aspects of discharge. Parameters like pulse width or the polarity of the high voltage signal were investigated. It was observed that positive and negative discharges generate different plasma. Positive pulse produces plasma which spreads in through dispersed streamer channels. While the negative pulsed discharge gives a round or oval shaped plasma (corona type plasma). Two current peaks are produced by a single voltage pulse. For positive pulse signals, the amount of the steady voltage spike has a significant impact on energy deposition due to the second current peak. The development of a strength filament propagating on the dielectric wall causes a large drop in accumulated energy, which results from a change in charge distribution.

Martiqua L. Et al. - This study involves the separation control over airfoil at high angle of attack. Aerodynamic parameters at high angle of attack were documented. To attach the flow over the airfoil (NACA 663-018) weakly ionized plasma was used. The main focus was on the flow characteristics post stall angle. Freestream velocity used ranges from 10 to 30m/s. Two actuators were manufactured : one was attached at the leading

edge ($x/c=0$) and the other one was attached at the maximum thickness point ($x/c=0.5$). Experimental data shows that there was a significant amount of increment in L/D ratio when plasma was turned on.

Chuan He Et al. - In this documentation two spanwise plasma actuators are attached on an NACA0015 airfoil , one at leading edge and the other one at the trailing edge. The leading edge actuator represents slat and the trailing edge actuator represent flap, respectively. Experiments were conducted at Reynolds number 0.217×10^6 and 0.307×10^6 in a low-speed wind tunnel. There was an increment in both maximum lift coefficient and stall angle. Also there was an increase in L/D ratio by 340%. These actuators can be used instead of flap, slat and also ailerons.

CHAPTER-3

AIM AND SCOPE

3.1) AIM :

This project documents the effects of electrohydrodynamics force generated by a DBD actuator on the airflow over an airfoil. The fundamental concept of this project is to increase the value of lift coefficient by the use of plasma. This DBD actuator has the ability to mimic the effects of flaps. They also have advantages over the conventional flaps used to increase the C_L value, they are discussed further in this project.

3.2) SCOPE :

- 1) To fabricate a single DBD actuator which can be used as a device for active flow control and increase lift.
- 2) To replace the conventional existing plasma actuators with saw-toothed electrodes plasma actuators.
- 3) To introduce a device which has the ability to mimic the property of a flap and can be used in place of the same.

CHAPTER-4

METHODOLOGY AND EXPERIMENTAL SETUP

4.1) METHODOLOGY : The fundamental concept of this project is usage of electrohydrodynamic (EHD) for active flow control. The plasma generated by the DBD actuator will direct the incoming flow. The mentioned experiment is divided in three phases as given below :

- 1) Fabrication of a DBD and an Airfoil.
- 2) Conduction experiments with DBD off.
- 3) Conduction experiments with DBD on.

The data obtained will be tabulated and compared and the observed data will be discussed.

4.2) WORK APPARATUS :

The following data represented below clearly signifies the work materials that were used for the process. The main work material required is a DBD , an airfoil model and high voltage power supply.

4.2.1) HIGH VOLTAGE POWER SUPPLY :

As mentioned earlier in the report, for the generation of plasma a high AC voltage power supply is required. In this project a high voltage of 10 KV is used for the generation of plasma.

Further details of the electric supply are mentioned in the table no. Fig no.4.1 is a picture of power supply.

SPECIFICATION SUMMARY :

Table No 4.1: Power Supply Electric Specification

INPUT SPECIFICATION :	
Input Voltage	230 V
Input current	Less than 5A
OUTPUT SPECIFICATION:	
Output Voltage	10,000 V
Output Current	10mA
Line Regulation	Less than 1%
Load Regulation	Less than 1%

Short-Circuit Protection : The output current would remain fixed at the same value on the occasion of an output short circuit.

Over-current Protection : The output current would remain fixed at the same value on the occasion of an output over-current.

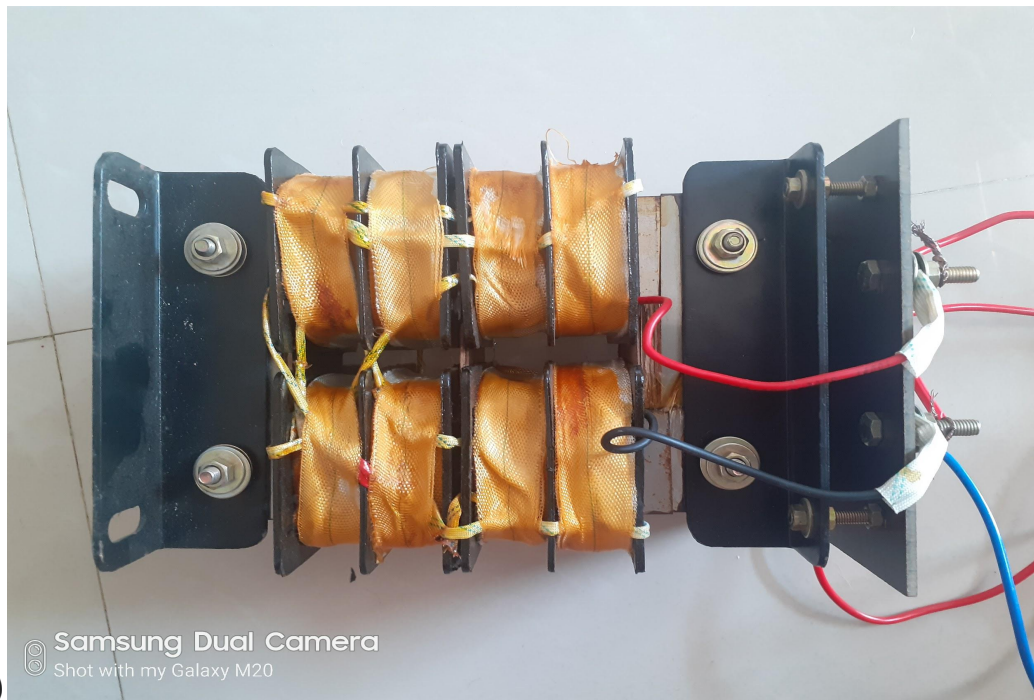
GEOMETRIC SPECIFICATION :

Table No 4.2 : Geometric Specification of Power Supply

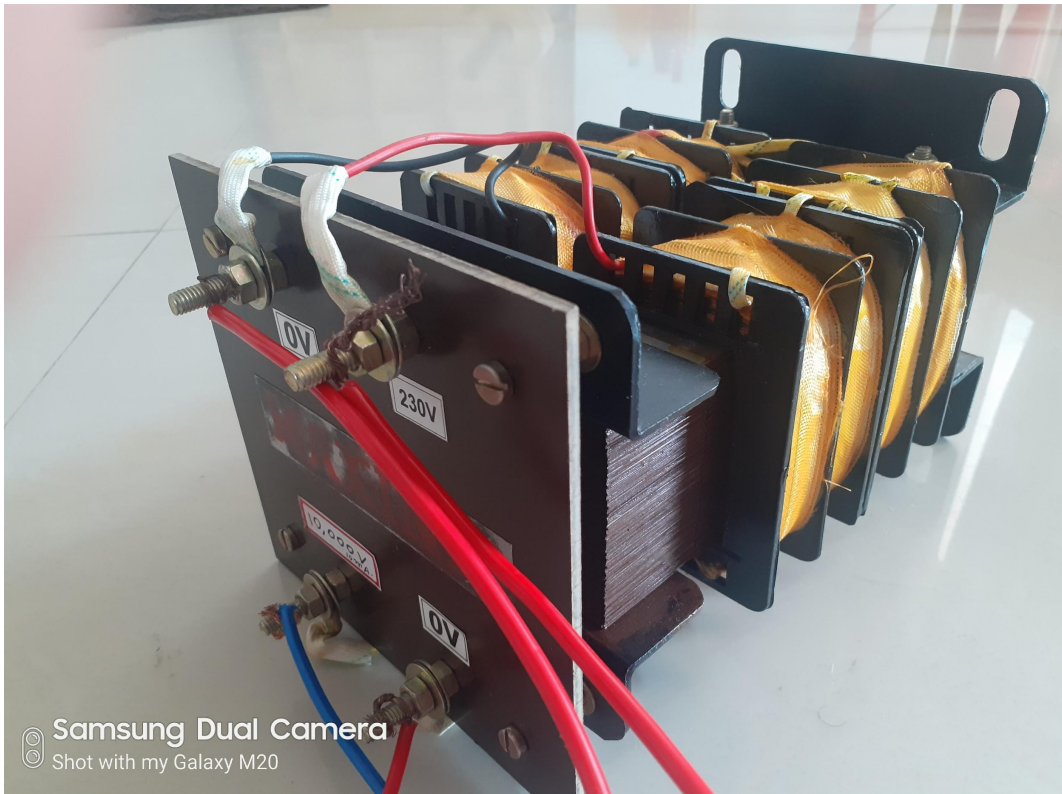
Width	150mm
Height	140mm
Length	230mm
Weight	5kg



(a)



(b)



(c)

Fig 4.1: Power Supply's a) Front View b) Top View c) Full picture

4.2.2) CONSTRUCTION OF A DBD PLASMA ACTUATOR :

As mentioned before in the introduction, the actuator contains the two electrodes separated by a dielectric material, one of the electric will be exposed while the other one will be encapsulated under the dielectric material.

For electrodes copper foil is used. Usually in SDBD's the edge of the exposed electrode is kept straight, this configuration is known as standard plasma actuator. While in this project the edge of the electrodes is given a saw-toothed shape. Though the encapsulated electrode isn't modified. The thickness of copper foil used is 0.98mm. From a sheet of copper foil two long strips of length 230 mm and breadth 20 mm are cropped out. The exposed electrode out of 20 mm of breadth, 10 mm which is half of the value of breadth is given a serrated shape. Additional dimensions of the electrode are explained in Fig no.4.2.



Fig No 4.2 : Dimensions of the exposed electrode

The electrodes are separated by three layers of Kapton tape (shown in Fig No 4.3) which is used as the dielectric material. Each layer has a thickness of 0.5mm, which gives the total thickness of the dielectric is 1.5 mm.



Fig No 4.3: Kapton (Polyamide) Tape



Fig No. 4.4 : Resulting manufactured DBD actuator with serrated electrode.

4.2.3) FABRICATION OF AIRFOIL :

The NACA 0015 airfoil model with span 23 cm and chord length of 20 cm is selected for conducting experiments. A total of 8 pressure holes were made on the airfoil. Five at the leading edge and three at trailing edge. Each pressure hole has a diameter of 3mm. Copper tubes were passed through these pressure holes for proper measurement of pressure. The airfoil model is fabricated with the help of 3D printing. For designing the airfoil model Fusion360 software was used. The designed model is attached below captioned as Fig No 4.5.

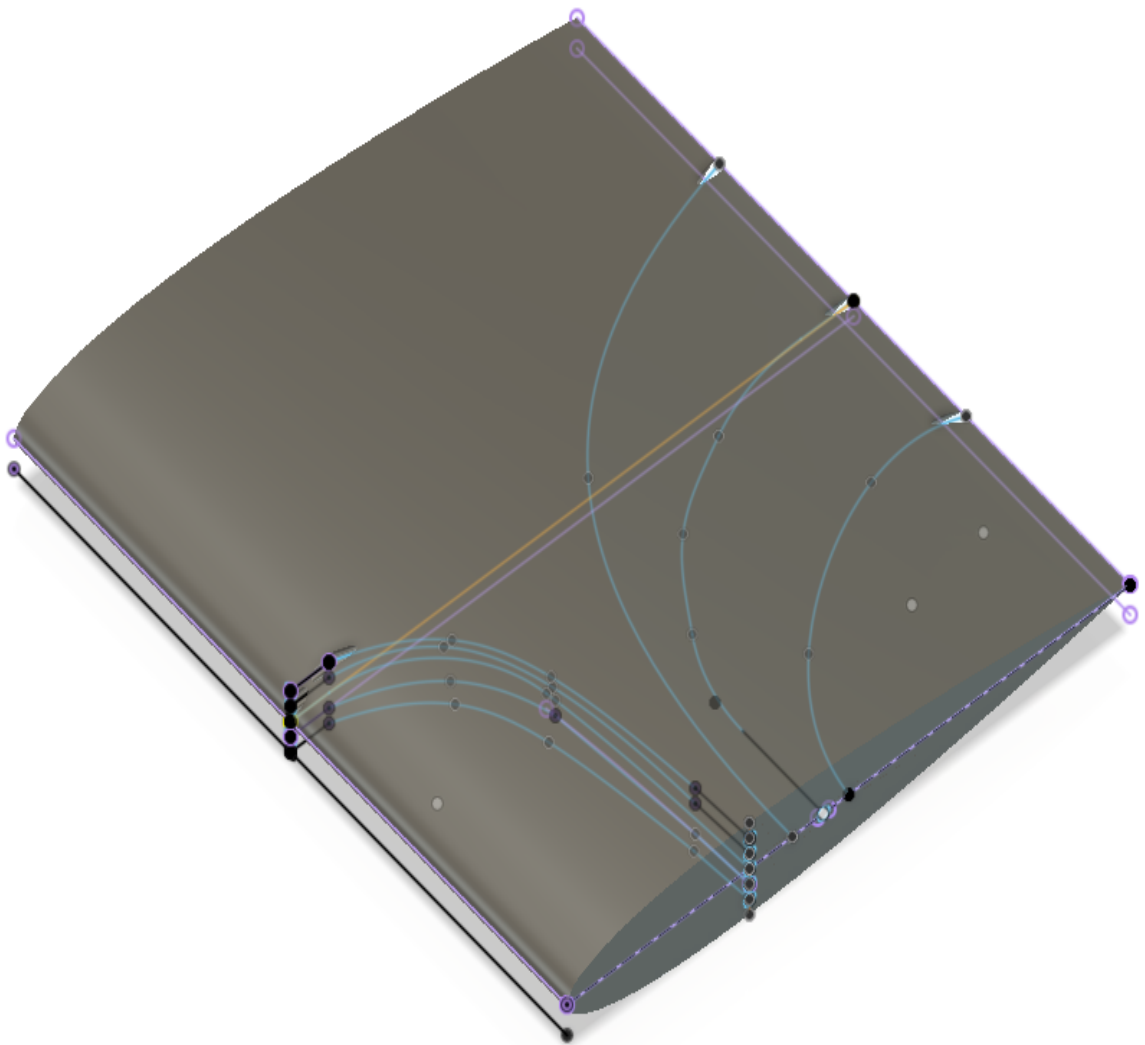


Fig No. 4.5 : NACA 0015 airfoil model designed in Fusion360

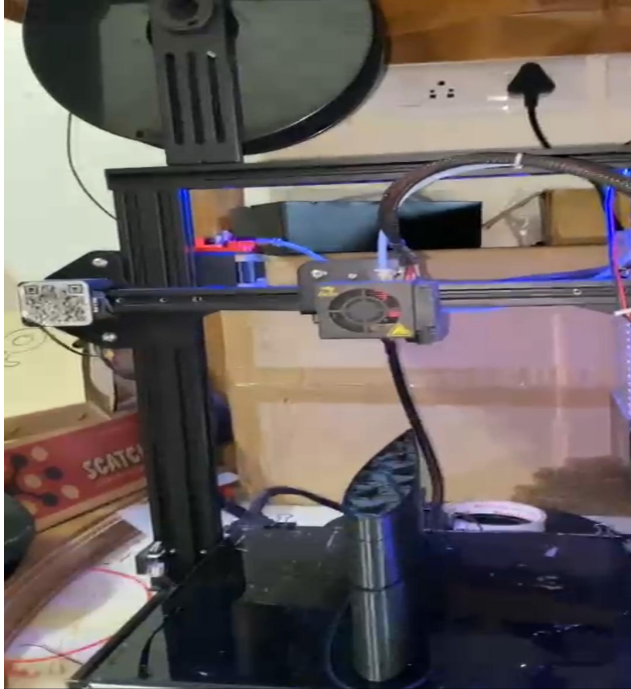


Fig No. 4.6 : 3D Printing of the airfoil



Fig No. 4.7 : Resulting Airfoil Model NACA0015



Fig No. 4.8 : Side View of the Airfoil : 8 Pressure Hole of 3mm diameter



Fig No. 4.9 : Copper tubes of 3mm diameter

4.3) EXPERIMENTAL SETUP :

Experiments were conducted in a subsonic wind tunnel of Sathyabama Institute of Science and Technology. The wind tunnel has a test section of 60x60 cm. Plasma actuator was attached on the airfoil at $x/c=0.5$. The exposed electrode of the actuator was connected to the 10 KV port, while the buried electrode was connected to the 0 V port on the high voltage power supply. The wire passed through a Poly-vinyl chloride tube of 1 inch diameter. The airfoil was placed in the test section with the help of the same tube. An input power supply was provided to the power supply for experimentation. Wind tunnel test condition are tabulated below :

Table No. 4.3 : Experimental Wind Tunnel Condition

Velocity	5 m/s
Reynolds Number	70,388
Density	1.2256 kg/m ³
RPM set in wind tunnel	70

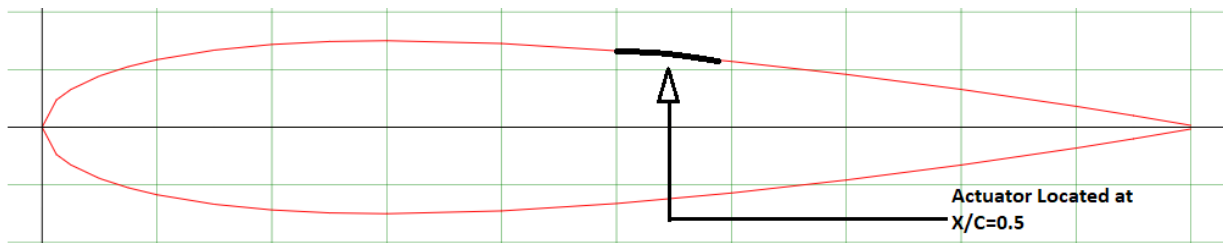


Fig No. 4.10 : Actuator location on the airfoil

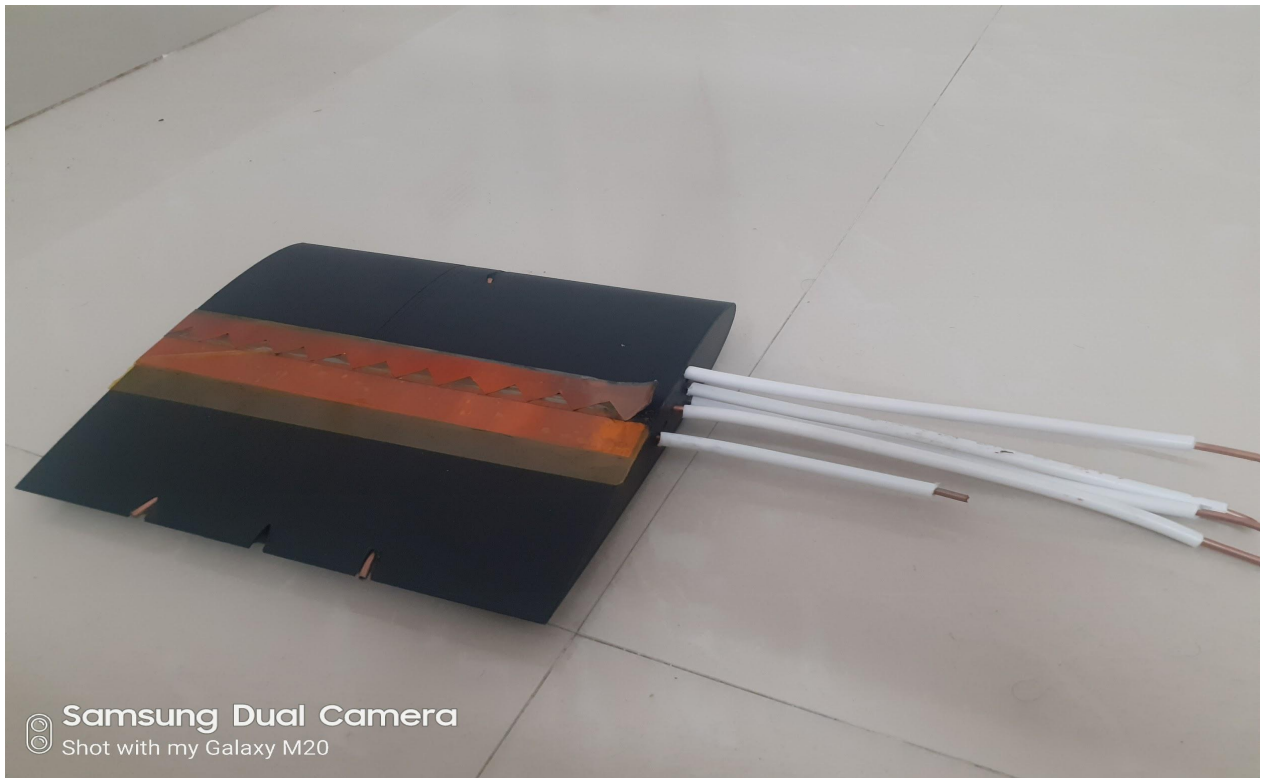


Fig No. 4.11 : Airfoil loaded with actuator and copper tubes.



Fig No. 4.12 : Wind Tunnel

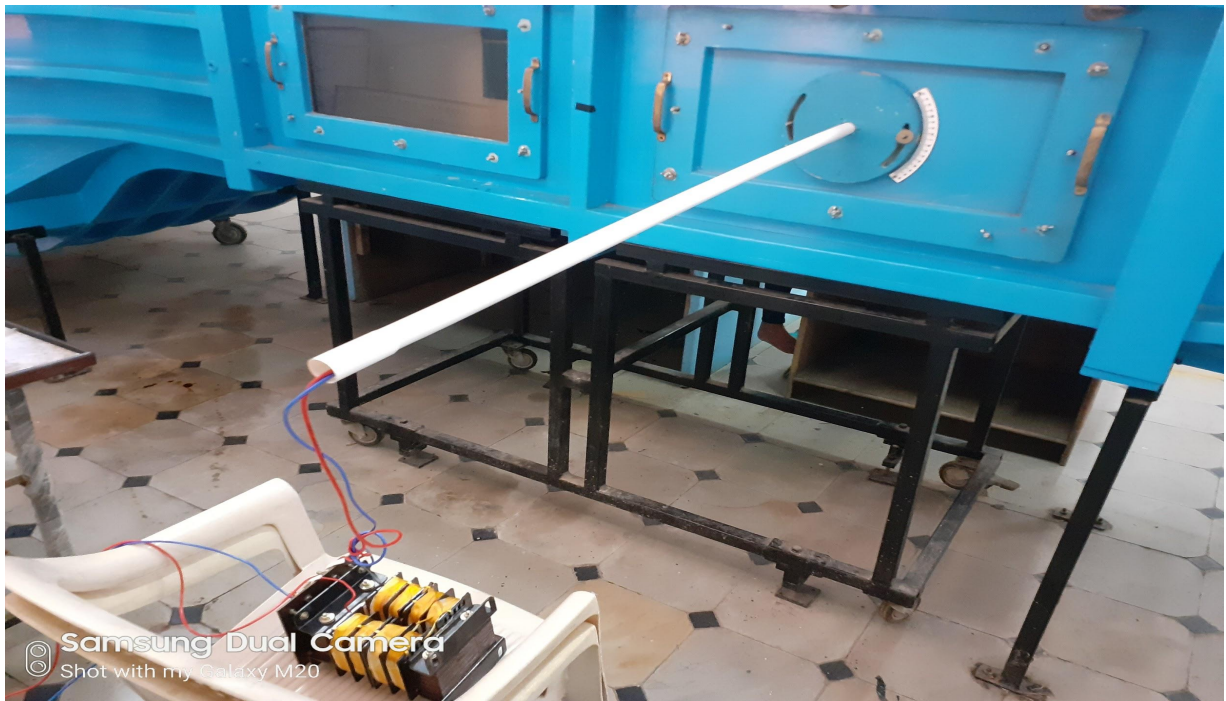


Fig No. 4.13 : Power supply connected with the airfoil

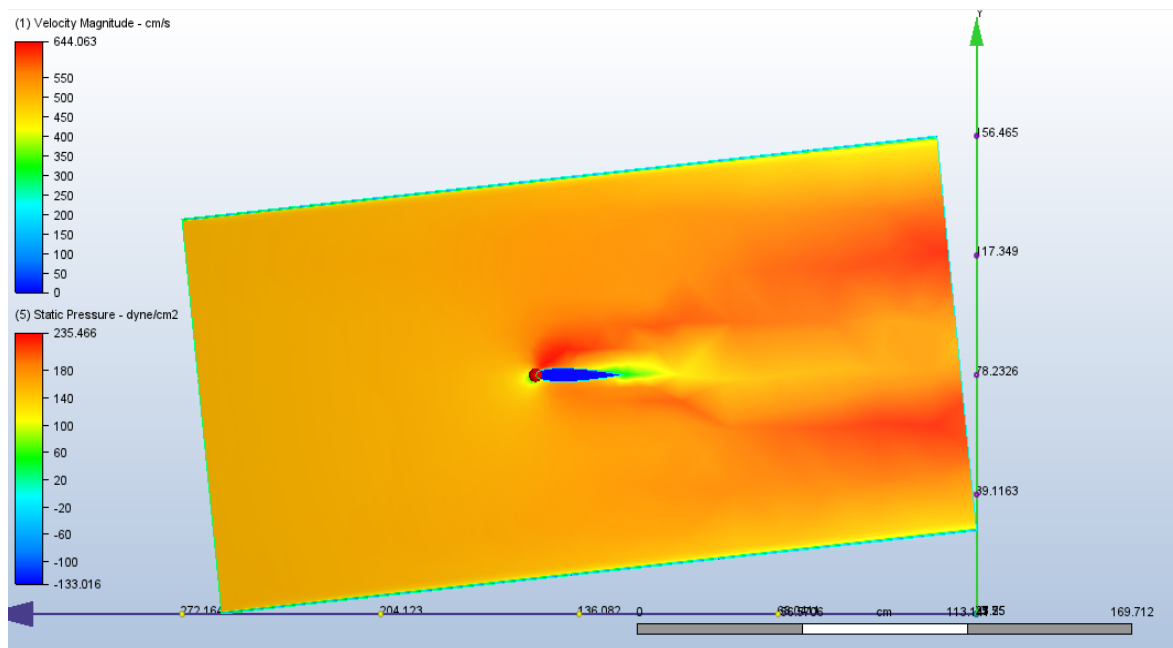


Fig No. 4.14 : Airfoil installed in test section

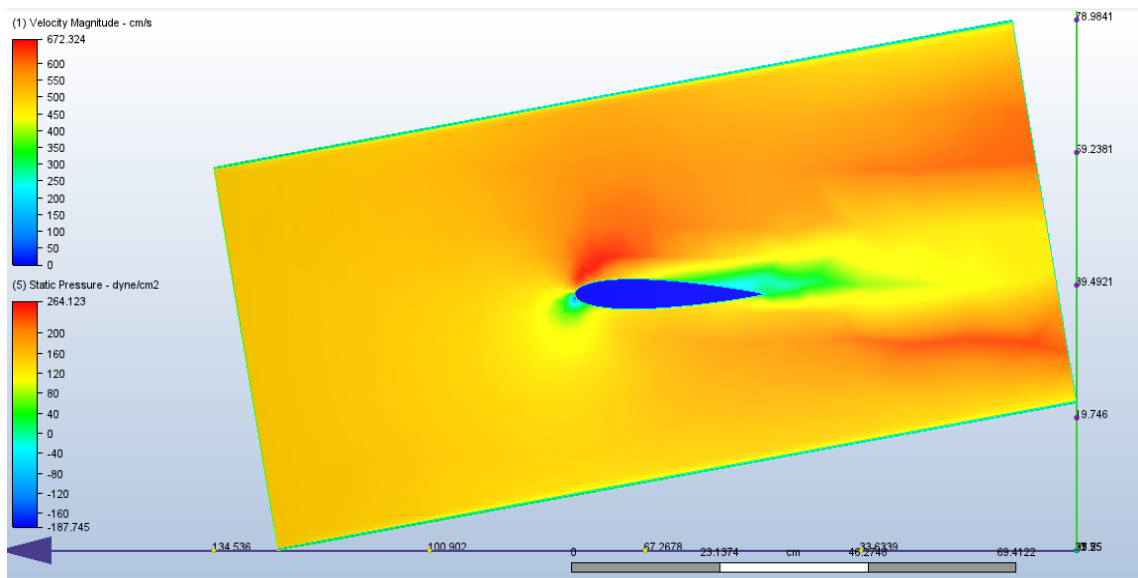
4.4) CFD ANALYSIS :

In this project CFD analysis was done over NACA 0015 at $9^\circ, 12^\circ$ and 15° at 5 m/s velocity. Results are attached below.

a)



b)



c)

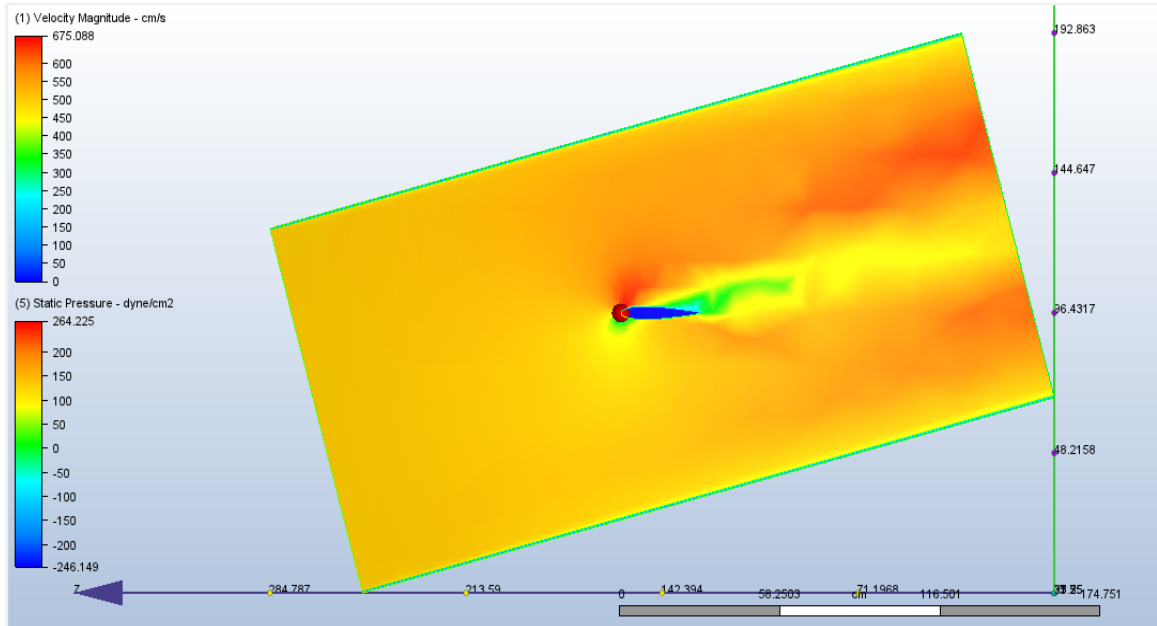


Fig No. 4.15 :CFD analysis of NACA0015 airfoil at : a) 9° b) 12° c)15° angle of attack.

CHAPTER-5

RESULT AND DISCUSSION

5.1) RESULT : Lift and drag coefficient of NACA 0015 airfoil at different attack angles between 0° and 18° were measured at both plasma actuator on and off condition. The data obtained was tabulated and compared.

Aerodynamic Parameters Values at Actuator OFF condition :

Table No. 5.1 : Lift Coefficient Value at different angle of attack with actuator OFF.

Angle of Attack (in degree)	Coefficient of Lift - C_L
0	0
3	0.143
6	0.320
9	0.429
12	0.564
15	0.698
18	0.640

Table No. 5.2 : Drag Coefficient Value at different angle of attack with actuator OFF.

Angle of Attack (in degree)	Drag Coefficient - C_D
0	0.0371
3	0.0389
6	0.0478
9	0.0622

12	0.0995
15	0.124
18	0.223

Aerodynamic Parameters Values at Actuator ON condition :

Table No. 5.3 : Lift Coefficient Value at different angle of attack with actuator ON.

Angle of Attack (in degree)	Coefficient of Lift - C_L
0	0
3	0.1716
6	0.3904
9	0.5148
12	0.6768
15	0.8376
18	0.768

Table No. 5.4 : Drag Coefficient Value at different angle of attack with actuator ON.

Angle of Attack (in degree)	Drag Coefficient - C_D
0	0.0178
3	0.0195
6	0.0243

9	0.055
12	0.0898
15	0.110
18	0.186

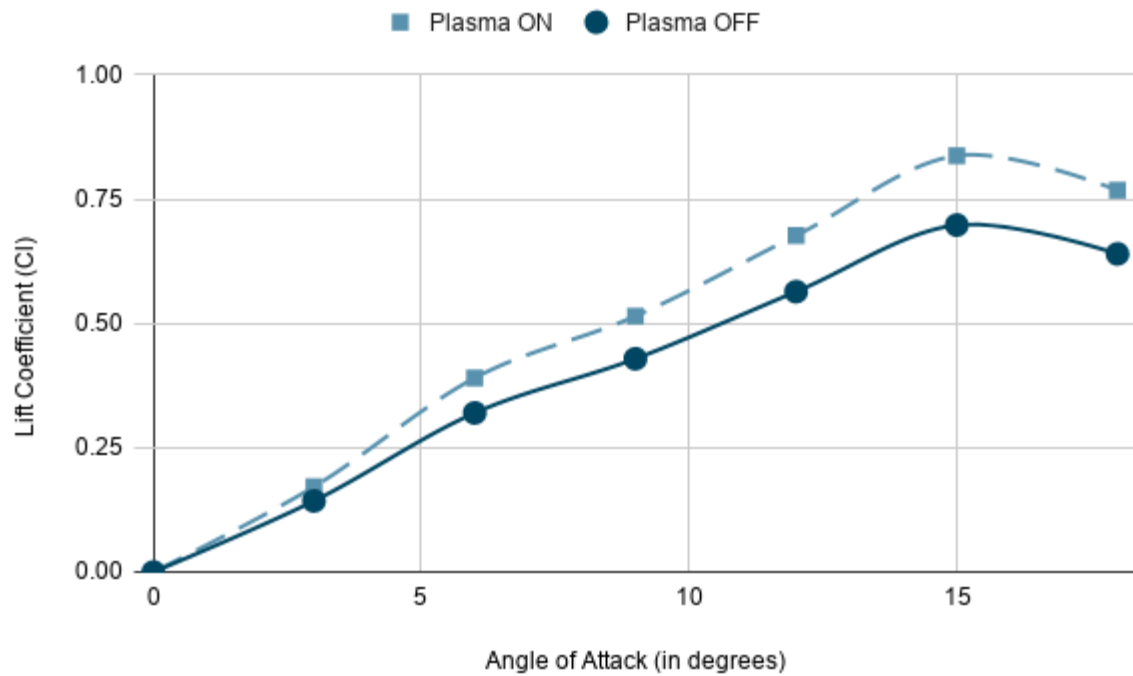


Fig No. 5.1 : Comparison Graph of C_L values when plasma was functional and not functional

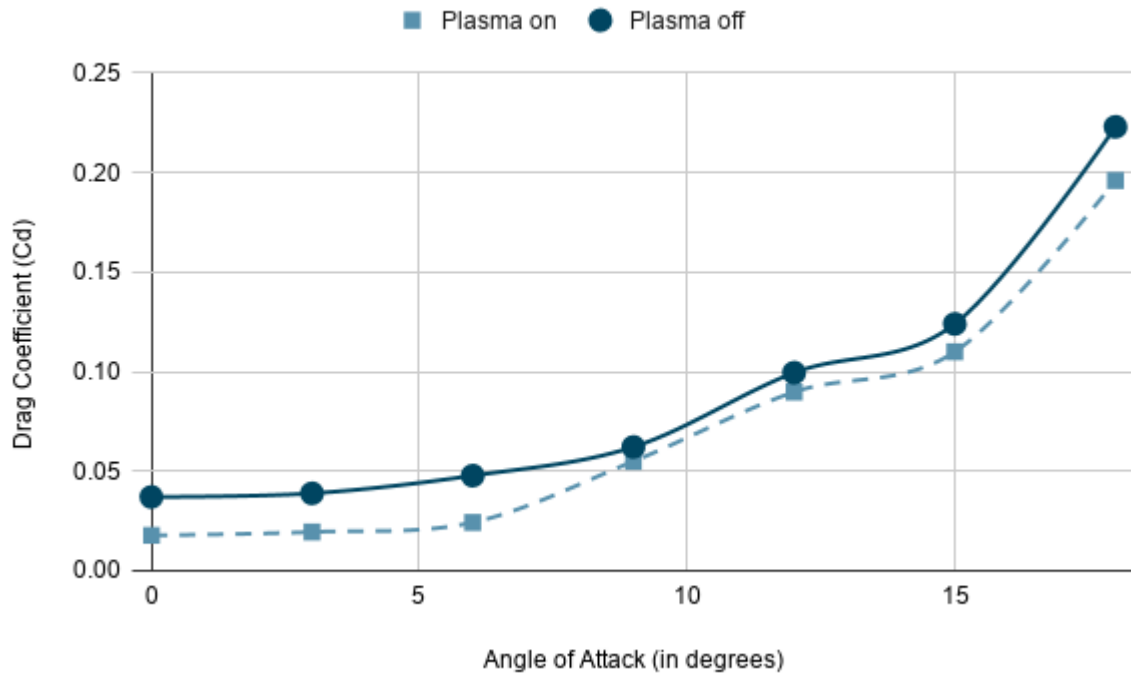


Fig No. 5.2 : Comparison Graph of C_d values when plasma was functional and not functional.

5.2) DISCUSSION :

Clearly from the experimental data it is visible that the value of lift coefficient increases when plasma comes into effect. On an average there is an increment of 20% in the lift coefficient value. The maximum increment was attained when the angle of attack was in between 10 to 15 degrees. To be precise the maximum increase took place at nearly 15 degree, which is also near to stall angle. The stall angle is also slightly increased by 3 degrees.

For Drag coefficient when the plasma was functioning the decrement was more when the angle of attack was at lower value, 0 to 6 degrees. After 8 degrees the drag coefficient increased but after a few degrees there was slight decrement in the value.

CHAPTER-6

CONCLUSION

The main objective of this project was to increase the lift coefficient value over airfoil NACA 0015 at higher angle of attack by plasma. DBD plasma actuators were used for the purpose of generating plasma. To generate more plasma the exposed electrode was given a saw-toothed shape which increases the area for plasma generation. From the CFD simulation it was concluded that the separation started at the midsection of the airfoil, which will increase the value of drag and inturn decrease the value of lift. That is why the actuator was attached at $x/c=0.5$. From the data it can be distinctly concluded that the actuator was effective in increasing the lift coefficient when the angle of attack was in between 10 to 15 degrees and the maximum decrement in drag occurred when the angle of attack was in between 0 to 6 degrees.

The result implies that further research and studies on DBD actuators may replace the flaps as they mimic its function. Also electric actuators have advantages over conventional flaps as they dont have mechanical linkage , and have a short-response time. The same DBD can also pose the application of slats and ailerons as they can be used to control flow if used the right way.

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