Aerodynamic Characterization of Fins for Maneuvering Missile using CFD

Submitted in partial fulfillment of the requirements of the degree of

Bachelor of Technology

In

Aerospace Engineering

By

Vaibhav Bhoge (180101051025)

Under the Supervision of

Mr. Teleti Mahesh Kumar

Department of Aerospace Engineering

School of Engineering & Technology

Sandip University Nashik

2021-2022

SANDIP UNIVERSITY NASHIK

SCHOOL OF ENGINEERING & TECHNOLOGY

Department of Aerospace Engineering

Recommendation

This is to certify that the dissertation entitled **“Aerodynamic Characterization of Fins forManeuvering Missile using CFD”** submitted by **Vaibhav Bhoge (180101051025)** has been carried out under my guidance and supervision. The dissertation is approved for submission towards partial fulfillment for the award of the degree of **Bachelor of Technology** in **Aerospace Engineering.**

It is further certified that this work has not been submitted for the award of any other degree or diploma to my knowledge.

Mr. Teleti Mahesh Kumar
Assistant Professor

Department of Aerospace Engineering

School of Engineering & Technology

SANDIP UNIVERSITY

Certificate

This is to certify that

Vaibhav Bhoge

Student of B. Tech with specialization in “Aerospace Engineering” were examined

in a dissertation entitled

“**Aerodynamic Characterization of Fins for Maneuvering Missile using CFD**” on / /2022

at

Department of Aerospace Engineering

School of Engineering & Technology, Sandip University, Nashik

Internal Examiner **External Examiner**

Date:-

Place:- Sandip University Nashik

Department of Aerospace Engineering
School of Engineering & Technology

SANDIP UNIVERSITY

Candidate Declaration

I declare that this written submission represents my ideas in my own words and where other's ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated, falsified or plagiarized any idea/data/fact/source in my submission. I understand that any violation of the above may cause for withdrawal of my degree by the institute and can also evoke penal action from the sources which have not been properly cited or from whom proper permission has not been taken when needed.

Vaibhav Bhoge
(180101051025)

Acknowledgment

It would not have been possible to complete this project work without the kind support and help of many individuals and organizations. I would like to extend my sincere thanks to them. I wish to express a true sense of gratitude towards my project guide, Mr. Teleti Mahesh Kumar, Aerospace Department, who at very discrete steps in the study and implementation of this project, contributed their valuable guidance and helped to solve every problem that arose. I would like to thank HOD Aerospace Department for their support and for providing all facilities to project work. I would also like to express my sense of gratitude to all the people who directly or indirectly supported me in completing this project work. I would like to express my special gratitude and thanks to my parents, who encouraged and inspired me with their blessings.

Vaibhav Bhoge
(180101051025)

Dedication

I dedicate this project work to my family and many friends. A special feeling of gratitude to my loving parents, whose words of encouragement pushed me to achieve great things in my life. I also dedicate this work to many friends who have supported me throughout the process. I will always appreciate all they have done. This project is also dedicated to the teaching staff of Aerospace Department for their continuous support and guidance.

Abstract

The project investigates computationally the aerodynamic coefficients of clipped-delta fins. The primary function of the movable fins is to provide stability to the missile and enable control of the direction. The aerodynamic behavior of the fins was studied in ANSYS fluent, where the input of different parameters was made and analyzed. Computations were performed at different Mach nos. and angles of attack. In order to understand the position and size of fins, calculations for the centre of mass and centre of pressure were done. Stability increases as the distance between the centre of mass and the centre of pressure increases. Hence, placing fins at the tail end of a missile moves the centreof pressure closer to the tail end and increases stability. Additionally, the missile has a pyro-based FinLocking System that holds the fins in locked condition at the time of launch and releases them after attaining a safe separation distance.

Table of Contents

List of Tables

Table of figures

List of Symbols, Abbreviations

C_l roll moment coefficient

C_m pitching moment coefficient

C_n yawing moment coefficient

Δy first cell spacing off the wall

M Mach number

y^+ nondimensional turbulent boundary-layer coordinate

α angle of attack, deg

U_∞ free stream velocity

ρ free stream density

μ dynamic viscosity

S reference area

L reference length

C_t tip chord

C_r root chord

C_{avg} chord average

φ sweep angle

CP centre of pressure

CG centre of gravity

Chapter 1
Introduction

1.1 Introduction

A missile is a rocket-propelled weapon designed to deliver an explosive warhead with great accuracy at high speed. The performance of a missile during its operation is the primary concern, which depends upon the flight stability of the missile. Here comes the role of fins. It works in the same way as placing feathers at the tail of an arrow. The greater drag on the feathers keeps the tail of the arrow at the back so that the point of the arrow travels straight into the wind. The equations governing the dynamics of these fins in flight are non-linear partial differential equations that are difficult to model analytically and are expensive. Hence numerical methods using computational fluid dynamics come into use. CFD is attractive to the industry since it is more cost-effective than physical testing.

Early rockets and current air-to-air missiles typically use movable fins at the rear of the rocket. The movable fin adjusts the amount of the aerodynamic force on the rocket. The aerodynamic force acts through the center of pressure which is normally not located at the center of gravity. The difference in location generates the torque about the center of gravity, or center of mass. On the figure, the trailing edge of the fin facing us has been colored magenta and has been deflected to the right. The resulting aerodynamic force would move the nose of the rocket to the right.

Many different methods have been developed to control rockets in flight. The motion of any object in flight is a combination of the translation of the center of gravity and the rotation of the object about its center of gravity, which is also called the center of mass. All of the control methods produce a torque about the rocket's center of gravity which causes the rocket to rotate in flight. Through an understanding of the forces acting on the rocket and the resulting motion, the rocket guidance system can be programmed to intercept targets or to fly into orbit.

Currently, in space and defense applications, the pyro-operated mechanism is widely used. These devices are used in separation mechanisms and flow control values. These are highly reliable systems and their usage improves the reliability of the overall system. In defense applications, one of the areas where these pyros are widely used is holding the control surfaces of air-launched weapons. One such system developed is Fin Locking Mechanism (FLM). The above technique is also used for holding the fins in locked condition at the time of launch and unlocking them after attaining a safe separation distance.

The only issue with the Fin locking mechanism lies in the Pyro cartridge which is quite high in cost and the standard Pyro cartridge is available in the global market. The main reason for focusing on the Pyro cartridge is due to the sensitive nature of the circuit that affects the total performance of the Fin locking system. Various studies are being carried out to improve the Pyro techniques as in the research carried out by Danali S.

In this context, the proposed work also deals with a detailed study of the Fin locking mechanism and the functioning of the system. At the same time, this project allows understanding the designparameters of a mechanism that suits the applications of missiles.

1.2 Overview

There are four major components to any full-scale rocket; the structural system or frame, the payload system, the guidance system, and the propulsion system. The guidance system of a rocket includes very sophisticated sensors, onboard computers, radars, and communication equipment. The guidance system has two main roles during the launch of a rocket; to provide stability for the rocket, and to control the rocket during maneuvers.

Current air-to-air missiles typically use movable fins at the rear of the rocket. They are ideally suited to work because of many reasons such as fins are lightweight, produce low drag, are easily made and attached, and most importantly provide good assurance of stability. The movable fin adjusts the amount of the aerodynamic force on the missile. Fins provide high restoring lift force even at small angles of attack. It is important to reduce turning momentum (due to the mass of the missile), which can lead to underdamped wobbling of the missile. We have designed the fin geometry to be a clipped delta shape as it has a streamlined look and also low weight.

1.3 Objective

1. To design fin for the missile.
2. Analyze the effect of the fin at a various angle of attacks.
3. Observe the movement of fins to achieve stability of the missile.

Chapter 2

Literature Review

2.1 History

The use of missiles dates back to the Vedic age in India. Indian warriors have used "Astras" as missiles and various forms from that period in the subcontinent, proofs of which can be drawn from a number of epics such as Mahabharata and the Ramayana. The deadly weapons and the scriptures regarding the technology were later concealed to prevent any future happenings, for the sake of the survival of mankind. In the olden days, the supernatural weapon was controlled by "Mantras" that could be correlated to the mission controls software of the modern-day missiles.

Fighting the British colonial army, Tipu Sultan and his army use thousands of rockets resulting in the defeat of the troops in the Srirangapatna war in 1792. The rockets were attached with bamboo Steel spears and powered by gunpowder, propellant compacted in a cast iron chamber with nozzle and ignitors capable of attacking enemy cavalry and soldiers.

The modern-day missiles have their roots in Germany as the country developed the first successful guided missiles V1 and V2. After the second World war, several other Nations developed a variety of missile systems.

India had mastered missile technology from the olden days, but it was left behind in this field when the Britishers rule the country for hundreds of years, resulting in lack of resources, research environment, and capabilities. This was the time in India decided to go ahead with its integrated guided missile development program (IGMDP) headed by eminent scientist and former President of India Dr. APJ Abdul Kalam who launch the first satellite launch vehicle, SLV 3 putting the Rohini satellite in orbit.

The IGMDP project begin on July 26, 1983 at defence research in the development laboratory (DRDL) in Hyderabad. A host of missiles, including the strateAgni-relatedated range ballistic missile (IRBM), the tactical Prithvi, the Aakash, the Trishul surface to air missiles, and the nag anti-guided missiles were developed under programme. The project gave India the capability to produceindigenous missiles in other key areas as well.

Indigenous development of the weapon was required to negate the dominance of Western Nations who impose their will on developing countries by enforcing parts like the Missile TechnologyControl Regime (MTCR). Such pacts were aimed at controlling access to and availability of advancedweapon systems to India.

A new world order emerged after India carried out the nuclear experiment in May 1998 and became a nuclear-weapon state. Today, India is one of the few countries in the world to have indigenously developed missile systems including critical technology is like the re-entry tip for ballistic missiles.

Since the early 90s, India has faced the threat of ballistic missile attacks from Pakistan against which it has fought multiple wars in the past, and also from China. With the heightening of tensions in the region, and in response to Pakistan's deployment of M-11 missiles bought from China, the Indian Government in August 1995 procured six batteries of S-300 Surface-to-air missiles to protect New Delhi and other cities. In May 1998, India for the second time (since its first test in 1974) tested nuclear weapons (*see Pokhran-II*), followed by Pakistan with its first-ever nuclear test. With Pakistan's testing of nuclear weapons and missile delivery systems, this threat intensified. India has also developed and tested missile delivery systems during Integrated Guided Missile Development Programme (IGMDP).

Development of an anti-ballistic missile system began in late 1999,[11] suggesting that India initiated the program in light of Pakistan's eschewing of a nuclear No first use policy and heightened tensions during the Kargil War including a possibility of full-scale nuclear war.

The Indian Ballistic Missile Defence Program is an initiative to develop and deploy a multi- layered defence system to protect India from ballistic missile attacks. Phase 1 has been successfully tested and completed and deployment awaits final official permission. Phase 2 is under development.

Introduced in light of the ballistic missile threat from Pakistan and China, it is a double-tiered system consisting of two land and sea-based interceptor missiles, namely the Prithvi Air Defence (PAD) missile for high altitude interception, and the Advanced Air Defence (AAD) Missile for loweraltitude interception.

- P. Sethunathan, R. N Sugendran, T. Anbarasan proposed Aerodynamic Configuration Designof a Missile. They explained aerodynamic characteristics of the missile body using analytical methods. They concluded that an Anti-aircraft missile's performance can be inversely proportional to the Drag value. When the diameter of the missile decreases and increasing Nose fineness ratio, the Drag value is reduced. Mach number is directly proportional to the Drag value. Whereas Drag value is inversely proportional to the Altitude.

- Nenad Vidanovic, Boško Rašuo, and Gordana Kastratovic´ proposed Aerodynamic–structural missile fin optimization. An aerodynamic–structural surrogate-based evolutionary optimization was carried out on a short-range ballistic missile model.

- Amandeep Singh proposed Aerodynamic analysis on missile design. He analysed aerodynamic characteristics of an anti-aircraft missile using analysis software ANYS2020R1. He observed that Drag values are increasing with increasing Mach number. At the end he concluded the effect of variation of flow over a missile body.

- T V Karthikeyan, A K Kapoor proposed detailed study of Guided missiles. They explained history of missile, missile propulsion and design of missile body based on various conceptualstudy. Also explained national and international scenarios of launching missiles.

- Mehraj, K. Sai Priyanka, D. Govardhan studied Aerodynamic Design of MissileMaintaining High L/D by Increasing Lift and Minimizing Drag. He concludes that an aircraftwith a high L/D ratio is used for a long time, over a long distance to carry a large payload.

  L/D ratio is proportional to ratio of the lift and drag coefficients. This can maintain high aerodynamic efficiency.

Hence from the above literature survey, it is evident that the different designers studied the Aerodynamic characteristic of the missile and analyzed the same in different methods. The designers focused on the existing missile body but in the proposed project the performance analysis of the missile body is based on the grooves which are replaced by fins.

Chapter 3

Methodology

3.1 Flow analysis over missile

3.1.1 Geometry of missile

The missile has been designed using the software called OpenRocket. OpenRocket is a fully featured model rocket simulator that allows to design and simulate your rockets before actually building and flying them. It carries Real-time view of CG and CP position; Real-time flight altitude, velocity and acceleration information.

The missile was designed with a length of 100cm and a diameter of 5.5cm.

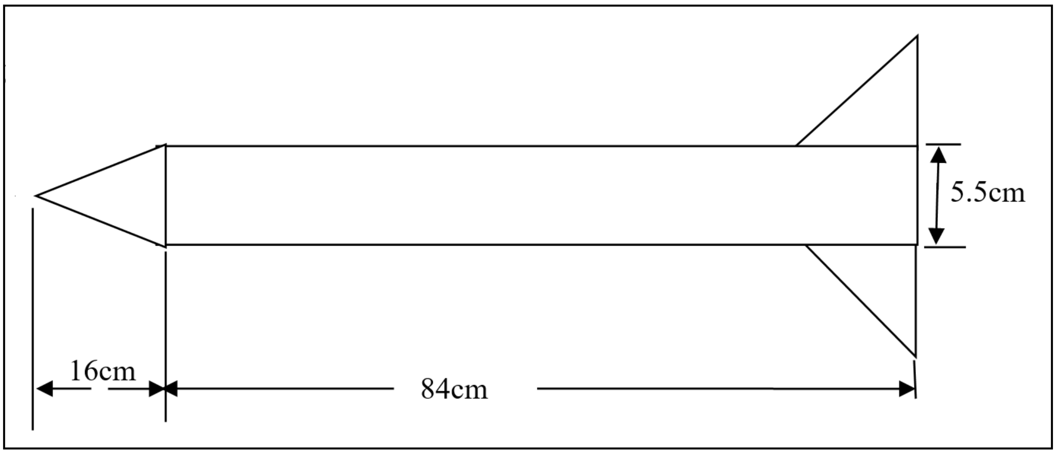


Figure 3.1 Missile dimensions

3.1.2 Parameters required for Missile Stability [CG and CP]

Let us take a little overview of CG and CP. In order to fit fins on the missile surface understanding centre of pressure and centre of gravity is necessary. Otherwise, the system will go dynamically unstable which is caused by restoring force being insufficient to overcome turning momentum. It is important to note that the centre of pressure should always be after the centre of gravity to achieve stability.

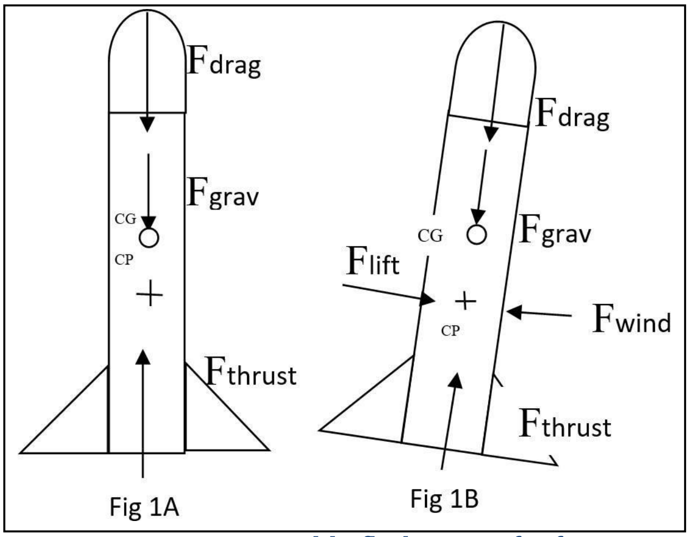


Figure 3.2 Stable flight: CP aft of CG

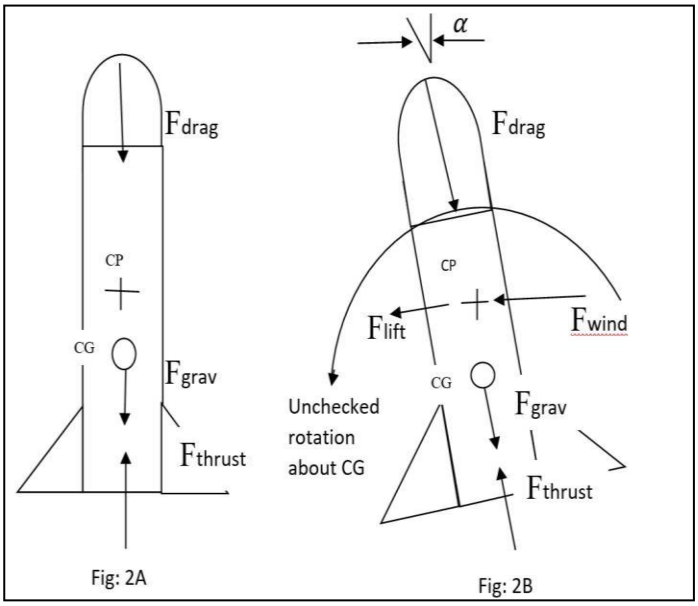


Figure 3.3 Unstable flight: CP before CG

From the above two sets of figures, it can be said that as long as the centre of mass is in front of the centre of pressure, the missile will resist any urge to turn due to the pressure of air on the sides of the missile. As soon as the missile starts to turn, there will be an imbalance in the force from a drag on one side of the missile, and this will produce torque around the centre of mass. The missile will right itself and keep flying.

3.1.3 CAD Model of Missile

Designing and modelling of missile has been done using the Fusion 360 software. The total length of the missile is 100cm including the nose cone.

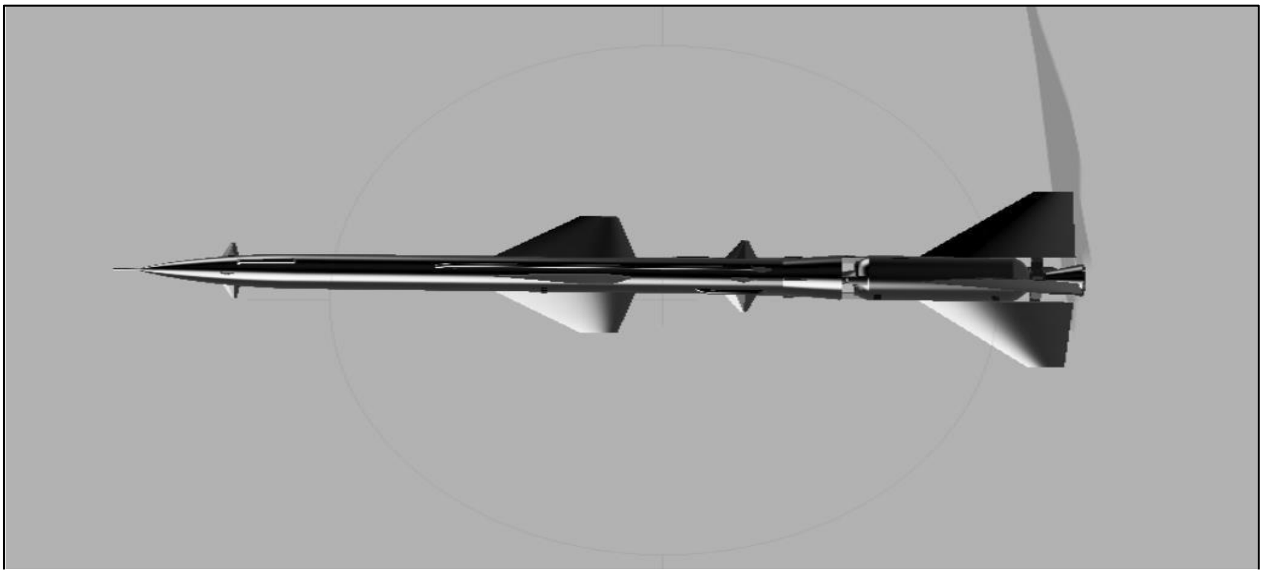


Figure 3.4 CAD Model of missile

3.1.4 2D Analysis over Missile

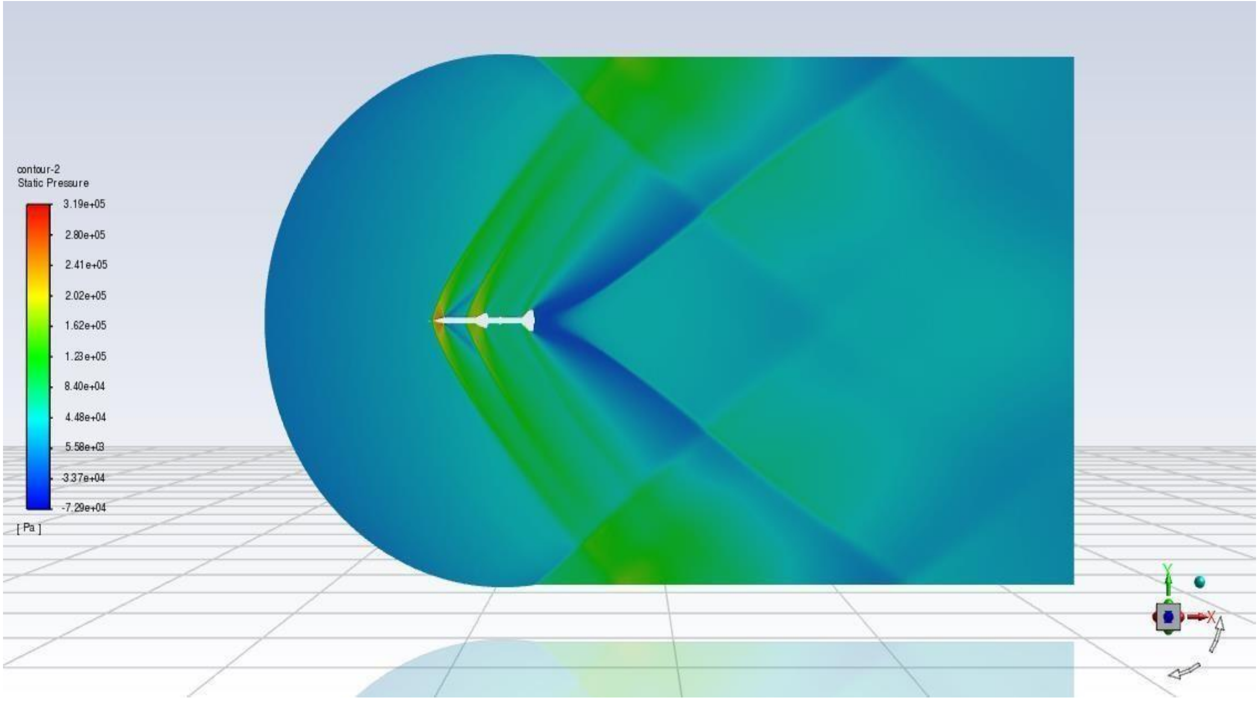


Figure 3.5 Pressure contours

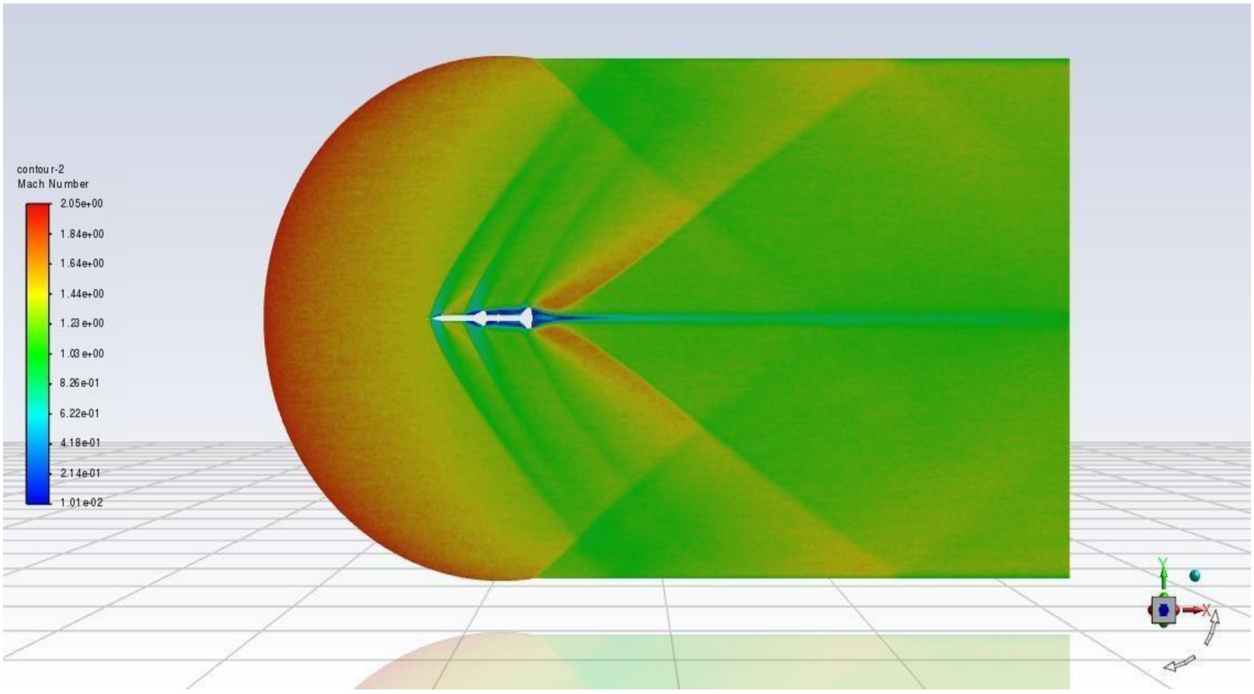


Figure 3.6 Mach contours

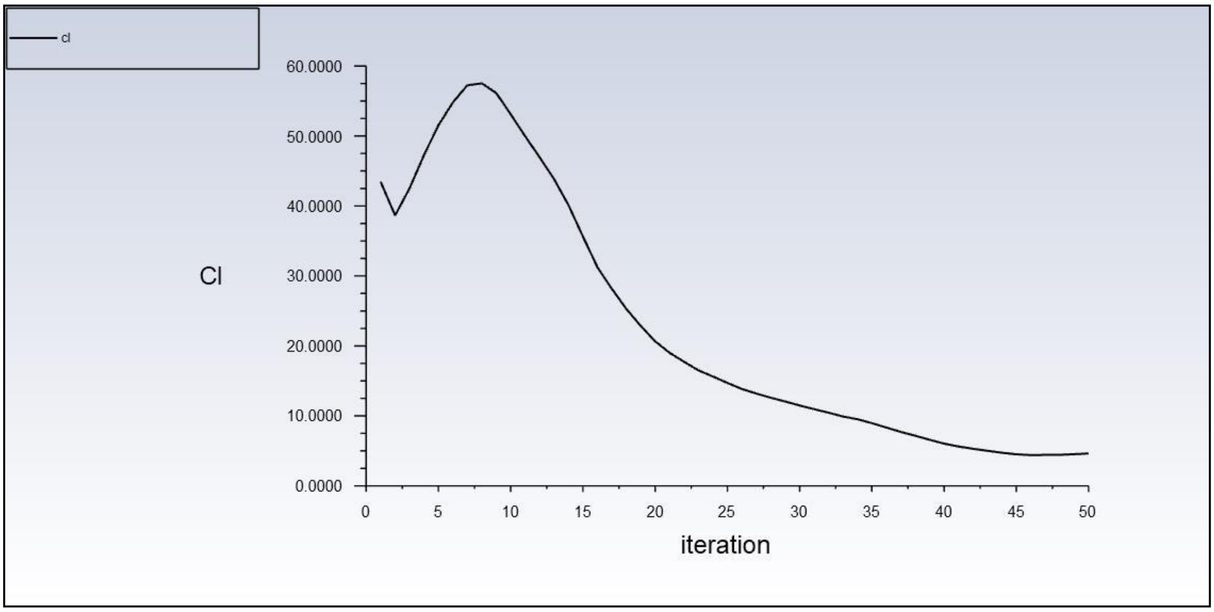


Figure 3.7 lift coefficient graph

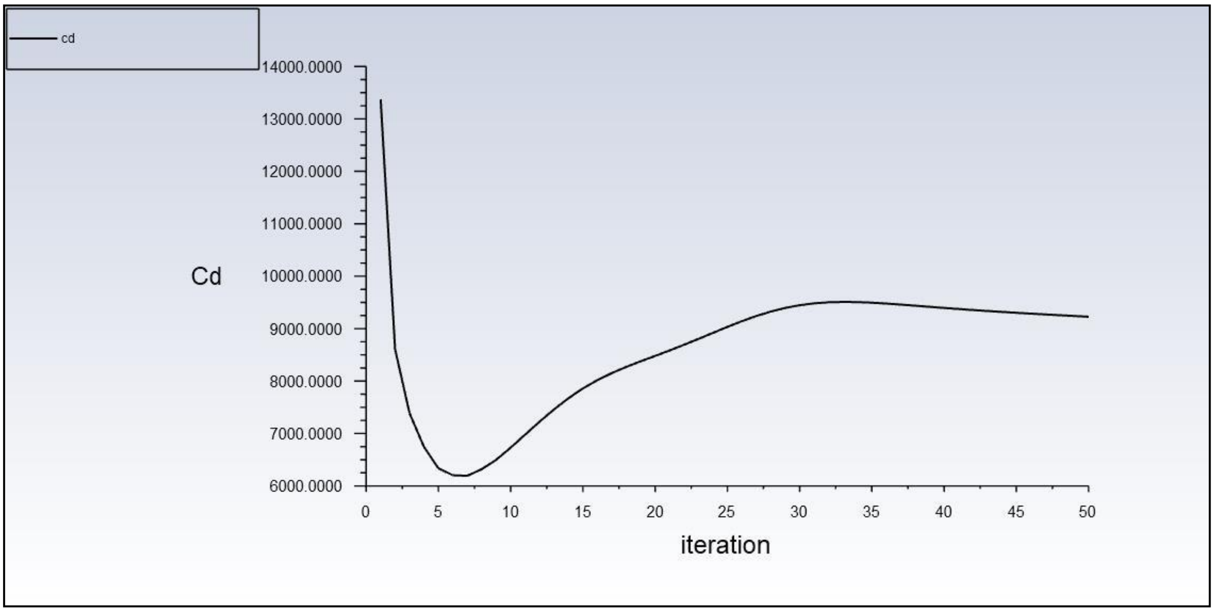


Figure 3.8 Drag-coefficient graph

3.2 Fin analysis

3.2.1 Geometrical model of fin

Fin studied in this work is a clipped delta shape created in Solidworks, having the dimensions indicated in mm. Solidworks is CAD software helpful for designing and modelling 3D objects. It is used to develop mechatronic systems from beginning to end. At the initial stage, the software is used for planning, visual ideation, modelling, feasibility assessment, prototyping, and project management. The software is then used for the design and building of mechanical, electrical, and software elements. The primary design parameters.

The primary design parameters useful for the modelling are the root cord C$\boldsymbol{r}$, tip chord C$\boldsymbol{t}$, the semi-span $\boldsymbol{b}$ i.e. the span of a single fin and the entire span will be $\mathbf{2}\boldsymbol{b}$, the sweep angle (φ), and the maximum airfoil fin thickness
$\boldsymbol{tmax}$.

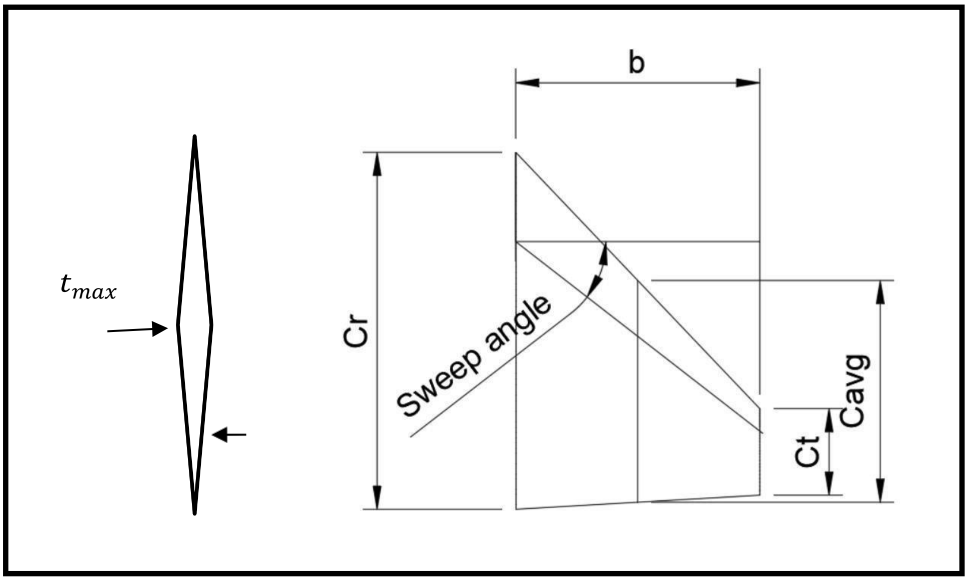


Figure 3.9 Fin Geometry

The derived Design Parameters are; Aspect ratio (AR), Average Chord (Cavg), Taper Ratio (λ), and Panel Area(S) mathematically expressed as follows.

$$AR = \frac{b}{C_{avg}}$$

$$C_{avg} = C_r + C_t/2$$

$$\lambda = C_t/C_r$$

$$S = (C_r + C_t)b/2$$

Geometric parameters	Value (in mm)
C_r	64
C_t	36
b	70
C_{avg}	50
t_{max}	5
φ	37.5
Calculated parameters	Value (in mm)
AR	1.4
S	$3500 mm^2$
$\boldsymbol{\lambda}$	1.77

Table 3.1 Geometrical and calculated data of fin

3.2.2 Modelling and Meshing

The designed geometry is then into a 3D object as shown below in the figure.

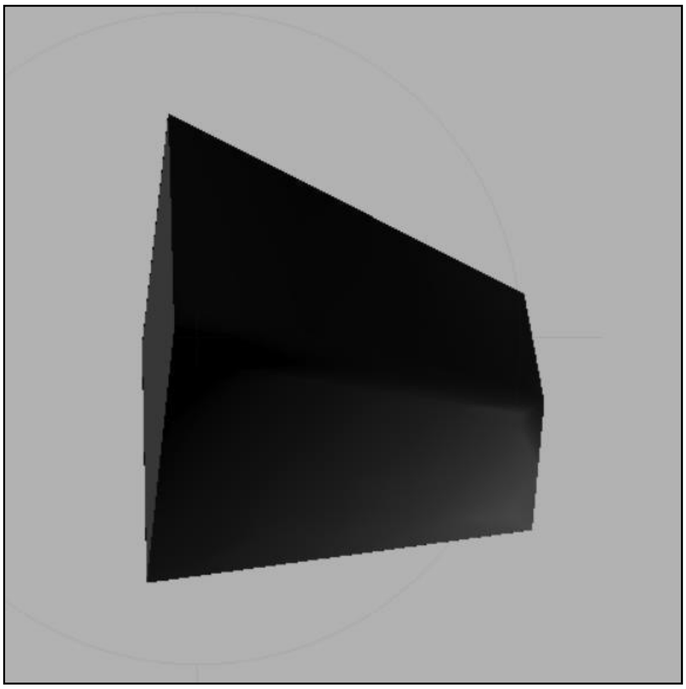


Figure 3.10 3D Fin model

After Importing the geometry, the next process that comes is meshing. Meshing is the process in which the continuous geometric space of an object is broken down into thousands or more of shapes to properly define the physical shape of the object. The more detailed a mesh is, the more accurate the 3D CAD model will be, allowingfor high fidelity simulations. Computers cannot solve simulations on the CAD model's actual geometry shape as the governing equations cannot be applied to an arbitrary shape. Mesh elements allow governing equations to be solved on predictably shaped and mathematically defined volumes. Typically, the equations solved on these meshes are partial differential equations. Due to the iterative nature of these calculations, obtaining a solution to these equations is not practical by hand, and so computational methods such as Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) are employed.

For this study, ANSYS fluent has been used to generate a mesh and obtain results as well. ANSYS Fluent is a Fluid Simulation software that uses the principles of Computational Fluid Dynamics to solve problems or to simulate mathematical models.

Provide proper named selections to each part of the geometry such as inlet, outlet and walls. This is to define our boundary conditions for further analysis.

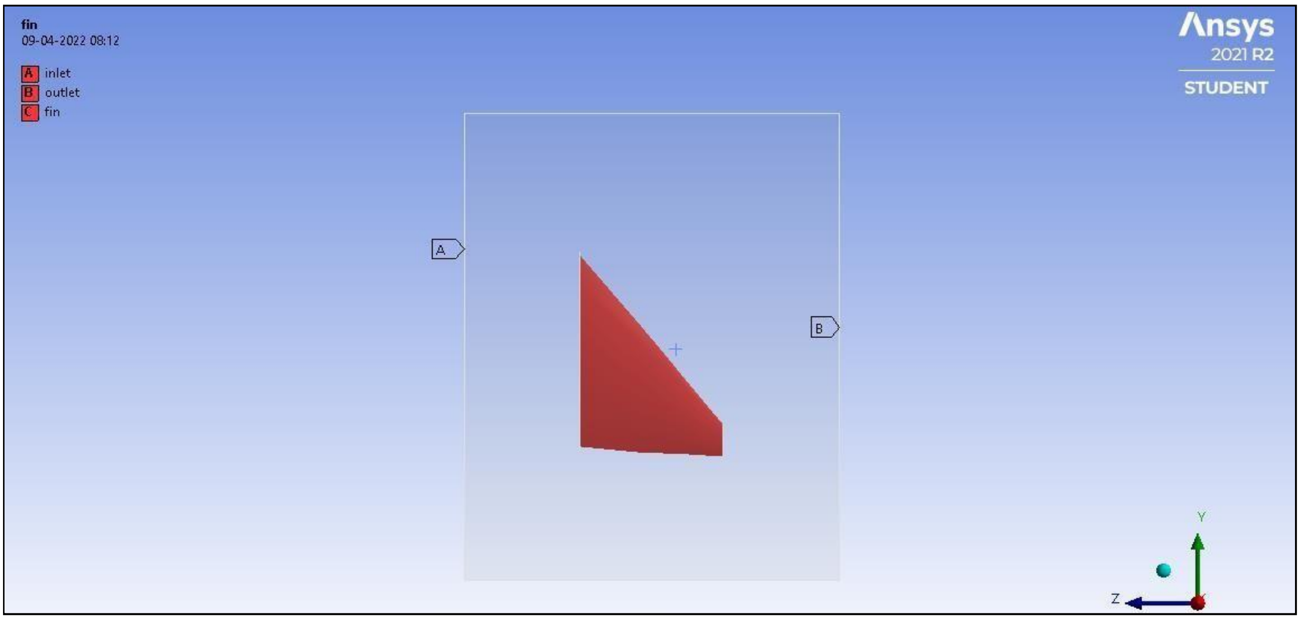


Figure 3.11 Defining boundary conditions

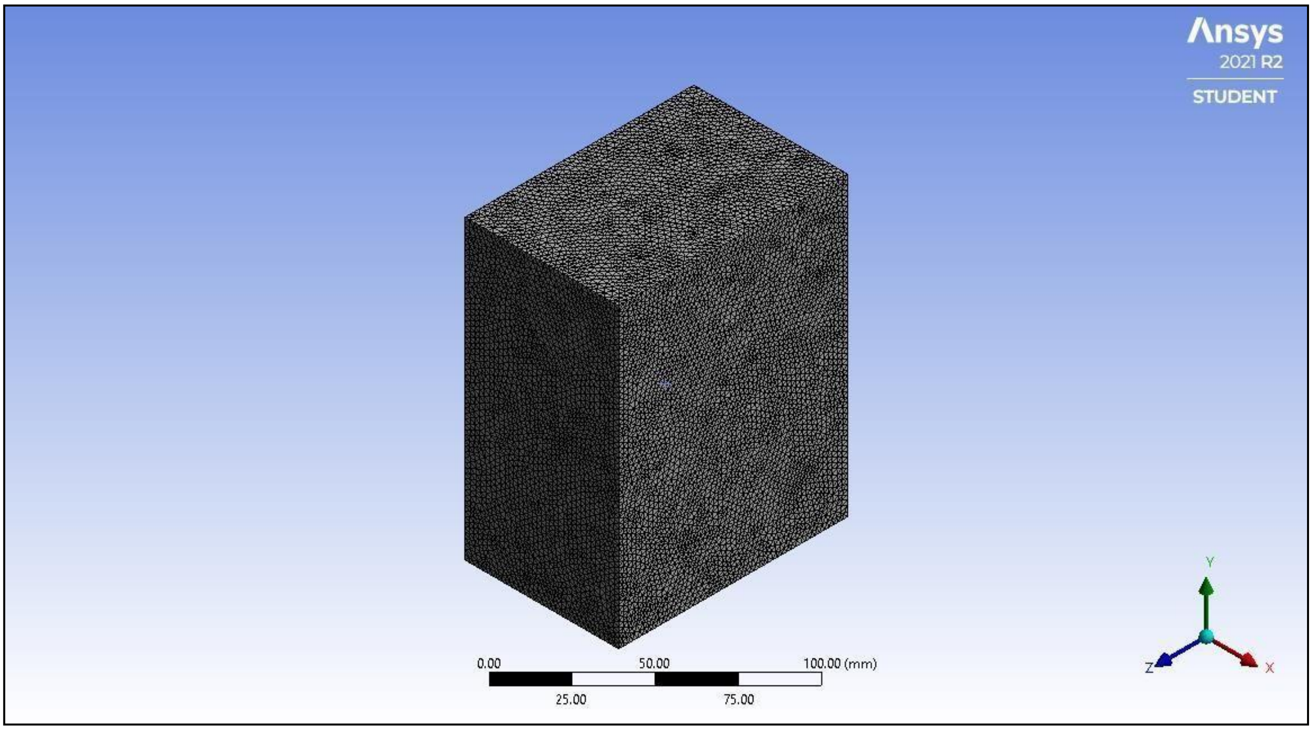


Figure 3.12 Meshing

The Inflation function of ANSYS Fluent allows to stack of cells and elements in an unconventional way normallyat their boundary. For this purpose, all layers can go in from one another up until you reach the depth of the boundary layer. Using this method, the boundary layer can be analyzed more accurately.

To resolve the effects near the wall i.e., in the viscous sub layer then the size of the mesh size should be small and dense enough near the wall so that almost all the effects are captured. However, then the question follows is how small? Thus, here comes the concept of y^+ , it is dimensionless wall, distance and based on the value $y^+$the first cell height or first layer thickness can be calculated. The near-wall region is meshed using the calculated firstcell height value with gradual growth in the mesh so that the effects are captured and avoid an overall heavymesh count.

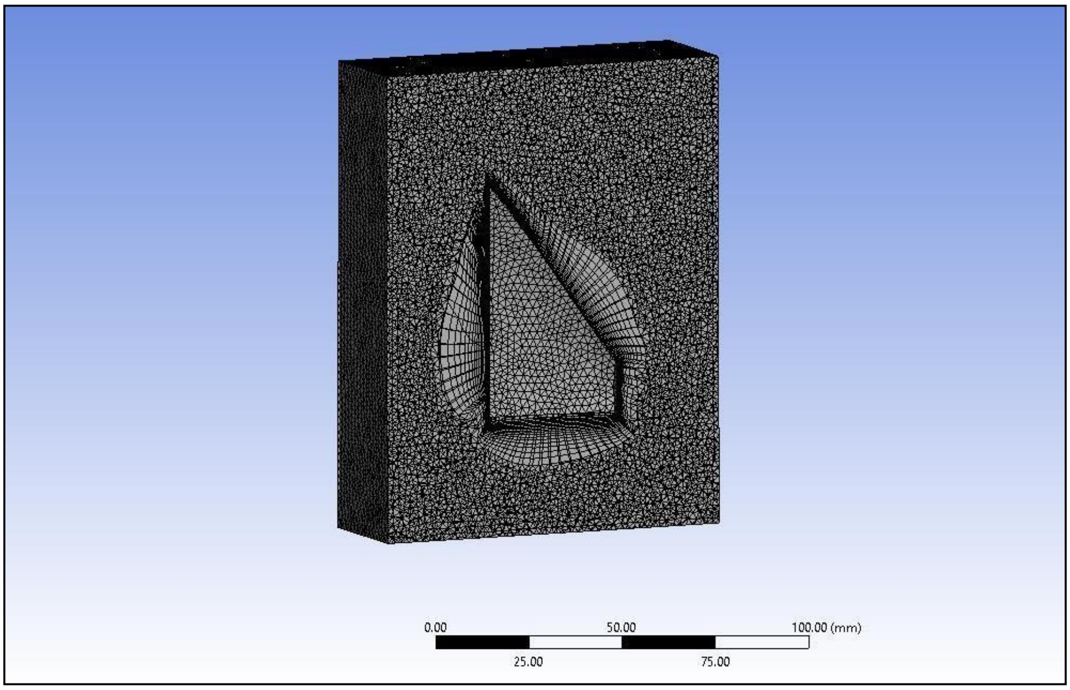


Figure 3.13 Section view to observe inflation layers

Calculating first layer thickness:

The calculation will follow as: $y^+ = \frac{yu_c}{v}$

Where, y^+ is dimensionless wall distance

u_c is the friction velocity

y is the absolute distance from the wall

v is the kinematic viscosity

Further, $u_c = \sqrt{\frac{C_\omega}{\rho}}$

r_ω is wall shear stress and it can be calculated using skin friction coefficient C_f.

$$r_\omega = \frac{1}{2} C_f \rho U_\infty^2$$

Where $C_f = 0.058\ Re^{-0.2}\ for\ external\ flows$
and $C_f = 0.079\ Re^{-0.25}\ for\ internal\ flows$

And $Reynolds\ number = \frac{\rho VD}{\mu}$

3.3 Manufacturing of missile systems

3.3.1 Fin Locking Mechanism [FLM]

A locking and unlocking mechanism for moveable control fins extending from the surface of a missile.

Components: Arduino UNO, Servo motors, Metal gears, Lithium Battery.

A servo motor is a closed-loop system that uses position feedback to control its motion and final position. Their main feature is the ability to precisely control the position of their shaft. The functioning of the Fin Locking System is based on Arduino programming. Servo motors are connected to the fins and the motion of servo motors is controlled by Arduino settings.
In this study servo motors with metal gears have been used. Servo motor is connected to the Arduino board. Arduino sends control signals to control the motion of servomotors. To make that possible Connect the control pin of the servo to any digital pin of the Arduino board, connect the Ground and the positive wires to the external 5V power supply, and also connect the Arduino ground to the servo ground.

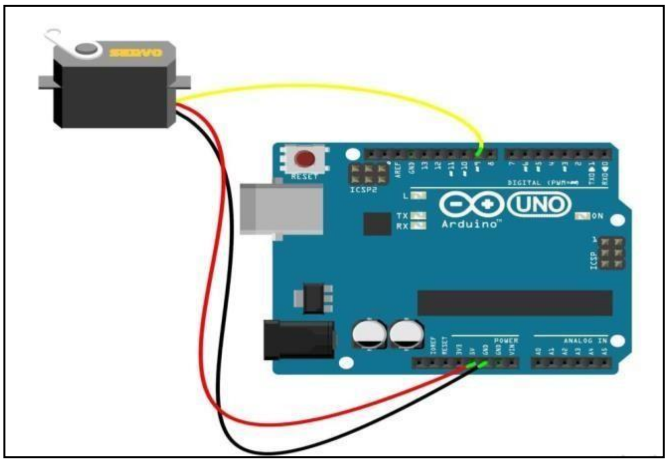


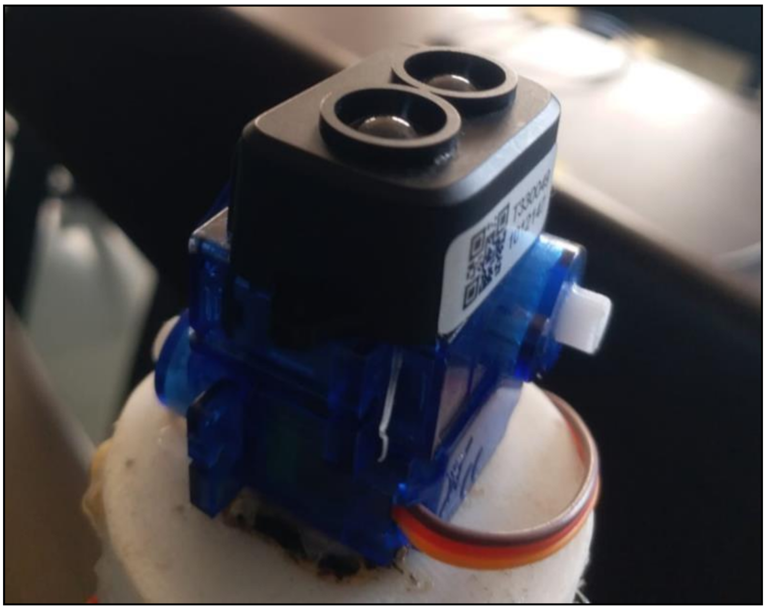
Figure 3.14 Servo motor connection with Arduino board

Servo motors have three wires: power, ground, and signal. The power wire is typically red and should be connected to the 5V pin on the Arduino board. The ground wire is typically black or brown and should be connected to a ground pin on the Arduino board. The signal pin is typically yellow, orange or white and should be connected to a digital pin on the Arduino board. Note that servos draw considerable power, so if there is the need to drive more than one or two, then probably there's a need to power them from a separate supply (i.e., not the 5V pin on Arduino). Connect the grounds of the Arduino and the external power supply together.

3.3.2 LIDAR System

Lidar, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges.

The LiDAR that is used in this project work uses focused IR LED instead of Laser and it hasInternal Processor with serial input and output.



.

Figure 3.15 LiDAR Distance sensor

Operating Range	0.1m~8m
Accuracy	±6cm@(0.2m-3m), ±2%@(3m-8m)
Distance Resolution	1cm
Operating Temperature	-10ºC~60ºC
Weight	<5g
Dimension in mm (L*W*H)	25*17.5*12
Supply Voltage	5V

Table 3.2 Specifications of LiDAR

Principle of working of Lidar

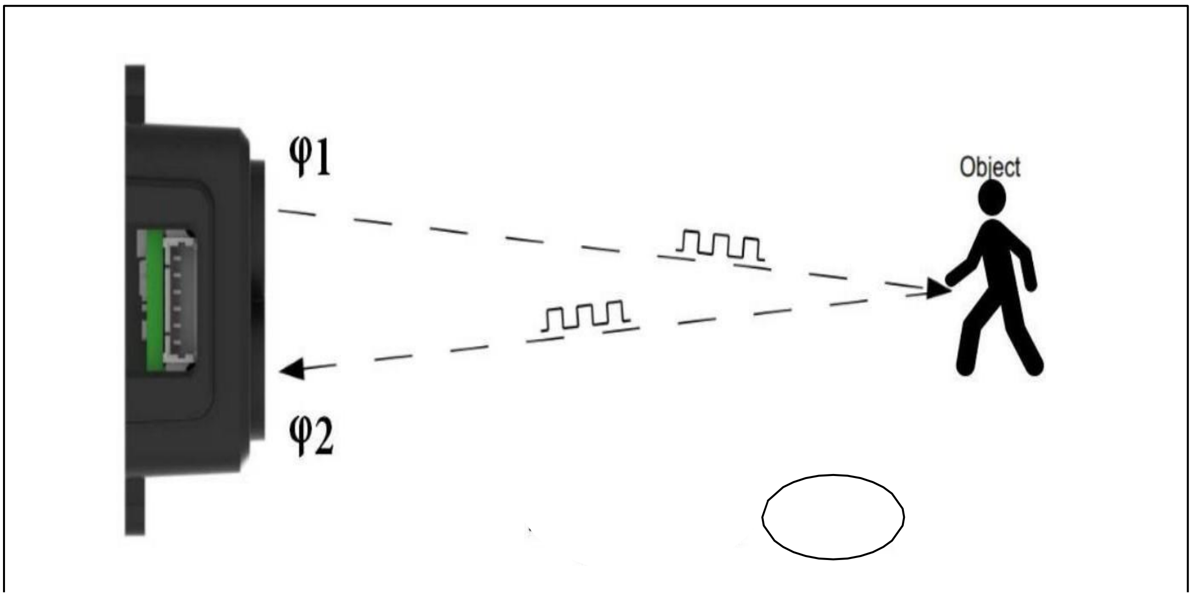


Figure 3.16 Schematics of TOF

LiDAR is based on TOF, namely, Time of Flight principle. To be specific, the product emitsmodulation wave of near infrared ray on a periodic basis, which will be reflected after contacting object. The product obtains the time of flight by measuring round-trip phase difference and then calculates relative range between the product and the detection object, as shown in above Figure.

Distance calculation:

$$D = \frac{c}{2} \cdot \frac{1}{2\pi f} \cdot \Delta\varphi$$

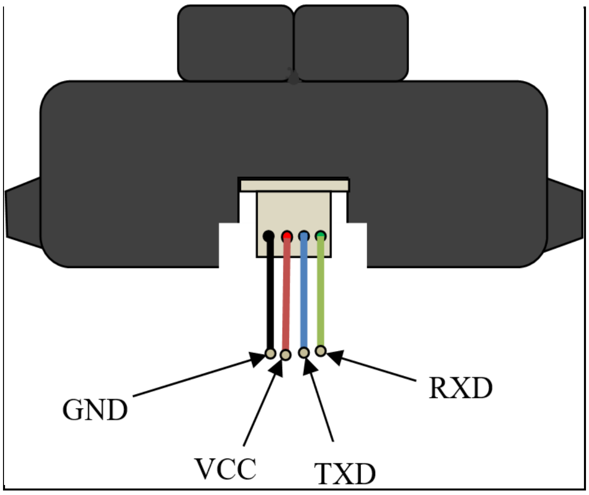


Figure 3.17 LiDAR cable connections

- GDN: Ground
- VCC: Supply DC voltage (4.5-6V)
- TXD: Transmit Data (3.3V)
- RXD: Receive Data (3.3V)

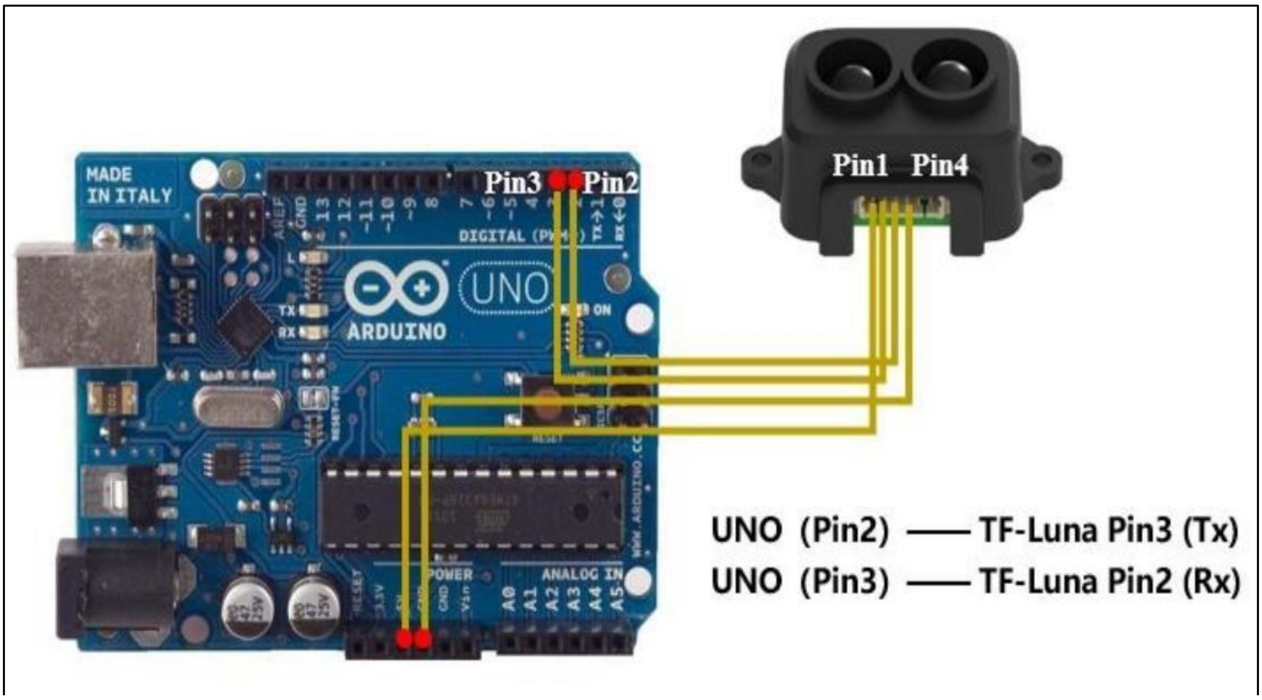


Figure 3.18 Schematic diagram of connection between LiDAR and UNO board

3.3.3 MPU6050 Sensor

MPU6050 is a Micro Electro-mechanical system (MEMS), it consists of three-axis accelerometer and three-axis gyroscope. It helps us to measure velocity, orientation, acceleration, displacement and other motion like features.

MPU6050 consists of Digital Motion Processor (DMP), which has property to solve complex calculations.

MPU6050 consists of a 16-bit analog to digital converter hardware. Due to this feature, it captures three-dimension motion at the same time.

MPU6050 is less expensive, its main feature is that it can easily combine with accelerometer and gyro.

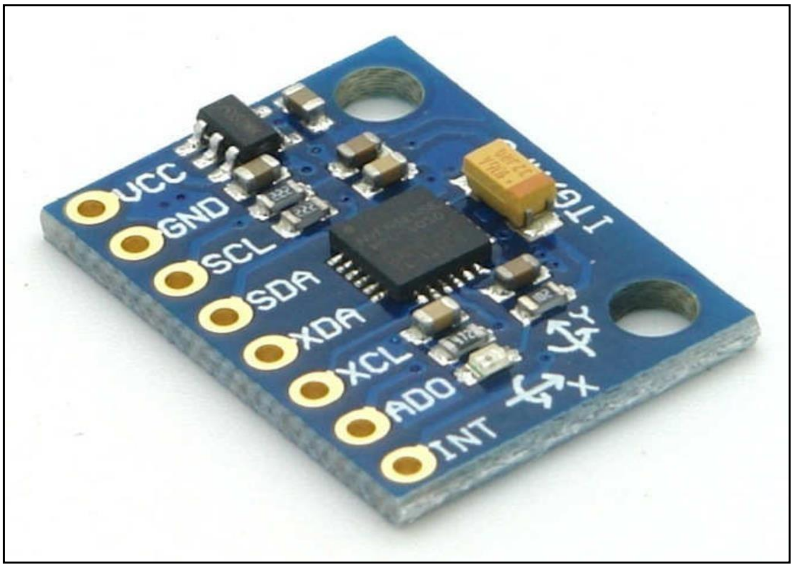


Figure 3.19 MPU6050 module

Gyroscope and accelerometer reading along X, Y and Z axes are available in 2’s complement form. Temperature reading is also available in signed integer form. Gyroscope readings are in degrees per second (dps) unit; Accelerometer readings are in g unit; and Temperature reading is in degrees Celsius.

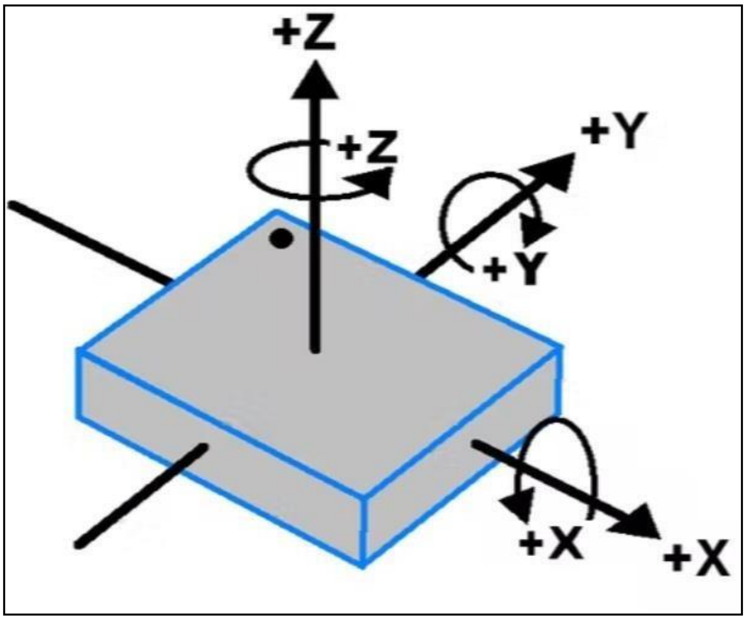


Figure 3.20 MPU6050 Orientation and polarity of Rotation

This module has some famous features which are easily accessible, due to its easyavailability it can be used with a famous microcontroller like Arduino.

This module uses the I2C module for interfacing with Arduino.

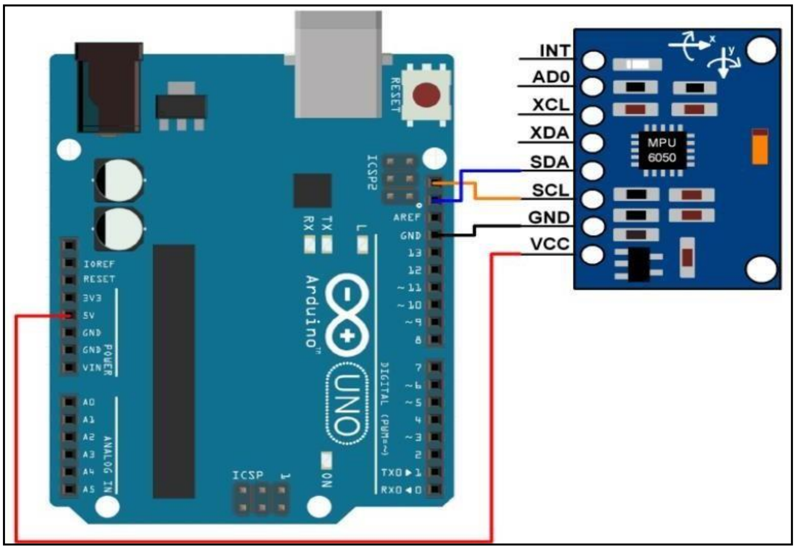


Figure 3.21 MPU interfacing Arduino UNO

3.3.4 Missile Model

We have used PLA material for 3D printing for our missile. The missile structure weighs 1.43kgs without the avionic system.

Figure 3.22 Missile model

Chapter 4
Results

Results were obtained at four different angles of attack i.e., 0º, 10º, 12º, and 15º.
It can be observed from the graphs that increasing angle of attack increases drag coefficient.

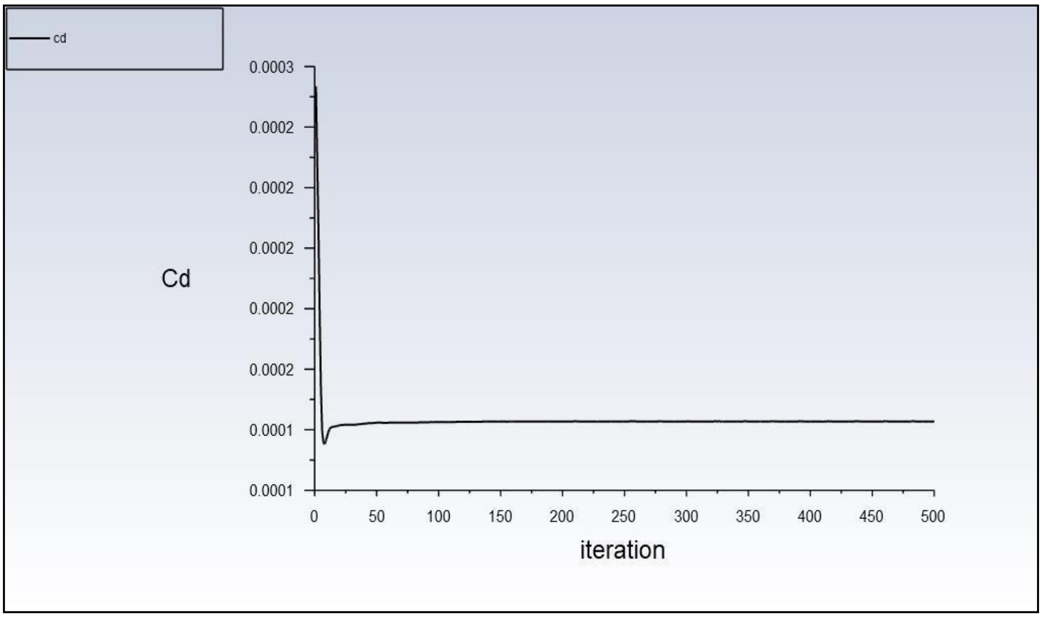


Figure 4.1 Drag Coefficient at 0º angle of attack

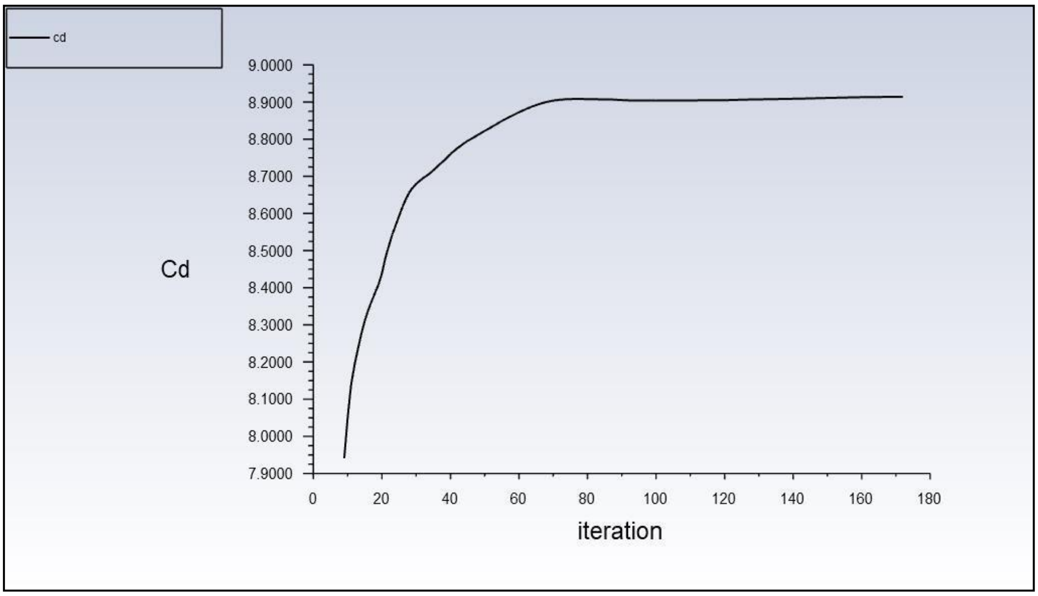


Figure 4.2 Drag Coefficient at 10º angle of attack

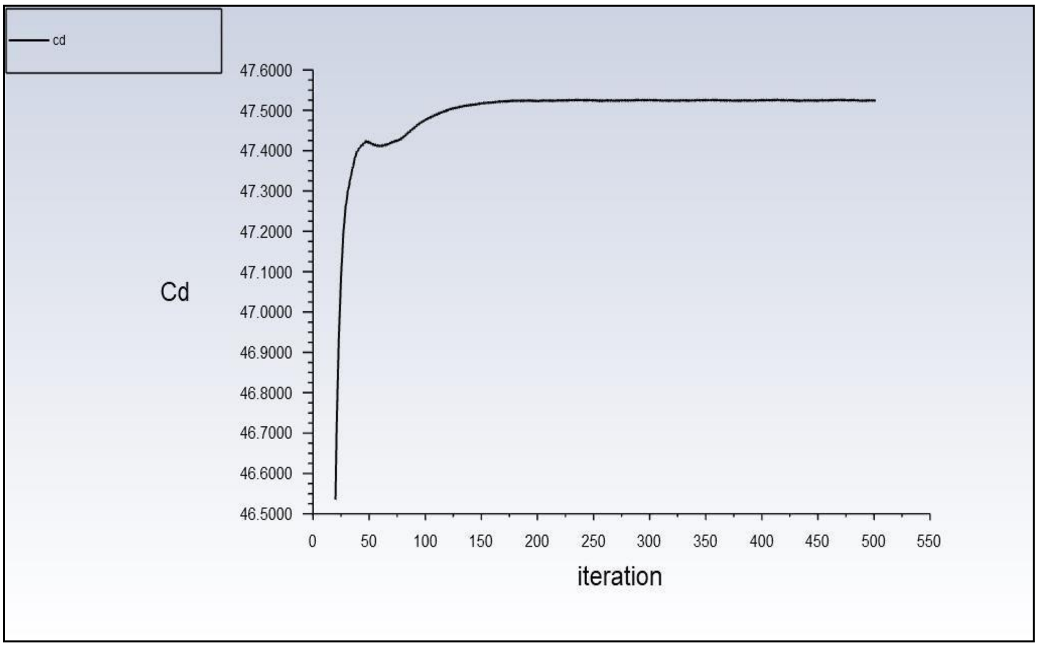


Figure 4.3 Drag Coefficient at 12º angle of attack

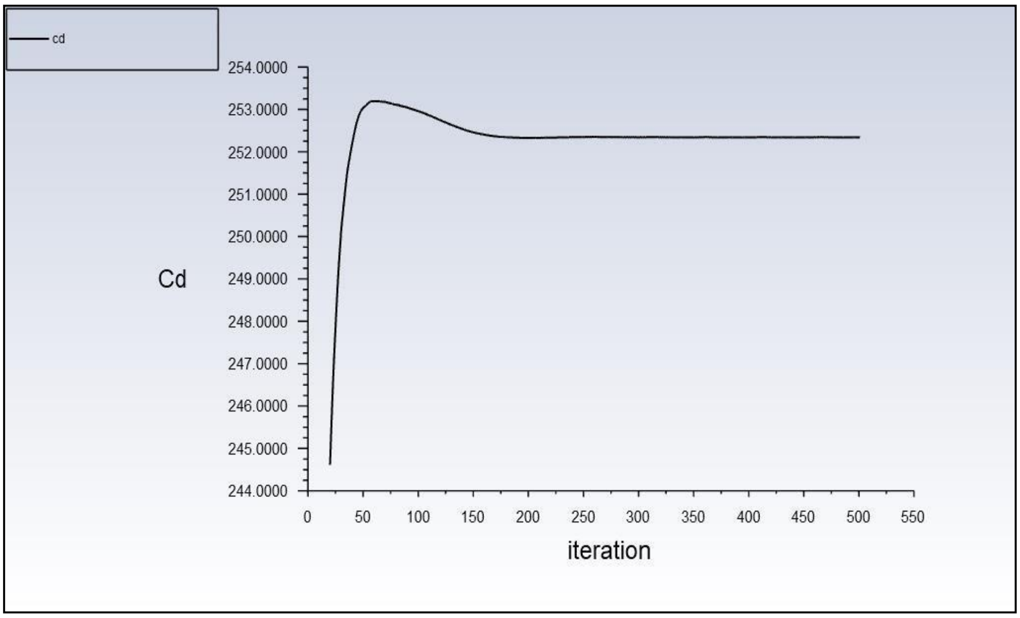


Figure 4.4 Drag Coefficient at 15º angle of attack

Inlet velocity	Angle of attack	ANSYS Fluent DragCoefficient
686m/s	0º	1×10^{-4}
686m/s	10º	8.9
686m/s	12º	47.5
686m/s	15º	253

Table 4.1 Observation table for drag coefficient

The drag is nearly constant at smaller angle of attack As the angle increases above certain degrees, the drag quickly rises because of increased frontal area and increased boundary layer thickness.

Chapter 5

Conclusion and Future Scope

•

5.1 Conclusion

In conclusion, the project study has gone through the introduction of missile aerodynamics, stability control using movable fins as wellas some important for equations and definitions. ANSYS Fluent computation has been conducted successfully over the fin structure designed in Solidworks, inputting the inlet velocity of 686m/s. During the course of this studya detailed knowledge of missile's structural system and guidance system was done. Additionally, a study upon analysis of movable fin at different angles of attack was attempted to obtain the coefficient of drag.

The magnitude of the drag generated by an object depends on the shape of the object and how it moves through the air. For the fin structure that is used for this project work, the drag is nearly constant at smaller angle of attack As the angle increases above certain degrees, the drag quickly rises because of increased frontal area and increased boundary layer thickness.

5.2 Future Scope

The data collected serves as a base for further studies and research to be done such as varying the speed at subsonic to supersonic and increasing the number of data to be collected by changing structural parameters and trying at different angles of attack.

References

[1] P. Sethunathan, R. N Sugendran, and T. Anbarasan, Aerodynamic Configuration Design of a Missile, Vol. 4 Issue 03, March-2015, International Journal of Engineering Research & Technology (IJERT).

[2] Nenad Vidanovic, Boško Rašuo, and Gordana Kastratovic, Aerodynamic–structural missile fin optimization, Volume 65, June 2017, Pages 26-45, Aerospace Science and Technology.

[3] Jack N. Neilsen, Missile Aerodynamics, 1960, Mc Graw-Hill Book Company.

[4] Craig J. Coyle and Sidra I. Silton, CFD Aerodynamic Characterization of a High Maneuverability Airframe, 22-26 June 2015, 33rd AIAA Applied Aerodynamics Conference.

[5] Mehraj, K. Sai Priyanka, D. Govardhan, Aerodynamic Design of MissileMaintaining High L/D by Increasing Lift and Minimizing Drag, vol.10 Issue 05, May-2021, International Journal of Engineering Research & Technology (IJERT).

[6] Amandeep Singh, Aerodynamic analysis on missile design, October 2020 Vol 5 Issue 10, The International Journal of Scientific Development and Research (IJSDR).

[7] T V Karthikeyan, A K Kapoor , Guided missiles, 1991, Defence Scientific Information & Documentation Centre, Defence Research & Development Organization, Ministry of Defence.

[8] Silton, S. I., Fresconi, F., and Celmins, I., 2014, "High Maneuverability Airframe: Investigation of Fin and Canard Sizing For Optimum Maneuverability," U.S. Army Research Laboratory, September.

[9] Fresconi, F., Celmins, I., and Silton, S. I., 2014, "Theory, Guidance, and Flight Control for High Maneuverability Projectiles," U.S. Army Research Laboratory, January.

[10] Fresconi, F. and Harkins, T., "Aerodynamic Characterizations of Asymmetric and Maneuvering 105-, 120-, and 155-mm Fin-Stabilized Projectiles Derived From Telemetry Experiment," Aberdeen Proving Ground, MD, 2011.