

EXPERIMENTAL AND NUMERICAL AERODYNAMIC ANALYSIS OF AIRCRAFT WING WITH TIP MOUNTED ENGINE

Submitted in partial fulfilment of the requirements for the award of

Bachelor of Engineering degree in
Aeronautical Engineering

By

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(DEEMED TO BE UNIVERSITY)

Accredited with grade “A” by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **PATTEM PURNA SEKHAR(Reg No. 38260031) AND KELLI KARTHIKEYAN(Reg. No. 38260019)** who carried out the project entitled "**EXPERIMENTAL AND NUMERICAL AERODYNAMIC ANALYSIS OF AIRCRAFT WING WITH TIP MOUNTED ENGINE**" under our supervision from September 2021 to April 2022

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ABSTRACT

The goal of this study is to figure out how propeller installed locations affect wing aerodynamics. The propeller is situated on the tip of the wing and in the middle of the wing. Particularly, how a tip-mounted propeller can reduce wing induced drag and how distributed propulsion might improve high-lift aerodynamics are examined. Analyses will be conducted using a Virtual Disk Model on CFD software, with good agreement between numerical and experimental results acquired using a wind tunnel. For studies, a scaled model of a wing tip engine with propeller will be used to achieve cruising performance while lowering induced drag. The use of distributed propeller engines on the wing improves low-speed performance while also boosting the lift coefficient of the aircraft. At a low cruise lift coefficient, induced drag can be reduced by around 2-3 percent, increasing to 8-10 percent at a relatively high cruise lift coefficient. In a clean configuration, the maximum attainable lift coefficient could be raised by 20-30%, while in a flapping design, it could be enhanced by more than 50%. The wing tip propeller and dispersed aerodynamic effect on the wing will be investigated, with the goal of reducing induced drag (from 2% to 10% in a range of lift coefficient 0.4 to 1.0) while enhancing high lift capabilities by roughly 20% (flap up) and 60-80% (flap down) (flap down). To maximise drag reduction, the tip propeller diameter must be suitably dimensioned according to nacelle size and thrust settings. Distributed wing aerodynamics can improve wing design and aircraft performance by ensuring a better lift coefficient. Fusion 360, Solid works programming is utilized to build up the models of aircraft wing with mounted engine. Keywords: Aircraft propeller effects for wing aerodynamic, tip propeller effects, distributed wing aerodynamic, Trailing vortices, Lift-induced drag, Aero elasticity, Turbulence flow modelling.

TABLE OF CONTENTS

CHAPTER No.	TITLE	PAGE No.
	ABSTRACT	iv
	LIST OF FIGURES	ix -xii
	LIST OF TABLES	xiii
	LIST OF ABBREVIATIONS	xiv-xv
1	INTRODUCTION	1
1.1	BACKGROUND	2
1.1.1	Engine	2
1.1.1.1	Electrical engines	2
1.1.1.2	Physical engines	2
1.1.1.3	Internal combustion engines	3
1.1.1.4	External combustion engines	3
1.1.2	Engine position on aircraft	3
1.1.2.1	Types of engine positions	3
1.1.3	Airfoils	3
1.1.4	Drag	4
1.1.5	Induced drag	5
1.1.6	Parasite drag	5

1.1.7	Lift of co-efficient	5
1.1.8	Polar drag	5
1.1.9	Flutter(vibrations)	5
1.1.10	Aero elasticity	5
1.2	BENEFITS	6
1.3	FUSION 360	6
2	LITERATURE REVIEW	7
2.1	HISTORY OF ENGINE POSITIONS	7
2.2	TYPES OF ENGINE MOUNT LOCATIONS	7
2.1.1	Top of the fuselage	7
2.1.2	Top of the wing	8
2.1.3	Side of the fuselage	9
2.1.4	Mounted on aft of the fuselage	9
2.1.5	Mounted on tail	9
2.1.6	Pylon mounted under the wing	10
2.1.7	In the wing	10
2.3	ELECTRICAL MOTORS	11
2.4	TYPES OF ELECTRIC MOTORS	12
2.4.1	Brushed motor	12

	2.4.2	Brushless motor	13
	2.4.3	Stepper motor	13
2.5		ADVANTAGES CLAIMED	13
	2.5.1	Induced drag phenomena	13
3		AIM AND SCOPE	16
	3.1	SCOPE	17
4		ANALYTICAL ANALYSIS	18
	4.1	FLOW TRAJECTORY	18
	4.2	STREAM LINES AND COUNTOURS	20
	4.3	PRESSURE DISTRIBUTION OVER THE WING	21
	4.4	FORMULA'S TO FIND CL AND CD	23
	4.5	NUMERICAL CALCULATION OF CL AND CD	24
	4.6	AERO ELASTICITY	31
5		FABRICATION	36
	5.1	Parameter's	37
6		EXPERIMENTAL ANALYSIS	38
	6.1	CALIBRATION FORMULA'S	39

6.2	WIND TUNNEL TESTING	39
6.3	EXPERIMENTAL RESULTS	40
6.4	FINDING THE CO-EFFICIENT OF PRESSUE	40
6.5	CALCULATING X/C AND Y/C FOR EACH PORT	41
6.6	FORMULA'S FOR CL,CD and CM	42
6.7	FORMULA'S FOR ECCENTRICITY	43
6.8	FORMULA'S FOR INDUCED DRAG	43
7	RESULTS AND DISCUSSION	47
8	CONCLUSION	49
9	REFERENCES	50
10	FUTURE SCOPE OF THE PROJECT	51

LIST OF FIGURES

FIGURE No	TITLE	PAGE No.
2.1	Top of the fuselage	8
2.2	Top of the wing	8
2.3	Top of the wing	8
2.4	Side of the fuselage	9
2.5	Mounted on aft the fuselage	9
2.6	Mounted on tail	10
2.7	Mounted on tail	10
2.8	Pylon mounted under the wing	10
2.9	In the wing	11
2.10	In the wing	11
2.11	Electric motor	12
2.12	Brushed motor	12
2.13	Brushless motor	13
2.14	Different forms of drag	14
2.15	Distribution of drag component	14
2.16	Flow pattern of the velocity	15
2.17	Vortex sheel from trailing	15

FIGURE No	TITLE	PAGE No.
3.1	Three design's of different engine positions	16
4.1	Design 1 flow trajectory	18
4.2	Design 2 flow trajectory	19
4.3	Design 3 flow trajectory	19
4.4	Design 1 stream lines and contours	20
4.5	Design 2 stream lines and contours	20
4.6	Design 3 stream lines and contours	21
4.7	Design 1 pressure distribution over the wing	21
4.8	Design 2 pressure distribution over the wing	22
4.9	Design 3 pressure distribution over the wing	22
4.10	Cl vs alpha of design 1	24
4.11	Cl vs alpha original	25
4.12	Cd vs alpha of design 1	25
4.13	Cd vs alpha original	26
4.14	Cl vs alpha of design 2	27
4.15	Cl vs alpha original	27
4.16	Cd vs alpha of design 2	28

FIGURE No	TITLE	PAGE No.
4.17	Cd vs alpha original	28
4.18	Cl vs alpha of design 3	29
4.19	Cl vs alpha original	30
4.20	Cd vs alpha of design 3	30
4.21	Cd vs alpha original	31
4.22	Design 1 aero elasticity	31
4.23	Design 1 aero elasticity	32
4.24	Design 2 aero elasticity	32
4.25	Design 2 aero elasticity	33
4.26	Design 2 aero elasticity	33
4.27	Design 3 aero elasticity	34
4.28	Design 3 aero elasticity	34
4.29	Design 3 aero elasticity	35
4.30	Design 3 aero elasticity	35
5.1	Geo tagged picture's of fabrication	36
5.2	Geo tagged picture's of fabrication	36
6.1	Hf vs rpm	38
6.2	Wind tunnel testing	39

FIGURE No	TITLE	PAGE No.
6.3	Wind tunnel testing	39
6.4	Wind tunnel testing	39
6.5	x/c and y/c port locations	41
6.6	Cl vs alpha of experimental analysis	44
6.7	Cd vs alpha of experimental analysis	45
6.8	Cm vs alpha of experimental analysis	45
6.9	E vs alpha of experimental analysis	46
6.10	Cdi vs alpha of experimental analysis	46
7.1	Cl vs alpha of analytical analysis	47
7.2	Cd vs alpha of analytical analysis	47
7.3	Cl vs alpha of experimental analysis	48
7.4	Cd vs alpha of experimental analysis	48

LIST OF TABLES

TABLE No	TITLE	PAGE No.
4.1	Calculation of Cl and Cd of design 1	24
4.2	Calculation of Cl and Cd of design 2	26
4.3	Calculation of Cl and Cd of design 3	29
5.1	Parameters	37
6.1	Calibration	38
6.2	Manometer readings of experimental analysis	40
6.3	Cp calculation values	41
6.4	x/c and y/c values	42
6.5	Cl, Cd, Cm, E & Cdi	44

LIST OF SYMBOLS AND ABBEREVIATIONS

AE	Aircraft energy
ATR	Airplane Transport Region
C_l	Co-efficient of lift
C_d	Co-efficient of drag
C_m	Co-efficient of momentum
E	Eccentricity
C_{di}	Induced drag co-efficient
CATIA	Computer Aided Three Dimensional interactive Application
UAV	Unmanned Aerial Vehicle
OWM	Over the Wing Mounted
CFD	Computational Fluid Dynamics
STOL	Short Take Off And Landing
DC	Direct Current
BLDM	Brush Less Direct Current
ECM	Electronically Commutated Motor
L	Length
ρ	Density

V	Velocity
A	Area
D	Drag
AOA	Angle Of Attack
MAC	Mean Aerodynamic Chord
RPM	Rotation Per Minute
h_i	Initial reading of inclined manometer
h_f	Manometer reading at different RPM
ρ_{eth}	Density of Ethanol
ρ_a	Density of air
ρ_w	Density of water
C_p	Co-efficient of pressure
P_{s1}	Static pressure in different angle of attack
P_s	Static pressure
P_t	Total pressure
C_{Do}	Co-efficient of drag or polar drag
K	Constant
Π	Pie
AR	Aspect Ratio
VBA	V Bird airlines
UDF	User development fee

CHAPTER 1

INTRODUCTION

The main motto of this project is an overview of the aerodynamic effect of tip-mounted engines and the, and flutter. Mainly with respect to electric engines, the advantages of such adoption are application distribution of wing aerodynamics on a commuter aircraft wing. Nowadays the main concentration of airline companies is working for the betterment of capabilities, design (selection of better airfoil or wing, different position/location on the wing) of unfamiliar aircraft configuration. Aircraft performances like a polar drag, aeroelasticity in the respective areas like safety, community noise, operating costs, emission, etc. On the other hand development, research, and eventual production projects, are concentrating on the low power, low range, limited utility platforms related to the flight training market as we are noticing in the X-57 Maxwell, Air Energy AE-1 Silent, Velis Electro, Robinson R44, Siemen SP200D. These are having tremendous growth in the modernization of aircraft. In the modern era, most of the technology is shifting to renewable resources (electrical propulsion, solar-powered) energy due to the shortage of non-renewable resources/less availability of fuels. The first and foremost thing to adopt electrical propulsion is the lack of non-renewable resources in the universe. But, there are some significant barriers like the weight of energy storage cells in electric aircraft. Present energy storage cells have the capability of 60-100x less energy stored per unit mass when compared to the fuels used in the aircraft industry. As it is very difficult to match with performance of normal aircraft with electric aircraft. Because they carry heavy payload and will have more efficiency. It is a tough challenge for all the aviation industries to attain the performance as the normal aircraft. Finally, due to the scale-invariant propulsion efficiency versus power level, electric aircraft will be designed around a specific set of criteria, benefiting from propulsion integration. Considering the current situation in this modernization, there is a huge increase in fuel prices as there is tremendous growth in civil aviation. Noticing this they are showing much more interest in non-renewable resources like electric and solar energy which will reduce the pollution and price. During the EWADE 2011 conference, ATR Senior Vice President of Operations Luigi Lombardi stated that the airline will require 3000 new turboprop aircraft, each with 70 seats. There is a new segment of 90+ seats which is a strong percentage of the total of 39%. In the next two decades, there will be strong demand in future for the aircraft like 90+ seat configuration in the industry which was expressed as optimistic by Bombardier Commercial Aircraft Vice President Marketing, Philippe Poutissou. There is an estimation of new aircraft deliveries 20-149 range of seat market in the coming 20 years and 5800 aircraft will be delivered in the segment of 60-99 seats. In the category of 100-149 seat segment which has the delivery of 6300 aircraft.

1.1 BACKGROUND

1.1.1 Engines

Engines are manufactured in such a way to transform more forms of energy into mechanical energy. Where ever we want to go, using engines we can go. But, all engines are not made of the same methods. Engines are made depending on the region the engines used. The way we can differentiate the engines are the energy that uses power for propulsion. In this scenario, there are different types of engines like

1. Electrical engines
2. Physical engines
3. Internal combustion engines
4. External combustion engines

1.1.1.1 Electrical engines

In electric engines, the electricity is produced by generators or alternators and the engines are manufactured depending on the aircraft used. This type of engines are engine driven and also powered by the APU (Auxiliary power unit) which provide an additional amount of power in any situation like loss of generator engine. These engines provide

1. Less maintenance
2. Reduces the cost
3. More efficiency

The main reason behind the adoption of electrical engines is the present scenario in our society is depletion and wastage of non-renewable resources excessively. The other thing is heavy consumption of fuels causing more deforestation around the world. So, the current industries are mostly concentrating on electrical aviation development

1.1.1.2 Physical engines

Physical engines are nothing but aero engines, jet engines, piston engines, etc. These engines are powered by an aircraft propulsion system that drives the aircraft to the next level that where ever we want to travel. But, they have less efficient when compared to electrical engines. As they are less weight and comprise of batteries.

1.1.1.3 Internal combustion engines

In this system, the fuel is burnt inside the engine. This type of engine has become very common since it has been widely used to power motor cars, airplanes, ships, etc.

1.1.1.4 External combustion engines

In this system, the fuel is burned outside the engine. An example is the railway locomotive, where the fuel (coal) is burnt outside the engine to generate steam which is used to power the locomotive. The figure below shows the working of an external engine. As can be seen, the coal is burnt outside to produce steam that is used to move a piston to produce the required propulsion.

1.1.2 Engine positions on aircraft

Engine position on aircraft plays a major role in all aircraft performances. As the engine also comes under the structure of aircraft. There are so many forces that act on the structure of the aircraft like aerodynamic forces, aeroelasticity, fluttering, polar drag, etc. These forces vary depending on the different positions of the engine.

1.1.2.1 Types of engine positions

Power plants are also called engines which are placed in various positions like

- Top of the fuselage
- Side of the fuselage
- Mounted on the aft fuselage
- Mounted on tail
- Mounted over wing
- Pylon mounted under the wing
- In the wings
- Above the wings

Different types of engine positions have different aerodynamic forces depending upon the types of aircraft and domain they will use. This causes the difference in performance in various aircraft.

1.1.3 Airfoil

Airfoil is nothing but the cross-sectional shape of a wing which creates more lift than drag to create aerodynamic lift. As it is flying in the atmosphere or fluid flow produces aerodynamic force. The shape

of an airfoil is designed in a particular method with invariant geometry. The aerodynamic forces are drag, thrust, lift, weight.

- The drag force act parallel to the thrust which is produced while the aerofoil passes through the fluid flow
- Thrust will act parallel to the drag. It is created opposite to the movement of aircraft which act on the surface of the aircraft.
- Lift acts perpendicular to the aircraft in a free stream velocity. When the lift is acting on an airfoil then simultaneously it leads to an angle of attack.
- Weight is a force that will act opposite to lift which will resist the force.

An airfoil, there are different series like NACA 4 series, 5 series, 6 series, etc.

1.1.4 Drag

Drag is a force that resists the moment of aircraft/acts opposite to the thrust. The drag forces are classified into different types as mentioned below

- Drag
- Induced drag
- Wave drag
- Parasitic drag
- Surface coating and drag reduction
- Friction drag
- Form drag
- Polar drag

In this project, we are mainly concentrating on a few areas which are essential elements in aerodynamics. They are

- Reduce induced drag
- Reduce parasitic drag
- Increase lift co efficient
- Polar drag
- Flutter
- Aero elasticity

1.1.5 Induced drag

Induced drag is produced due to lifting. As, when the aircraft is flying through the atmosphere then the air passes over the surface of the aircraft. As it produces the induced drag.

1.1.6 Parasitic drag

Parasitic drag is nothing but profile drag. It is a type of drag that comes under one of the aerodynamic forces. It acts on any object when they are moving through a fluid flow. Both form drag and profile drag is the combination parasitic drag. Despite everybody, act on the whole part of the body.

1.1.7 Lift co efficient

The lift coefficient (CL) is a dimensionless coefficient that connects the lift created by a lifting body to the fluid density around it, the fluid velocity, and a reference area. A lifting body, such as a fixed-wing airplane is a foil or a whole foil-bearing body.

1.1.8 Polar drag

The relationship between drag and some variables like lift, speed and co-efficient. Drag can be created as actual drag / co efficient of drag.

1.1.9 Flutter(vibration)

Flutter is known as the disturbance that occurs due to the aerodynamic forces, inertial forces, and elastic forces. It can be rectified by controlling the stick in a particular way.

1.1.10 Aero elasticity

The study of the interaction between the aircraft aerodynamic, inertial, and elastic forces. When an elastic body is exposed to a fluid flow, then there is a formation of elastic, inertial, and aerodynamic forces. It is known as aeroelasticity. It is classified into dynamic aeroelasticity and static aeroelasticity which refers to the body being in a vibrational state or moving and the body is in a steady state. Aeroelasticity is a vulnerable effect in the aircraft because the aircraft has to be very lightweight and should resist the aerodynamic effects on the surface of the airfoil. There are some problems due to aeroelasticity. The aerodynamic forces which increase the angle of attack on an airfoil further increase the force that affects the structure of the airfoil are called divergence. Control reversal is known as the pilot controlling the stick during the movement of the controls due to aerodynamic forces. In this type of case, there will be opposite aerodynamic moment will be applied to reduce the reverses which will be the control effectiveness. Fluttering is due to aerodynamic forces acting on the surface of the aircraft which leads to the wear and tear of the aircraft.

1.2 BENEFITS

Since 1973, when the cost of fuel started spiraling upward, carriers and airplane producers have taken a gander at numerous approaches to improve the working effectiveness of their airplanes. Electric aviation has gotten one of the business's most obvious fuel-saving advancements and their utilization keeps on extending. Electric aircraft increment an airplane's working effectiveness by diminishing what is called an electric-driven aircraft. An electric-powered aircraft is molded to provide better efficiency and to bring a new modernization in the coming future. The changing of engine position will lead to observe the different conditions like fluttering, induced drag, parasitic drag, etc. For studies, a scaled model of a wingtip engine with a propeller will be used to achieve cruising performance while lowering induced drag. The use of distributed propeller engines on the wing improves low-speed performance while also boosting the lift coefficient of the aircraft. At a low cruise lift coefficient, induced drag can be reduced by around 2-3 percent, increasing to 8-10 percent at a relatively high cruise lift coefficient. In a clean configuration, the maximum attainable lift coefficient could be raised by 20-30%, while in a flapping design, it could be enhanced by more than 50%. Wingtip propeller and distributed aerodynamic effect on the wing will be analyzed, showing the possibility to reduce the induced drag (from 2% to 10% in a range of lift coefficient $0.4 < CL < 1.0$), enhancing high lift capabilities by 20% (flap up) and 60-80% (flap down). To maximize drag reduction, the tip propeller diameter must be suitably dimensioned according to nacelle size and thrust settings. Distributed wing aerodynamics can guarantee a higher lift coefficient, improving the wing design and aircraft performance electric aircraft increment an airplane's working effectiveness by diminishing what is called an electric-driven aircraft. An electric-powered aircraft is molded to provide better efficiency and to bring a new modernization in the coming future. The changing of engine position will lead to observe the different conditions like fluttering, induced drag, parasitic drag, etc.

1.3 FUSION 360

Airplane configuration is a perplexing cycle that has numerous stages whereas Fusion 360 is very useful to design a part accurately and easily. The user interface is eco-friendly. Numerous airplane makers like Boeing, Dassault, and Fusion 360 is a CATIA programming device which is received by Airbus to limit the lead time and to evade delayed span in the plan interaction.

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORY OF ENGINE POSITIONS

In early 1903, the first flight of Wright brothers up to the late 1930's gas-powered reciprocating internal combustion engines with a propeller was the sole in sense used to propel the aircraft. A British pilot Frank Whittle designed and patented the first turbo jet engine in 1930. The main purpose of the

engine is to propel the aircraft by producing the thrust against the air present in the surrounding of the aircraft. The amount of thrust produced and the lift produced is also a function of wing profile and wing area available which depends on the size of the aircraft. So, the best way to use the wings area is to suspend the engines beneath the wing surface. From the 1970s the electrically powered models came into existence and were used in various fields in such a way in unmanned aerial vehicles (UAV). Where in the 21 century widely used for various purposes. There were a number of researches are going on simultaneously in the aviation field regarding the electrically propelled. In the mean, while crewed flights were powered electrically and although helicopters from 1917's. MB-E1 is the first crewed flight which was introduced in 1973. It is the first crewed flight until 1973. In this modernization, the experimentation is still going on electrically powered prototypes. The first certified electric-powered crewed aircraft is Velis Electro on 10 June 2020. They are getting enthusiastic about electrically powered aircraft for commercial and private aircraft for better environmental circumstances in aviation.

2.2 TYPES OF ENGINE MOUNT LOCATIONS

There are different types of engine mount locations in a design of an aircraft which depends on the size of the aircraft. They are

- Top of the fuselage
- Side of the fuselage
- Mounted on the aft fuselage
- Mounted on tail
- Mounted over wing
- Pylon mounted under the wing
- In the wings
- Above the wings

2.2.1 Top of the fuselage

As it is a podded engine and built in such a way that embedded in the nacelle itself. It can supersonic speed due to the pre-compression of the fuselage and there will low moment of inertia in the roll.



Figure.2.1 Top of the fuselage

2.2.2 Top of the wing

Engine mounted on top of the wing is also called the podded engine. Mounting an on the wing causes the bending relief for the flight. The engine arranged further away from the fuselage provides more bending relief.



Figure.2.2



Figure.2.3

Top of the wing

2.2.3 Side of the fuselage

The engines at the side of the fuselage create more lift due to the air intake on is the side of the fuselage. This type of engine position will avoid noise for the passengers.



Figure.2.4 Side of the fuselage

2.2.4 Mounted on aft of the fuselage

Aft-mounted engines will not create any asymmetric thrust when we compared to the engine mounted underneath the wing. These engine positions won't produce any yawing while in a steady flight.



Figure.2.5 Mounted on aft of the fuselage

2.2.5 Mounted on tail

Tail-mounted engines work as efficiently as we compared to engines under the wing. But, there is a problem with the flow of fuel from the fuel tank to the engine mounted on the tail. In this situation, we cannot use gravity to flow the fuel to the tail part.



Figure.2.6



Figure.2.7

Mounted on tail

2.2.6 Pylon mounted under the wing

CFD methods are used to investigate the aerodynamic interference issues and potential benefits of an over-the-wing mounted (OWM) engine placement. The reference configuration is a unique STOL-capable transport aircraft idea. The wing/body configuration is compared to the power-off nacelle wing/body/engine configuration. Following that, jet-on computations are run to see how the presence of the jet affects the engine/airframe interference effects. At first, the engine is assumed to be in a reference position. The engine's position is varied to study the interaction with the supersonic area and shocks on the upper surface of the wing. To wrap off the research, a preliminary assessment of the installation drag is carried out to look into the possibility of advantageous interference effects and reduced drag when compared to more traditional under-the-wing mounted engines.



Figure.2.8 Pylon mounted under the wing

2.2.7 In the wing

The engines used in the aircraft which were buried in the aircraft wing are turbofan engines. They occupy more space than turbojet engines. Rolls-Royce Conway is the first turbofan engine that has a bypass ratio of 0.25 to have a small diameter to insert in the wing roots. The change in the ratio of the engine causes the reduction of fuel efficiency. As the engine is equipped in the root of wings there is no scope to use any leading-edge devices for increasing the lift at low-speed conditions while landing and takeoff. It requires a larger wing surface area to use high lift devices is not possible. The engines maintenance will last at a high cost.



Figure. 2.9



Figure. 2.10

2.3 ELECTRICAL MOTORS

The DC motor, also known as a direct current motor, is utilized in a broad range of applications, including radio-controlled airplanes. Its primary function is to convert electrical energy to mechanical energy. Brushed, stepper and brushless direct current motors are the three types of direct current motors available today. Brushless motors are most commonly found in model planes and helicopters. These devices come in a wide range of sizes to suit a variety of applications. There has been a significant increase in the use of simple and low weight model electric aircraft as a result of the use of these motors. The model airplanes may now ascend vertically thanks to these brushless and sophisticated batteries. Another reason for their growing popularity is that, when compared to internal combustion engines, these motors are less noisy and filthy. Direct Current Motors, on the other hand, is rarely employed in commercial aircraft. It can only be found in model planes. These are more expensive than other types of electric motors, but they are more efficient. There is reduced or no friction in these motors because they do not have brushes. In comparison to other types of motors, it requires less maintenance. A rotor and a commutator are used to reverse the current direction. Apart from airplanes, it may be utilized for a wide range of applications due to its excellent durability.



Figure.2.11 Electric motor

2.4 TYPES OF ELECTRIC MOTORS

There are three types of motors used in aircrafts such as

- Brushed motors
- Stepper motors
- Brushless motor

2.4.1 Brushed motor

A brushed DC electric motor is an internally commutated electric motor that can be powered by direct current. Brushed motors were the first commercially significant use of electric power to drive mechanical energy, and DC distribution systems have been used to power motors in commercial and industrial facilities for more than a century. The operating voltage or the strength of the magnetic field can be changed to change the speed of brushed DC motors. The speed and torque characteristics of a brushed motor can be changed depending on how the field is connected to the power source to produce a stable speed or speed that is inversely proportional to the mechanical load. Electrical propulsion, cranes, paper machines, and steel rolling mills all use brushed motors. Brushless DC motors with power electronic devices have superseded brushed motors in many applications since the brushes wear out and need to be replaced.

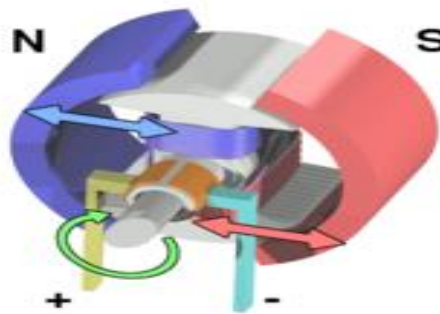


Figure.2.12 Brushed motor

2.4.2 Brushless motor

A brushless DC electric motor (BLDC motor or BL motor) is a synchronous motor that uses a direct current (DC) electric power source. It is also known as an electronically commutated motor (ECM or EC motor) or synchronous DC motor. It employs an electronic closed-loop controller to switch DC currents to the motor windings, resulting in magnetic fields that revolve in space and are followed by the permanent magnet rotor. To control the motor's speed and torque, the controller changes the phase and amplitude of the DC pulses. The mechanical commutator (brushes) utilized in many conventional electric motors is replaced by this control method.

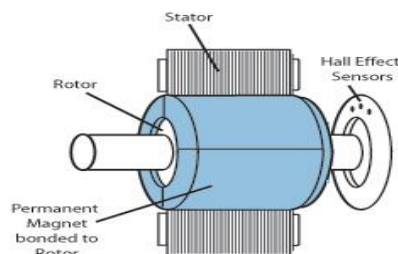


Figure.2.13 Brushless motor

2.4.3 Stepper motor

A plane's main motor is a stepper motor. They are inefficient, slow, and hefty. The pole count of stepper motors is typically between 50 and 100. In a closed-loop system, stepper motors move progressively with a consistent pulse. Stepper motors provide precision drive control for motion control applications due to their high pole count. They offer a lot of torque at low speeds and are quite cheap and widely available.

2.5 ADVANTAGES CLAIMED

2.5.1 Induced drag phenomena

In Aerodynamics, the four primary powers which follow up on an airplane during the flight are Lift, Drag, Thrust, and Weight. Drag is perhaps the most basic wonder among all and is the restricting power of an airplane's forward movement. It very well may be grouped momentarily into parasite drag (not because of lift) and lift initiated drag. In a common vehicle airplane, frictional drag and prompted drag together offer over 80% of all outhaul, yet different types of drag couldn't be barred surely.

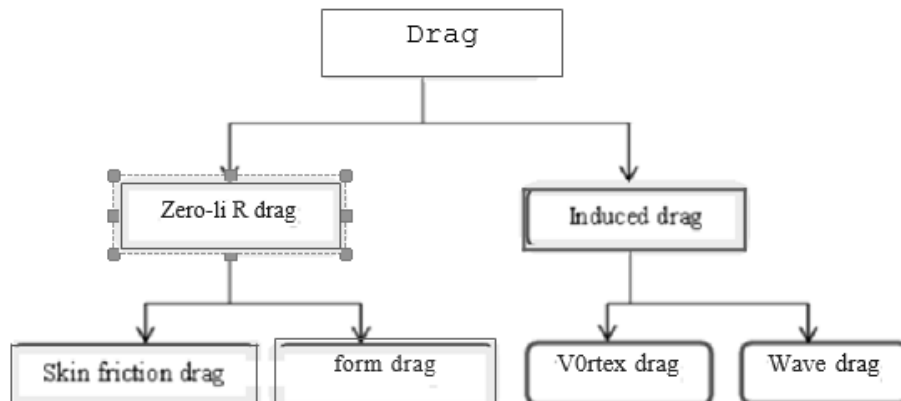


Figure.2.14 Different forms of drag 1

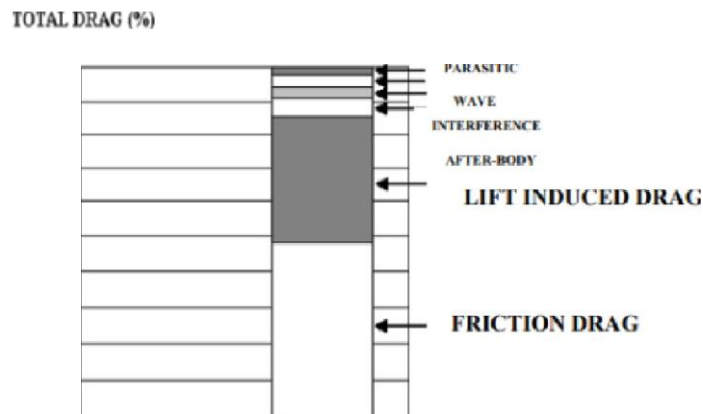


Figure.2.15 Distribution of drag component

Actuated drag produces active energy which will cause the descending movement opposite to the wind current. This descending power could be perceived as the lift vector and this part is viewed as the instigated drag. Prompted drag contrasts from different types of drag through a wonder of



changing over the scattered active energy into heat slowly. Vortex wake is a novel component of initiated drag. Mixture McLean has proposed the misinterpretations of the actuated drag and the vortex wake delivered by the wing. Regularly the vortex wake is created from the stream design because of the distinction in speeds at the upper and lower surface of an airplane. The speeds at the down surface move towards the upper surface and consequently, it makes a roundabout stream design. This stream design is liable for the vortex sheet that created from the whole range of the wing. As referenced by Douglas, the basic misconception with the vortex sheet was that the prompted drag was caused because of the proposal vortices delivered from the speed stream design. Moreover, lessening the strength of the vortex couldn't significantly affect the initiated drag. The examination has been directed to decrease the initiate drag and various techniques have been created to figure this lift incited drag. Utilizing one of the proposed techniques, actuated drag for a business stream transport airplane is determined and will be examined in the forthcoming segment.

Figure.2.16.flow pattern of the velocity

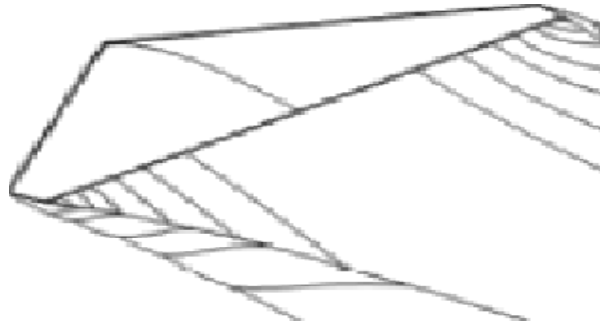
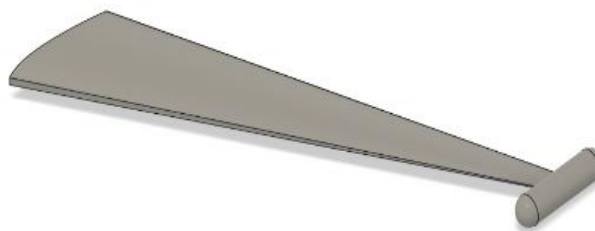


Figure.2.17.vortex sheel from trailing edge

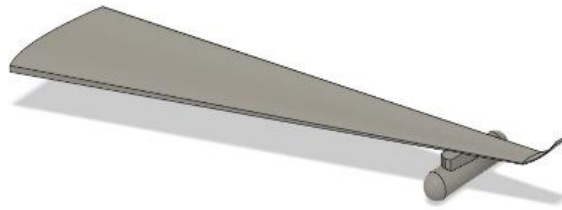
CHAPTER 3

AIM AND SCOPE

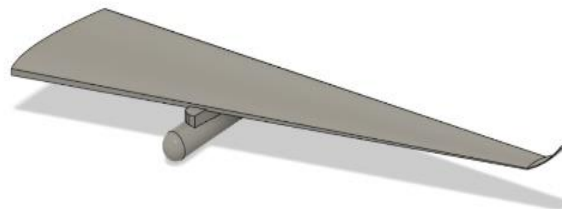
The objective of this study is to develop an automated parametric model for different types of electrical engine locations on a wing using the software Fusion 360 and solid works. To find the induced drag, distributed wing aerodynamic, Trailing vortices, Lift-induced drag, Aeroelasticity, Turbulence flow modeling contribution in an aircraft by a conceptual approach. The fundamental part of the model is to diminish the time taken by the creator during the plan measure. The created nonexclusive model can switch between various sorts of engine positions according to the client's necessities with accessible boundaries. The model made will be valuable in airplane wing configuration.



a) First design



b) Second design



c) Design three

Figure.3.1(a,b,c) The designs of engine positions

3.1 SCOPE

- *Reduce induced drag*

To reduce induced drag, we have to maintain the low aspect ratio of the wing. The span and the chord of the wing will have lower induced drag.

- *Reduce parasite drag*

Parasitic drag can be reduced by making sure the surface of the aircraft should be plain and stream lined to avoid skin friction. As, it is the main cause for parasitic drag.

- *Increase lift co efficient*

Lift co efficient increases by increasing the curvature of the wing using the flaps fixed at the leading edge of the wing. Slats also used to increase the lift by increasing the wing area of aircraft.

- *Max/Min of flutter (vibrations)*

Flutter is defined as the vibration created due to the aerodynamic forces flow around the aircraft.

- To optimize vibrational behavior of wing mounted engine using Aero elasticity methods.

CHAPTER 4

ANALYTICAL ANALYSIS

Before proceeding to the fabrication and experimental analysis we have to observe the design behavior when it is subjected to different conditions by inserting in versatile software like solid works and analysis to see the aeroelasticity and aerodynamics of the model. We have chosen fabrication material as aluminum (6061 aluminum alloy) and we used mixed mesh (polyhedral and tetrahedral mesh). We created an enclosure around the design model as a test section, which helps to apply the conditions within the enclosure limit. We have introduced the design to a different angle of attacks within the test section to calculate the lift and drag. The velocity chosen for analysis of the design model is 30m/s. As the electric motors never exceed Mach no.1. After applying all these conditions stimulation has been done successfully and drawn the following results and plotted the graphs.

- Flow trajectory
- Countours
- Stream lines
- Pressure distribution over the wing
- Lift
- Drag
- Side force
- Aero elasticity

4.1 FLOW TRAJECTORY'S

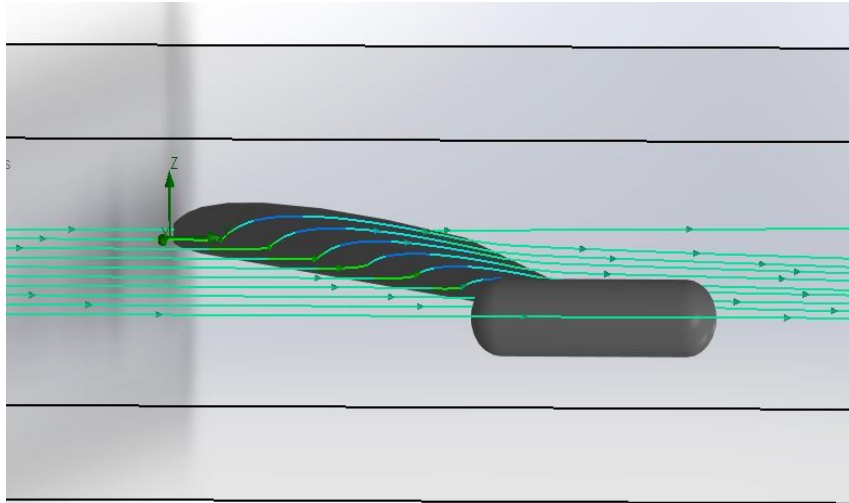


Figure.4.1 Design 1 flow trajectory

The above figure describes the flow trajectory that flows over the surface of the wing of the design

1

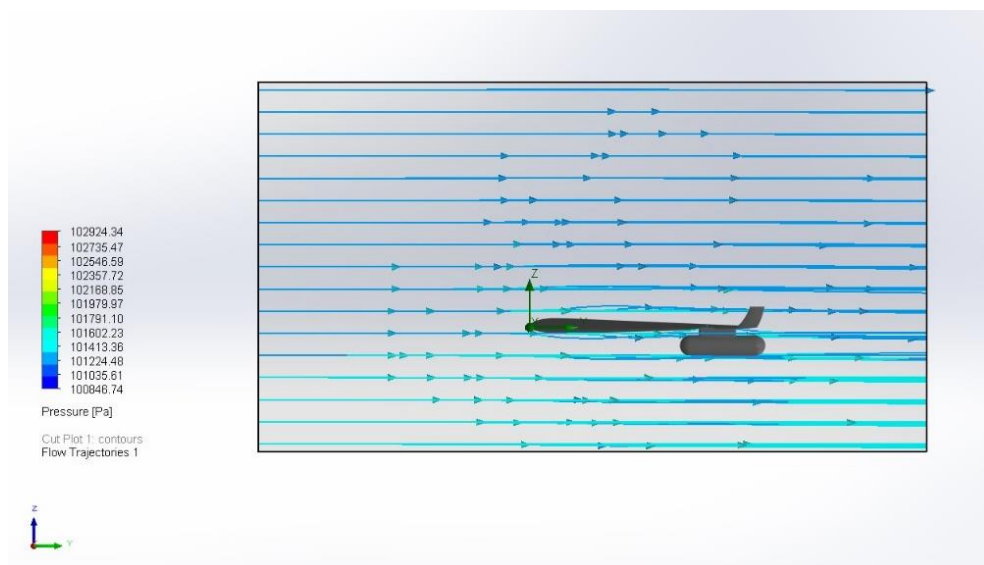


Figure.4.2 Design 2 flow trajectory

The figure illustrates side view of the second design where the engine is attached at a distance away from the tip of the wing. We can observe the flow trajectory around the airfoil.

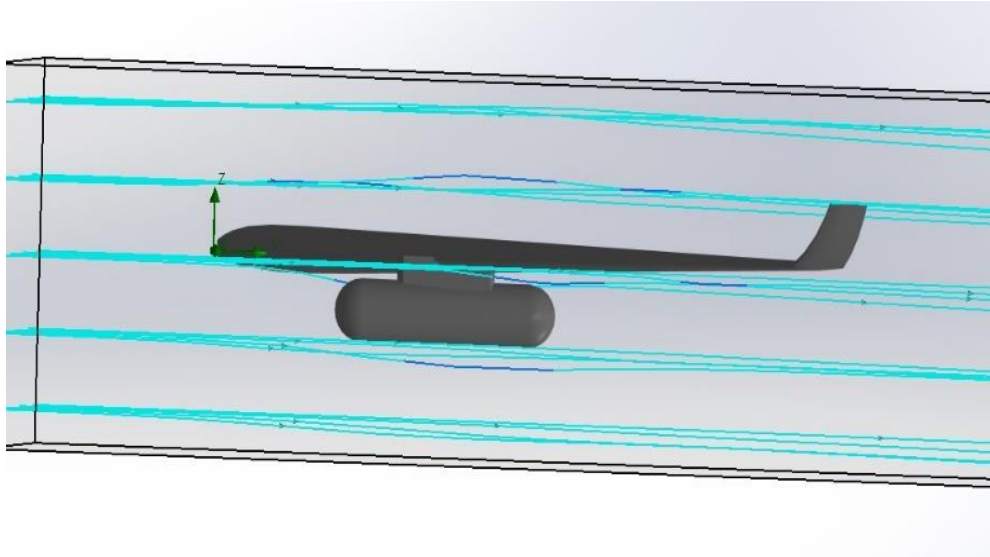


Figure.4.3 Design 3 flow trajectory

The above figure denotes the design 3 where the engine position will be varied compared to second design where we can observe a little flow trajectory around the wing.

4.2 STREAM LINES AND CONTOURS

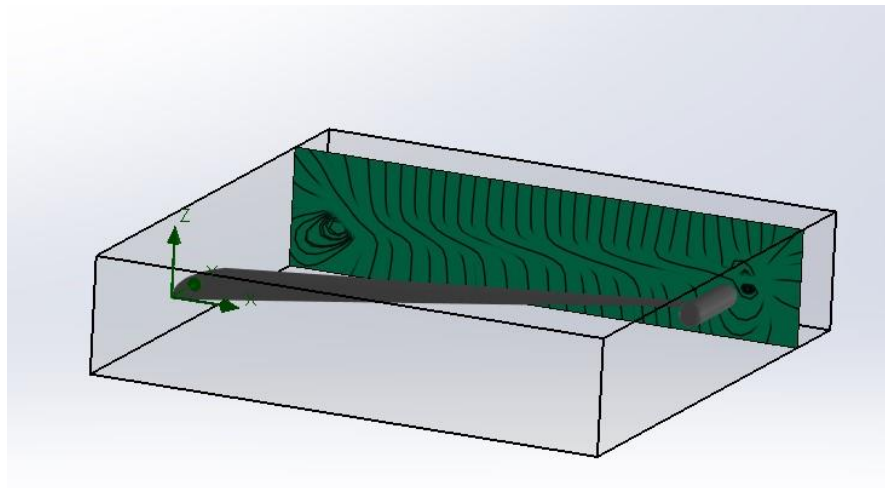


Figure.4.4 Design 1 stream lines and contours

The above figure illustrates the less contours are produced at the root and tip of the airfoil and rest of the airfoil we can observe streamline flow over the airfoil.

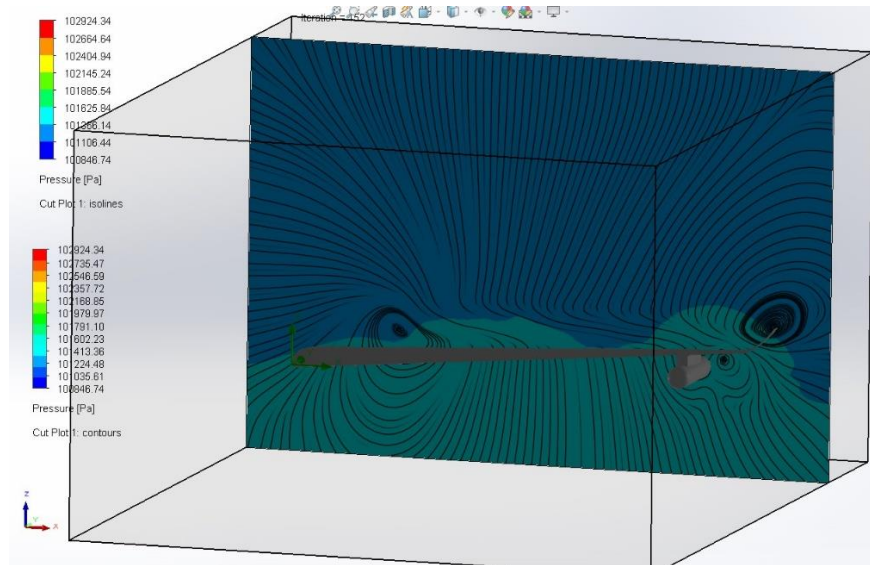


Figure.4.5 Design 2 stream lines and contours

We can observe the figure that the contour created at the tip and root are huge in design 2 when we compared to design 1

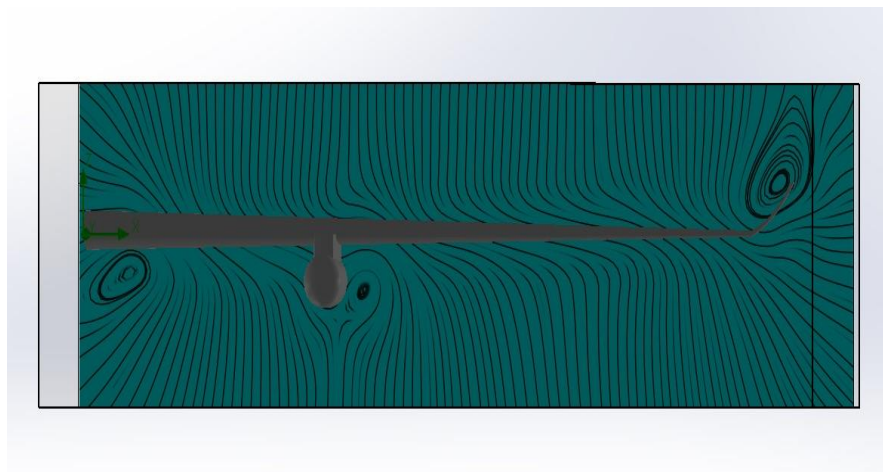


Figure.4.6 Design 3 stream lines and contours

In the third design we can observe the contours created at three locations of the airfoil like engine, root, tip.

4.3 PRESSURE DISTRIBUTION OVER THE WING

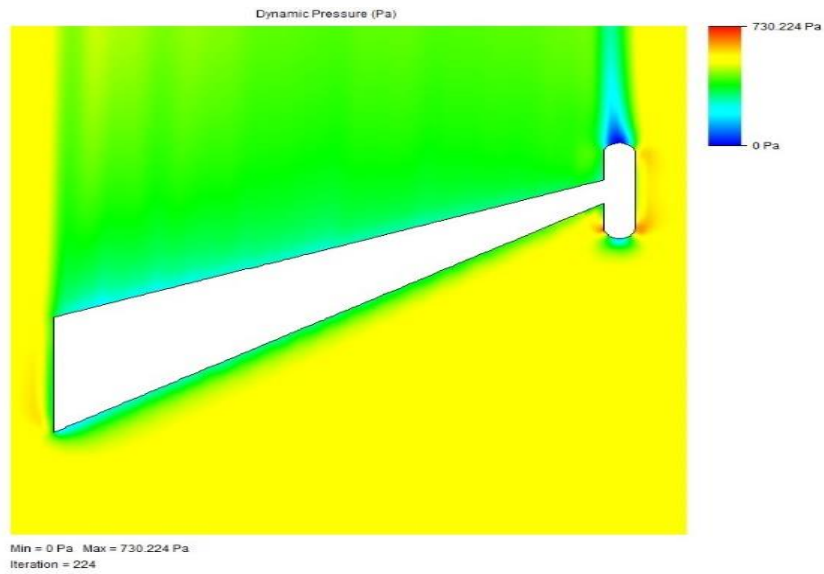


Figure.4.7 Design 1

Here in the above figure we can observe the pressure distribution around the airfoil at maximum of 730.224pa. There is a high pressure distribution across the engine

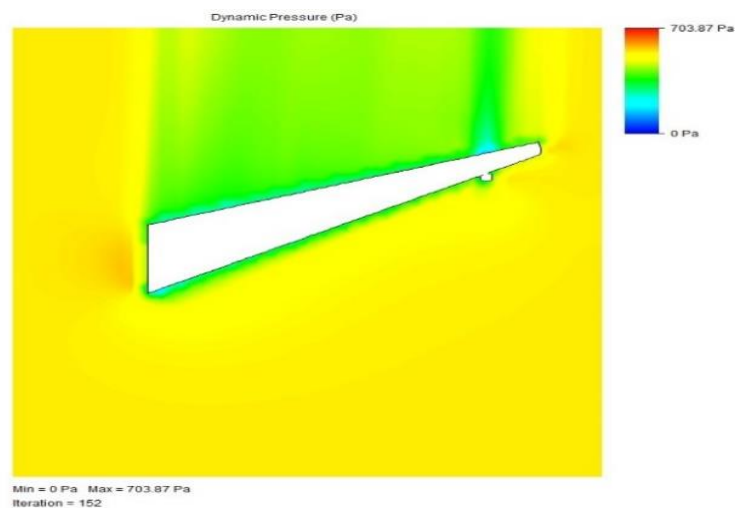


Figure.4.8 Design 2

We can observe the pressure distribution around the wing is maintained. There is no maximum or minimum pressure distribution in second design.

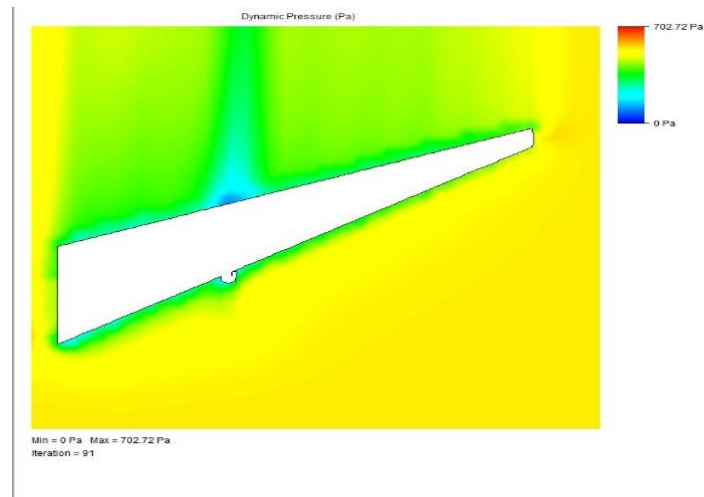


Figure.4.9 Design 3

In this figure we can see the dynamic pressure(702.72pa) is less at the engine position and the rest of the airfoil is maintained in a medium pressure distribution.

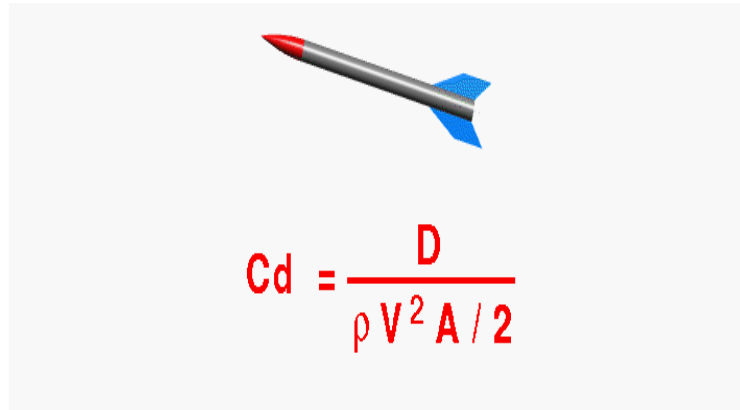
4.4 FORMULA TO FIND CL AND CD

Co efficient of lift =



$$C_l = \frac{2 L}{\rho \times V^2 \times A}$$

Co efficient of drag =



4.5 NUMERICAL CALCULATION OF CL AND CD

Design 1 plotted graphs

Table.4.1 Calculation of cl and cd of design 1

Angle	Drag(Y)	LIFT(Z)	X	CL	CD
0	1.81	1.66	-0.45	0.018026	0.019655
1	1.8	4.25	-0.44	0.04615	0.019546
2	1.75	6.22	-0.42	0.06754	0.019003
3	1.75	8.25	-0.42	0.08959	0.019003
4	1.69	9.52	-0.29	0.10338	0.01835
5	1.64	8.4	-0.3	0.09121	0.01781
6	1.54	13.51	-0.2	0.1467	0.016723
7	1.24	11.81	-0.02	0.12824	0.013465
8	1.22	13.71	0.05	0.14888	0.013248
9	1.04	15.85	0.1	0.1721	0.011293
10	0.97	17.49	0.18	0.18992	0.010533
11	0.89	19.67	0.2	0.2136	0.009664
12	0.75	21.72	0.19	0.23586	0.008144
13	0.75	23.59	0.27	0.25616	0.008144
14	0.62	25.63	0.3	0.2783	0.006733
15	0.49	27.56	0.21	0.2993	0.005321

The formula used to find the $cl = \frac{2L}{\rho v^2 A}$ and $Cd = \frac{D}{\rho v^2 A / 2}$ by using the analytical values taken from software by inducing the model in various angle of attacks.

Cl vs alpha compared with original aircraft

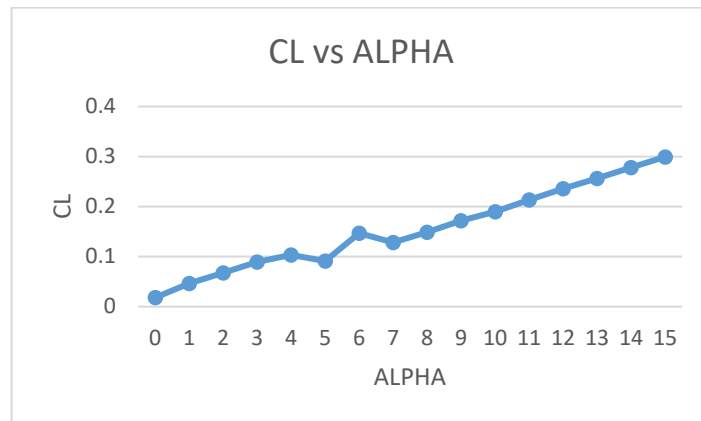


Figure.4.10

The graph indicates a constant increase in the lift from 0.02 to 0.3 by inserting the design 1 in different angle of attacks.

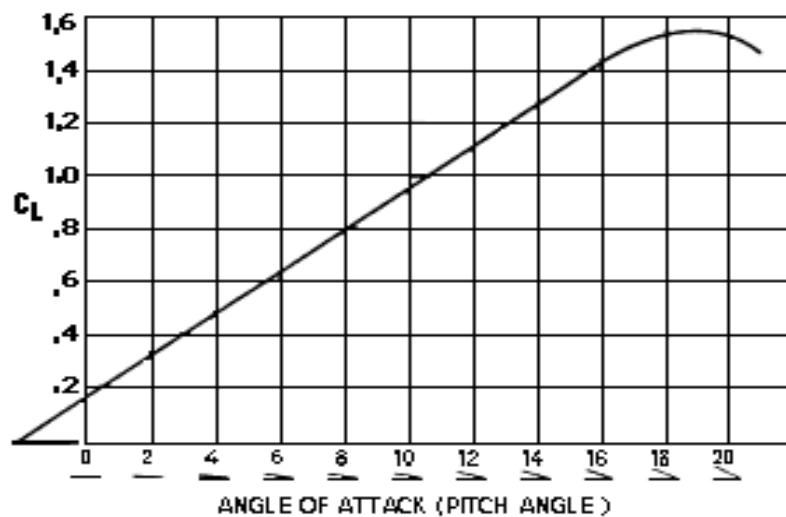


Figure.4.11

As the graph indicates high increase in the lift without any fluctuation when compared to the design1.

Cd vs alpha compared with original aircraft

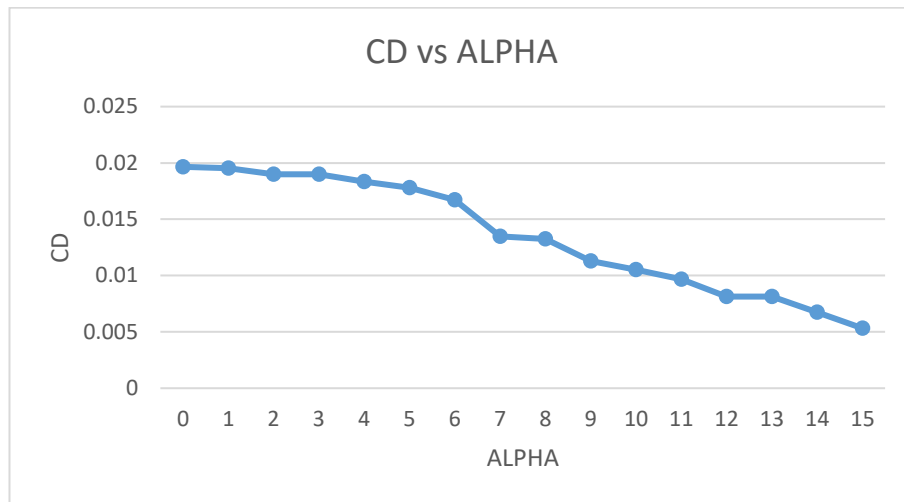


Figure.4.12

The graph illustrates that the co efficient of drag is gradually decreasing from 0.02 to 0.005

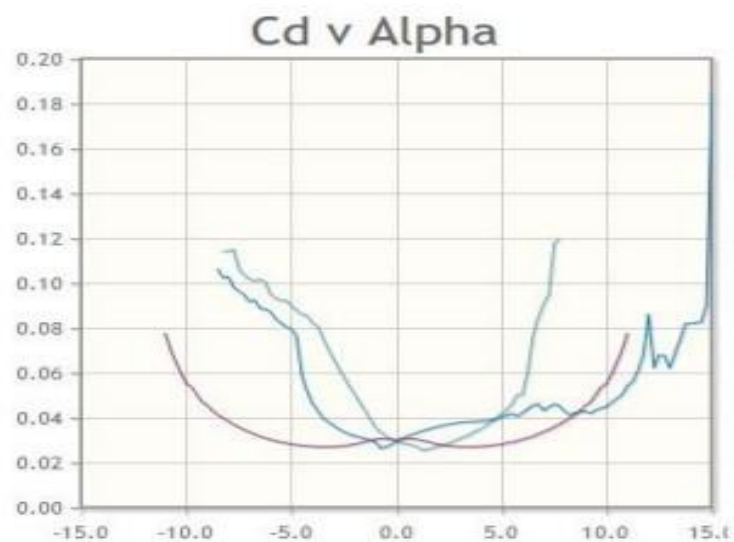


Figure.4.13

The above graphs resembles there is a fluctuation from the 0.12 to 0.18 in different angle of attacks.

Design 2 plotted graphs

Table.4.2 Calculation of c_l and c_d of design 2

Angle	Drag(Y)	LIFT(Z)	X	CL	CD
0	2.37	3.25	-1.08	0.03529	0.0257
1	2.57	5.697	-0.79	0.06179	0.02791
2	2.66	8.52	-0.87	0.09252	0.02888
3	2.95	10.7	-1.04	0.1162	0.032034
4	3.01	12.99	-1.08	0.14106	0.032685
5	3.44	14.52	-1.2	0.15767	0.037355
6	3.73	15.95	-1.46	0.1732	0.0405
7	4.02	17.16	-1.77	0.18634	0.04365
8	4.44	18.37	-1.72	0.19948	0.04821
9	4.58	18.44	-1.9	0.20024	0.04973
10	3.46	21.52	-1.32	0.2337	0.03757
11	3.65	22.34	-1.45	0.2426	0.039635
12	4.28	22.57	-1.47	0.2451	0.04648
13	1.53	27.6	-0.002	0.2997	0.016614
14	1.68	28.72	-0.12	0.31187	0.018243
15	1.88	30.46	-0.27	0.33076	0.020415

The formula used to find the $cl = \frac{2L}{\rho v^2 A}$ and $Cd = \frac{D}{\rho v^2 A/2}$ by using the analytical values taken from software by inducing the model in various angle of attacks.

Cl vs alpha compared with original aircraft

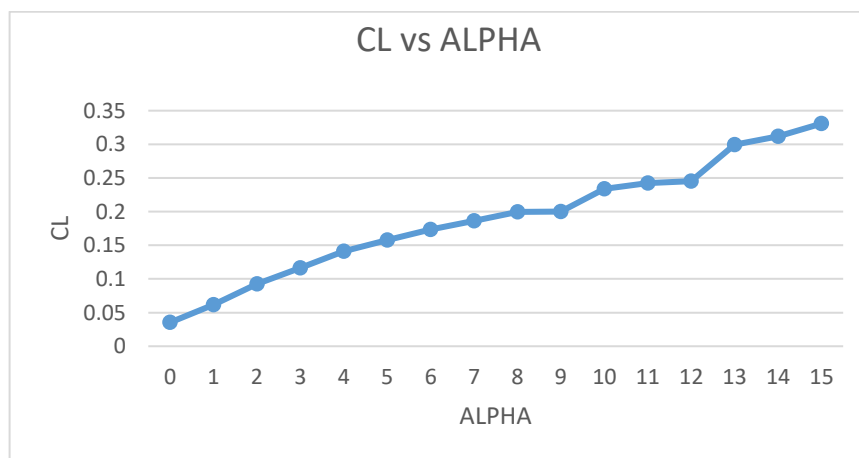


Figure.4.14

The above graph describes the partial increase in lift from 0.004 to 0.2. Following that there is a fluctuation from 0.2 to 0.30.

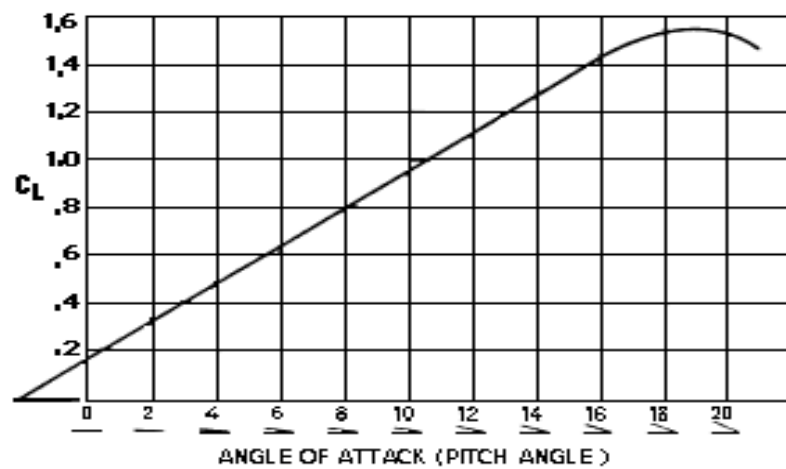


Figure.4.15

The graphs shows a surge of lift from 0 to 1.5 for design 2 and there is no fluctuations like the design 2 graph.

Cd vs alpha compared with original aircraft

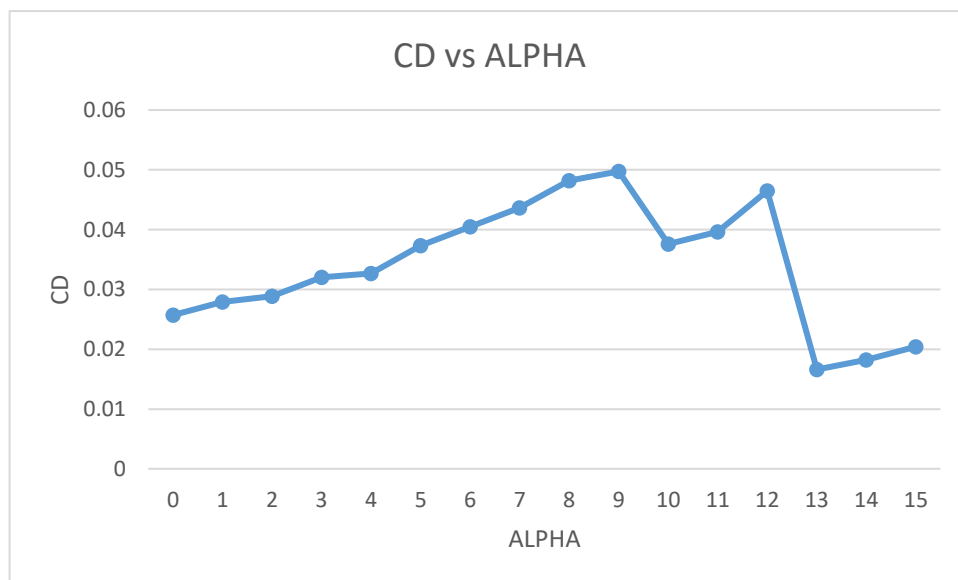


Figure.4.16

The above graph depicts there is a surge from 0.025 to 0.05 and fluctuated down to the 0.02. As, the drag increased and simultaneously decreased after the 0.05.

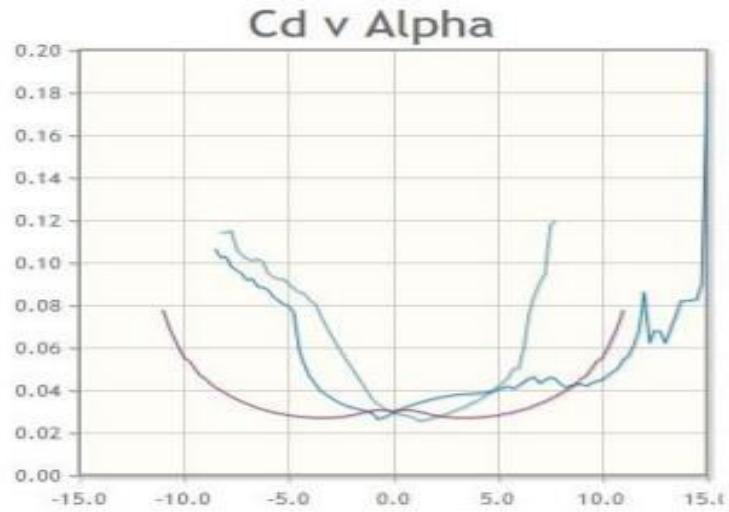


Figure.4.17

The above graphs resemble that there is a fluctuation from the 0.12 to 0.18 in different angle of attacks.

Design 3 plotted graphs

Table.4.3 Calculation of c_l and c_d of design 3

Angle	Drag(Y)	LIFT(Z)	X	CL	CD
0	2.89	2.64	-1.03	0.02867	0.03138
1	2.52	5.27	-0.89	0.05723	0.027364
2	2.75	6.82	-1.04	0.07406	0.02986
3	2.84	9.45	-0.95	0.10262	0.03084
4	3.2	11.39	-1.26	0.12368	0.03475
5	3.56	12.63	-1.29	0.13715	0.03866
6	3.09	14.55	-1.18	0.158	0.033554
7	3.05	16.39	-1.24	0.17798	0.03312
8	2.95	17.82	-0.97	0.1935	0.032034
9	4.16	17.74	-1.35	0.19264	0.04517
10	4.03	18.85	-1.28	0.2047	0.04376
11	3.81	20.4	-1.13	0.2215	0.04137
12	4.52	21.19	-1.63	0.2301	0.04908
13	4.52	21.19	-1.63	0.2301	0.04908
14	4.52	21.19	-1.63	0.2301	0.04908
15	1.35	29.23	-0.12	0.3174	0.01466

The formula used to find the $c_l = \frac{2L}{\rho v^2 A}$ and $C_d = \frac{D}{\rho v^2 A/2}$ by using the analytical values taken from software by inducing the model in various angle of attacks.

Cl vs alpha compared with original aircraft

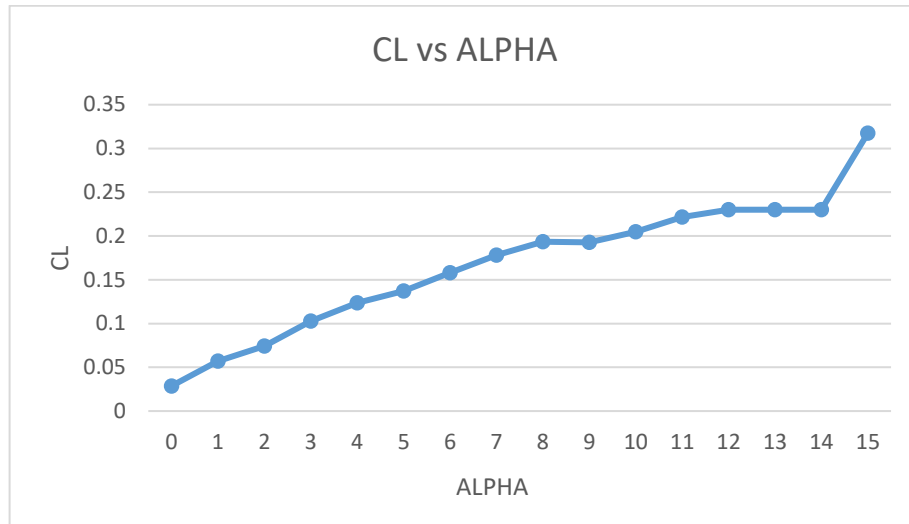


Figure.4.18

The above graph illustrates that there is a gradual increase in c_l vs α from 0.03 to 0.32 up to end of the angle 15 degrees.

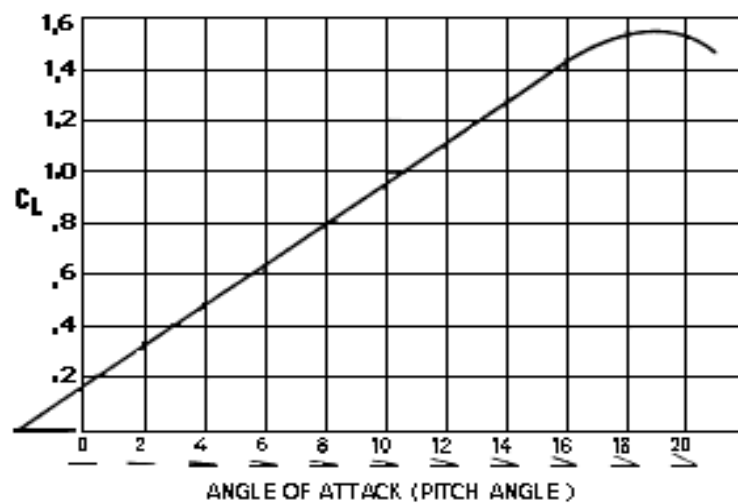


Figure.4.19

The graphs shows a surge of lift from 0 to 1.5 for design 2 and there is no fluctuations like the design 2 graph.

Cd vs alpha compared with original aircraft

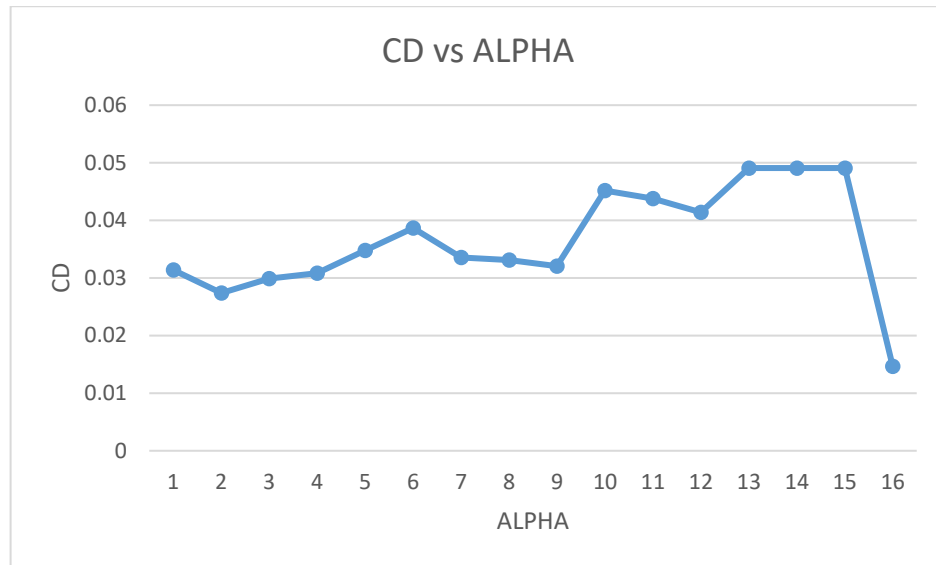


Figure.4.20

The graph indicates that there is a period of variation approximately from 0.03 to 0.01 where there is a fluctuation in the drag.

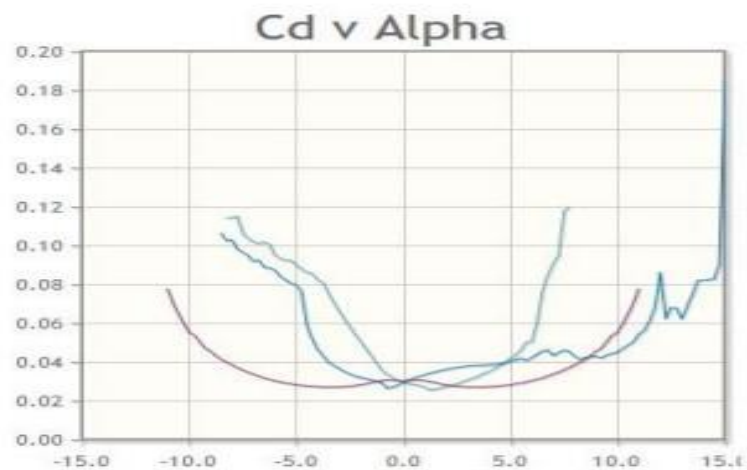


Figure.4.21

The above Cd graph denotes that there is a fluctuation approximately from 0.12 to 0.12 in different angle of attacks.

4.6 AERO ELASTICITY

DESIGN 1

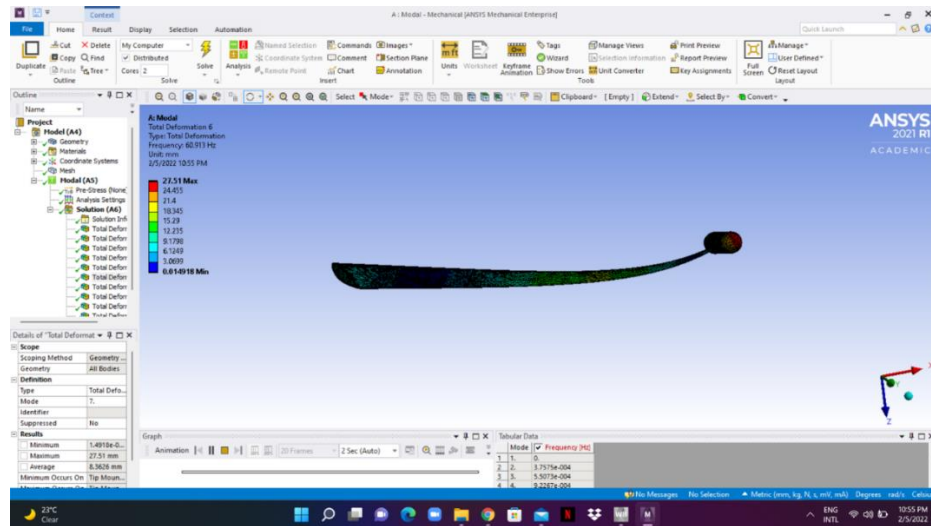


Figure.4.22

The above figure illustrates the aero elasticity of the design 1 airfoil which experiences the bending movement towards upwards due to aerodynamic forces which act in different direction and withstand.

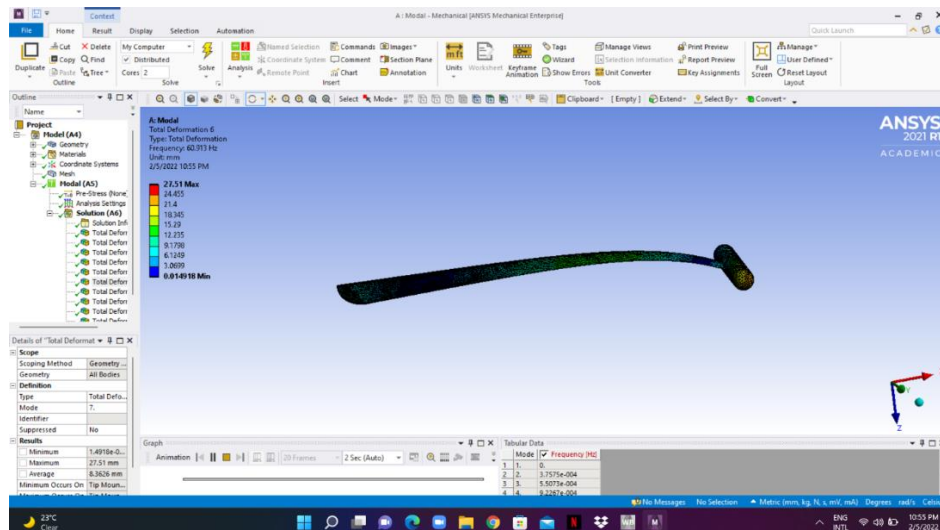


Figure.4.23

The figure shows that the aerofoil experience the bending movement towards downwards as the aerodynamic forces are unnatural due weather conditions.

DESIGN 2

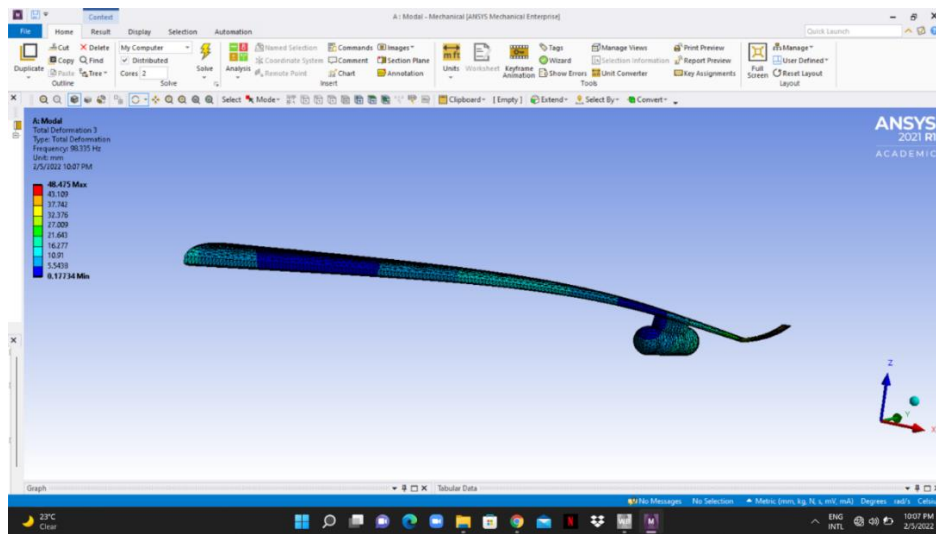


Figure.4.24

The above figure shows that it went through different forces acting on it through different directions which causes deformation called aero elasticity.

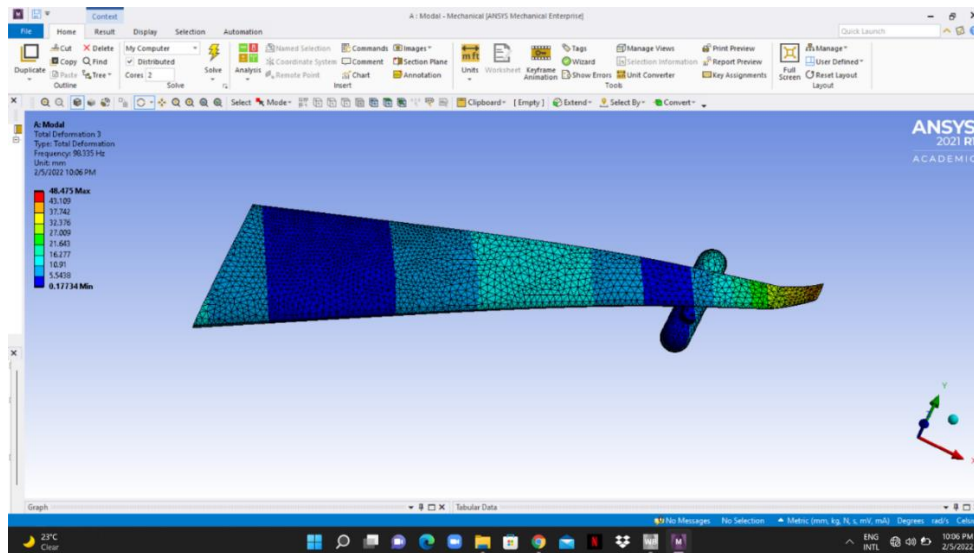


Figure.4.25

Figure shows the top view of the airfoil and the red colour denoted that the place where more deformation takes place.

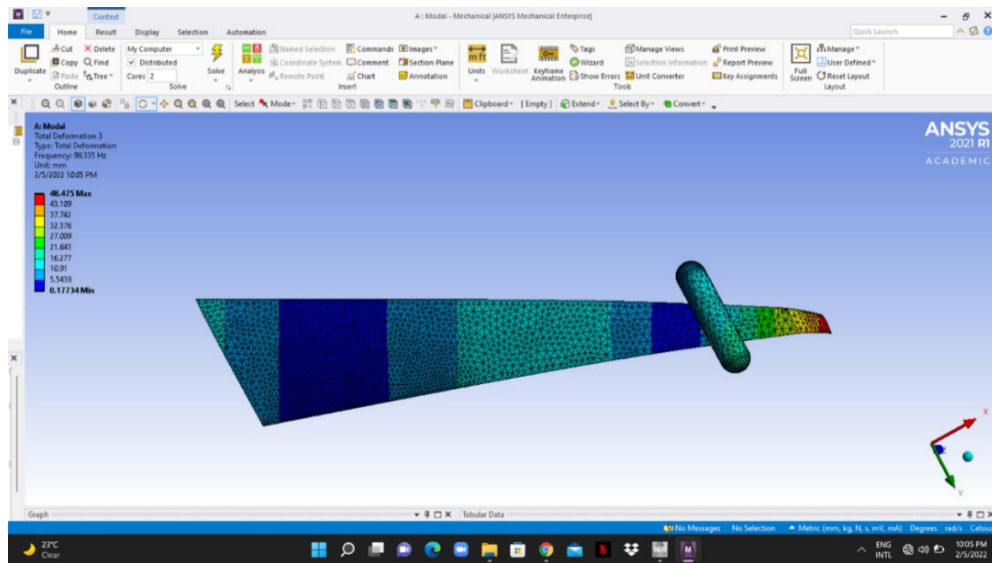


Figure.4.26

Figure shows the bottom view of the airfoil. As, I have mention in the previous the impact varies depending on the area of the airfoil that expose to the aerodynamic forces.

DESIGN 3

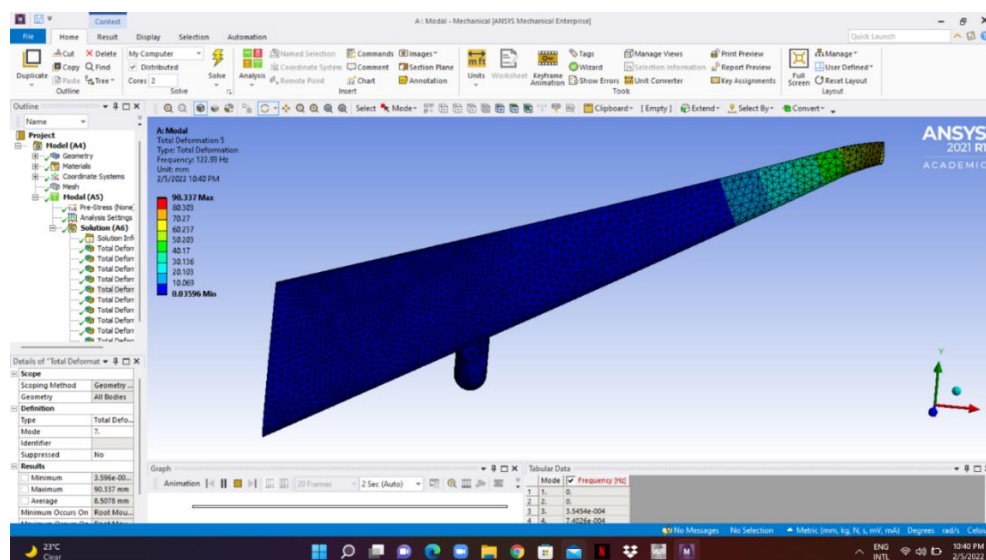


Figure.4.27

The above figure illustrates the top view of the design 2 airfoil which have high deformation on the tip of the airfoil.

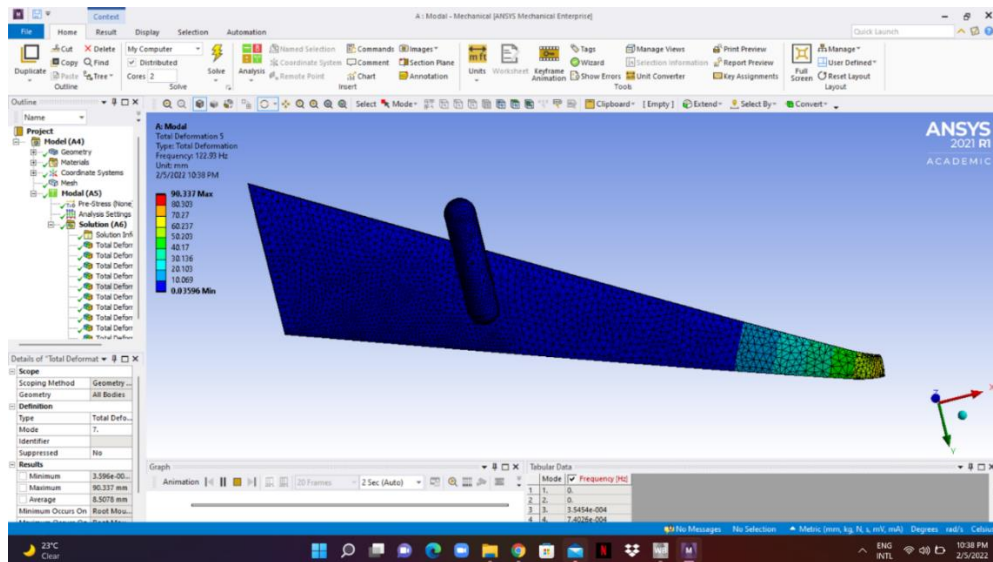


Figure.4.28

The figure shows the bottom view of the airfoil where the engine location is changed towards tip to root.

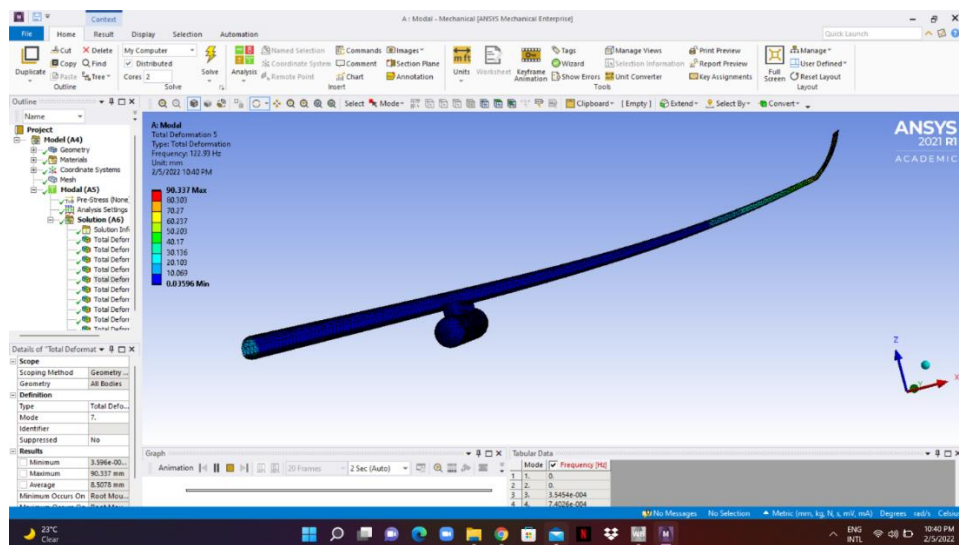


Figure.4.29

Figure denotes the front view of the airfoil that the deformation occurred towards down slightly near to the tip of the airfoil.

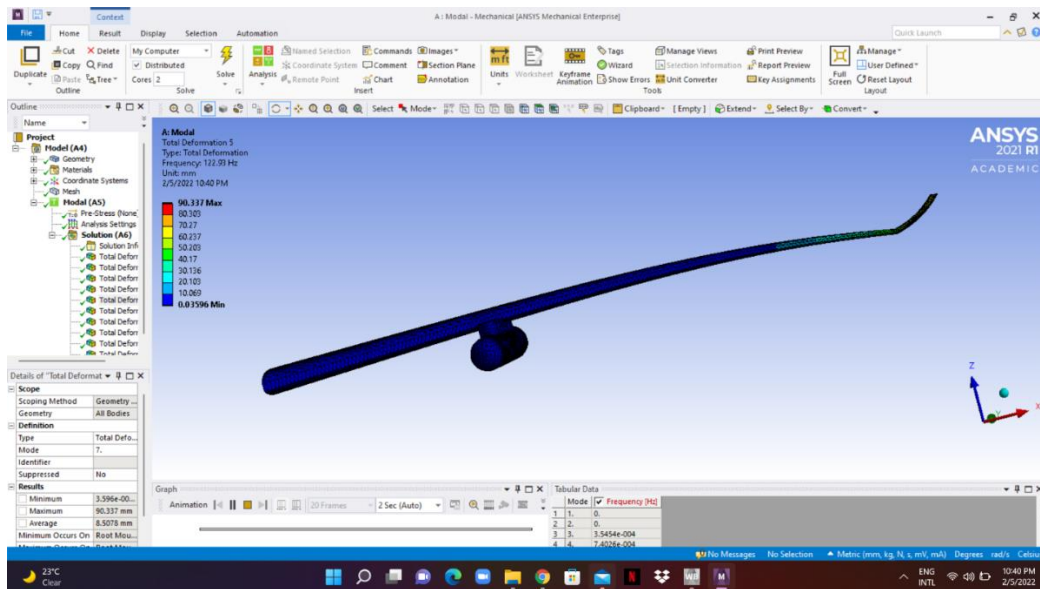


Figure.4.30

In the above figure the airfoil bends upwards as the airfoil experiences the aerodynamic force from different directions which causes the deformation.

CHAPTER 5

FABRICATION

After the completion of the analytical analysis of the design through design tools. We have gone through fabrication with wooden carpentry. We have created 12 tapping's on the root chord for the experimental analysis. By the tapping we can observe the pressure distribution on the surface of the airfoil through the manometer.



Figure.5.1



Figure.5.2

Geo tagged picture's of fabrication

5.1 PARAMETERS

Table.5.1 Parameters

PARAMETERS	MAIN WING
Wing span	0.145m
Wing surface area	0.083528m ²
Aspect ratio	2.4
Chord length	6cm
MAC	0.25m
No. of tapping holes	12

CHAPTER 6

EXPERIMENTAL ANALYSIS

Completion of the fabrication further the fabricated model had inserted into the test section of the subsonic wind tunnel for the experimental analysis. Initially, the calibrations have been done without placing the model in the wind tunnel to attain the velocity of 30 m/s at a certain RPM. After completion of the calibration, the model has inserted in the test section and set the rpm to 900 at which this

velocity will attain. Further noted the monometer reading through 12 tapping's by arranging the model in different angle of attack's from 0 degrees to 15 degrees.

Table.6.1 Calibration table

		hi=0.2	
x	y(hf)	h	Vm/s
100	0.3	0.05×10^{-2}	2.51
200	0.65	0.225×10^{-2}	5.33
300	1.15	0.475×10^{-2}	7.74
400	1.9	0.85×10^{-2}	10.36
500	2.85	0.425×10^{-2}	7.32
600	4.1	1.95×10^{-2}	15.69
700	5.55	2.675×10^{-2}	18.38
800	7.25	3.525×10^{-2}	21.1
900	9.25	4.525×10^{-2}	23.91
1000	11.45	5.625×10^{-2}	26.66
1100	13.85	6.825×10^{-2}	29.36
1200	16.4	8.1×10^{-2}	31.99

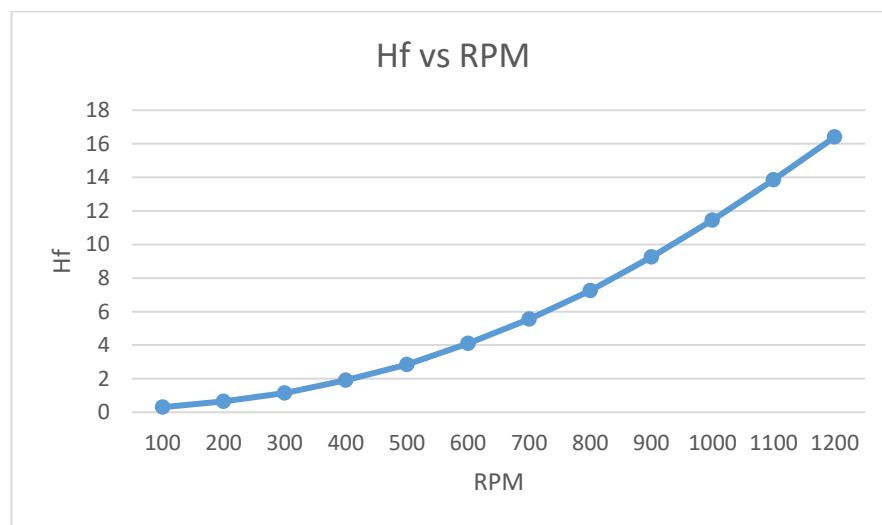


Figure.6.1 Hf vs RPM graph

The above graphs illustrate the static pressure vs rpm that the wind tunnel rotates. As, the rpm increases gradually from 100 to 1200.

6.1 CALIBRATION FORMULA'S

$$H_a = \left(\frac{h_1 - h_2}{2} \right)$$

$$V = \sqrt{\frac{2\rho_w g H_a}{\rho_a}}$$

6.2 WIND TUNNEL TESTING



Figure.6.2

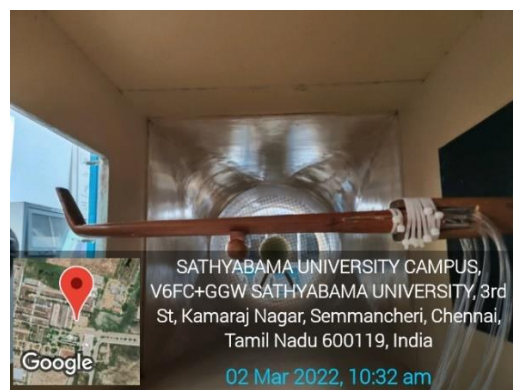


Figure.6.3

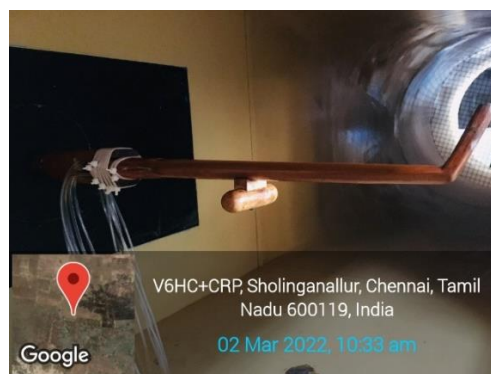


Figure.6.4

The above model is inserted in the subsonic wind tunnel for experimental analysis where the pressure exert on the model. The model will let us know the pressure distribution throughout the airfoil. The amount of pressure on the airfoil have noted through the tapping. By setting the model in different angle of attacks to know the different streamline flow around the airfoil.

6.3 EXPERIMENTAL RESULTS

Table.6.2 Manometer reading table

angle of attack	0	2	4	6	8	10	12	14	15
manometer readings									
1	6.6	6.9	7.1	7.2	7.3	7.4	7.4	7.4	7.2
2	7.4	7.5	7.7	7.7	7.8	7.8	7.8	7.7	7.6
3	9.3	9.4	9.3	9.2	9.1	8.9	8.8	8.5	8.5
4	8	7.9	7.7	7.4	7.2	7	6.8	6.4	6.2
5	5	4.9	7.8	4.6	4.5	4.3	4.2	3.9	3.8
6	7.3	6.9	6.6	5.9	5.5	5	4.6	4.1	4
7	2.4	2.5	2.8	3	3.3	3.6	3.9	4.3	4.5
8	8.8	8.1	7.9	8	8.1	8.1	7.9	7.9	7.9
9	6.6	6.7	6.7	6.8	6.9	6.8	6.8	6.8	6.7
10	7.9	8.1	8.1	8.3	8.4	8.4	8.3	8.2	8.4
11	7.4	7.5	7.6	7.8	7.8	7.8	7.7	7.7	7.6
12	7.4	7.5	7.6	7.8	7.8	7.9	7.9	8	7.9

6.4 FINDING THE CO EFFICIENT OF PRESSURE

The coefficient of pressure is calculated through the below formula for every angle of attack by the manometer readings.

Formula

$$C_p = \frac{P_{s_1} - P_s}{P_t - P_s}$$

- Cp = co-efficient of pressure
- Ps1 = static pressure in different angle of attacks
- Ps = static pressure
- Pt = total pressure

Table.6.3 Cp calculation values table

angle of attack cp	0	2	4	6	8	10	12	14	15
1	-0.451612903	-0.548387097	-0.612903226	-0.64516129	-0.677419355	-0.709677419	-0.709677419	-0.709677419	-0.64516129
2	-0.709677419	-0.741935484	-0.806451613	-0.806451613	-0.838709677	-0.838709677	-0.838709677	-0.806451613	-0.774193548
3	-1.322580645	-1.35483871	-1.322580645	-1.290322581	-1.258064516	-1.193548387	-1.161290323	-1.064516129	-1.064516129
4	-0.903225806	-0.870967742	-0.806451613	-0.709677419	-0.64516129	-0.580645161	-0.516129032	-0.387096774	-0.322580645
5	0.064516129	0.096774194	-0.838709677	0.193548387	0.225806452	0.290322581	0.322580645	0.419354839	0.451612903
6	-0.677419355	-0.548387097	-0.451612903	-0.225806452	-0.096774194	0.064516129	0.193548387	0.35483871	0.387096774
7	0.903225806	0.870967742	0.774193548	0.709677419	0.612903226	0.516129032	0.419354839	0.290322581	0.225806452
8	-1.161290323	-0.935483871	-0.870967742	-0.903225806	-0.935483871	-0.935483871	-0.870967742	-0.870967742	-0.870967742
9	-0.451612903	-0.483870968	-0.483870968	-0.516129032	-0.548387097	-0.516129032	-0.516129032	-0.516129032	-0.483870968
10	-0.870967742	-0.935483871	-0.935483871	-1	-1.032258065	-1.032258065	-1	-0.967741935	-1.032258065
11	-0.709677419	-0.741935484	-0.774193548	-0.838709677	-0.838709677	-0.838709677	-0.806451613	-0.806451613	-0.774193548
12	-0.709677419	-0.741935484	-0.774193548	-0.838709677	-0.838709677	-0.870967742	-0.870967742	-0.903225806	-0.870967742

6.5 CALCULATE X/C AND Y/C FOR EACH PORT

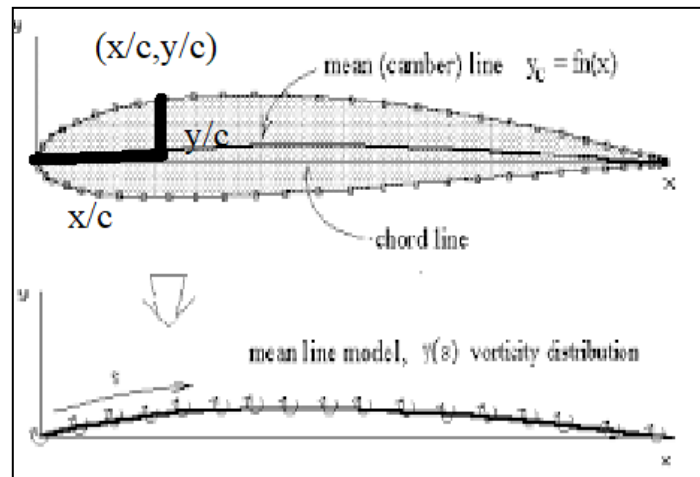


Figure.6.5

Further x/c (distance one tapping to the other in horizontal direction) is measured from the fabricated model. y/c is measured in such a way that distance from each tapping to the chord line in vertical direction. Calculation of C_l , C_d and C_m will be calculated using the x/c and y/c values by choosing only negative value max and min for calculating at every angle of attack.

Table.6.4 x/c and y/c values table

SI.NO	x/c	y/c
1	0.9	0.5
2	1	0.8
3	0.7	1
4	1	1.1
5	0.8	1
6	0.5	0.9

7	1	0
8	1	0.9
9	1	1
10	1	0.9
11	0.9	0.8
12	0	0.5

6.6 FORMULA'S FOR CL,CD and CM

$Cl = (\text{max value upper camber} - \text{min value lower camber}) * (x/c_{\text{max}} - x/c_{\text{min}})$

$Cd = (\text{max value upper camber} - \text{min value lower camber}) * (y/c_{\text{max}} - y/c_{\text{min}})$

$Cm = (ac - x/c_{\text{max}}) * (Cl * \cos(\text{AOA}) + Cd * \sin(\text{AOA}))$

- Cl- Co-efficient of lift
- Cd- Co-efficient of drag
- Cm- Co-efficient of momentum
- x/c- Distance between one tapping to another in horizontal direction
- y/c- Distance between tapping to chord line
- ac- Aerodynamic chord (ac=0.25)
- AOA- Angle of attack

Following these Cl, Cd, and Cm calculations, we calculate the eccentricity of the airfoil at every angle of attack from 0 to 15 degree's.

6.7 FORMULA'S FOR ECCENTRICITY

For the complete airplane, the drag coefficient is written as

$$C_D = C_{D_0} + K C_L^2$$

This equation is the *drag polar* for an airplane.

Where: C_{D_0} drag coefficient at zero lift (or parasite drag coefficient)

$K C_L^2 =$ drag coefficient due to lift (or induced drag coefficient C_{Di})

$$K = 1/\pi e AR$$

By converting the above formula in such a way into $k=\text{constant}$. Finding the constant, we can submit it in the eccentricity formula.

$$E = 1 / \pi K AR$$

- E - Eccentricity
- K - Constant
- AR - Aspect ratio

Through this formula, we calculated the eccentricity.

6.8 FORMULA'S FOR INDUCED DRAG

$$C_{Di} = K C_L^2$$

- C_{Di} - Induced drag co-efficient
- C_L - Co-efficient of lift
- K - Constant

Induced drag is calculated by the above formula.

Table.6.5 C_l, C_d, C_m, E & C_{di} values table

angle of attack	C_L	C_D	C_M	E	C_{di}
0	1.11285	1.33542	0.83463	0.12444	1.32055
2	1.11285	1.33542	0.78758	0.12444	1.32055
4	1.0483	1.25796	0.69658	0.1173	1.24309
6	0.99995	1.19994	0.53741	0.11196	1.18507
8	0.93545	1.12254	0.53857	0.10482	1.10767
10	0.8548	1.02576	0.45328	0.0959	1.01089
12	0.79025	0.9483	0.38255	0.08877	0.93343
14	0.6774	0.81288	0.29628	0.0763	0.79801
15	0.6451	0.77418	0.26697	0.072725	0.75931

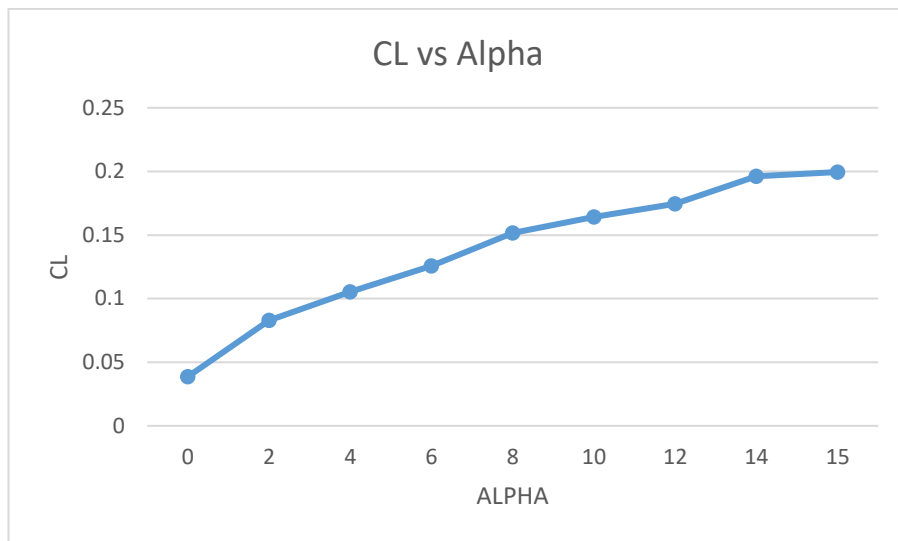


Figure.6.6 Cl vs alpha of experimental analysis

The above graph represents the analytical data of experimental analysis of Cl vs alpha that increased from 0.04 to 0.2.

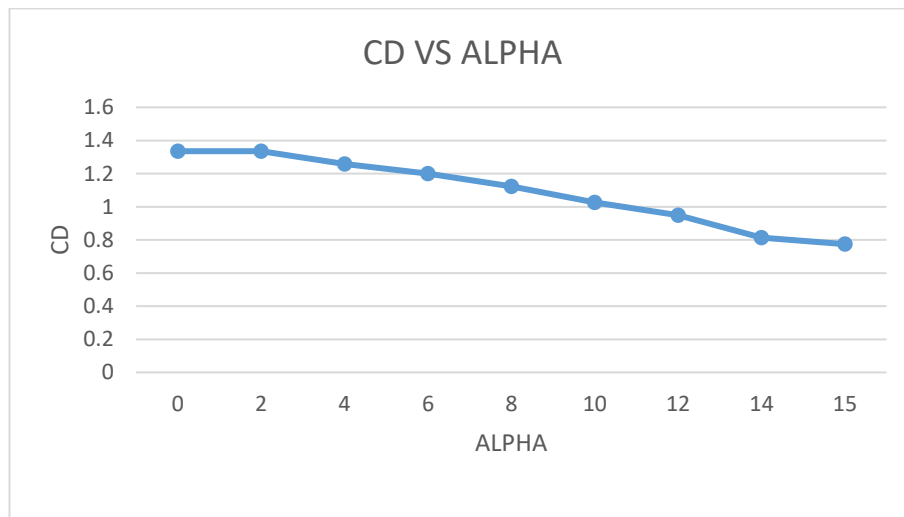


Figure.6.7 Cd vs alpha of experimental analysis

In the above graph it shows the drag has been reduced from 1.3 to 0.8 lasting from 0 to 15 angle of attack in the experimental analysis.

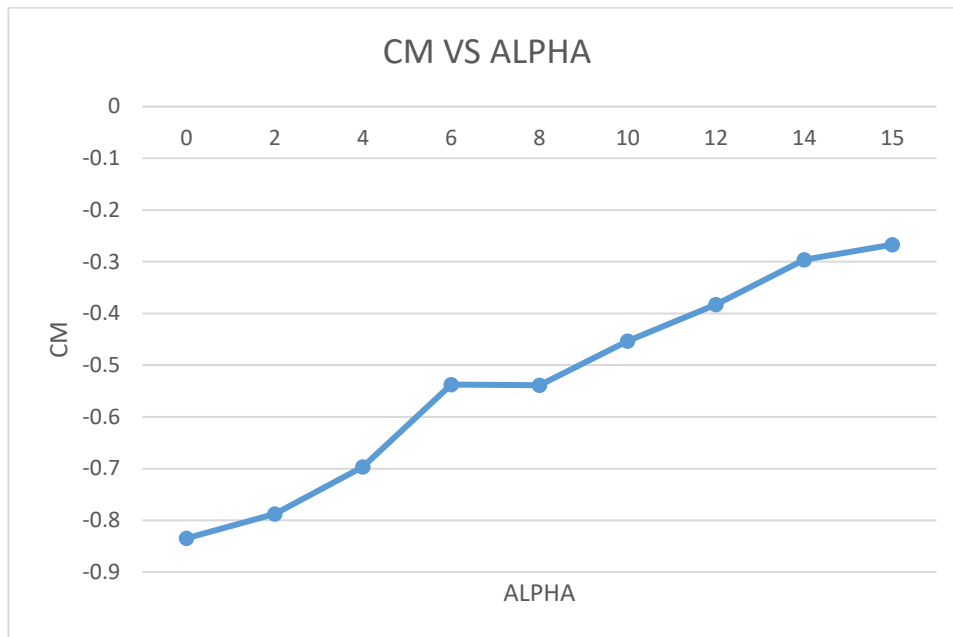


Figure.6.8 Cm vs alpha of experimental analysis

In the Cm vs alpha graph we can observe the co efficient of momentum gradually increased.

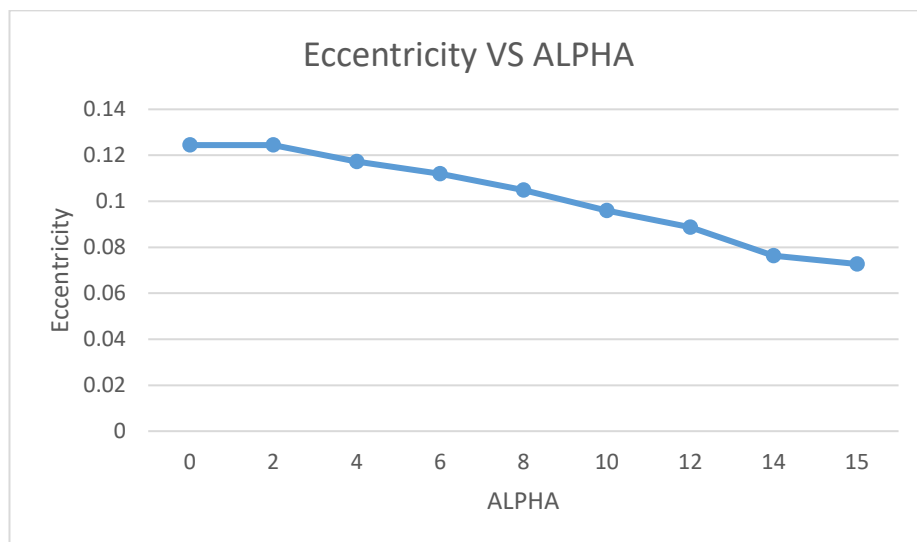


Figure.6.9 E vs alpha of experimental analysis

The line graph shows that the eccentricity dropped gradually rpm from 0.23 to 0.7 approximately.

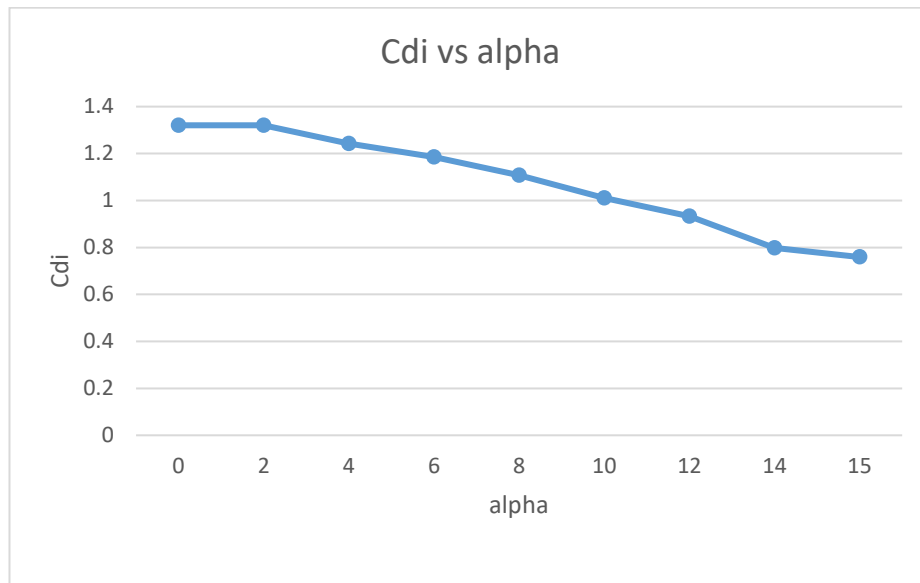


Figure.6.10 Cdi vs alpha of experimental analysis

In the Cdi vs alpha graph the Cdi dipped constantly from 1.3 to 0.8. Compared to both eccentricity and induced drag have decreased.

Plotted Graphs of C_l , C_d , C_m , E and C_{di}

CHAPTETR 7

RESULTS AND DISCUSSION

Finally, when we compare the graphs of the already existing model and the Introduced model we have found a difference. It shows that the drag force of the introduced model is greater than the existing model with the normal engine locations and type of electrical engines. The comparison of graphs of both analytical and experimental looks similar. The drags and lift of both the models are as follows.

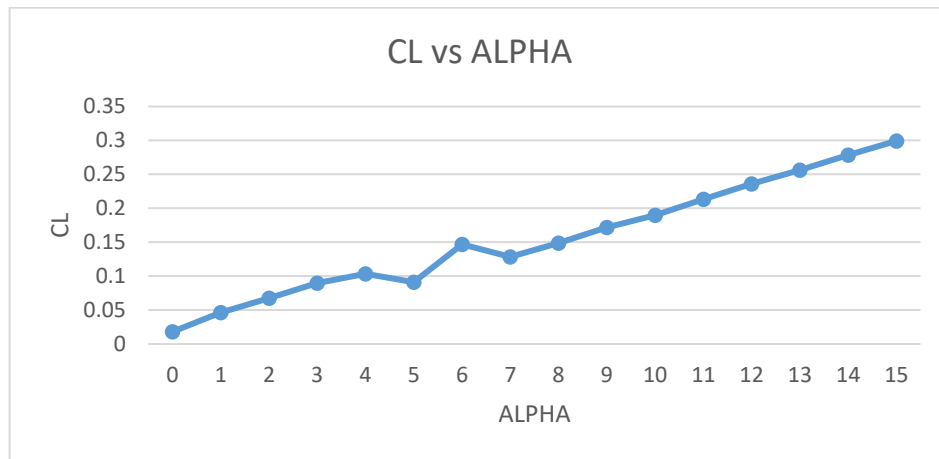


Figure.7.1

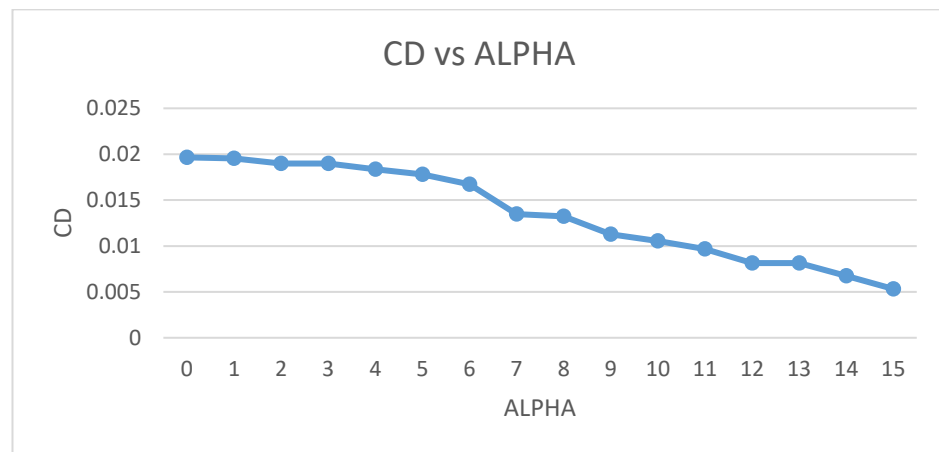


Figure.7.2

Lift and Drag force of analytical analysis

The lift and drag force graphs for analytical analysis clearly give the less drag with best like that is being able to produce. Similarly, if checked the graph of experimental analysis the lift and drag force seems to be increasing radially which is as follows.

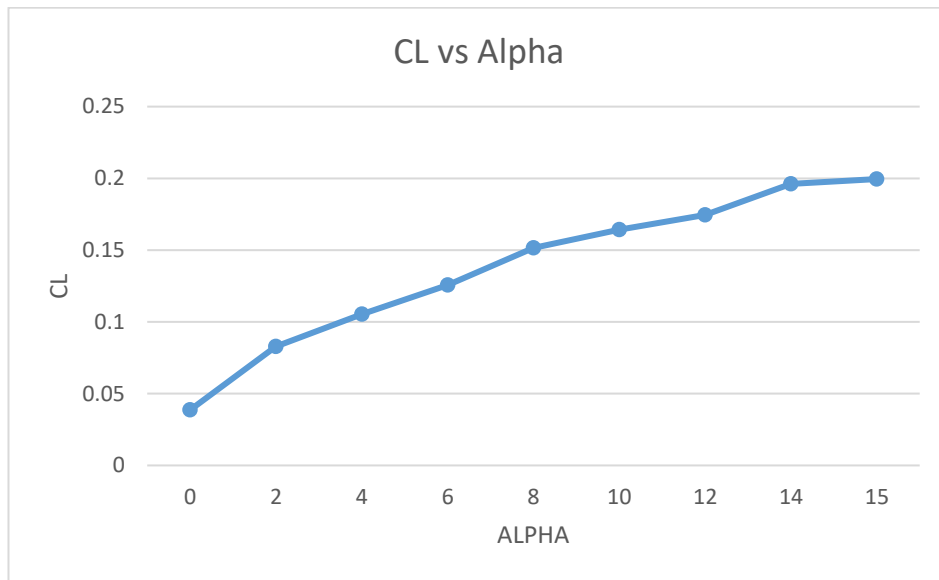


Figure.7.3

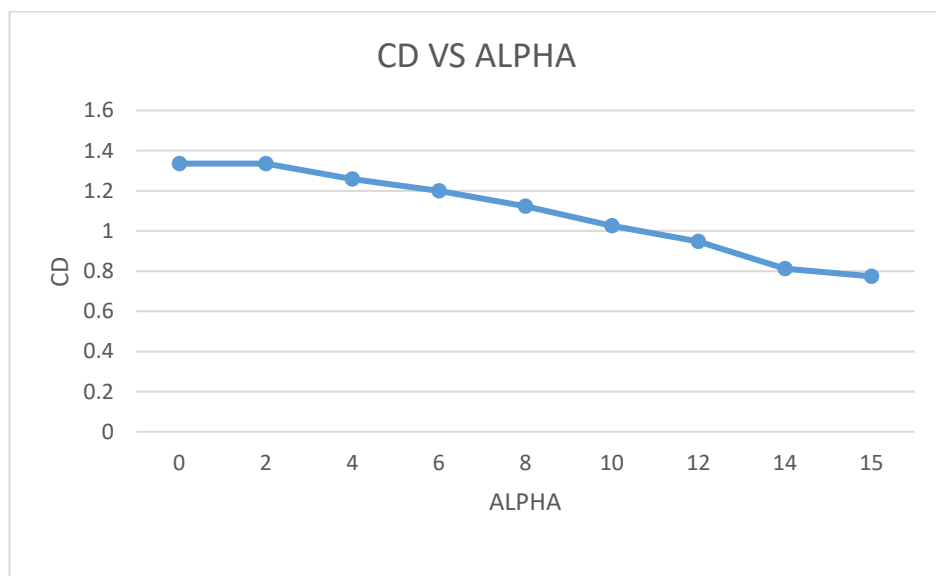


Figure.7.4

Lift and Drag force of experimental analysis

CHAPTER 8

CONCLUSION

Through the graphs, we have concluded that the lift has increased 2 to 3 % and drag is decreased slightly comparative to analytical in experimental analysis. Cruise is done using tip mounted engine, profiting by the consequent drag reduction. Higher cl_{max} permit to design wing of the smaller surface. this brings to a further reduction of drag, in the lower wetted area. Complete automatic CFD procedure available for design analysis, DOE, SRM, and methodologies development. A study of the effect of wingtip propeller and distributed propulsion on general aviation commuter wings has demonstrated ways to reduce the induced drag (from 2-3%) in a range of lift coefficients up to $0.4 < CL$. Comparing the SkyVultur aircraft to other designs, the standout feature we observed was the efficient wingtip device, which increases effective AR, reducing induced drag and improving flight performance. As a result of the drag reduction, fuel efficiency was enhanced (a 6% reduction in block fuel burn), which reduced emissions, and operating costs were reduced, when compared to similar configurations. Even though the benefits of wingtip devices for induced drag reduction are well documented in the literature, no study has examined their net advantages on tactical transport aircraft. Due to the wingtip mounted engine, aerodynamic efficiency was improved despite a modest increase in wingspan and surface, so the wing primary structure did not change and flights did not suffer.

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FUTURE SCOPE OF THE PROJECT

The main scope of the project is to gain the better performance by the aerodynamic shape given to the wing and the engine, that helps to increase the lift, reduce induced drag, minimizing the aero elasticity using the electric propulsion. As, electric propulsion is better way to get more efficiency, high performance, low maintenance. We have created a new design of the engine cowl for electric propulsion and testing in different positions on the wing. The future scope of the project is to induct an electric driven engine to have better efficiency and performance.