

**INVESTIGATION OF AN EHD CORONA FLOW IN NITROGEN GAS USING AN
ASYMMETRIC CAPACITOR**

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

By

YERRA MADHU BABU (39260044)

MUTHI GOPI (39260006)



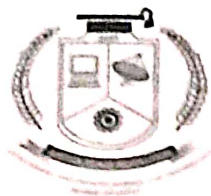
**DEPARTMENT OF AERONAUTICAL ENGINEERING
SCHOOL OF MECHANICAL ENGINEERING
SATHYABAMA**

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

Accredited with grade "A" by NAAC 12B status by UGC I Approved by AICTE

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI – 600119

April – 2023



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Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai-600119

www.sathyabama.ac.in

DEPARTMENT OF AERONAUTICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of YERRA MADHU BABU (39260044) and MUTHI GOPI (39260006) who carried out the project entitled "INVESTIGATION OF AN EHD CORONA FLOW IN NITROGEN GAS USING AN ASYMMETRIC CAPACITOR" under our supervision from November 2022 to April 2023.

Internal Guide
Mr. S. VENKATESH, M.E., (Ph.D.),

Head of the Department
Dr. P. BOOMADEVI, ME., PhD.,

Submitted for Viva voce Examination held on 24th April

Internal Examiner

External Examiner

DECLARATION

I YERRA MADHU BABU (39260044) here by declare that the Project Report entitled "INVESTIGATION OF AN EHD CORANA FLOW IN NITROGEN GAS USING AN ASYMMETRIC CAPACITOR" done by me under the guidance of Mr. S. VENKATESH, M.E., (Ph.D.), is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Aeronautical Engineering.

DATE: 24-4-2023

PLACE: CHENNAI



SIGNATURE OF THE CANDIDATE

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ABSTRACT

The objective of the current research is to characterize the propulsive force generated during a positive corona discharge in nitrogen gas using an asymmetric capacitor design. To gain a better understanding of the forces acting on different types of capacitors surrounded by any gas, the study employs the concepts of electrohydrodynamics (EHD) and electrostatics to compute all hydrodynamic and electrostatic forces acting on the geometry. The findings reveal that the main driving force for propulsion is the electrostatic interaction force between the capacitor electrodes and the surrounding positive ion charge in the atmosphere, which causes the ion wind. The ion wind is a by-product of the electrostatic interaction, and the force propelling the capacitor is primarily electrostatic rather than hydrodynamic. The experiment focuses on understanding the effects of applied voltage, electrode geometry, and gas flow rate on the corona discharge. The study aims to provide insights into the behavior of EHD corona flows, which have potential applications in air purification and aerosol transport. Results from the experiment can contribute to the development of efficient and effective corona-based technologies for various industrial and environmental applications.

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LIST OF ABBREVIATIONS

SYMBOLS	ABBREVIATIONS
E.H.D	Electrohydrodynamics
e	Electons
Ar	Argon
Ars	Argon species
v	Voltage potential
o	Fluids dielecttic
j	Current density
D	Ion diffusion coefficient
E	Strength of electric field
d	Electrode radii
C	Empirical value
FEA	Finite element analysis
F/P	Thrust to power ratio
μ	Dynamic viscosity
ρ	Density of fluid
d	Distance
Ω	Parameter
J	Current continuity

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CHAPTER-1

INTRODUCTION

Ionocrafts are a type of aircraft that employ electrohydrodynamic (EHD) to produce the necessary thrust for flight. However, flight of their capability is currently Confined to just maintaining. The portion of the aircraft that generates thrust while in flight. Despite numerous designs being created and tested overtime, very few have achieved success or received critical acclaim. This is partly due to the inherent Limitations or disadvantages of ion propulsion generation. In comparison to other types of propulsion, the weaknesses or drawbacks of ion thrust. Nevertheless, the potential advantages of ion thrusters shouldn't be disregarded when considering Potential practical uses. This investigation aims to Examine Ionocrafts in detail, investigate The scientific principles underlying their operation, and propose practical applications for this technology. Several steps are required, including researching the history of similar technologies that use EHD to function, examining past mistakes and achievements, overviewing the physical forces involved and the energy transfer mechanisms that enable the device to fly, determining the parameters that influence the efficiency and power of this device, and suggesting potential applications for this technology. This project aims to conduct a comprehensive literature review on atmospheric ion propulsion, different types of designs and applications, and investigate various methods for studyingthis phenomenon. The tasks required to achieve this aim include conducting a thorough literature survey, analyzing the relevance and novelty of scientific research, exploring the history of ion propulsion, examining the physics of ion propulsion, generating1 computational models for simulations, and conducting practical experiments. Ultimately, the goal of this study is to enhance our understanding of ion propulsion and explore various designs and applications for ionocrafts. Overall, the project will involve a comprehensive analysis of ionocrafts and their potential applications, focusing on the technology's physics and engineering aspects. The results of the study could provide valuable insights into the feasibility and practicality of using ion propulsion for various purposes, as well as contribute to the development of more efficient and effective ionocraft designs.

- A literature survey about ion craft history
- A literature survey about the ion craft's physics behind it
- A survey about simulations of ion propulsion for computational model generation
- Modelling and Presentation of an Ion-propelled drone.
- Calculation of conventional ventilation systems and ion-powered ventilation system.
- Ion propulsion with practical experiments

CHAPTER-2

LITERATURE REVIEW

2.1 RELEVANCE OF THE STUDY:

Indeed, the reduction of noise pollution is a major driving force behind the development of ion engines for aircraft. Traditional jet engines generate a significant amount of noise, which can cause a variety of health issues for individuals living near airports or under flight paths. Additionally, there are strict noise regulations in place that limit the hours of operation for noisy aircraft, making it difficult for airlines to operate efficiently. Ion engines have the potential to significantly reduce noise pollution, as they produce much less noise than traditional jet engines due to the lack of moving parts and combustion. Furthermore, ion engines have the potential to be more efficient than traditional jet engines, which would reduce the amount of fuel required for flight and lower emissions. This is particularly important as the aviation industry is one of the largest contributors to greenhouse gas emissions, and reducing emissions is a critical component in mitigating climate change[1]. And require aircraft manufacturers to comply with them. These programs have resulted in the development of new technologies and designs that help to reduce engine noise, including the use of ion engines. Ion engines have the advantage of producing very little noise compared to traditional engines, which makes them an attractive option aircraft manufacturers. Additionally, ion engines have a very high specific impulse, which means they can produce more thrust with less fuel compared to traditional engines. This can lead to significant savings in fuel costs over the lifetime of an aircraft. Overall, the use of ion engines in aviation has the potential to revolutionize the industry by reducing noise pollution and increasing fuel efficiency. However, there are still challenges to be overcome, such as the relatively low thrust produced by ion engines compared to traditional engines. Nevertheless, ongoing research and development in the field of ion propulsion hold promise for future aviation advancements[2]. That's correct. Even though drones are much smaller than commercial aircraft, they can still produce significant noise pollution, especially in residential areas. Therefore, EASA and other aviation authorities have established

regulations for drone noise emissions to protect the public and prevent noise-related disturbances. These regulations set maximum noise levels for drones and require manufacturers to conduct noise tests to ensure compliance. In this context, ion drives offer an advantage over traditional engines as they produce significantly less noise, making them more compliant with regulations and potentially more acceptable to the public[3].such as aerodynamics and structural design. Furthermore, ion drives have the potential to provide a much higher specific impulse than conventional rocket engines. Specific impulse is a measure of the efficiency of a rocket engine, indicating how much thrust is generated per unit of propellant consumed. Ion drives can achieve specific impulses of several thousand seconds, which is significantly higher than the specific impulse of conventional chemical rockets. This means that ion drives can achieve higher speeds with less propellant, making them more fuel-efficient and cost-effective in the long run. Overall, ion drives have the potential to revolutionize the aerospace industry by providing a silent, efficient, and low-maintenance source of propulsion for a wide range of applications. From drones to spacecraft, ion drives offer a promising alternative to conventional engines that could significantly reduce noise pollution, maintenance costs, and fuel consumption while increasing speed and efficiency[4].Of the harmful emissions that are typical of traditional combustion engines are produced. This makes ion drives an attractive option for reducing the environmental impact of aviation. Additionally, the lack of moving parts in ion drives means that they produce less vibration than traditional engines, which in turn can lead to a smoother and more comfortable ride for passengers. Overall, the potential benefits of ion drives for aviation are numerous. From noise reduction to simplified maintenance and environmental friendliness, this technology has the potential to revolutionize the way we think about aircraft propulsion. While there are still challenges to overcome, such as the need for more efficient power sources, the progress made in recent years is promising, and it will be interesting to see how this technology evolves in the future[5].That's correct. A lifter, also known as an Ionocraft or Electrohydrodynamic (EHD) thruster, is an electrical propulsion device that generates lift by creating an ionic wind between two electrodes. It is essentially an asymmetrical capacitor, with a sharp- edged wire (usually the anode) and a flat plate (usually the cathode) separated by a small distance, typically a few millimeters. When a high voltage is applied between the

electrodes, the sharp edge of the wire ionizes the air molecules around it, creating a cloud of positively charged ions. These ions are attracted to the negatively charged plate, but as they travel through the air, they collide with neutral molecules, creating a flow of air, or an ionic wind, which propels the lifter in the opposite direction. Since there are no moving parts, ionocrafts are silent, vibration-free, and require minimal maintenance[6]. The absence of parts that are not moving appears to be an encouraging aspect of this design. Unlike other propulsion systems which employ intricate methods generate thrust, such as rotating turbines, the lifter has the potential to be remarkably dependable because it lacks any mechanism that would wear out over time due to friction[7].

2.2 THE INNOVATIVE NATURE OF SCIENCE RESEARCH:

A significant advancement in the field of ionocraft was achieved on November 21, 2018, when a group of engineers at MIT accomplished a successful test flight of a drone that utilized ion thrusts as its power source, without any moving part involve(Fig. 1). Although specifically a lifter device demonstrated ionocrafts contain the energy to be high than just recreational project team's final design was a big, underweight glider featuring a massive, elongated wing with two big rows and four columns of big lift thrusters attached to wires attached to a positive voltage +20,000V. The wing, in a certain distance, of an airfoil made from foam enclosed with aluminium foil, is set to a negative voltage of -20,000V[8]. The energized particles that move between the wires and the airfoils generate a wind-like effect that propels the entire aircraft forward. Although it is not capable of taking off without assistance, it has the potential for long and steady flight. The aircraft was incredibly lightweight, weight of 2.3 kilograms, but boasts an impressive 5m wingspan. The planes fuselage houses contain of lithium-polymer batteries that have been specially made changes to power six-stage, in-house-built fully waved Cockcroft-Walton voltage that produces the 40,000 volts necessary to pass current through the wires and airfoils and produces the high electrical field that required to speed up the surrounding air particles[9].

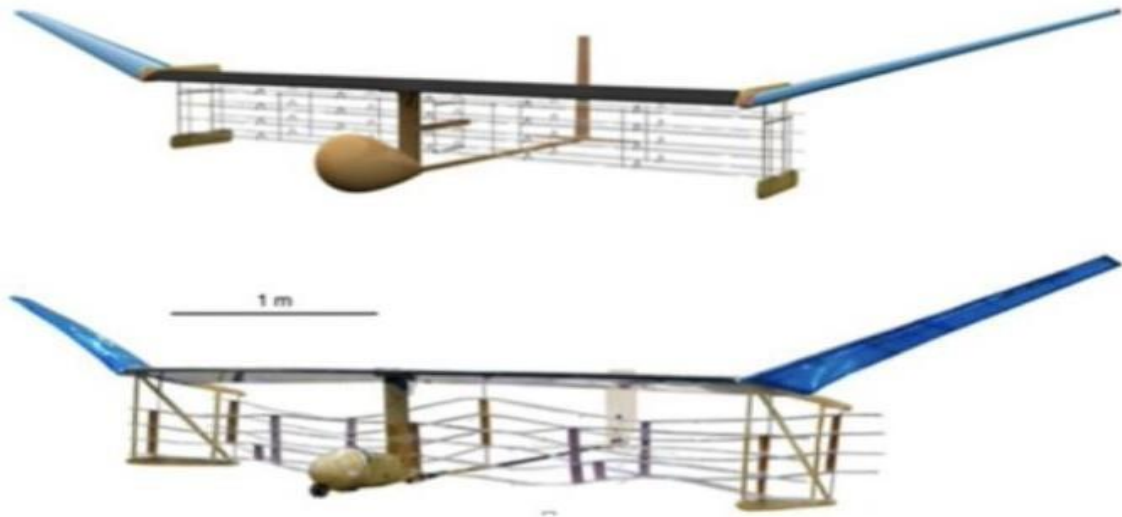


Fig:2.1 MIT ion-powered drone plane

There is another project that is on the cusp of revolutionizing the use of electrohydrodynamic (EHD) force on a mass scale, which is the development of flying microrobots. At the University of California, Berkeley, Daniel S. Drew and Kristofer S. J. Pister have been working on small-scale aerial vehicles for several years. Their aim is to utilize EHD force to propel tiny drones that can be deployed for various applications, with search and rescue being the most crucial one, as swarms of drones could be dispatched to locate survivors. Harvard University has also presented similar projects with their microrobots, the Robobees[10]. Unlike EHD devices, other flying devices like Robobees rely on The utilization of electromagnetic or piezoelectric mechanisms for flapping the robots. This contains moving parts and complexity to the device, making it difficult to control for precise directional flight. On the other hand, EHD devices have no moving parts, making them easier to build. They can also adopt A thoroughly investigated flight scheme for quadcopters, with a different control scheme available. In 2017, the team at the University of California, Berkeley, performed a flight test of an ionocraft that has weight of only 10 milligrams, measured 1.8 centimetres by 1.8 centimetres and operated at 2400 volts (see figure 2). Despite the ionocraft's low thrust density, which makes it unsuitable for carrying passengers, the team discovered that its thrust scales invariantly, meaning that it remains the same even for a very small device. This makes the development of super small EHD aircraft possible. The

team conducted several studies on ionocraft characteristics, which will be discussed in detail in the study[11].

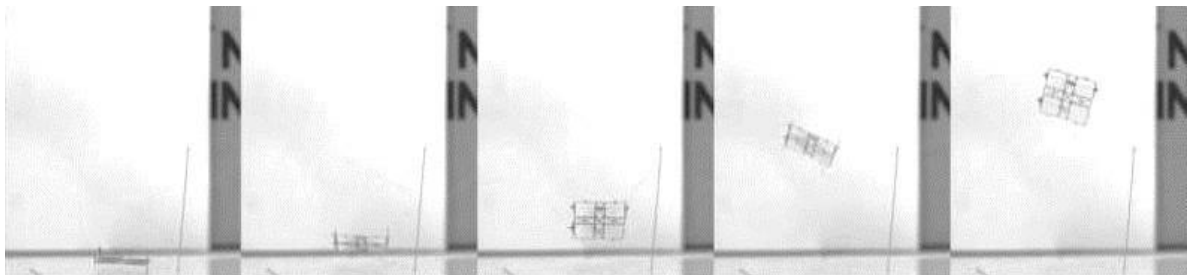


Fig:2.2 The launch of a microfabricated ionocraft as studied by Daniel S.Drew [11]."

The importance of this study is reflected in increasing the number of Patentable design concepts for ion propulsion aircraft. J.R. Iwaszko from Australia has taken out one such patent, which defines untethered ion propulsion aircraft mechanisms. While many of the designs look unfeasible, one design that stands out is the blimp. By removing as much of the blimp's covering as much surface area as feasible with elements that conductive collectors and Sustaining a non-conductive outer layer, a completely silent vehicle that can carry its own power source and payload can be made. However, The blimp requires control over all six degrees of freedom, whereas the suggested design only encompasses motion in a single direction. Using fins To include adjustments for both pitch and yaw severely limits their possible uses[12].

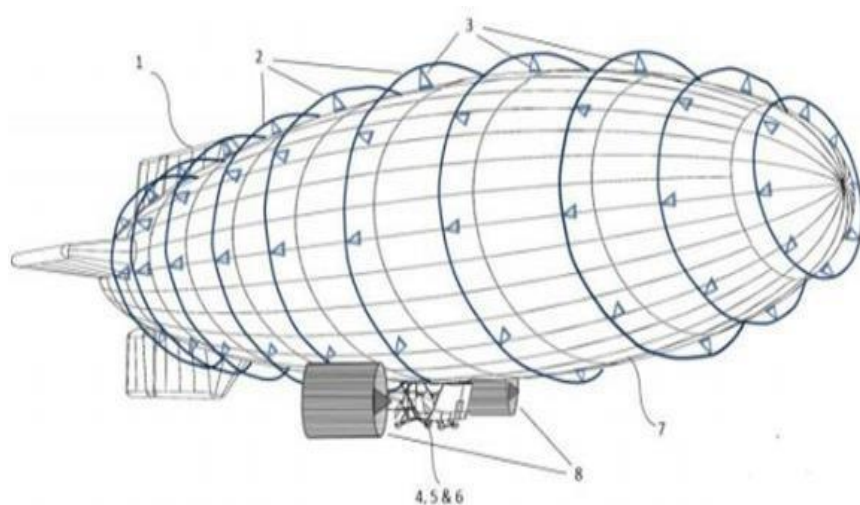


Fig:2.3 Ion drive airship concept

Indeed, increased number of patent applications related to ion-powered aircraft reflects the growing interest and potential for this technology. While some patent applications may be driven by a desire for patent hoarding, the fact that many legitimate attempts to create new business ventures using ion drive are being made demonstrates the relevance of this technology. As research and development in this area continues, it is likely that more practical applications for ion propulsion aircraft will emerge, further solidifying its place in the market

2.3 HISTORY OF ION PROPULSION:

Hauksbee's discovery was made in 1709, when he noticed a flow of air created by an electrostatic generator. He noticed that the flow of air was stronger when the generator was placed in a partial vacuum. He later built a device called the "electric whirl" or "Hauksbee's machine," which was used to study electrostatic phenomena, including EHD. Hauksbee's work laid the foundation for later research on EHD and its practical applications[13]. Further progress in understanding EHD was made by William Thomson (also known as Lord Kelvin) in the mid-19th century, who introduced the concept of electric potential and the role it played in generating EHD. He proposed that the ions generated by an electrical field would migrate towards the electrode of opposite polarity, and this motion would cause air molecules to move along with them, generating a flow of air and thus thrust. Since then, EHD has been extensively studied and applied in various fields, such as electrostatic air cleaners, gas pumps, and air ionizers. With the recent advancements in micro/nano technology and the surge of interest in electric propulsion, EHD has once again gained attention for its potential use in creating small-scale, silent, and highly maneuverable aircraft[14]. Goddard's experiments were aimed at developing a propulsion system that would work in the near-vacuum conditions of high altitudes. He used a cathode ray tube to generate a stream of ions and demonstrated that the ions could be accelerated to high velocities using an electric field. This was the first demonstration of ion propulsion, although the technology was not yet advanced enough for practical applications at that time[15]. Harold R. Kaufman developed the initial working ion thrusters 1959 at

the Glenn Research Center of NASA, which employed a grid electrostatic ion thruster and utilized Mercury gas as a propellant. The thrusters underwent suborbital tests starting in 1960, and by 1970, a successful orbital test had been carried out[16]. Although the concepts of ion propulsion were researched in the start 1900s the ion wind had been seen earlier, design of the lifter originated the high-voltage cable that Thomas Townsend Brown connected, asymmetrical when the capacitor was connected to a 100 kilovolt DC input, the capacitor plate produced thrust to one side. Thomas and another scientist, Dr. Paul Biefeld, obtained numerous patents for the novel "Lifter" phenomenon they found. They along with most researchers who examined this effect, thought they had found antigravity and produced numerous theories on "Electrogravitics"[17]. Presently, it is understood that the ion wind, which generates thrust, is created by the movement of particles from a positive charge to a negative charge. This phenomenon was later named after Thomas Townsend Brown and Dr. Paul Biefeld, and is now called the "Biefeld- Brown"[18]. After the research, Brown constructed a disc that flew, which he showcased to the UNITED STATES in 1950 at Navy. However, the technology in its early stages, the disc had to be attached to the ground as it was incapable of lifting its own power source. In 1964, a report on Major de Seversky's proposal for ion aircraft was published in "Popular Mechanics" magazine. The Major presented a functional small-scale model of a lifter to the media, which amazed many people. They referred to it as a "magic carpet" of the future. Although scientists at that time considered the potential use of these gadgets in helicopters or other traditional flying machines operating at higher-than-normal altitudes, it never came to fruition. This was primarily due to the ion drive's dismal thrust density and the inadequate battery and conductor technologies that were available at the time[19]. Despite the earlier setbacks, there was still progress in the development of ion engines. In July 2001, engineer Jeff Cameron proposed a new lifter design featuring a triangular shape made of aluminium foil with balsa wood. Following these fruitful tests, scientist Jean- Louis Naudin enhanced the same design, resulting in a power-to-weight ratio of about 1 gramme per watt. NASA's DAWN was the first well-known mission to use an ion engine. As well as

being the first expedition to orbit two extraterrestrial planets, an asteroid, and a dwarf planet, it was also the first mission to orbit two interplanetary bodies. The ion thrusters used xenon gas instead of mercury like earlier ion propulsion systems. Because of its enormous molecular mass and moderate reactivity, xenon was chosen. The NSTAR technology was the foundation for the ion thrusters used[20].

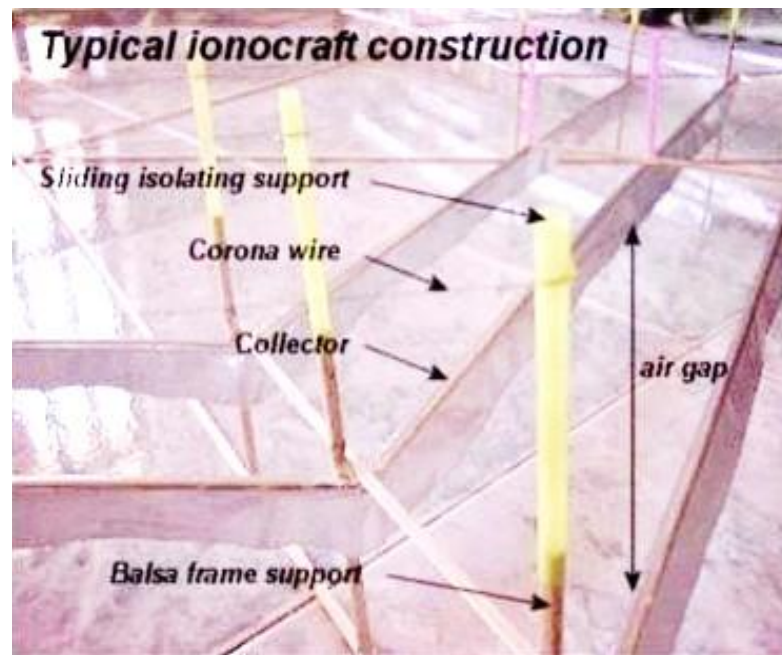


Fig: 2.4 Typical Ionocraft construction [20]

2.4 ION PROPULSION PHYSICAL PHENOMENON

A high voltage is used to ionise the air in an ionocraft, which causes the ionised molecules to move and interact with the surrounding air molecules to propel the craft forward. The voltage is applied between two conductors, one of which has a sharp edge and the other of which is more spherical in form and serves as an ion collector. The conductors are separated by a particular air gap. (as shown in Figure 4). Due to the size disparity between the two conductors, only the sharp edge electrode experiences a strong electric field from the high voltage, which causes the air molecules to travel widely from the sharp edge to the rounded electrode. The movement, or "ionic wind," creates a powerful downward force that accelerates the aeroplane upward. Ionocraft are incredibly efficient and dependable due to their simplicity and absence of moving parts[21]. A simpler

explanation of how an ionocraft works can be found in a workshop science article on how to build one. The article explains how to construct an ionocraft and the necessary components, as well as the underlying physics in It starts and discussing As the sharp conductor has a higher concentration of electric field lines, it has a greater capacity to transport ions to the blunt conductor. (as shown in Figure 5).

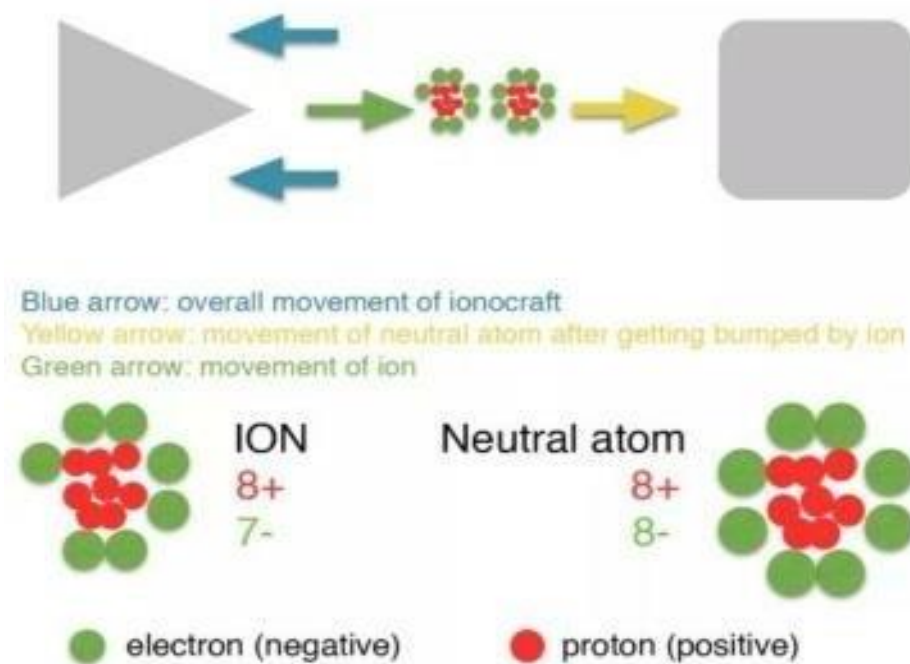


Fig:2.5 Ionocraft function explanation [22]

In addition, there are a lot of neutral atoms in the air near the blunt item that don't respond to the electric field created between the conductors. These charged travelling ions will slow down when these neutral atoms clash with them, but the neutral atoms will continue to proceed in the direction of the blunt conductor. Most of the thrust is produced by this event, which also produces the ion wind. This explanation is clear and simple to understand (as depicted in Figure 6)[22]. E, it is possible to derive a relationship between V and E in the region of interest. This relationship can then be used to simulate the behavior of ions and electrons in the corona discharge. In general, the corona discharge in fluids occurs when a high voltage is applied to a conductor in contact with a fluid. The high voltage creates an electric field around the conductor, which ionizes the fluid near the conductor. This ionization creates a plasma of ions and electrons, which can interact with the electric field to generate an ion wind. The ion wind is

generated because the electric field around the conductor accelerates the ions and electrons in opposite directions. The electrons are much lighter than the ions, so they are accelerated much more strongly than the ions. This means that the electrons collide with the neutral molecules in the fluid, creating more ions and electrons.

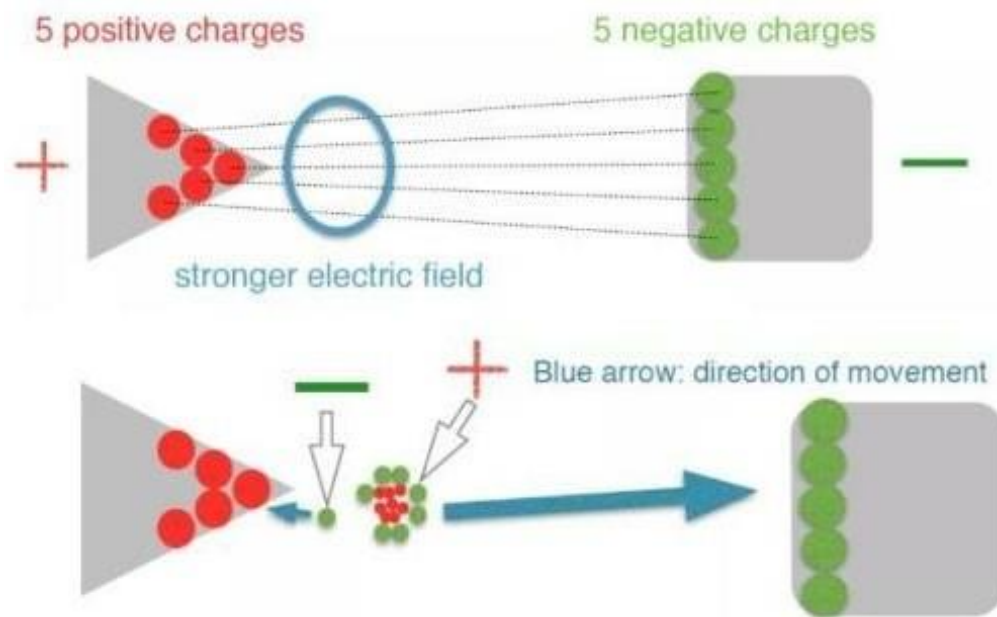


Fig:2.6 Particle movement in ionocraft [22]

creates an electric field around the conductor, which ionizes the fluid near the conductor. This ionization creates a plasma of ions and electrons, which can interact with the electric field to generate an ion wind. The ion wind is generated because the electric field around the conductor accelerates the ions and electrons in opposite directions. The electrons are much lighter than the ions, so they are accelerated much more strongly than the ions. This means that the electrons collide with the neutral molecules in the fluid, creating more ions and electrons. The ions are then accelerated away from the conductor by the electric field, generating a flow of charged particles or an "ion wind". In an ionocraft, the ion wind creates a net force that propels the craft. The sharp edge of the electrode is designed to create a strong electric field that ionizes the air near the electrode. The blunt electrode then collects the ions, creating a net flow of charged particles that generates thrust. In summary, the mechanism behind ion drives and ionocraft is

based on the corona discharge in fluids, which generates a flow of charged particles or an "ion

$$\nabla^2 V = -\frac{\rho}{\epsilon_0}; \quad E = -\nabla V \quad (1)$$

wind". The ion wind creates a net force that propels the craft. The sharp edge of the electrode is designed to create a strong electric field that ionizes the air near the electrode, while the blunt electrode collects the ions to create thrust. Where V is the voltage potential of the emitter electrode, ϵ_0 is the fluid's dielectric permittivity and ρ is the space charge density. The current density j can be used to explain it if the current continuity is taken into account as follows:

$$\nabla \cdot j = 0 \quad (2)$$

The following parameters can be combined to get the parameter j , or density of current: 1) the ions moving because of the electric field, 2) the charges transferred via the molecules because of the fluid flow, and 3) due to diffusion. Current density can be described as follows:

$$j = (\mu_e \rho E + \rho U - D \nabla \rho); \quad (3)$$

where e is ion mobility, D is the ion diffusion coefficient, and U is the ions' mobility.

The fluid motion is described by the Navier-Stokes equation, which is as follows:

$$\rho \cdot \left[\frac{\partial U}{\partial t} + (U \cdot \nabla) U \right] = -\nabla p + \mu \nabla^2 U - \rho \nabla V; \quad (4)$$

where ρ is the density of fluid, and μ is dynamic viscosity of the fluid. The equation becomes if the fluid is incompressible and the density is constant.:

$$\nabla \cdot U = 0; \quad (5)$$

Hence, the mathematical equations offer a viable solution provided that specific boundary conditions are met. Nonetheless, it should not be assumed that the solution can be easily obtained or that the math involved is not intricate. In fact, solving these equations can involve complex mathematical procedures, particularly in cases where voltage V is a function of multiple coordinates in complex geometries. As a result, numerical techniques are recommended for handling such problems. Consequently, in the past, research on the EHD field was significantly restricted due to the absence of these advanced techniques.

However, with the availability of faster computers and greater computational power, the interest in investigating EHD was revived when Finite Element Analysis (FEA) techniques became more widely accessible[13]. Alternative equations for assessing lifter performance are presented in a study by MIT researchers Kento Masuyama and Steven R.H. Barrett on the performance of electro hydrodynamic propulsion. The usage of single-staged and dual- staged electrodes in lifter design is examined by the authors. They offer a formula for a one-dimensional electrohydraulic thruster model that may be used to determine thrust based on current through put, or the current flowing between the electrodes. The authors first define the current density before calculating the total current using the ion drift velocity and a characteristic area A perpendicular to the distance between electrodes.

$$I = \int i \cdot dA = \int \rho \mu E \cdot dA = \rho \mu EA; \quad (6)$$

Where E is the strength of the electric field, μ is the ion mobility, and ρ is the charge density. Ion thruster's volume of ions is affected by the Coulomb force.

$$F_{ss} = \int \rho E dV = \int_0^d \rho EA dx = \frac{Id}{\mu}; \quad (7)$$

The electrode radii are denoted by d. Using the corona discharge-specific voltage- current relationship

$$I = CV(V - V_0); \quad (8)$$

The thrust can be represented as a function of voltage using C /d²:

$$F_{ss} = \frac{C'V(V - V_0)}{d}; \quad (9)$$

Where C' is an empirical value based on the thruster's shape.

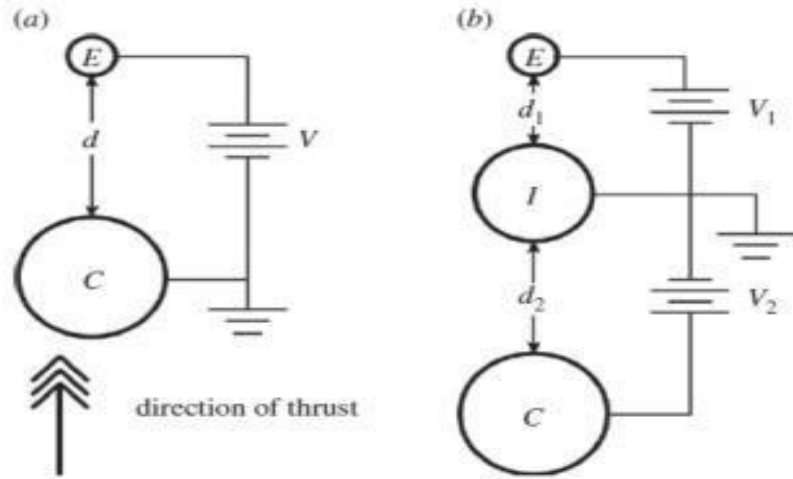


Fig:2.7 single-stage thruster electrodes vs Dual stage thruster electrodes[23]

Ionization and ion acceleration can be facilitated by the thruster. (as shown in figure 7). To retain the corona characteristic of a single-stage thruster, the intermediate electrode's size should be comparable to the collector's while still being small enough to not obstruct the collector's operation. To ignite the corona discharge at the emitter, the distance between the emitter and collector, or d_1 , is extended to a sizeable potential distance. Ionization does not take place in the narrower field of the second gap, d_2 . However, it permits ionised atoms to move faster and cross potential drops, lengthening their travel route and producing

$$I_2 = \psi * I_1 \quad (10)$$

greater thrust. A new model for ion losses due to their accumulation at the intermediate electrode is presented. The addition of a new factor, denoted by ψ , is made. The two gaps' currents interact with one another. By accounting for all of this, the authors arrive at the following formula:

$$F_{DS} = \int_{d_1} \rho_1 E_1 A dx + \int_{d_2} \rho_2 E_2 A dx = \frac{I_1(d_1 + \psi d_2)}{\mu}; \quad (11)$$

The thrust to power ratio, or F/P , which is a statistic used to compare EHD thrust to other competing technologies, is then presented by the authors as the

$$\eta = F_v/P \quad (12)$$

most crucial feature for an EHD thruster. They offer it as a component of total efficiency, and is inversely related to the thrust SFC. Assuming a fuel flow rate of $m(\text{kg s}^{-1})$ and a fuel calorific value of 43MJ kg^{-1} , which is the lesser of the two values for the customary unit of fuel per hour per measurement of thrust, the following thrust calculation results:

$$SFC = \frac{(P_{th}/LCV \times 60^2)}{F/g}; \quad (13)$$

where $g=9.812$ is the heating rate assuming full fuel utilisation. F/P can therefore be represented as

$$\frac{F}{P_{th}(\text{NkW}^{-1})} = \frac{0.821}{SFC}; \quad (14)$$

Due to the data that was supplied for SFC of other modes of transportation, this is where the most of the comparison will be made.

$$F/P_{ss} = \frac{Id}{\mu IV} = \frac{d}{\mu V}; \quad (15)$$

-The output of current and voltage for a specific power source is the input for a single stage electro hydrodynamic thruster. It is the total of the products from both power supplies for a dual-stage thruster, whose currents are related by the parameter ψ as previously indicated. Therefore:

$$\frac{F}{P_{DS}} = \frac{I(d_1 + \psi d_2)}{\mu I_1(V_1 + \psi |V_2|)} = \frac{d_1 + \psi d_2}{\mu(V_1 + \psi |V_2|)}; \quad (16)$$

For a single staged thruster, the following formula is used to determine the F/P :

$$\frac{d_1 + \psi d_2}{\mu(V_1 + \psi |V_2|)} = \frac{d_1 + d_2}{\mu(V_1 + |V_2|)} + \frac{(\psi - 1)(d_2 V_1 - d_1 |V_2|)}{\mu(V_1 + \psi |V_2|)^2} + O(\psi^2) \quad (17)$$

Although it may appear that effectiveness will rise as the air gap widens. distance, d , increases based on formula, it is important to note that the electric field must be strong enough to ignite the corona. If the electric field is too weak, no thrust will be produced, while if it is too strong, it may cause discharge, which could result in the craft catching fire. In the case of the dual-staged thruster, it may seem

possible to vary efficiency by adjusting the fixed air gap, δ . For instance, increasing the voltage to achieve higher thrust could result in lower efficiency at takeoff, while lowering the voltage could lead to higher efficiency but lower thrust. To examine the impact, the authors increase the efficiency formula to the first order by adding the ψ parameter to the equation. The denominator of the second term is

$$\Omega = \frac{F_{\mu} V_{total}}{P d_{total}} \quad (18)$$

positive with the defined factor $0 < 1$, but the numerator is negative with $1/1 > 2/2$

To limit ionisation to only the top gap of the dual-stage thruster. The first term is independent of δ and positive. As a result, it is anticipated that a greater value of δ , which would result in a larger part of the current passing the second gap, would minimise loss and increase thrust. In order to compare their experimental thrust to power ratio with the nominal theoretical condition, the author presents a non-dimensional efficiency to calculate

$$F = - \int \nabla p d^3x \quad (19)$$

the quality of a thruster configuration. The optimum situation for a dual stage thruster is for there to be no ion loss from the intermediate stage where it is possible to measure F and P experimentally [23]. It is recommended to employ finite element methods for precise calculations where these formulas show how to compare findings with experimental data. Further analysis of the model reveals that no ion loss due to the intermediate electrode is optimal for dual-stage thrusters, which leads to the following statements for both types of thrusters:

2.5 MODELING EHD USING FINITE TECHNIQUES:

One example is the work by Cheng and Huang (2003), who used a finite element method to simulate the corona discharge and ion flow in a needle-to-plate electrohydrodynamic thruster. They used a commercial finite element software package to solve the governing equations, including Poisson's equation and the continuity equation for ion current. They found that the distribution of ion current density is strongly influenced by the needle geometry and the voltage applied, and that the maximum ion current density occurs at the needle tip. Another example is

the work by Xiong et al. (2018), who developed a numerical model for a wire-to-plate ionocraft. They used the lattice Boltzmann method to simulate the gas flow and the particle-in-cell method to simulate the ion motion. They found that the thrust generated by the ionocraft is mainly due to the ion wind, and that the ion density and the electric field strength are the key factors affecting the thrust. They also found that the thrust efficiency is higher for smaller gap distances and higher voltages. These are just a couple of examples, but there are many other works that use computational methods to analyze EHD thrusters or drives. That's correct. The geometry of a simple lifter can be easily recreated employing a two-dimensional cross-section analysis in a computer environment. An asymmetrical capacitor with a small-scale positive conductor (emitter) and a correspondingly bigger collector is what the ionocraft lifting unit essentially is.. The emitter is usually in the shape of a wire or needle, while the collector is often shaped like a flat plate or a curved surface. The shape of the emitter and collector can have a significant impact on the performance of the ionocraft, and optimizing their design is a key area of research in the field of EHD propulsion. Once the geometry of the ionocraft is defined, it can be used as the basis for finite element analysis to simulate the behavior of the electric field, ionization, and ion flow within the device (as shown in 8) [24].

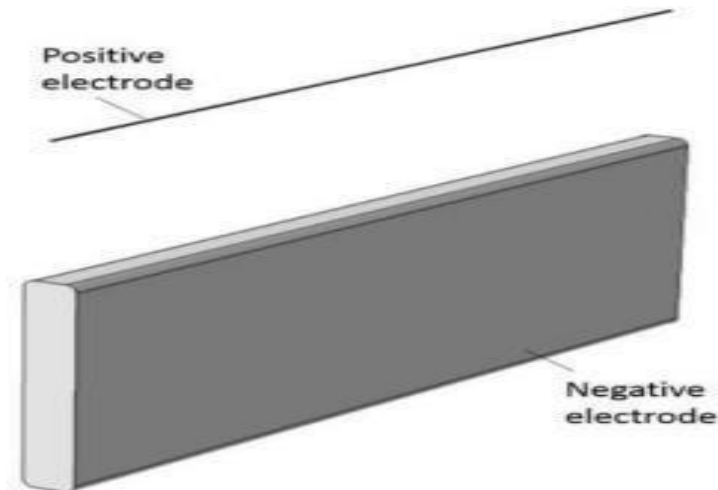


Figure 2.8 lifter model of EHD [24]

There are a few presumptions that must be made in order to calculate:

- The air will become totally ionised in a given zone where the electric density exceeds a certain threshold, indicating that molecules will be charged by a

unit. Outside of this region, the air is not fully ionised. ThV (threshold volume, V/ m) is the symbol for the threshold. The charge viscosity, or measurement $\beta(C/m^3)$, is used to represent the percentage.

- Because there are uniform and statistically distributed charges in the ionisation zone, the volume force may be calculated by simply multiplying the electric field density by the coefficient.

Two parameters, ThV and, can be used to define how the electric field will interact with air molecules under specific assumptions. Despite the fact that this methodology uses fewer parameters than other computational techniques, it is significant to remember that is an average charge density that is thought to be constant in space. The maximum charge density of $3.9 \times 10^6 C^3$, which may be attained by one molecule per unit at 1 atmosphere of pressure and about 300 Kelvin of temperature, is much smaller than the parameter value of $0.115 C^3$. The electric field accelerates charges in an area where ionisation takes place, and collisions give non-ionized molecules outside the ionisation field momentum. The parameter was added to reflect this relationship, and the counterforcebe observed .The force generated is not due to pressure difference, but instead it has considered as the flow of recoil rather than pressure effect. To avoiddivergence, a reference pressure of $1 \cdot 10^2[atm]$ is set, and a turbulent flow $k-\epsilon$ model framework is used. For the solver's convenience, an inlet and outlet are defined to meet the boundary conditions. Using these methods, it is possible to construct a computational model of an ionocraft and perform an analysis. The findings of a study carried out by Ma Chen,Guo Jia, Tang Yuanhui, Lu Rong-de, and Ye Bang-Jiao at the University of Science and Technology of China, Hefei, Anhui, are presented below, which compare the outcomes of the proposed model with experimental data[25].shown in Figure 9, the data closely matches for a rangeof values.It can be concluded that the computer simulations conducted are accurate to real-life testing within a certain margin of error. However, the presence oferrors indicates the potential for further improvement of the computational model.

2.6 POWERING A DRONE USING EHD BY MIT:

The use of ion flow to power a drone has been successfully demonstrated by students from the Massachusetts Institute of Technology (MIT). However, due to the heavy weight of batteries and the low thrust density of ion flow, a blimp is a

more suitable platform for stable flight using this technology. A theoretical airship, Electric Aerodynamic Lighter Than Air, or EAD-LAT, drone, will be designed to determine the volume required to become buoyant when transporting necessary Transformers and batteries are used as power sources for the ion propulsion system and control elements. To keep the overall weight of the craft low and maximize performance, the weight of the structure, batteries, control surfaces, and other mechanisms must be minimized. the Department of Aeronautics and Astronautics at MIT's technology as a reference, It is possible to presume that the drone's propulsion and battery systems, which produced 3.2 N of thrust and required 620 W of power, with a frontal area of 0.9 m², while weighing With a wingspan of 5.14 metres and a weight of 2.45 kg[28].

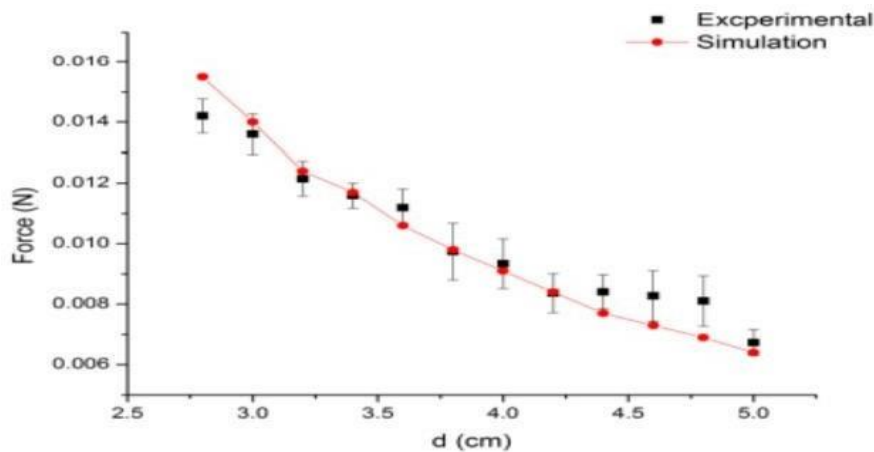


Fig:2.9 Experimental data and Simulation

It would be conceivable to size an aircraft that could theoretically employ ion thrust as a means of propulsion if one were to calculate the volume of helium needed to offset the weight of the battery (0.63 kg), power converter (0.51 kg), and electrodes (0.41 kg), as well as the structure of the blimp itself. It can be summed up to be about 1.5 metres in diameter and 3.1 metres in length, giving us 3800 litres of helium gas that could lift the entire propulsion system, weighing 1.15 kg, a supplement battery for longer flight times, 0.45 kg, as well as 1.9 kg of structure, control surfaces, and other weights various auxiliary systems, totaling 3.9 kg for the vehicle mass. Given that the disposable cylinder can fill up to 80 balloons of 18 inches in diameter, the cost of the blimp at current helium prices would be around 111.66 euros [29]. or any other CAD software is completed, the next step would be to design the ion thrusters that will be used for propulsion. The design of

the ion thrusters will depend on various factors such as the power output, the size and weight of the thrusters, and the amount of thrust required for stable flight. One of the key factors in the design of the ion thrusters would be the power source. Since the thrust density of the ion drive is low, the power source must be lightweight, yet powerful enough to generate the necessary amount of electricity to drive the thrusters. One potential solution would be to use high-capacity lithium polymer batteries, which have a high energy-to-weight ratio and are commonly used in drone and RC aircraft applications. Another important consideration in the design of the ion thrusters would be the type of electrode used. There are various types of electrodes that can be used in an EHD propulsion system, including wire, mesh, and blade electrodes. Each type has its own advantages and disadvantages, and the choice of electrode will depend on factors such as the desired thrust output, the size and weight of the thrusters, and the operating conditions of the system. Once the ion thrusters have been designed, the next step would be to integrate them into the blimp model and test the system for stability and flight performance. This would involve testing the thrusters at various power levels and adjusting the control surfaces to achieve stable flight. Overall, the design of an EHD-powered blimp presents a unique set of challenges and opportunities, and would require careful consideration of factors such as power source, electrode design, and flight performance. However, the potential benefits of such a system, including long flight times and low environmental impact, make it an exciting area of research and development [32]. A flow simulation is conducted to determine certain characteristics of the blimp, with a focus on the overall drag, which is expected to be a limiting factor due to the blimp's low thrust propulsion system. With a flow rate of 5 m/s, the simulation calculates a drag force of 1.327 N, which is less than the 3.2 N thrust produced by the ion thrust system. Now that the total blimp area is known to be 12.5 m², it is possible to calculate the blimp's coefficient of drag.

$$C_d = \frac{D}{\rho * A * V^2 / 2} = 6.934 * 10^{-3} \quad (20)$$

The coefficient of drag (C_d) is calculated using the formula: $C_d = D / (0.5 * \rho * A * V^2)$ Where A is the reference area, which is taken to be the entire surface area of the blimp, D is the drag force determined from Solidworks fluid calculations, ρ is the density of air at sea level (since the blimp is not expected to operate at high

altitudes and sea level density is sufficient for this initial calculation), and V is the velocity set to 5 m/s to match the experimental results from the MIT ion plane team. The top speed of the blimp, which is the speed at which the drag force

$$D = C_d * \frac{\rho * V^2}{2} * A = 7.782 \text{ m/s} \quad (21)$$

equals the thrust force, can be calculated using the Cd value and the fact that the ion thruster's thrust is 3.2 N. (as shown in Figure 10). The blimp's maximum speed, calculated based on the drag coefficient and the thrust provided by thruster, is found to be very low. This indicates that the blimp would not be able to effectively operate in outdoor conditions, considering that the calmest recorded wind speed average for a month in Lithuania was 1.75 m/s[30]. To manoeuvre and stabilize the blimp, several control components can be utilized, including three-axis gyroscopes, accelerometers, an optical flow camera for better hovering, and an Ardupilot board. The Ardupilot board offers updated code specifically designed for controlling lighter-than-air ships and facilitates the integration of various sensors control schemes. Implementing an integral, differential, proportional (PID) controller in the control loop can be considered to further stabilize the blimp. The blimp's control can be achieved by selectively activating and deactivating portions Using the blimp's rear-located ion thruster array to produce yaw and pitch moments, enabling effective control and orientation of the blimp.

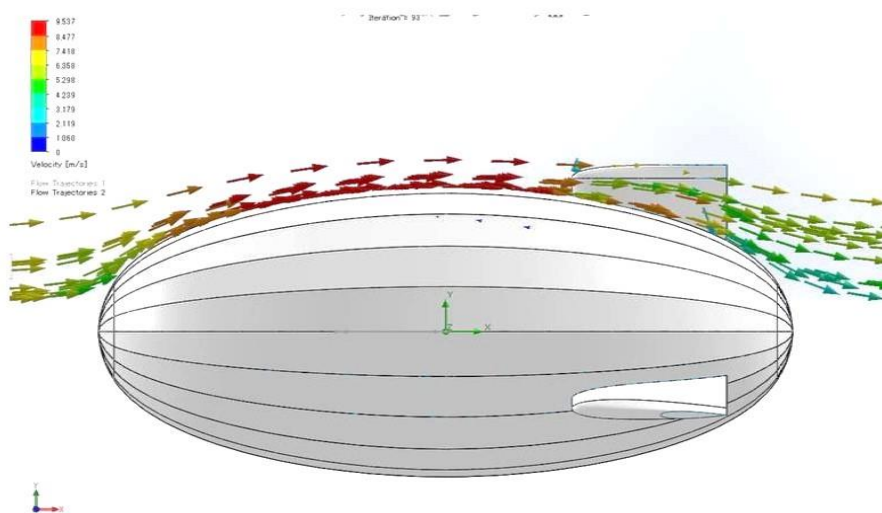


Fig:2.10 Solidworks flow Simulation

Based on the modeling results, it is estimated that the maximum powerflight time of the blimp with the larger battery pack size could be around 100 to 180 seconds (1.67 to 3 minutes) for controlled flight. However, it should be noted that Turning the ion flow propulsion system on and off for brief periods of time might not be effective due to the Cockcroft-Walton voltage multiplier's slow ramp-up time. As a result, the practical uses of this blimp with ion propulsion may be restricted to novelty uses like showing light advertisements or shocking people by quietly floating over a room. The blimp might not have enough mass to transport significant payloads, and the flight time may not be suitable for sustained long-term operations. It could be comparable to large-scale commercial blimps used for advertising purposes, like the Goodyear blimp "Spirit of Innovation".

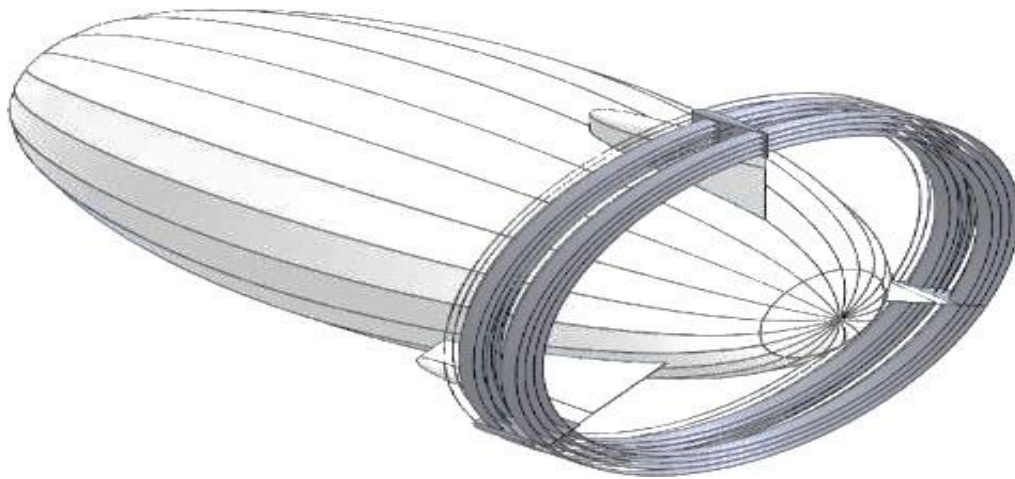


Fig: 2.11 isometric view of EHD propulsion

Indeed, with advancements in technology and further optimization studies, it is possible that more optimal designs could be achieved for the blimp powered by ion propulsion. Fine-tuning the size, shape, and control scheme of the blimp could potentially lead to improved performance and efficiency. However, it should be noted that the combined weight of the battery packs and electrical components required to step up the voltage for the coronal effects may still pose a significant drawback for the overall weight and payload capacity of the blimp. Balancing the weight of the propulsion system with the overall design and performance of the blimp would be an important consideration in further optimization efforts.

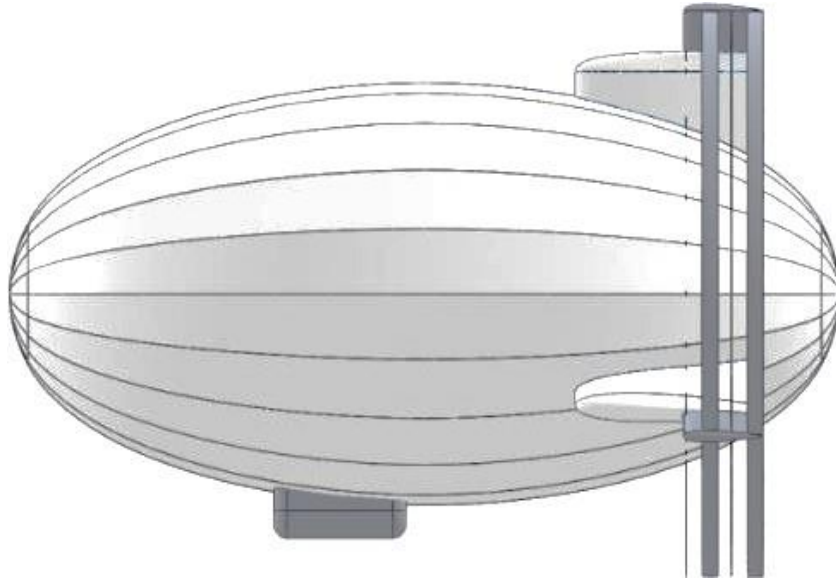


Fig:2.12 EAD-LAT side view of drone

Yes, the aesthetics of the aircraft, including the vehicle's rear is equipped with a two-stage ion thruster., can certainly add to its appearance. The placement of the ion thrusters at the rear of the vehicle can also serve a functional purpose by providing thrust without disturbing the fluid flow passing over the skin of the vehicle, which can help with maintaining stability and maneuver ability. Aesthetics can play a role in the overall design and appeal of a vehicle, and a visually pleasing design can enhance the overall experience and perception of the blimp powered by ion propulsion(fig 11 and fig 12).

2.6.1 DESIGN AND STUDY OF STRUCTURES:

Using thrust beam structure type for main bearing components the blimp, and designing it to hold the weight of the thruster while evenly distributing the weight of the battery and high voltage power converter, is a thoughtful approach. Balsa wood, with its low density and lightweight properties, can be a suitable material for constructing the thrust beams, as it can help keep the overall weight of the blimp low. Rigidity is also an important factor to ensure stability and structural integrity of the blimp, and the chosen thrust beam structure type can provide the necessary rigidity while keeping the mass within the design constraints. Careful consideration of the structural design is crucial to ensure that the blimp can effectively support the weight of its components and operate safely and efficiently(fig.13)

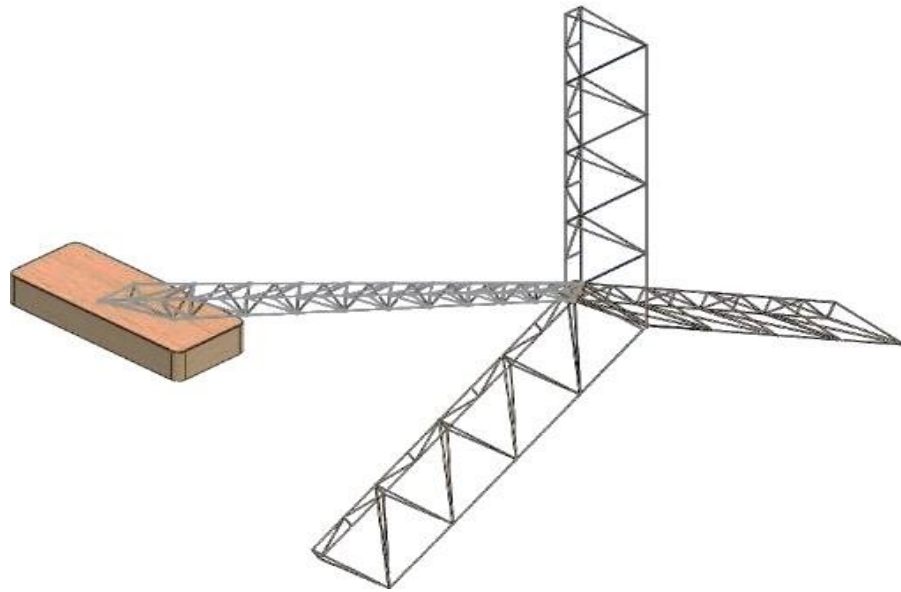


Fig:2.13 a basic structure concept for the drone

Selecting a standard lightweight blimp structure that features ribs and circular members to hold the skin is a practical choice for simplicity. This type of structure can effectively hold the shape of the blimp during the process of filling it with helium, which is important for maintaining the desired aerodynamic shape and stability of the blimp during operation. While it may not be rigid, the chosen structure can provide sufficient support for the blimp's skin and maintain its shape during inflation. This design approach can help streamline the manufacturing and assembly process, as well as reduce the overall weight of the blimp, which is a critical factor for its performance and flight characteristics. Careful consideration of the blimp's structure is essential to ensure its stability, durability, and functionality[31] (fig. 14) .

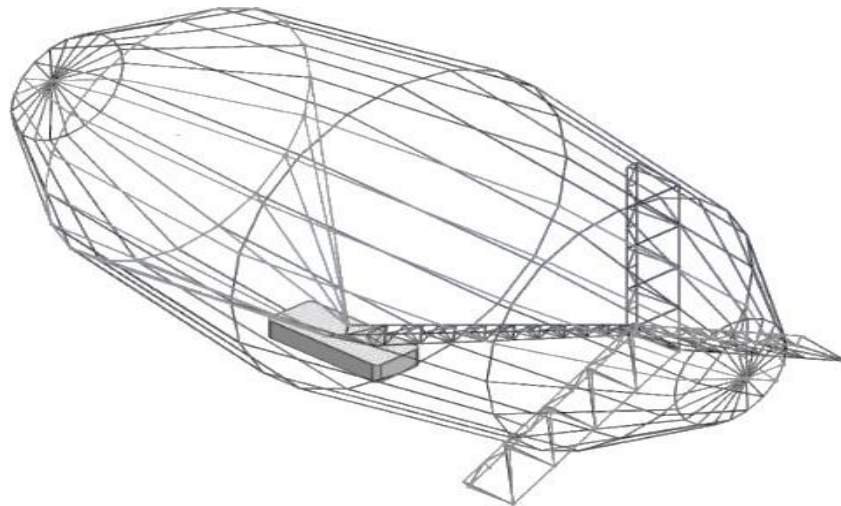


Fig:2.14 skin attached to battery pack and thruster structure

The static study of the blimp structure, considering The only load on the structure is the weight of the balloon surface, which shows that it can support itself with a small amount of weight. While the chosen structure may not be highly rigid, it is capable of maintaining its shape and supporting the weight of the blimp's skin. This is important for ensuring the structural integrity of the blimp during operation and maintaining its aerodynamic shape. However, it's important to note that the low rigidity of the chosen structure may result in some buckling or deformation under higher loads or external forces, which could affect the overall performance and stability of the blimp. Therefore, it's crucial to carefully consider the design and materials used in the blimp structure to ensure it meets the required strength and stability criteria, while also keeping the weight within the constraints of the blimp's weight budget. Further analysis, such as finite element analysis (FEA), can be performed to evaluate the structural performance and optimize the design of the blimp structure.

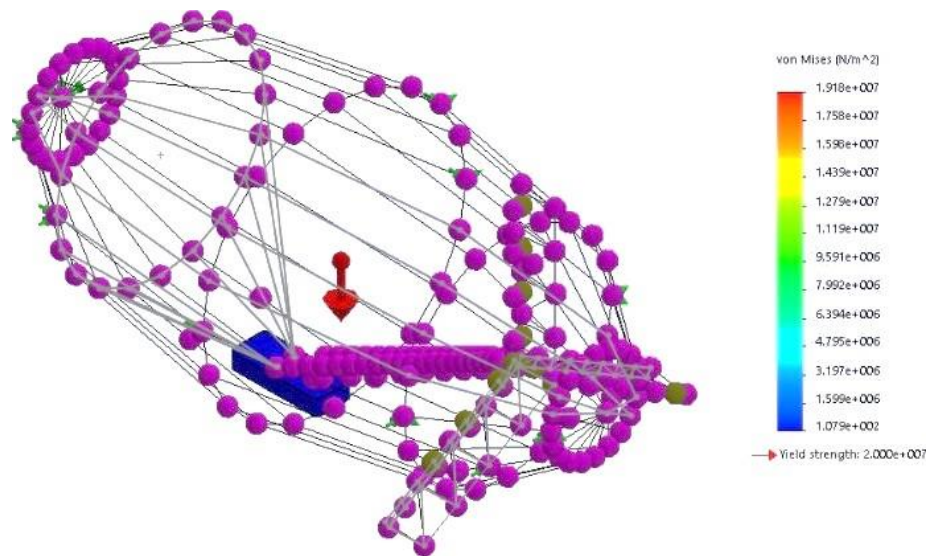


Fig:2.15 Analysis of the gravity load with structure

This can help identify any potential areas of weakness or deformation and make necessary design adjustments to increase the structure's overall strength and stiffness structure, while still maintaining the weight constraints of the blimp. By carefully balancing the trade-offs between weight, rigidity, and structural integrity, an optimal design for the blimp structure can be achieved to ensure safe and reliable operation of the blimp. Upon further analysis, it is evident that the chosen structure made of balsa wood, with a yield strength of 20 MPa along the grain (fig. 15), may not be sufficient to withstand the loads imposed by the battery and voltage converter mass. The stress levels within the structure are approaching the yield strength even without any additional loads applied, indicating that the structure may be at risk of deformation or failure. When the main load, which includes the mass of the battery and voltage converter, is applied, it is likely to result in even higher stress levels within the structure. This can further compromise the structural integrity and stability of the blimp, posing a safety risk during operation. To ensure the safe and reliable operation of the blimp, it is imperative to reconsider the design and materials used for the structure. This may involve selecting alternative materials with higher strength-to-weight ratios, optimizing the structural

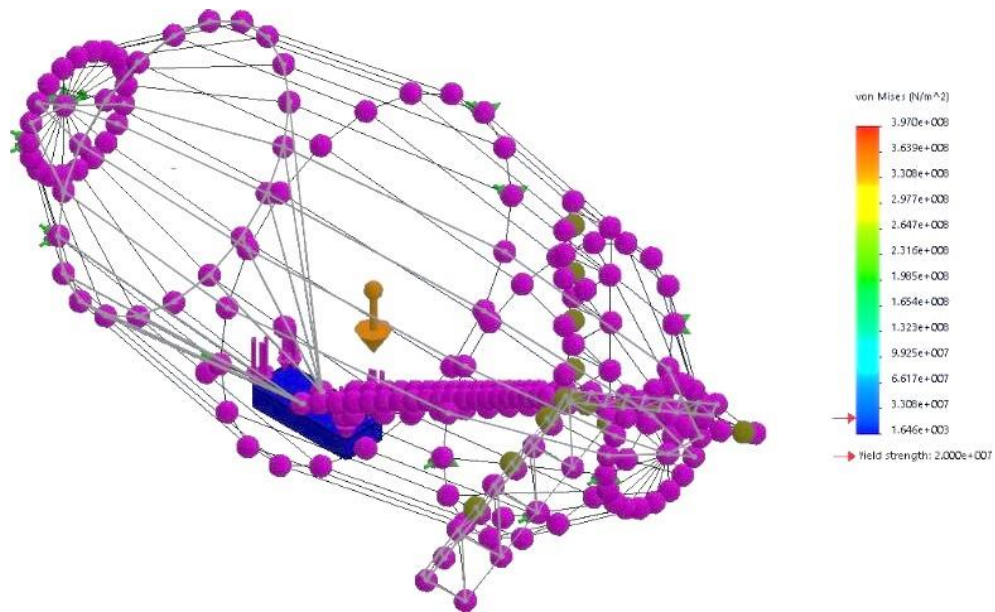


Fig:2.16 battery mass load with static

geometry to distribute loads more efficiently, or incorporating additional support elements to reinforce the structure. Finite element analysis (FEA) can be used to further evaluate the structural performance and identify any areas of concern, enabling appropriate design modifications to be made for achieving a more robust and reliable blimp structure. It is crucial to prioritize the structural strength and integrity of the blimp while still adhering to the weight constraints of the overall design. Using aluminum trusses as an alternative material for the blimp structure could potentially offer higher strength and rigidity compared to balsa wood. Aluminum is known for its lightweight and high strength-to-weight ratio, which makes it a suitable material for aerospace applications. After converting the trusses to aluminum, a static study is performed to evaluate the structural performance of the blimp. The results show that the stress levels within the structure are significantly reduced compared to the balsa wood trusses, and the structure is able to withstand the loads imposed by the battery and voltage converter mass without significant deformation or failure (fig. 16). This indicates that the aluminum trusses are better suited for supporting the weight of the blimp and the additional loads. However, it's important to note that using aluminum trusses will also add to the overall

mass of the blimp, which may impact its weight budget and affect other design considerations such as payload capacity and flight performance. Therefore, a trade-off between structural strength and weight constraints needs to be carefully considered during the design process.

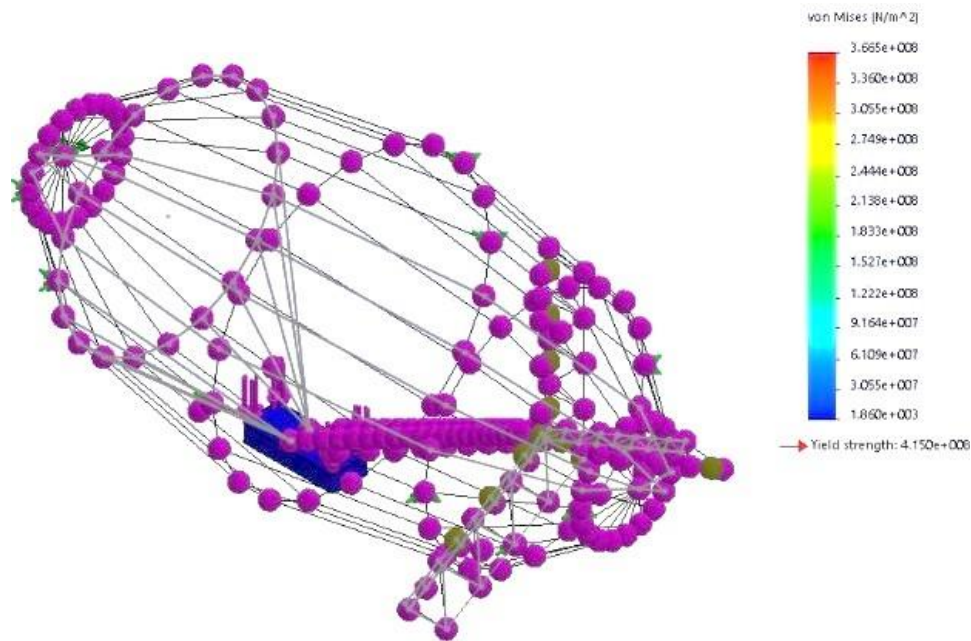


Fig: 2.17 Static study with Aluminum 2014

Further optimization and analysis may be required to fine-tune the design, including optimizing the size, shape, and distribution of the trusses to minimize weight while maintaining structural integrity. Additionally, other design considerations such as aerodynamics, stability, and safety should also be taken into account to ensure the overall performance and reliability of the blimp. Collaborating with structural engineers and using advanced simulation techniques such as finite element analysis (FEA) can provide valuable insights and guidance in making informed design decisions for a more optimal blimp structure. The blimp structure and the challenges faced in terms of weight, rigidity, and material selection. It is clear that the initial design using balsa wood trusses was not sufficient to support the loads imposed by the battery and voltage converter mass, and even with the alternative aluminum trusses, the structure still falls short of the desired safety coefficient of 1.5 and experiences stress levels close to the yield strength. You have identified that a complete redesign of the structure may

be necessary, and you are considering a tri-truss structure used in commercial blimps as a potential solution. This could involve adding more longitudinal girders and frames to increase rigidity, but it may also result in a higher overall mass for the blimp, requiring a larger volume of helium for buoyancy. It's important to carefully consider the trade-offs between structural strength, weight constraints, and overall performance of the blimp. Collaborating with structural engineers and using advanced simulation techniques such as finite element analysis (FEA) can be valuable in guiding the redesign process and ensuring that the structure is capable of safely supporting the loads and functioning in the intended flight configuration. As you continue with the balsa wood structure for the purposes of your work, be sure to keep in mind the limitations and potential risks associated with the structural design. Regular testing and validation of the structural integrity during the development process will be crucial to ensure the safety and reliability of the final blimp design[42].

2.6.2 EAD-LAT BLIMP DESIGN SPECIFICATIONS:

The final design of the blimp structure. It appears that you have chosen a semi-rigid design with a polyester skin of a balsa wood framework inside the blimp to give rigidity around the thruster component, and 0.15 mm thick. This design approach likely balances the need for lightweight materials and structural rigidity. The polyester skin, with its low thickness, can help reduce weight while providing a gas-tight enclosure for the helium gas, allowing the blimp to maintain its buoyancy. The balsa wood structure can provide the necessary rigidity around the thruster component, helping to distribute the weight and maintain the desired shape of the blimp. It's important to carefully consider the fabrication and assembly processes for the chosen materials and design. Ensuring proper attachment and integration of the balsa wood structure with the polyester skin, as well as thorough testing and validation of the overall structural integrity, will be crucial to ensure the safety and reliability of the blimp during operation. Additionally, it's important to keep in mind any regulatory requirements or standards for blimp design and construction, such as those set by aviation authorities or industry organizations. Compliance with these standards can help ensure that the blimp meets safety and performance requirements. The final design with a semi-rigid structure using a polyester skin and balsa wood components

appears to be a well-considered approach that addresses the challenges of weight, rigidity, and structural integrity in the blimp design. Regular testing and validation during the development process, as well as collaboration with experts in the field, can help ensure the success of the final design.

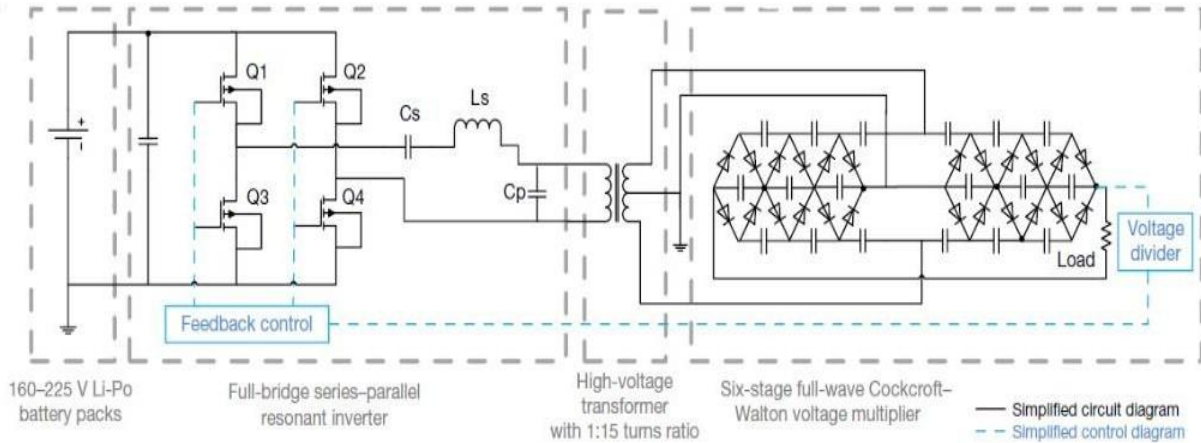


Fig: 2.18 The MIT's High voltage powerconverter [28]

The internal scheme for blimp, based on the design MIT's solid state propulsion aircraft team created it. (as shown in Figure 18), is a proven and tested approach that can provide reliable propulsion for the blimp. As the drone is heavily based on their design and experimental data, it's likely that their electrical scheme is well-suited for your blimp application. It's important to carefully review and understand the electrical scheme, ensuring that all components are properly integrated and connected according to the design provided by the MIT solid state propulsion airplane team. This may include components such as motors, batteries, voltage converters, and other electrical systems necessary for propulsion and control of the blimp. It's also essential to consider safety measures, such as proper grounding, insulation, and protection against overloading or short-circuiting. Following best practices for electrical design and installation, as well as any applicable regulations or standards, can help ensure the safe and reliable operation of the blimp. Regular testing and validation of the electrical system during the development process, as well as thorough functional testing before operation, can help identify and address any potential issues and ensure the proper functioning of the electrical scheme. Collaboration with experts in electrical engineering and propulsion systems can also provide valuable insights and

guidance for the successful implementation of the electrical scheme in the blimp. Overall, the use of the electrical scheme developed by the MIT solid state propulsion airplane team is a promising approach that can provide reliable propulsion for your blimp. Careful implementation, testing, and validation of the electrical system will be crucial for the safe and successful operation of the blimp.

2.6.3 EXPERIMENTS WITH EHD TECHNOLOGY HAVE BEEN CONDUCTED

The study team chose to build a lifter-style device to have practical experience building such things and to conduct a fundamental analysis of the physics process behind EHD cooling. The fabrication process likely involved designing and assembling the necessary components for a lifter-type EHD device. This could include electrodes, dielectric materials, power supply, and control mechanisms. The fabrication process may have involved precision machining, assembly, and wiring of the components to create a functional lifter-type device. Once the lifter-type device was fabricated, the team likely conducted experiments to analyze its performance and understand the physical phenomenon of EHD cooling. This could involve measuring various parameters such as voltage, current, airflow, and temperature, and analyzing the data to determine the effectiveness of the EHD cooling process. The analysis may have included evaluating the lift force generated by the device, studying the electrical properties of the ionized air or plasma created by the high-voltage field, and observing the interaction between the electric field, charged particles, and airflow. This could have provided insights into the fundamental principles and mechanisms of EHD cooling, helping the team to further refine their understanding of the technology. Additionally, the team may have performed comparative analysis with other cooling methods, such as conventional cooling fans or liquid cooling, to evaluate the performance and efficiency of the lifter-type EHD device in comparison to existing cooling technologies. The fabrication and analysis of a lifter-type device would have provided valuable practical experience and insights into the challenges and potential of EHD cooling technology. The findings from these experiments could have informed the team's further research and development efforts towards building more advanced EHD cooling systems for specific applications, such as personal computers or servers. It was determined to first have access to a high voltage power source before starting the physical tests. A request was made for a high

voltage power source capable of producing up to 35 kV with a 30 ma current for the Genvolt firm in Britain[39]. This gadget contained switches and interfaces, but after much debate with the deal-makers, the total cost of the device was estimated to be above 1000 euros. A new technology for carrying high voltage electricity was adopted because the exploratory budget did not allow for comparable high expenses. An outdated cathode tube used by kinescope observers charges to less than 24 kV. A little bit of tinkering is necessary in order to convert said device into a power source. A dated Panasonic monitor was purchased from a nearby used electronics shop. This specific monitor was practically free because the input connection had been damaged. The disassembly procedure was started in order to use the high voltage inside. It needed direct access to the wire that connects the cathode tube to the flyback transformer in order to be accessed. Because it is difficult to access and heavily isolated, the monitor must be disassembled. It was made sure that the grounding wires are in place. The monitor's housing was finally closed [40] after being disassembled and giving access to the flyback transformer wire seen on top. A few tests were conducted after ensuring that the case was properly closed to ensure the power supply and high voltage were produced. Everything seems to be in order. The lifter's construction gets underway. A short between a lifter's high voltage and grounded electrodes occurred during one of the lifter's initial testing, causing it to catch fire. A local air-breaking corona effect appears to have happened due to a serious miscalculation depending on the size of the distances between the electrodes and the voltage the power supply provides. Additionally, the testing was stopped since it appears that the incident short-circuited the power supply. Even though this occurrence was not documented with photographs, it is important to note that it is advisable to avoid conducting similar experiments in a home setting. While conducting these kinds of tests in a laboratory would be ideal, with the right tools and the capacity. In order to set voltages and carry out tests of litre shape, access to such locales between the years 2020 and 2021 was limited, therefore creativity was required. The fact that no one was hurt cannot be emphasised enough, but the situation was perilous enough to call for a halt to practical experiments and a shift in emphasis towards the theoretical portion of the study.

2.6.3 CONCLUSION

- The research team conducted a study on currently available ion propulsion technologies and reviewed relevant papers on the subject. Based on their findings, it was determined that ion propulsion technology is most likely to be used in aircraft and cooling-related applications.
- The team also designed ion thrusters were used to power a smaller, lighter-than-air drone, and its performance was compared to that of a typical motorised drone. The findings demonstrated that the efficiency differences were too great to warrant the practical use of ion thrusters in the drone industry.
- The researchers also created an electrohydrodynamic (EHD) driven ventilationsystem, however they discovered that it required 25 timemore space and was over 400 times less effective than traditional ventilation systems at movingthe same volume of air.
- Ion propulsion technology was tested in real-world applications, however the tests were unsuccessful. The testing brought to light the difficulties in establishing stable circumstances for ion thrust to function as well as the shortcomings of current designs frequently employed for ion propulsion.. This suggests that further research and development may be needed to improvethe stability and reliability of ion propulsion systems.

CHAPTER 3

AIM AND SCOPE

AIM:

The aim is to characterize the type of propulsive force that develops during a positive corona discharge in nitrogen gas within an asymmetric capacitor design. To gain a physical understanding of the force mechanism acting on two different types of capacitor encircled by any gas, it is possible to compute all hydrodynamic and electrostatic forces acting on the geometry under consideration using the concepts of electrohydrodynamic (EHD) and electrostatics. We shall show that the electrostatic interaction force between the capacitor electrodes and the surrounding positive ion charge, which is present in the atmosphere and causes the ion wind, is the primary cause of the propulsion force. The ion wind is merely a by-product of the electrostatic interaction; the force pushing the capacitor ahead is electrostatic rather than hydrodynamic.

SCOPE:

Ion propulsion, also known as ion thrusters or electric propulsion, is a type of propulsion technology that uses electric fields to accelerate ions and generate thrust. It has gained significant interest and attention in recent years. The objective of this study is not to determine the optimal thruster configuration but to observe the differences between the single and dual configurations. In this work a “lifter” type thruster was constructed and tested under both AC and DC. The scope for ion propulsion is vast and varied, ranging from deep space exploration to satellite propulsion, interplanetary missions, orbital maneuvers, in-space servicing and refuelling, small satellite propulsion, and in-space transportation. Ion propulsion offers significant advantages in terms of efficiency, high specific impulse, and long-duration thrust, making it a promising technology for future space missions.

CHAPTER 4

METHODOLOGY

Ionocraft use a very high voltage to ionise the air and then use that voltage to propel the ionised molecules, which interact with the unionised molecules of the air around them and push them along as well. As a result, a "Ion wind" is produced, which powers the aircraft. The voltage is often applied between two conductors that are spaced apart by a predetermined air gap; one of the conductors has a sharp edge, while the other is formed more spherically and serves as an ion collector. A strong electric field is only created around the electrode's sharp edge when a high voltage is applied. Air molecules flow widely from the sharp edge to the grounded electrode due to the size difference between the two conductors. The movement, or "ionic wind," generates a powerful downward force that propels the aeroplane upward. due to the aircraft's simplicity and lack of moving parts.

4.1 DESIGN:

The well-rounded, cambered airfoil section is well-suited to subsonic flight speed. They are generally not appropriate for high-speed and supersonic flight. Supersonic airfoils are distinctive in their geometric shapes in that they are thin (i.e., have a low thickness-to-chord ratio) with sharp leading edges. Supersonic airfoils generally have thinner sections formed of either angled planes called double wedge airfoils.

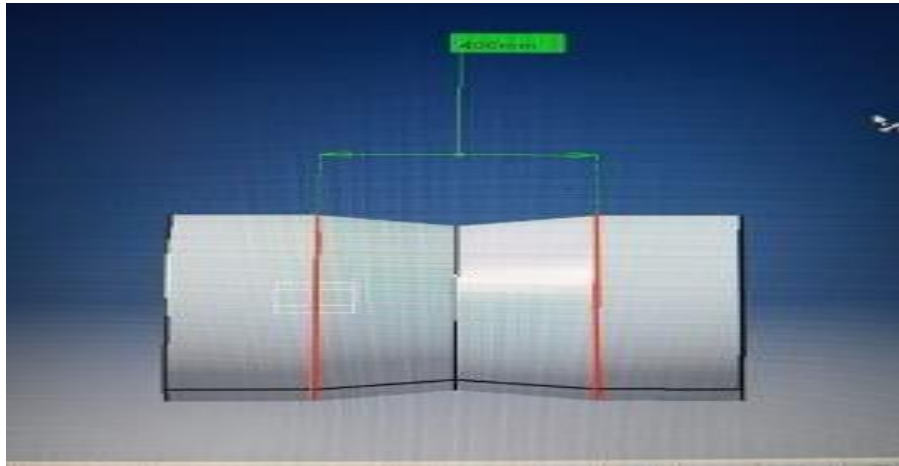


Fig:4.1 Side view of convergent-divergent nozzle

in this design we made a three different types of cores in the shape of double wedge airfoils by making our ionic thruster in

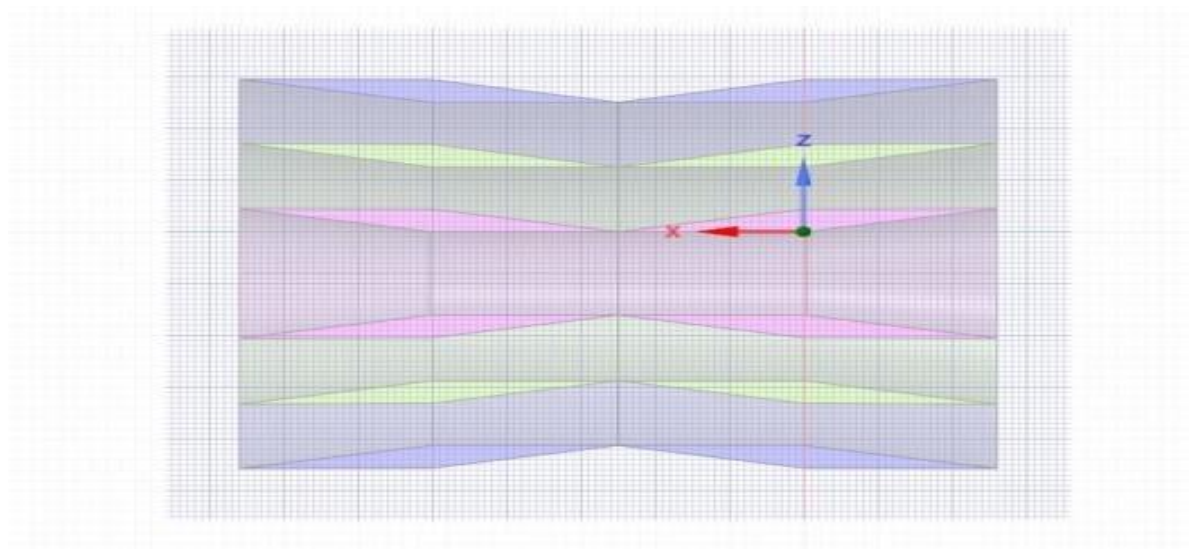


Fig: 4.2 Sliced view which shows superficial airfoil

convergent-divergent nozzle, is a tube which is pinched in the middle, making a carefully balanced, asymmetric hourglass shape. It is used to accelerate a compressible fluid to supersonic speeds in the axial (thrust) direction, by converging the thermal energy of the flow into kinetic energy. so, it helps to increase the thrust ionic thruster (as shown in figure 19, 20, 21)

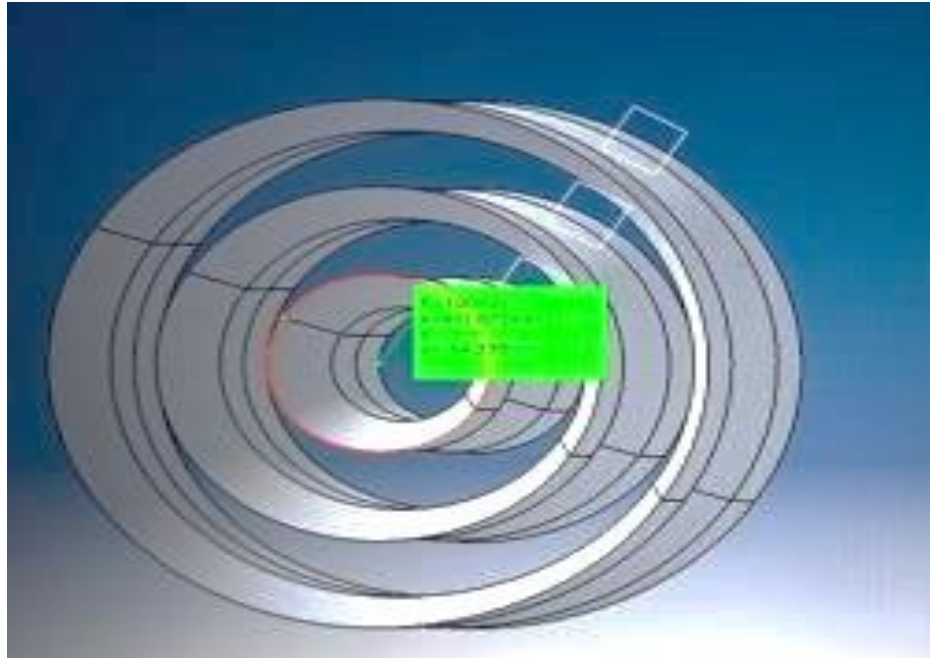


Fig:4.3 Dimensions of first convergent-divergent nozzle

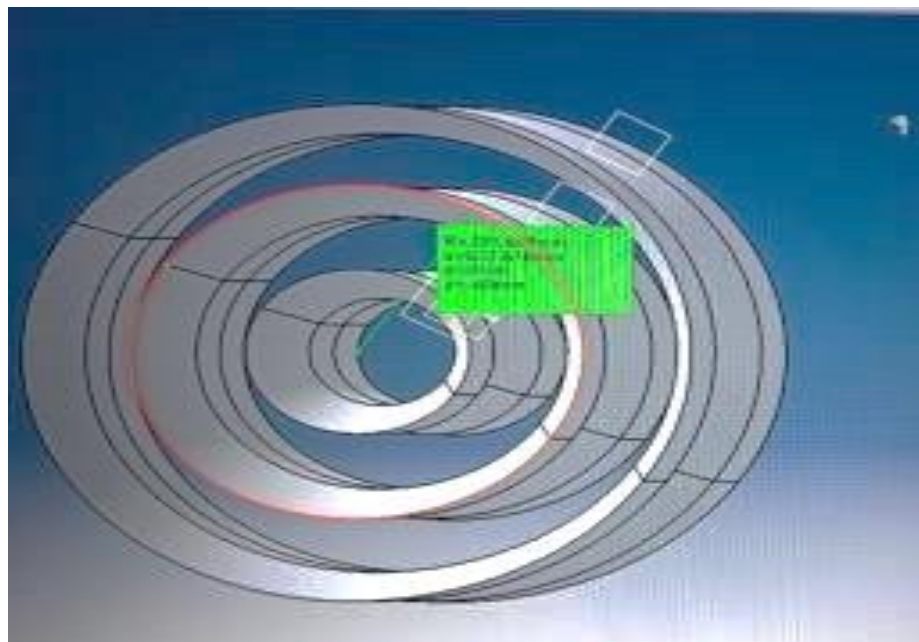


Fig:4.4 Dimensions of second convergent-divergent nozzle

At the other extreme, some high bypass ratio civil turbofans control the fan working line by using a convergent-divergent nozzle with an extremely low area ratio on the bypass stream. At low airspeeds, such a setup causes the nozzle to act as if it had variable geometry by preventing it from choking and allowing it to accelerate and decelerate exhaust gas approaching the throat and divergent section, respectively.



Fig:4.5 Dimensions of third convergent-divergent nozzle

Consequently, the nozzle exit area controls the ionic wind, which, being larger than the throat, pulls the ionic wind working line slightly away from the surge. At higher flight speeds, the ram rise in the intake chokes the throat and causes the nozzle's area to dictate the electrode match; the nozzle, being smaller than the exit, causes the throat to push the fan working line slightly toward surge. The airflow produced by the ionic wind also depends on the wire with respect to the electrode. There are different methods such as placing wire perpendicular or crossgrid structure, placing in front of the electrode but it increases sound and off-side electrode is the best; it produces less sound and high velocity. We used CATIA to design this model.

4.2 MATERIALS:

To conduct experiments comparing SS (Single-Stage) and DS (Double- Stage) thrusters, a square thruster frame with 40 cm sides was constructed using polytetrafluoroethylene (PTFE) material. The frame was suspended from scales and had holes placed at 1 cm increments from the top point of the collector surface to adjust the interelectrode gap. The collector, which formed one side of the square, was made of an aluminium 6061 tube with an outer diameter of 6.35 mm. The emitter wire was a 32 AWG solid tinned copper wire. For DS tests, a 4 AWG copper wire was used as the intermediate electrode. Since the diameter of a 4 AWG wire is not negligible (5.189 mm), the gaps d_1 and d_2 were adjustable in 1 cm increments from the top surface of the intermediate electrode and from the bottom surface of the intermediate electrode to the top surface of the collector, respectively. All electrodes had a length (L) of 40 cm as they extended along the frame. Thrust measurements were taken using an Ohaus Scout Pro digital scale with a capacity of 600 g and a resolution of 0.01 g. The thruster was hung from a hook underneath the scale, and the thrust was measured as a reduction in weight. The SS configuration of the thruster weighed approximately 240 g, while the DS configuration weighed around 320 g. Electrical power was supplied using Matsusada AU120P2.5 for positive polarity and Matsusada AU120N2.5 for negative polarity, both rated up to 120 kV and 2.5 mA, and equipped with over-current protection for arcing situations. Voltage and current readings were obtained

CHAPTER 5

RESULTS AND DISCUSSION, ANALYSIS

5.1 ANALYSIS:

Analysis is done using comsol software using argon gas

5.1.1 PARAMETERS:

Tabel 5.1: Parameters taken to analysis

Name	Expression	Value	Description
p0	1[torr]	133.32Pa	Initial and outlet pressure

Parameter p0 is 1 torr, whose value is 133.32pa and the required description is initial and outlet pressure. So the default model inputs to be given first are pressure, whose expression is 1 [atm], and selection is to the ratio of geometry 1: domain 1, where heat transfer in fluids is requested for fluid 1. Second is temperature, whose expression is 293.15 [K], and selection is to the ratio of geometry 1:domain 3, where the magnetic field is requested for coil 1. Third is mixed temperature expression with geometry 1: domains 1–2, 4. Here the magnetic field is requested to obey Ampere's law. So next are the components Here there are four frame coordinates, and each frame is divided into three columns. The first is the spatial frame coordinates, and the given three values for first, second, and third are r, phi, and z, respectively. The second is material frame coordinates, and the given three values for first, second, and third are R, PHI, and Z, respectively. Third, are geometry frame coordinates, and the given three values for first, second, and third are Rg, PHlg, and Zg, respectively. Fourth are mesh frame coordinates, and the given values for first, second, and third are Rm, PHlm, and Zm. And the given study setting is to generate default plots and convergence plots.

5.1.2 DIELECTRIC

The given data pertains to a geometric entity level called "Selection" and the associated domain of a geometry named "geom1". The dimension of the geometry is specified as 2, indicating that it is a two-dimensional shape. The domain of the geometry is also specified as 2, which likely refers to a second ring or area in a geometric space. In computer-aided design (CAD) or computer-aided modelling (CAM), a "Selection" typically represents a subset or group of geometric entities that have been chosen or highlighted for further operations or analysis. This could include entities such as points, lines, curves, or surfaces that are part of a larger geometric model.

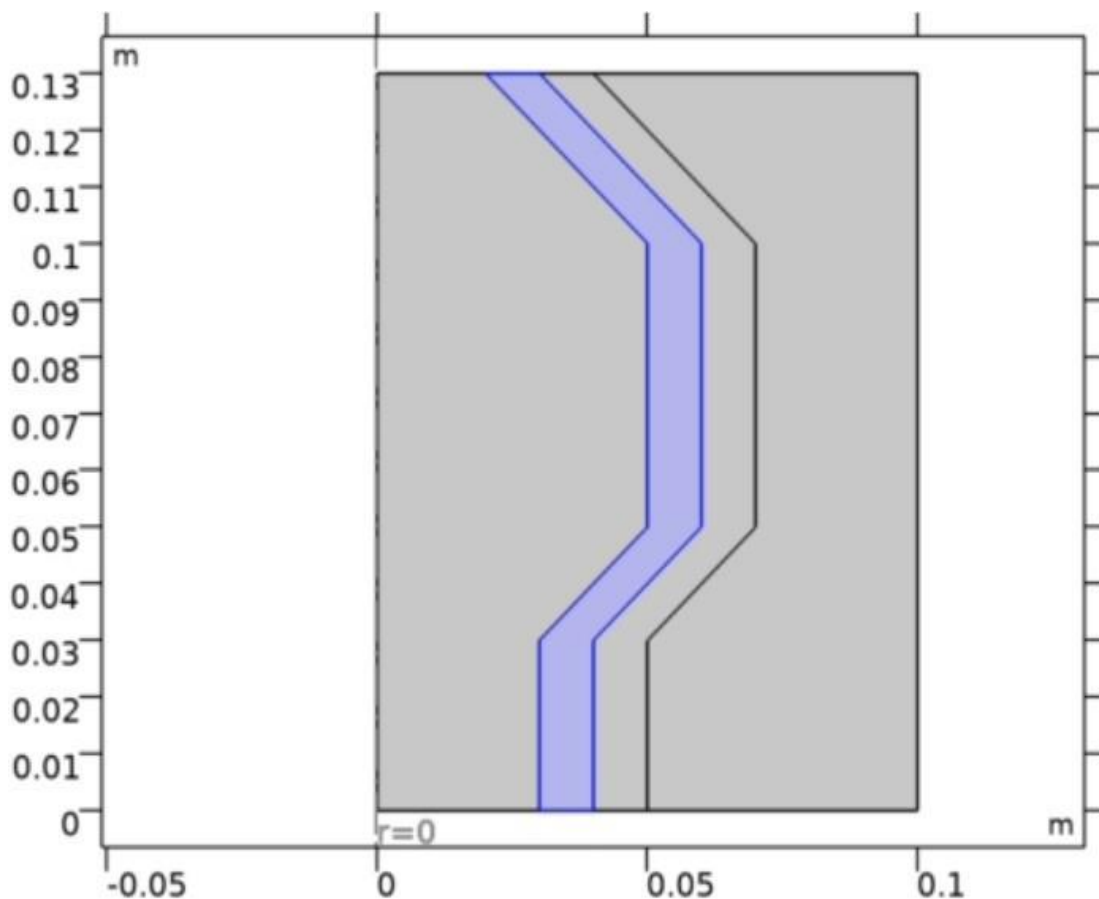


Fig: 5.1 Dielectric acting on 2nd ring

5.1.3 AIR

The given data relates to a geometric entity level referred to as "Selection" and the associated domain of a geometry labeled as "geom1". The dimension of the geometry is indicated as 2, which implies that it represents a two-dimensional shape. The domain of the geometry is specified as 4, which likely denotes a particular region or area within the geometric space.

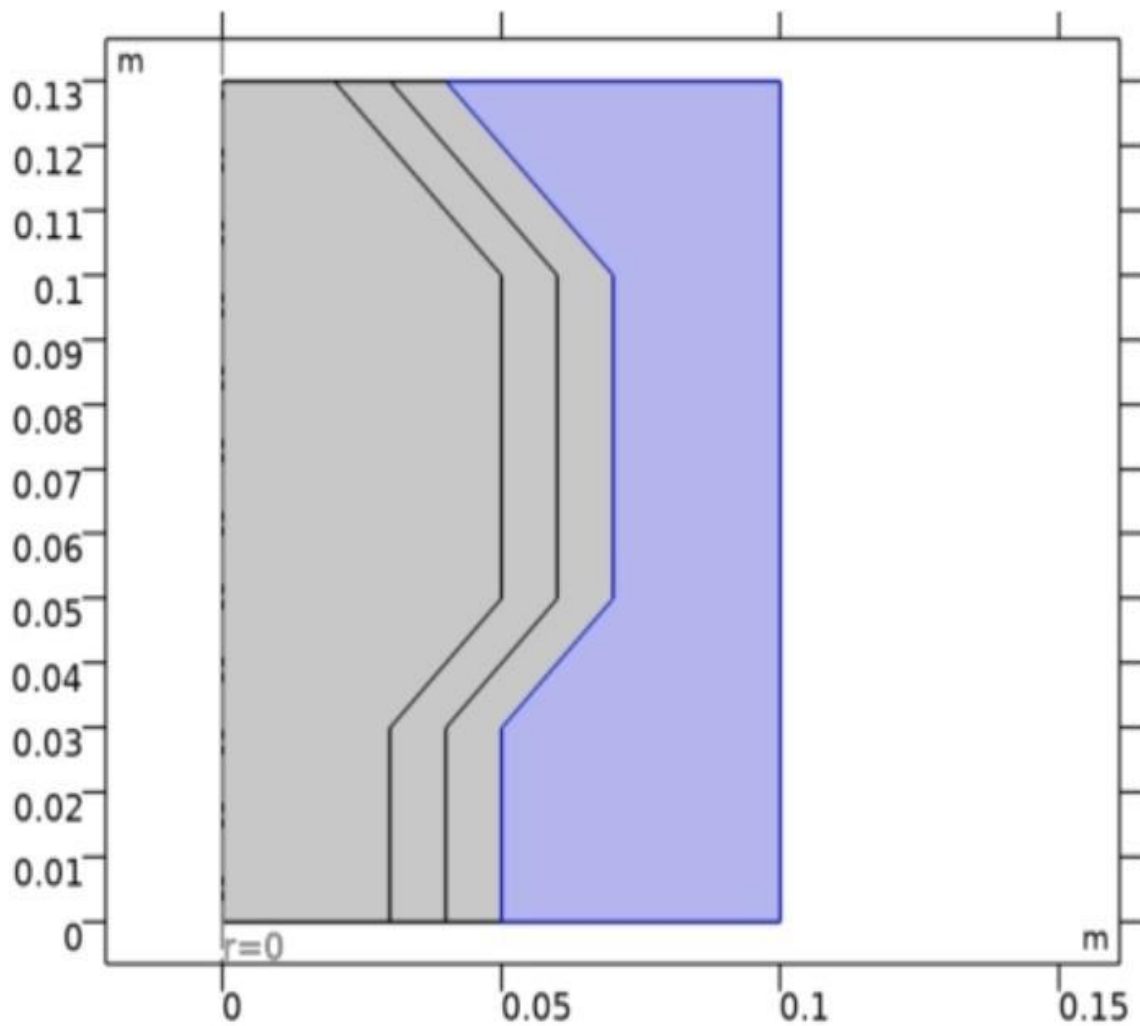


Fig:5.2 Air acting on outside of nozzle

5.1.4 COPPER COIL

The domain level, specifically related to a selection of geometry represented by "geom1". Let's break down the information provided :Geometry geom1: This refers to a specific geometric entity labeled as "geom1". The nature of this geometry is not explicitly mentioned in the given data, but it is indicated to have a dimension of 2. Dimension 2: This indicates that the "geom1" geometry has a dimensionality of 2. In geometry, dimension typically refers to the number of coordinates required to specify the position of a point, the length of a line, or the shape of an object. A dimension of 2 suggests that the "geom1" entity exists in a two-dimensional space, such as a plane. Domain 3: This suggests that the "geom1" entity is associated with or defined within a specific domain labeled as "3". The nature or characteristics of this domain are not provided in the given data.

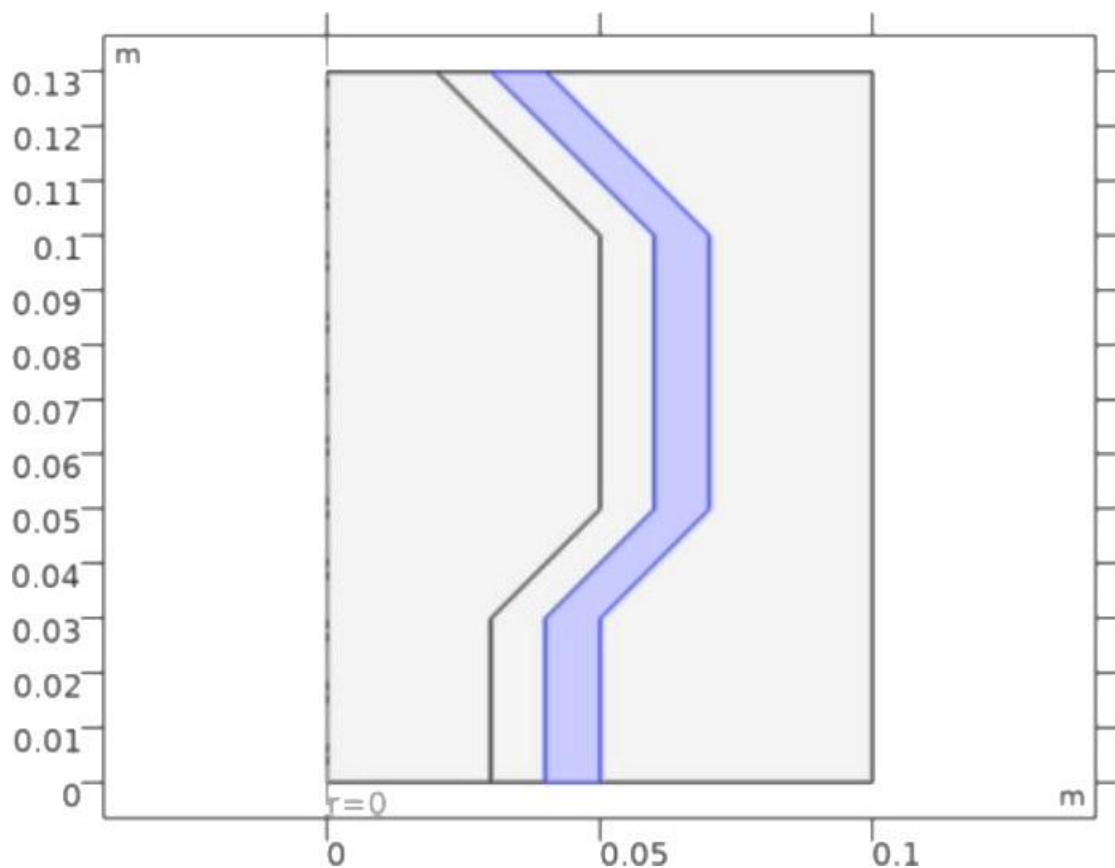


Fig: 5.3 Copper coil on 1st ring

5.1.5 Plasma

Table 5.2 Various gases acting on design

Name	Level
Cross Section Import 1	Point
1: $e + \text{Ar} \Rightarrow e + \text{Ar}$	Domain
2: $e + \text{Ar} \Rightarrow e + \text{Ar}_s$	Domain
3: $e + \text{Ar}_s \Rightarrow e + \text{Ar}$	Domain
4: $e + \text{Ar} \Rightarrow 2e + \text{Ar}^+$	Domain
5: $e + \text{Ar}_s \Rightarrow 2e + \text{Ar}^+$	Domain
6: $e + \text{Ar} \Rightarrow e + \text{Ar}$	Domain
7: $e + \text{Ar} \Rightarrow e + \text{Ar}_s$	Domain
8: $e + \text{Ar}_s \Rightarrow e + \text{Ar}$	Domain
9: $e + \text{Ar} \Rightarrow 2e + \text{Ar}^+$	Domain
10: $e + \text{Ar}_s \Rightarrow 2e + \text{Ar}^+$	Domain
11: $\text{Ar}_s + \text{Ar}_s \Rightarrow e + \text{Ar} + \text{Ar}^+$	Domain
12: $\text{Ar}_s + \text{Ar} \Rightarrow \text{Ar} + \text{Ar}$	Domain
Species: e	Domain
Species: Ar	Domain
Species: Ar _s	Domain
Species: Ar ⁺	Domain
1: $\text{Ar}^+ \Rightarrow \text{Ar}$	Boundary
2: $\text{Ar}_s \Rightarrow \text{Ar}$	Boundary
Plasma Model 1	Domain
Initial Values 1	Domain
Zero Charge 1	Boundary
Insulation 1	Boundary
Axial Symmetry 1	Boundary
Ground 1	Boundary
Wall 1	Boundary

list of various entities, levels, domains, species, and boundaries related to a plasma or physics simulation model. Let's break down the information provided:

- $e + \text{Ar} \Rightarrow e + \text{Ar}$: Domain: This indicates a domain (or a region of applicability) associated with a specific reaction or process involving electrons (e) and argon (Ar) in the plasma simulation. The given reaction involves the collision of an electron with an argon atom resulting in the scattering or exchange of particles.'
- $e + \text{Ar} \Rightarrow e + \text{Ar}_s$: Domain: This indicates another domain associated with a similar electron-argon reaction, but with a different outcome, resulting in the formation of
- $e + \text{Ar}_s \Rightarrow e + \text{Ar}$: Domain: This indicates a domain associated with a reverse reaction where the excited argon species (Ar_s) interacts with an electron, resulting in the relaxation of the argon species back to its ground state.
- $e + \text{Ar} \Rightarrow 2e + \text{Ar}^+$: Domain: This indicates a domain associated with a more complex reaction involving the ionization of an argon atom, where an electron is removed to form a singly charged argon ion (Ar^+).
- $e + \text{Ar}_s \Rightarrow 2e + \text{Ar}^+$: Domain: This indicates a similar domain as the previous entry, but involving the ionization of the excited argon species (Ar_s) instead.
- Species: This refers to different types of particles or species present in the plasma simulation, including electrons (e), argon (Ar), excited argon species (Ar_s), and argon ions (Ar^+).
- Plasma Model 1: This suggests that the data may be related to a specific plasma model or simulation.
- Initial Values 1: This may refer to initial conditions or parameters set for the plasma simulation.
- Zero Charge 1: This may refer to a boundary condition where the net charge of the plasma is set to zero.

- Insulation 1: This may refer to a boundary condition where the plasma is considered to be electrically insulated or isolated from external influences.

5.1.6 MAGNETIC FIELD

The data is related to model involving Ampère's Law, which is a fundamental law in electromagnetism that describes the relationship between magnetic fields and electric currents. Let's break down the information provided:

- Ampère's Law 1: Domain: This suggests that the data may be related to the application or domain of Ampère's Law within the simulation or model.'
- Axial Symmetry 1: Boundary: This indicates a boundary condition involving axial symmetry, which means the simulation or model assumes symmetry along a particular axis.
- Magnetic Insulation 1: Boundary: This indicates a boundary condition related to magnetic insulation, which implies that the simulation or model assumes a lack of magnetic flux or interaction across the specified boundary. The given data provides information about various entities, levels, domains, boundaries, and objects related to a simulation or model involving Ampère's Law. However, without additional context or details, it is difficult to fully explain the significance or implications of this data in the specific context of the simulation or model being described.

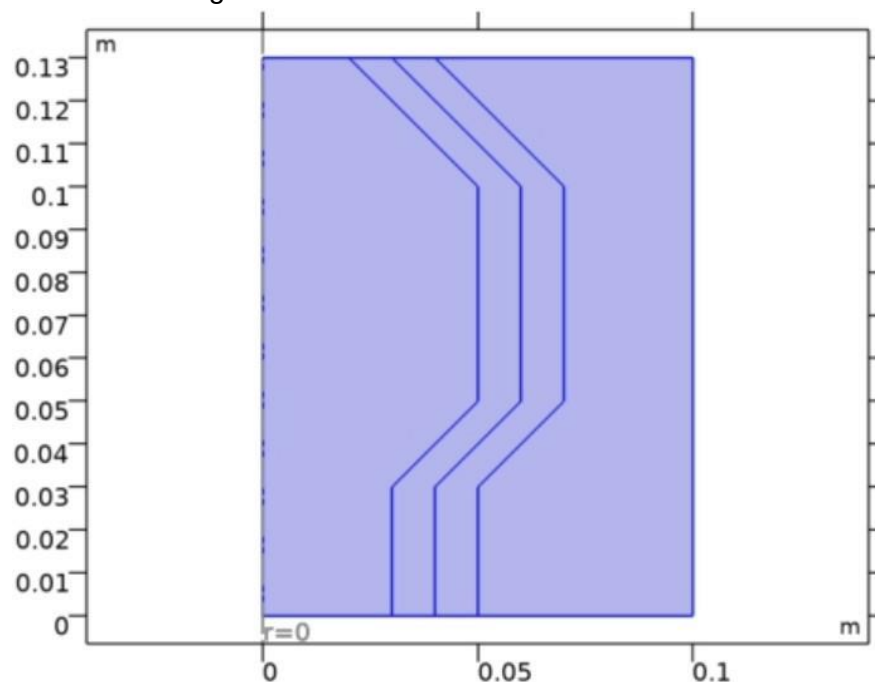


Fig: 5.4 Magnetic field acting on whole nozzle

5.1.7 LAMINAR FLOW

- Fluid Properties 1: Domain: This suggests that the data may be related to the domain or properties of the fluid being simulated or modelled.
- Initial Values 1: Domain: This may refer to the initial values or conditions set for the simulation or model, possibly related to the initial state of the fluid properties.
- Wall 1: Boundary: This suggests that the data may be related to a boundary condition associated with a wall, which could represent a physical boundary within the simulation or model.
- Inlet 1: Boundary: This indicates a boundary condition associated with an inlet, which could represent the point where fluid is introduced into the simulation or model.

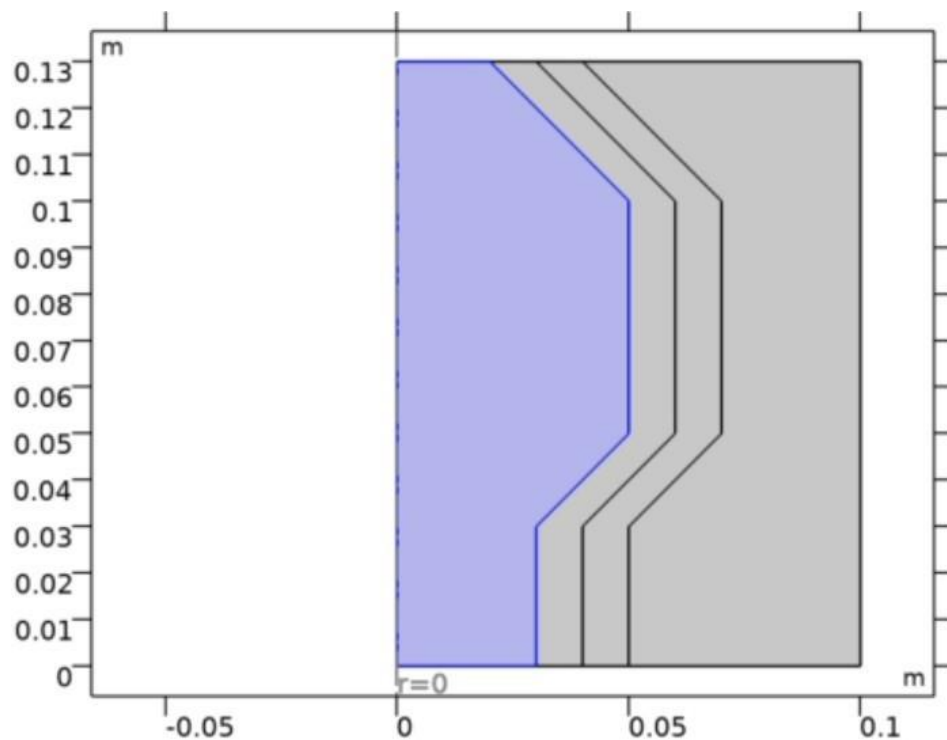


Fig: 5.5 Laminar flow acting inside nozzle

5.1.8 HEAT TRANSFER IN FLUIDS

The given data appears to be related to a simulation or model involving fluid dynamics and heat transfer. Let's break down the information provided:

- Fluid 1: Domain: This suggests that the data may be related to the domain or properties of the fluid being simulated or modeled.
- Thermal Insulation 1: Boundary: This suggests that the data may be related to a boundary condition associated with thermal insulation, which could represent a barrier that prevents or restricts the transfer of heat across the boundary.
- Heat Source 1: Domain: This indicates the presence of a heat source within the domain of the simulation or model, which could represent a region where heat is generated or added to the system.
- Temperature 1: Boundary: This indicates a boundary condition associated with temperature, which could represent the temperature at a particular boundary of the simulation or model.
- Outflow 1: Boundary: This indicates a boundary condition associated with outflow, which could represent a region where fluid is flowing out of the simulation or model. The given data provides information about fluid properties, initial values, axial symmetry, thermal insulation, heat sources, temperature boundaries, and outflow boundaries within a simulation or model that involves fluid dynamics and heat transfer. However, without additional context or details, it is difficult to fully explain the significance or implications of this data in the specific context of the simulation or model being described.

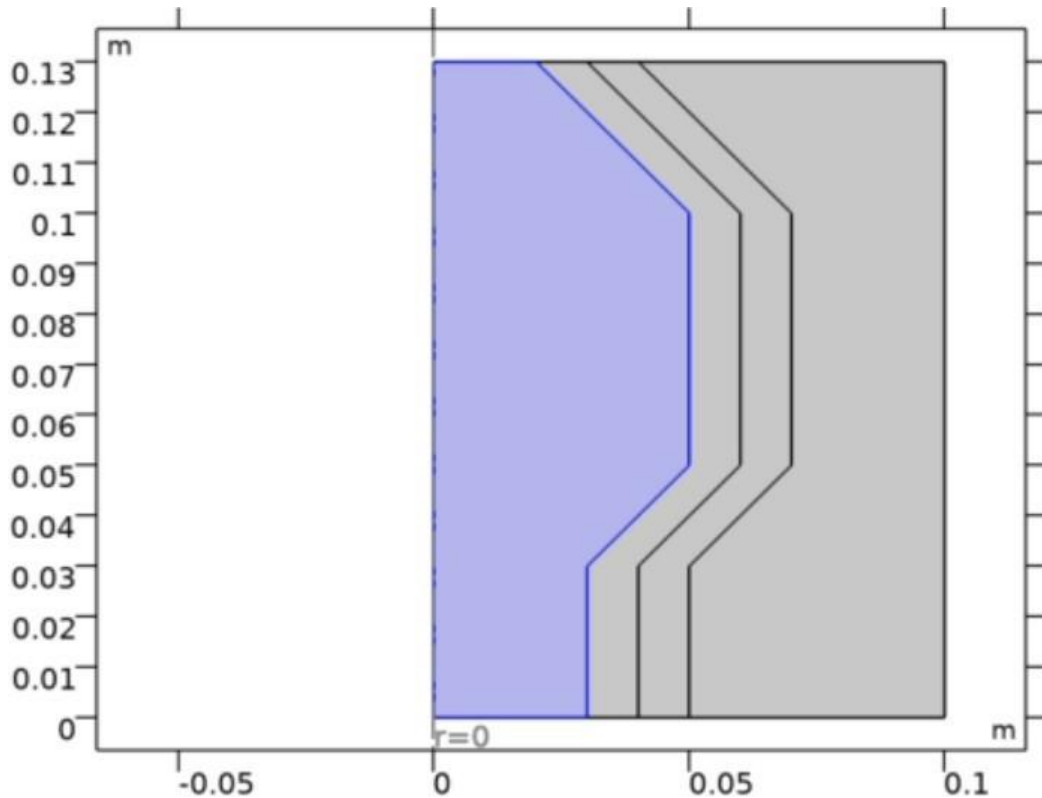


Fig: 5.6 Heat transfer in fluids taking place inside nozzle

5.1.9 MESH

A triangular mesh domain, also known as a triangulated mesh domain or simply a mesh domain, is a type of computational domain used in computer simulations, computer graphics, and numerical analysis. It is a discretization of a continuous domain into a collection of triangles that approximate the shape of the domain. A triangular mesh domain consists of a set of points, called vertices, and a set of triangles, each defined by three vertices. These triangles are connected along their edges, forming a network of interconnected triangles that cover the entire domain. The vertices and triangles in the mesh define the geometry of the domain and are used to represent the shape and boundaries of the domain in a discrete form.

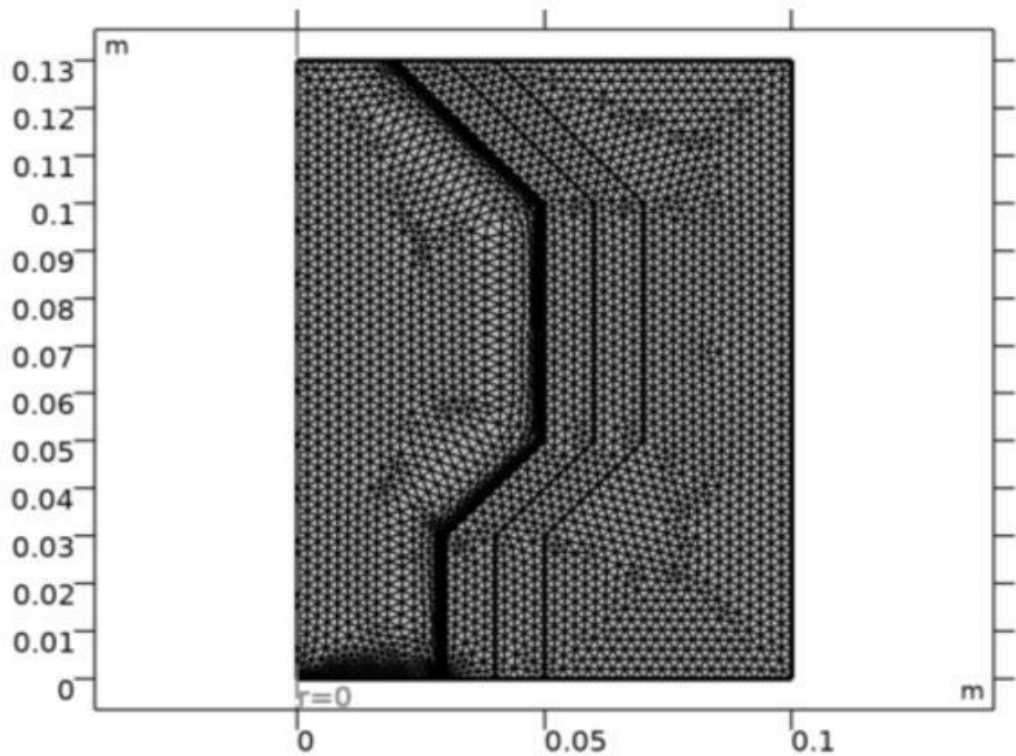


Fig:5.7 Mesh after giving certain parameters

5.2 RESULTS:

These results are formed after giving the parameters and boundary condationsfor the specific domain

5.2.1 ELECTRON DENSITY

The given equation, $Y = 0.01 - 0.13 (TIME)$, represents a linear relationship between the dependent variable Y (time) and the independent variable X (electrondensity), with a constant slope of -0.13 . The graph of this equation would be a straight line on a Cartesian coordinate system, where X is plotted on the horizontal axis (often referred to as the x-axis) and Y is plotted on the vertical axis (often referred to as the y-axis). The graph would have the following properties:

Y-Intercept: The Y-intercept is the point where the line intersects the y-axis. In this case, the y-intercept is at the point $(0, 0.01)$, which means that when X (electron density) is 0, Y (time) is 0.01.

Slope: The slope of the line is -0.13 , which means that for every unit increase in X (electron density), Y (time) decreases by 0.13 units. This indicates a negative linear relationship between X and Y , whereas X increases, Y decreases.

X-Intercept: The X- intercept is the point where the line

intersects the X-axis. In this case, the x-intercept occurs when Y (time) is 0, which means that the line crosses the x-axis at some point to the right of the origin (0,0). The exact x-intercept value can be calculated by setting $Y = 0$ in the equation and solving for X:

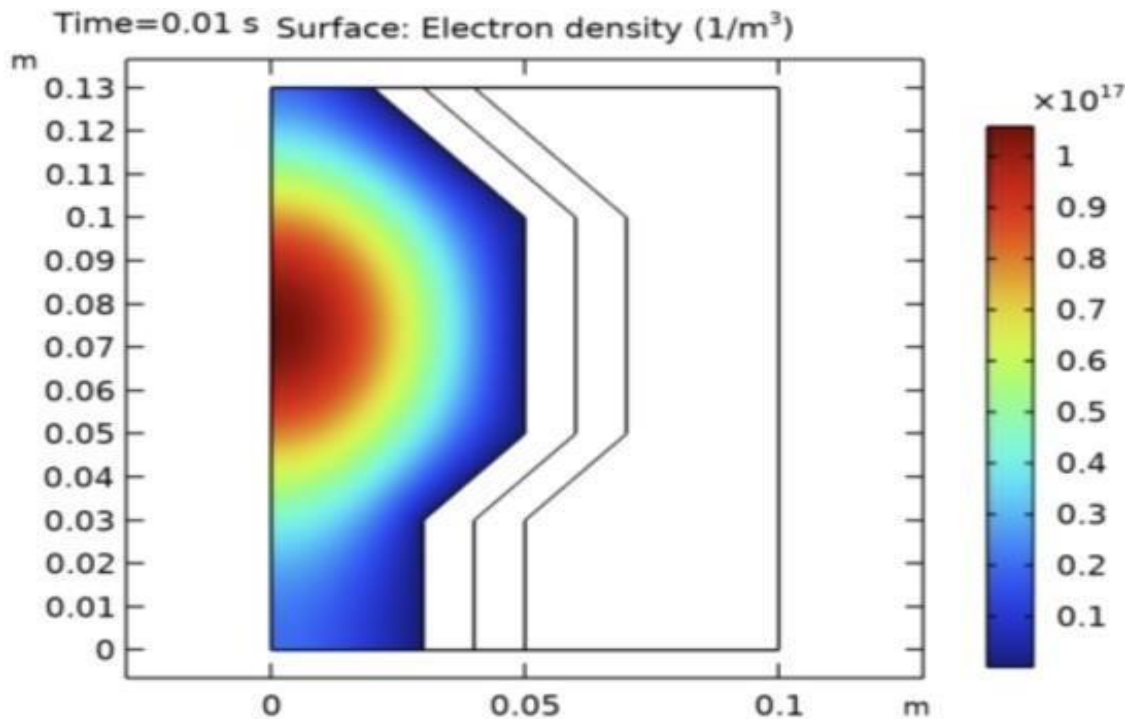


Fig: 5.8 Electron density analysis result

Direction: Since the slope is negative (-0.13), the line would be slanting downwards from left to right, indicating a negative relationship between X (electron density) and Y (time). Overall, the graph of the given equation would be a straight line with a negative slope, passing through the y-axis at the point (0, 0.01), and crossing the x-axis at approximately the point (0.077, 0). It would show how Y (time) changes with different values of X (electron density) based on the linear equation provided.

5.2.2 ELECTRON TEMPERATURE

The provided equation, $Y = 0.01 - 0.13 (\text{TIME})$, represents a linear correlation between the dependent variable Y (time) and the independent variable X (electron temperature), with a constant slope of -0.13. When graphed on a Cartesian coordinate system with X on the horizontal x-axis and Y on the vertical y-axis, the graph would be a straight line with the following characteristics: Y-

Intercept: The line intersects the y-axis at the point (0, 0.01), indicating that when X (electron temperature) is 0, Y (time) is 0.01. Slope: The line has a negative slope of -0.13, indicating that for each unit increase in X, Y decreases by 0.13 units. This implies a negative linear relationship, where higher X values result in lower Y values. X-Intercept: The line crosses the x-axis at the point (0.077, 0), meaning that when Y (time) is 0, X (electron temperature) is approximately 0.077. This is calculated by setting Y to 0 in the equation and solving for X. The graph of the given equation would be a straight line with a negative slope, passing through the y-axis at (0, 0.01), and crossing the x-axis at around (0.077, 0). It would visually depict how Y (time) changes with varying X (electron temperature) values based on the linear equation provided.

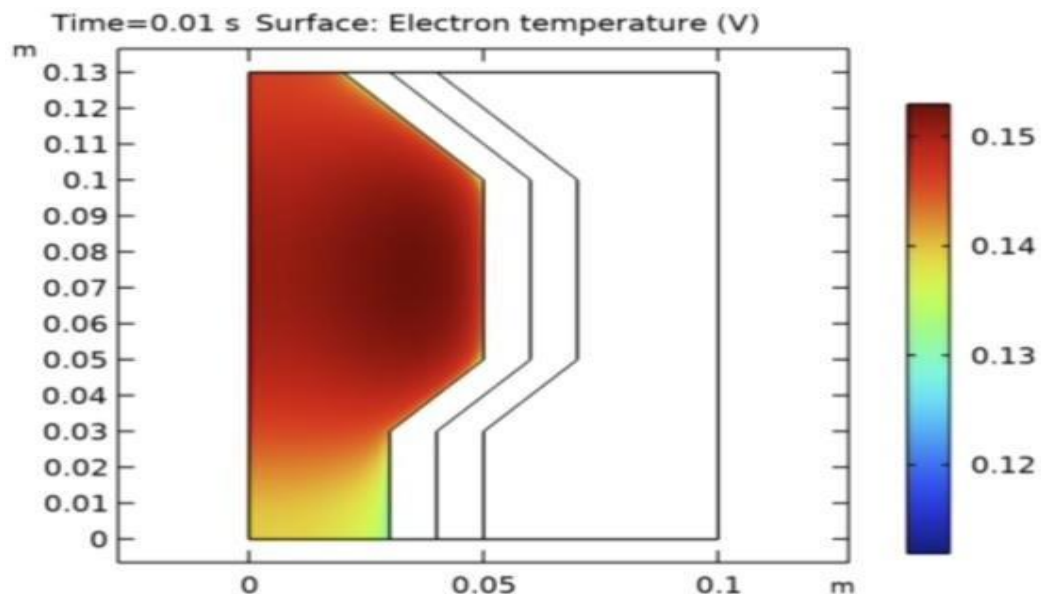


Fig: 5.9 Temperature of electron on EHD design

5.2.3 ELECTRIC POTENTIAL

The equation $Y = 0.01 - 0.13 (\text{TIME})$ represents a linear relationship between the dependent variable Y (time) and the independent variable X (electric potential), with a constant slope of -0.13. The graph of this equation would be a straight line on a Cartesian coordinate system, where X is plotted on the x-axis and Y is plotted on the y-axis. The line would intersect the y-axis at the point (0, 0.01), which is the y-intercept. This means that when X (electric potential) is 0, Y (time) is 0.01. The

slope of the line is -0.13, indicating a negative linear relationship between X and Y. For every unit increase in X, Y decreases by 0.13 units. The x-intercept occurs when Y (time) is 0, and it is located to the right of the origin at approximately (-0.077, 0). This means that the line crosses the x-axis at this point. The graph of the equation would show a straight line slanting downwards from left to right, reflecting the negative relationship between X (electric potential) and Y (time). Overall, the graph would pass through the y-axis at (0, 0.01) and cross the x-axis at approximately (-0.077, 0), representing how Y (time) changes with different values of X (electric potential) based on the given linear equation.

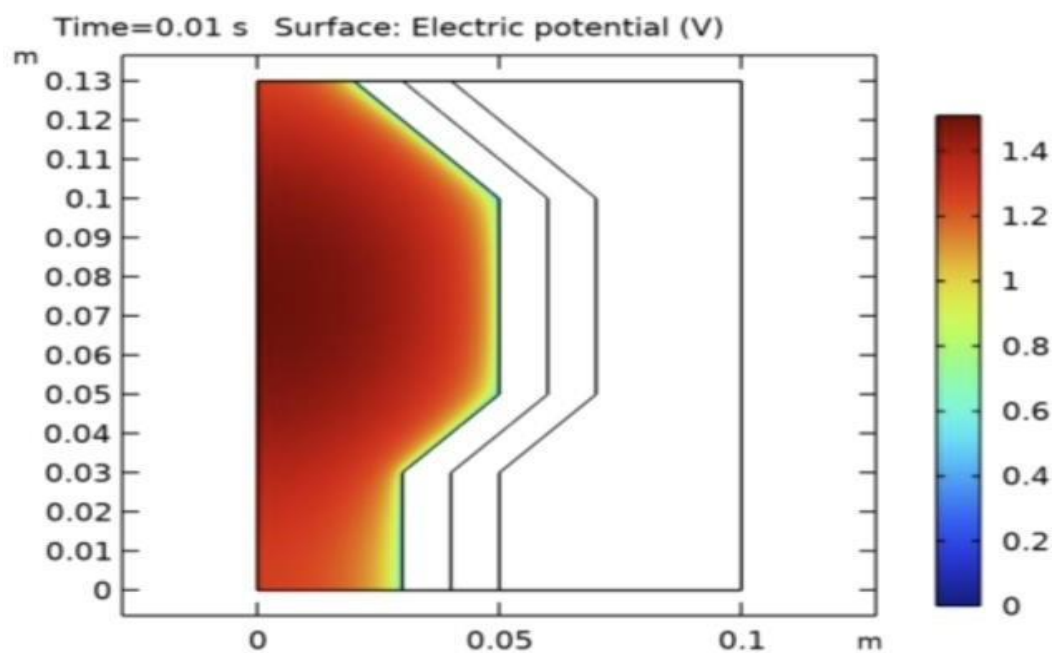


Fig: 5.10 Potential of electricity on EHD design

5.2.4 MAGNETIC FLUX DENSITY NORM

Based on the given equation $Y = 0.01 - 0.13 (\text{TIME})$, where Y represents time and X represents electric potential, the graph would be a straight line on a Cartesian coordinate system with the following properties:

Y-Intercept: The line intersects the y-axis at the point (0, 0.01), indicating that when X (electric potential) is 0, Y (time) is 0.01.

X-Intercept: The X-intercept occurs when Y (time) is 0, which means that the line crosses the x-axis at some point to the right of the origin (0,0). The exact x- intercept value can be calculated by setting $Y = 0$ in the equation and solving

for X: So, the x-intercept is approximately at the point (0.077, 0) on the x-axis. Direction: Since the slope is negative (-0.13), the line would be slanting downwards from left to right, indicating a negative relationship between X (electric potential) and Y (time). Overall, the graph of the given equation would be a straight line with a negative slope, passing through the y-axis at the point (0, 0.01), and crossing the x-axis at approximately the point (0.077, 0). It would show how Y (time) changes with different values of X (electric potential) based on the linear equation provided.

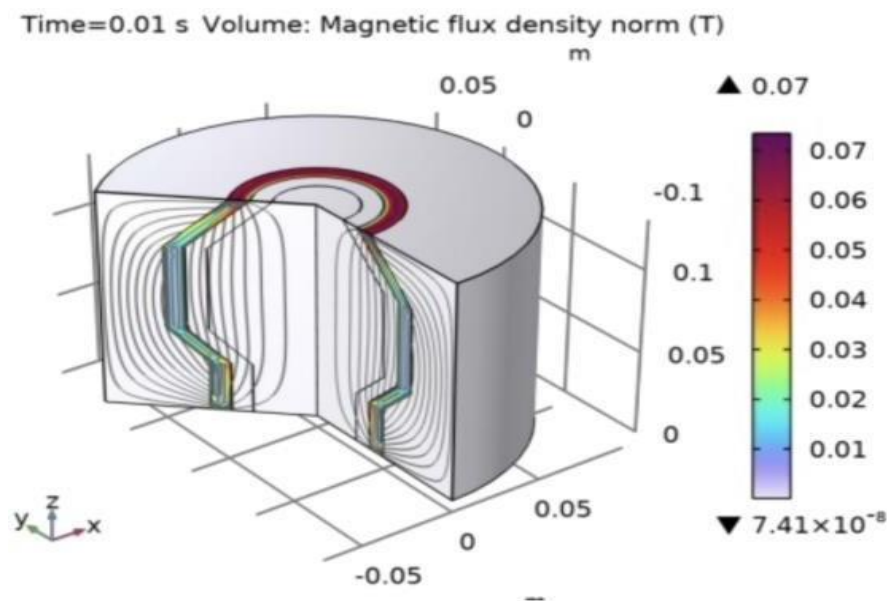


Fig: 5.11 Magnetic flux density norm of design analysis

5.2.5 VELOCITY

It appears that there was an error in the equation's interpretation. The right reading of $Y = 0.01 - 0.13(\text{TIME})$ is that Y indicates magnetic flux density and X represents time. The Y-intercept is the point at which the line contacts the y-axis. The y-intercept in this example is at (0, 0.01), which indicates that when X (time) is 0, Y (magnetic flux density) is 0.01. Y (magnetic flux density) falls by 0.13 units for every unit rise in X (time). This suggests a negative linear connection between X and Y, with X (time) increasing while Y (magnetic flux) decreases. The X-intercept is the point at which the line meets the x-axis. The x-intercept occurs when Y (magnetic flux density) is zero, implying that the line crosses the x-axis to the right of the origin. (0,0). Setting $Y = 0$ in the equation and

solving for X yields the precise x-intercept value: Because the slope is negative (-0.13), the line would slant downhill from left to right, suggesting a negative association between X and Y

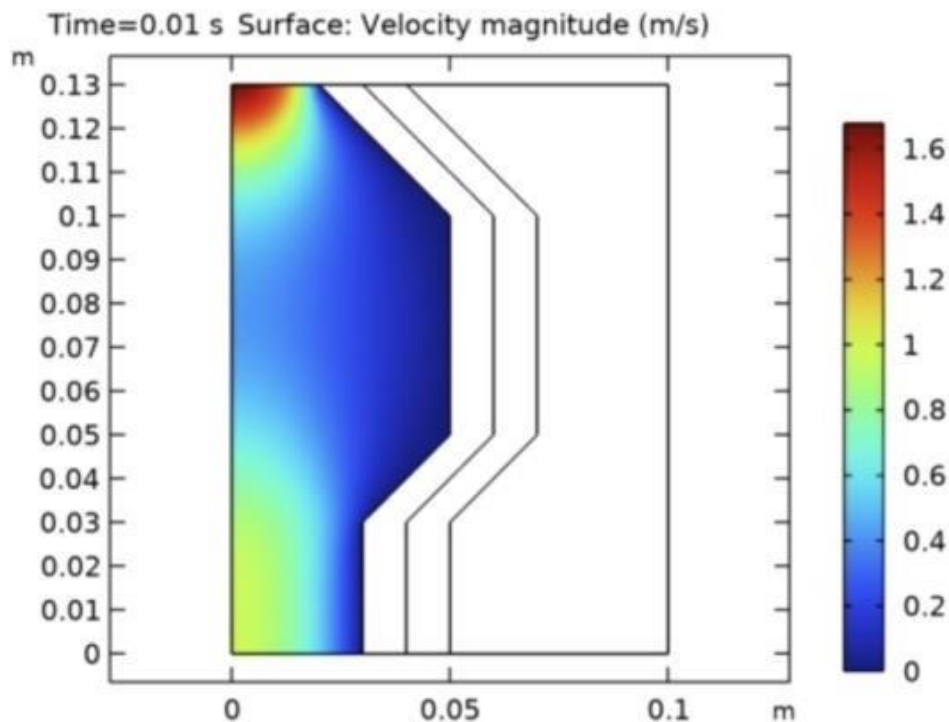


Fig: 5.12 Velocity of laminar flow

5.2.6 TEMPERATURE

The given equation $Y = 0.01 - 0.13 \text{ (TIME)}$ does not represent a linear relationship between time (Y) and temperature (X). Instead, it appears to be a mathematical expression where Y is a function of time, with a constant value of 0.01 subtracted by the product of 0.13 and TIME. As per the given equation, the Y-values (time) will remain constant at 0.01, regardless of the values of X (temperature). In other words, the equation suggests that Y (time) does not change with respect to X (temperature), and the graph of this equation would be a horizontal line parallel to the X-axis, passing through the point (0, 0.01). The X-values provided (0, 0.05, and 0.1) are not used in this equation to calculate the Y-values (time), as the equation does not involve X (temperature) as an independent variable. Therefore, the graph of this equation would not vary with different values of X (temperature) as per the given equation $Y = 0.01 - 0.13 \text{ (TIME)}$.

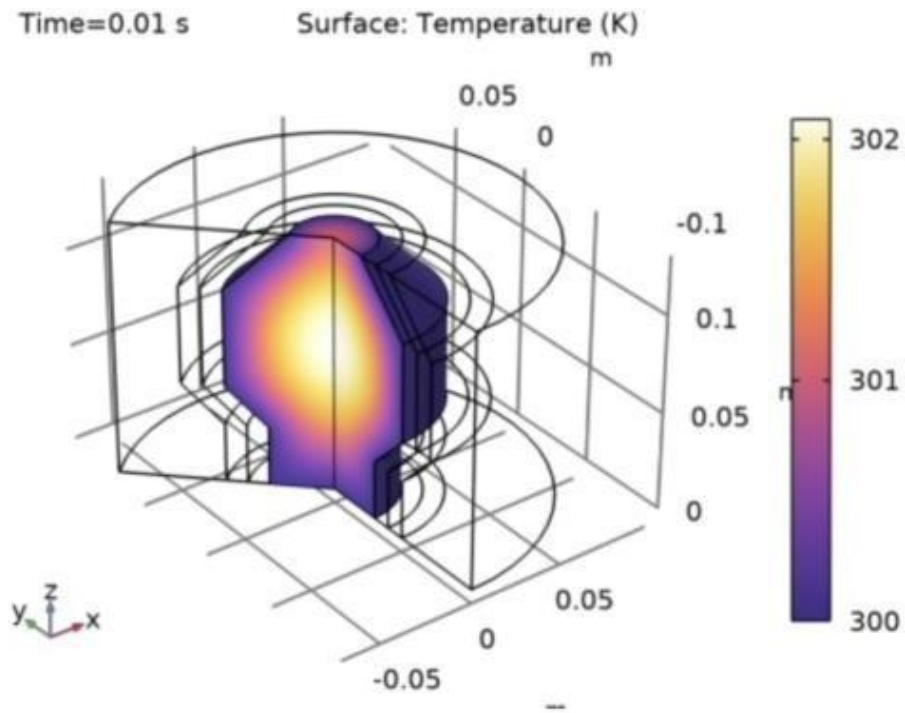


Fig: 5.13 Temperature of whole EHD body

5.2.7 ISOTHERMAL CONTOURS

The given equation $Y = 0.01 - 0.13 (\text{TIME})$ and X-values of 0, 0.05, and 0.1 for isothermal contours: The given equation $Y = 0.01 - 0.13 (\text{TIME})$ represents a linear relationship between time (Y) and isothermal contours (X), where Y represents time and X represents isothermal contours, which are presumably temperature values. The graph of this equation would be a straight line with a negative slope of -0.13, indicating that as the isothermal contours increase (i.e., as temperature increases), the time (Y) decreases by 0.13 units for every unit increase in isothermal contours (X). The y-intercept of the graph would be at the point (0, 0.01), indicating that at the beginning of time (when TIME = 0), the time (Y) would be 0.01. This is the point where the graph intersects the y-axis. The given X-values of 0, 0.05, and 0.1 represent different isothermal contours (presumably temperature values) for which the corresponding Y-values (time) can be calculated using the given equation. For example, when $X = 0$, Y would be 0.01 according to the equation, and when $X = 0.05$, Y would be $0.01 - 0.13 * 0.05 = 0.01 - 0.0065 =$

0.0035, and so on. The direction of the graph would be slanting downwards from left to right, indicating a negative relationship between time (Y) and isothermal contours (X), as the slope is negative (-0.13).

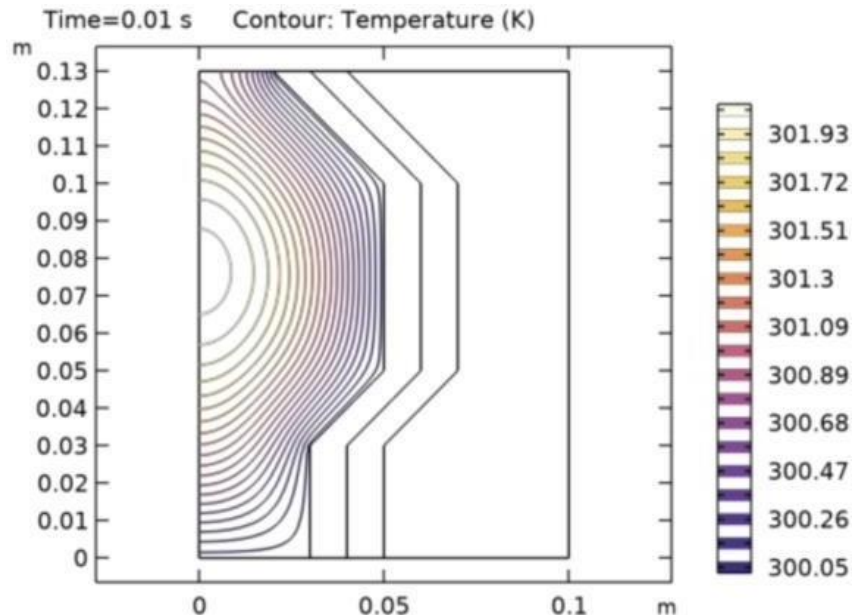


Fig: 5.14 Isothermal contours

5.2.8 ARGON MASS FRACTION

The given equation $Y = 0.01 - 0.13 (\text{TIME})$, where Y represents time and X represents argon mass fraction, and the provided X-values of 0, 0.05, and 0.1 for argon mass fraction, we can calculate the corresponding Y-values (time) as follows: So, when argon mass fraction (X) is 0.1, the time (Y) would be -0.003. Based on these calculations, we can make the following observations about the potential graph: The y-intercept would be at the point (0, 0.01), indicating that at the beginning of time (when TIME = 0), the time (Y) would be 0.01. The slope of the graph is -0.13, indicating a negative linear relationship between time (Y) and argon mass fraction (X). This suggests that as the argon mass fraction increases (i.e., as X increases), the time (Y) decreases by 0.13 units for every unit increase in argon mass fraction (X). The graph would pass through the point (0.05, 0.0035) and the point (0.1, -0.003), indicating the relationship between time (Y) and argon mass fraction (X) for these specific values of

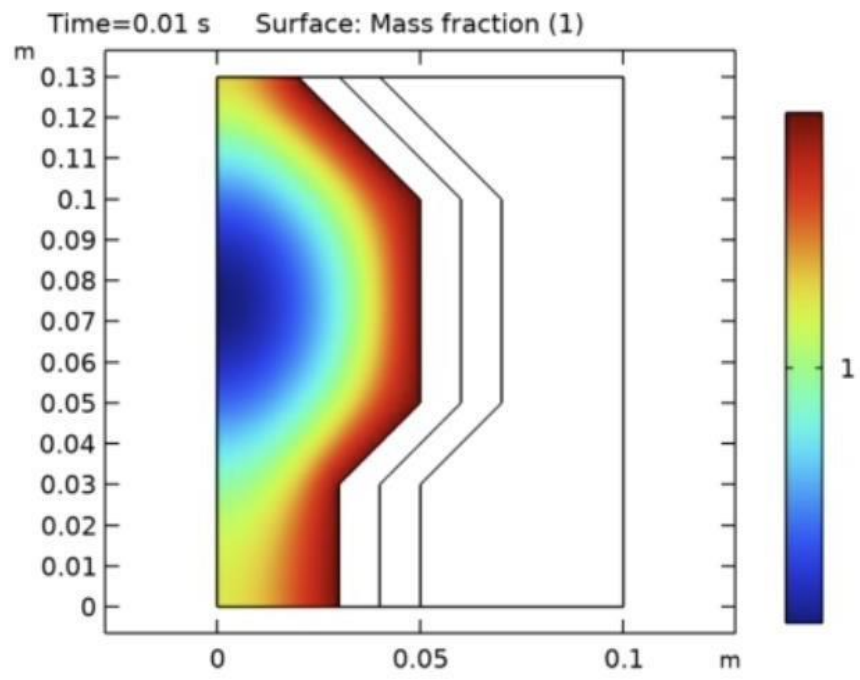


Fig: 5.15 Argon mass fraction

CHAPTER 6

CONCLUSION

In conclusion, ion propulsion is a state-of-the-art propulsion technology that has shown a great promise for colorful space operations. Ion propulsion systems use the principles of electromagnetism to accelerate ions and induce thrust, furnishing a largely effective and low-energy-consumption means of propulsion compared to traditional chemical rockets. One of the significant advantages of ion propulsion is its high specific impulse (Isp), which measures how efficiently a propulsion system uses fuel. Ion propulsion systems have much advanced Isp compared to chemical rockets, allowing for briskly and more effective space trip. This makes ion propulsion well-suited for long-duration operations, similar as deep space disquisition or interplanetary trip, where effectiveness and low energy consumption are pivotal factors. Ion propulsion has been successfully used in a number of space operations, including NASA's Dawn charge to study the dwarf earth Ceres and the asteroid Vesta, as well as ESA's BepiColombo charge to study Mercury. These operations have demonstrated the capabilities of ion propulsion in terms of furnishing nonstop and dependable thrust for extended ages, allowing spacecraft to reach their destinations with remarkable perfection. Still, ion propulsion also has some limitations. One of the major challenges is the low thrust produced by ion machines, which limits their connection for operations that bear high-thrust pushes, similar as planetary levees or rapid-fire route changes. Also, ion propulsion systems bear a significant quantum of electrical power, which can be grueling to induce and store for long-duration operations. Despite these challenges, ion propulsion continues to be an active area of exploration and development, with ongoing sweats to ameliorate its performance, effectiveness, and scalability. Ion propulsion has the implicit to revise space trip by enabling briskly, more effective, and cost-effective operations to explore and study our solar system and beyond. In summary, ion propulsion

is a promising propulsion technology that offers high effectiveness, low energy consumption, and long- duration thrust capabilities, making it well- suited for a wide range of space operations. While there are challenges to overcome, ion propulsion has shown great eventuality and is likely to play a significant part in unborn space disquisition trials.

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