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Investigation on 2D Hypersonic Scramjet Inlet of Mach 7 using CFD

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Abstract: In the era of space transportations there is a huge demand on space technology to improve on cost reduction and take the heavy loads into space. Thus the load carrying capacities will be increase with this air breathing engines. This paper gives a report of the analysis and design of optimal 2D optimal scramjet engine inlet operating at mach 7 without use of variable geometry. The test is conducted to obtain maximum total pressure recovery. Inlet efficiency parameters, followed by theoretical flow analysis utilizing some simplifying assumptions and the oblique shockwave relations. Next, 2D CFD simulations are carried out for some inlet geometries with one, two, three and four ramps that are constructed based shockwave analysis. This model is carried out in Fluent to take into consideration boundary layer phenomena that the theoretical analysis is not able to cover. Lastly, a conclusion summarizing the design process is drawn and the optimal model is recommended for the mach 7 inlet with different ramps.
Keywords: Scramjet, CFD, oblique shockwave, hypersonic

I. INTRODUCTION

The first component of a scramjet engine is the inlet. It is responsible for supplying a supersonic flow with suitable pressure, temperature and mass flow rate to the combustor for efficient combustion of fuel. Hence, the inlet is a critical component which affects greatly the overall efficiency of the whole scramjet engine. As the structure of the oblique shocks compressing the flow depends directly on the configuration of the inlet such as the number of ramps and the angles between each pair of adjacent ramps, the obvious solution for a scramjet engine to operate a Mach number is to change these parameters and thus change the geometry of the inlet. This study aims to tackle this challenge and attempts to design an inlet operating geometry of Mach 7. In this study, the oblique shockwave relation serves as the theoretical base for inlet analysis. CFD turbulence modeling in Fluent allows us to optimize the performance of the inlet and to capture complex phenomena of mach 7 operating inlet geometry.

India has successfully launched the first test flight of its Hypersonic Technology Demonstrator Vehicle (HSTDV) from Abdul Kalam Island in Odisha. The missile is part of India's efforts to develop a scramjet engine, which is the considered the next frontier for future missile, aircraft and spacecraft technology. The test flight of the HSTDV was conducted by the Defense Research and Development Organization (DRDO), which has been developing the scramjet engine.A scramjet engine consists of four major parts: inlet, isolator, combustor and nozzle. Throughout this paper, the scramjet engine is divided to different sections by the stations as described. Numerous programs aiming to develop aircrafts capable of hypersonic flight first appeared in the late 1950’s and early 1960’s and have developed ever since. It has been found that rocket propelled vehicles were not a practical option for hypersonic flight due to the need of onboard oxidizer tank, resulting in heavy load carrying. A more promising choice is an air breathing propulsion system and the best suitable air breathing engine cycle for hypersonic flight is scramjet supersonic combustion ramjet. Different from other types of air breathing engine like turbojet and turbofan, ramjet engine doesn’t rely on turbo machinery but shockwave for compression. As air passing through the engine inlet, it is compressed by shockwave and slowed down to a subsonic speed before entering the combustor where fuel is injected and burnt. Air is then accelerated through a nozzle to create thrust. Ramjet engine can only operate efficiently up to Mach 6 as at flight Mach number above 6, to achieve subsonic flow to the combustor, the compression ratio has to increase to a value at which shock losses become adversely substantial and the airflow temperature is so high that dissociation begins to occur in the nozzle, hence, less energy is extracted in form of thrust

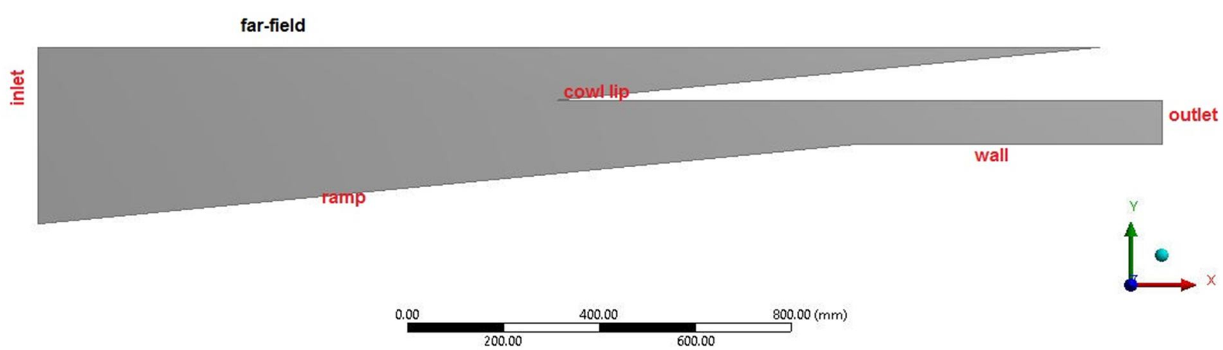
Ground tests of scramjet engines have shown the potential to reach a maximum speed up to at least Mach 15 also called as hypersonic scramjet engines [1]. The first scramjet development program was the NASA Hypersonic Research Engine (HRE) program which started in 1964, with about 52 tests completed [2]. After this, many other programs in several countries such as Russia, France and Germany also began. Three prominent projects with successful flight test were the HyShot program by the University of Queensland in Australia that marked the first flight of a scramjet propelled aircraft in July 2002 [2], the Hyper-X program and the X-51 program. The aircraft designed in the Hyper-X program is called X-43. It has made two successful flight tests, the first one took place on March 12: Analysis and Design of a Scramjet Engine Inlet Operating from Mach 5 to Mach 10 2004 with the aircraft reaching a speed of Mach 7 and the second one on November 2004. In this second flight, X-43 got to nearly Mach 10, which set speed record [3]. The most recent project involving scramjet is the SR-72, the successor of the SR-71 Blackbird. SR-72 is a hybrid turbojet – scramjet propelled aircraft which is expected to enter service by 2030 [4].when normal fuel injection was employed the thrust increase was approximately proportional to the fuel flow rate [5]. At the end first ramp the transition of laminar to turbulent occurs.

Transition point is modeled by setting the turbulent kinetic energy of all cells in the laminar area to zero. The point at the entrance a bubble is formed on the intake wall[6]. Another critical factor is the static temperature at the end of the compression process which has to be high enough to ensure enter into the combustion chamber[7]. Two dimensional scramjets inlets with up to five shock waves have been optimized for maximum total pressure recovery using the method of Lagrangemultipliers. The constraints placed on the inlets were a compression ratio equal consistent with a free stream dynamic pressure to exit pressure ratio equal to unity, one internal shock and exit flow parallel with incoming flow[8]. The Hypersonic scramjet working range extends to Mach 6, which is necessary for the transition point from ramjet to scramjet mode, and mach 12 or more [9]. The hypersonic inlets with/without boundary layer thickness of the inflow were optimized and the optimized functions, that is, the total pressure recovery coefficient were optimized by approximately 8-10% [10]. Therefore, to sustain a usable amount of thrust at higher speed, the air entering the combustor has to be at lower pressure and temperature, meaning that it still moves at a supersonic speed. This modification to the ramjet engine is called supersonic combustion ramjet, or usually referred to by acronym as scramjet.

II. METHODOLOGY

A. Basic Geometry

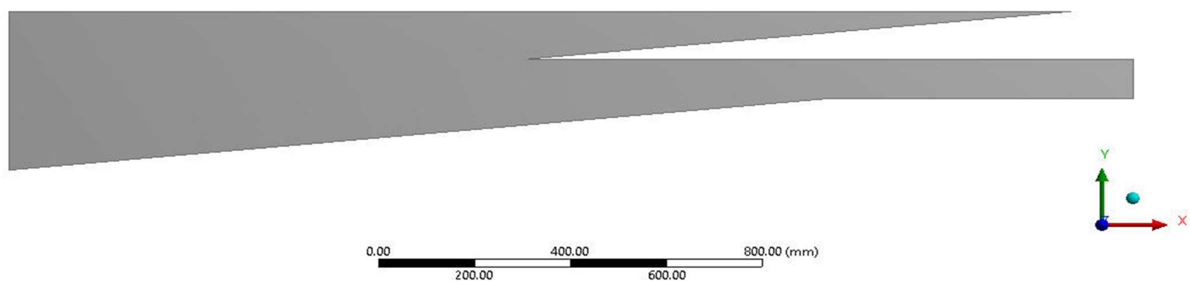
Using a 2-Dimensional geometry of the hypersonic scramjet inlet designed as per the required operating Mach 7 with the different ramps and produce shock wave in order to produce compressed air for the combustion in the isolator.Using Shock wave and Turing angle creating geometries of twoorder to get maximum pressure outlet.The shock waves should hit the cowl lip of start of isolator therefore the shock wave compress in isolator to give maximum pressure at outlet which will be connected to isolator. By this different number of ramps we can say that which is giving the maximum outlet pressure.

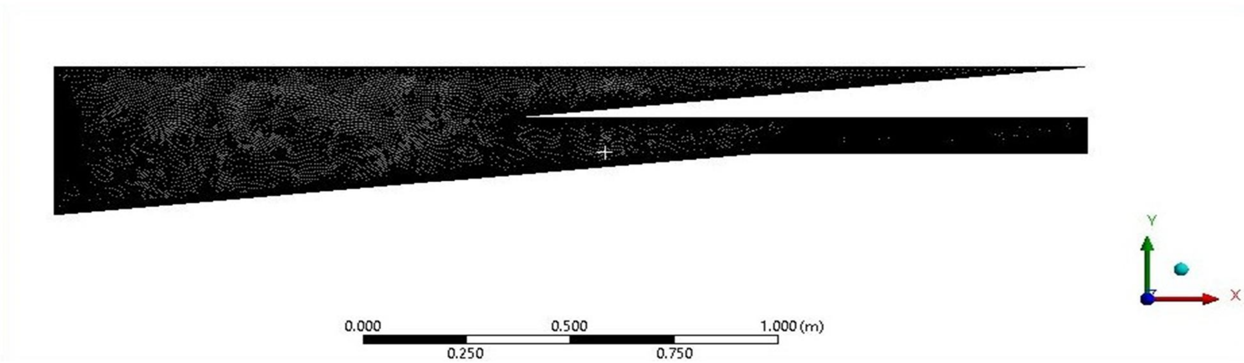


Basic structure of inlet geometry

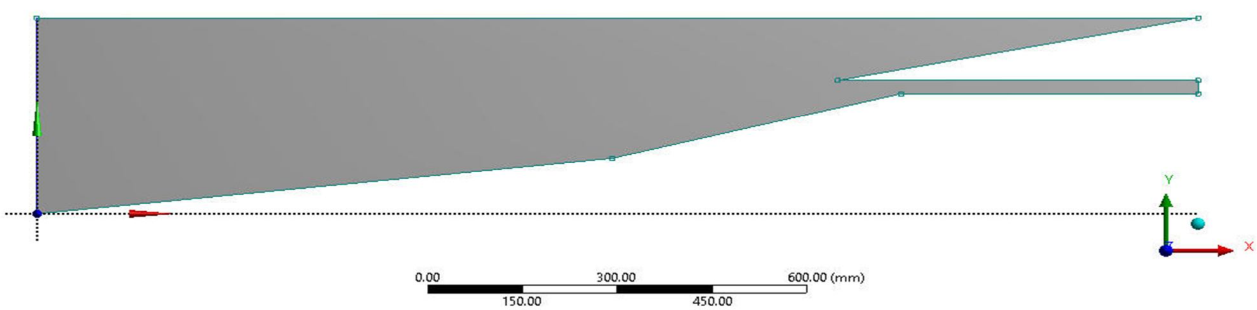
1) Dimensions

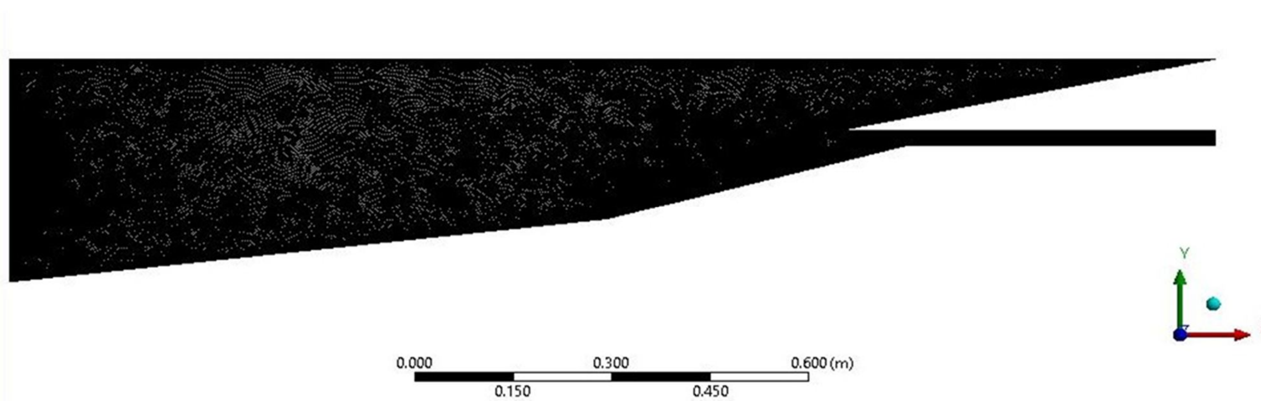
RAMPS	1ST RAMP ANGLE	2ND RAMP ANGLE	3RD RAMP ANGLE	INLET LENGTH	OULET LENGTH	TOTAL WIDTH
1	6	-	-	300	35	1532
2	5	15	-	280	25	1836
3	4	9	15.3	265	25	2956





B. 1-Ramp Inlet Geometry and Mesh





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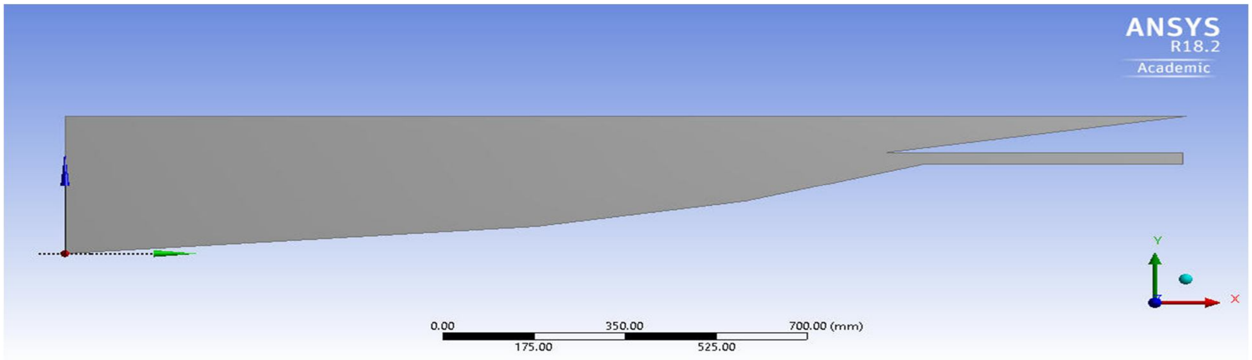
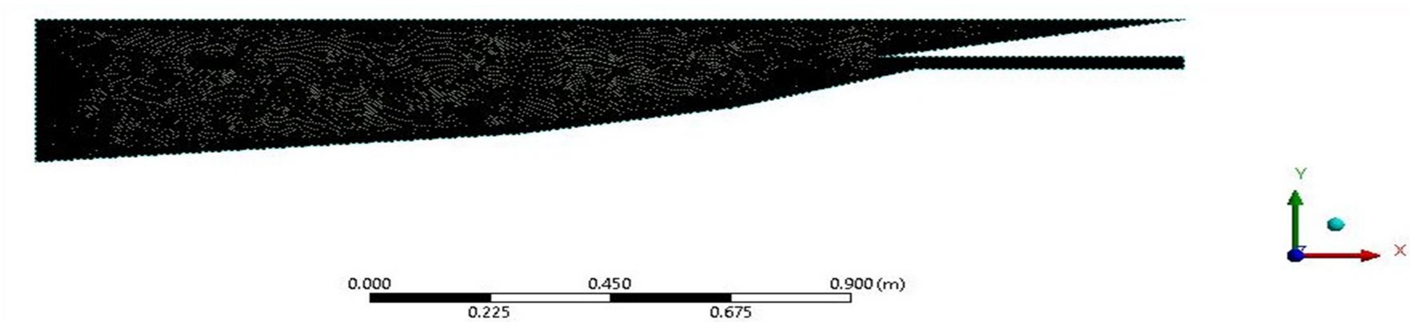
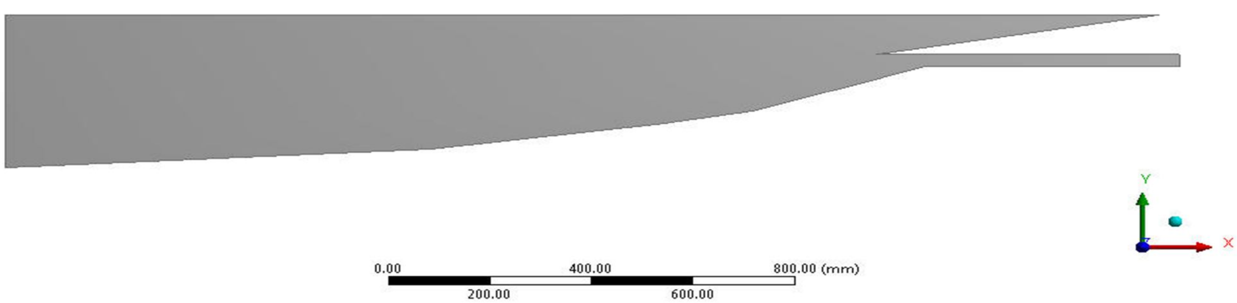
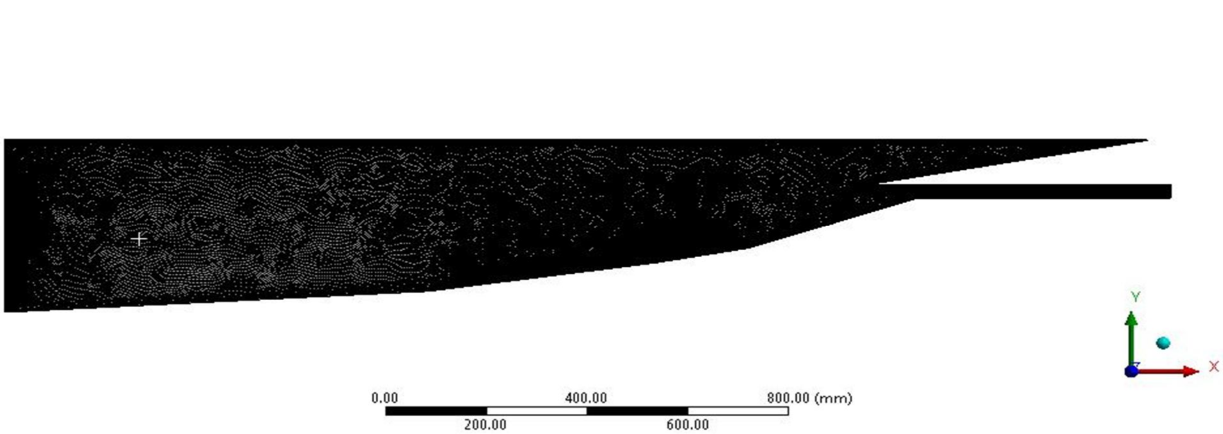
C. 2-ramp inlet Geometry and Mesh





D. 3-Ramp Inlet Geometry and Mesh





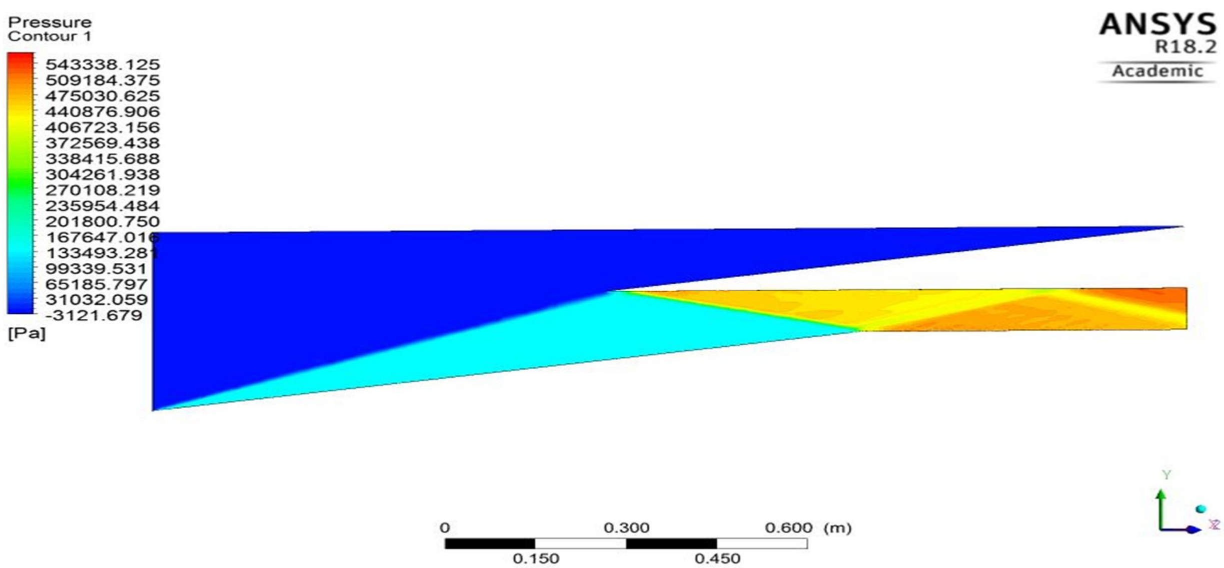
E. 4-Ramp Inlet Geometry and Mesh

F. Boundary Conditions

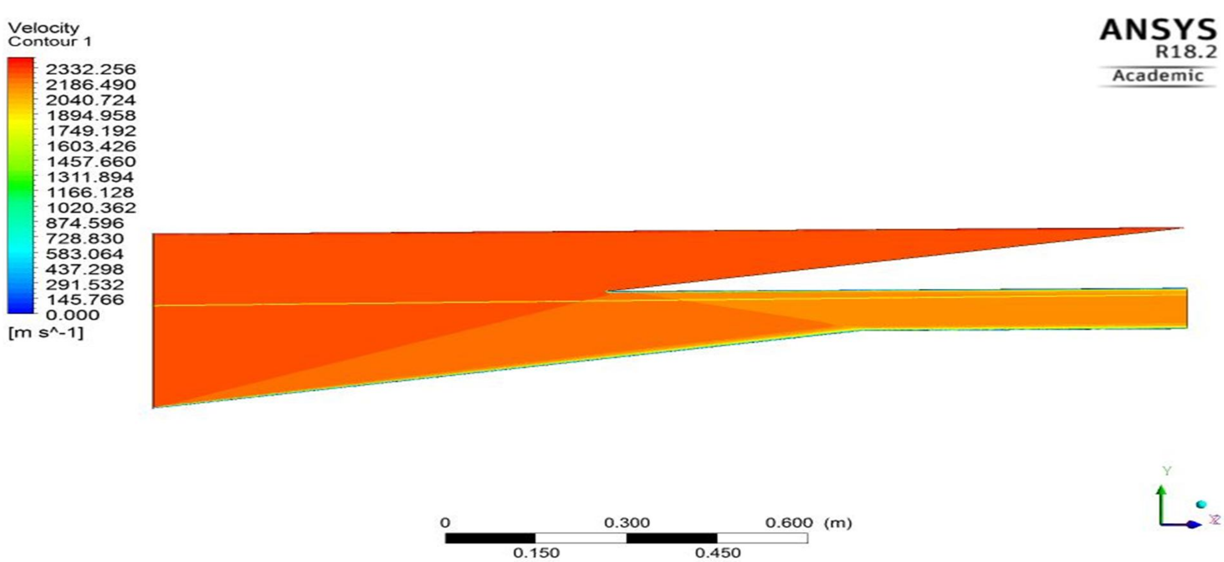
1) From the models of steady state k-omega SST model with no change in fluid properties with boundary conditions as follows.
2) Far-field Velocity-2310 m/s.
3) Mach number at the inlet-7.
4) Wall temperature- 300k.
5) Contraction ratio from 25 from inlet to outlet.

III.RESULTS AND DISCUSSIONS

A. Pressure recovery at outlet of isolator is about 26 bar results as follow.
B. Temperature profile of the inlet geometry of 2 ramps attains a temperature of nearly 1000° kelvin.
C. This geometry is preferred for maximum pressure recovery at outlet by using this inlet geometry.



Pressure counters of 1-ramp inlet geometry Mach 7



Velocity counters of 1-ramp inlet geometry Mach 7

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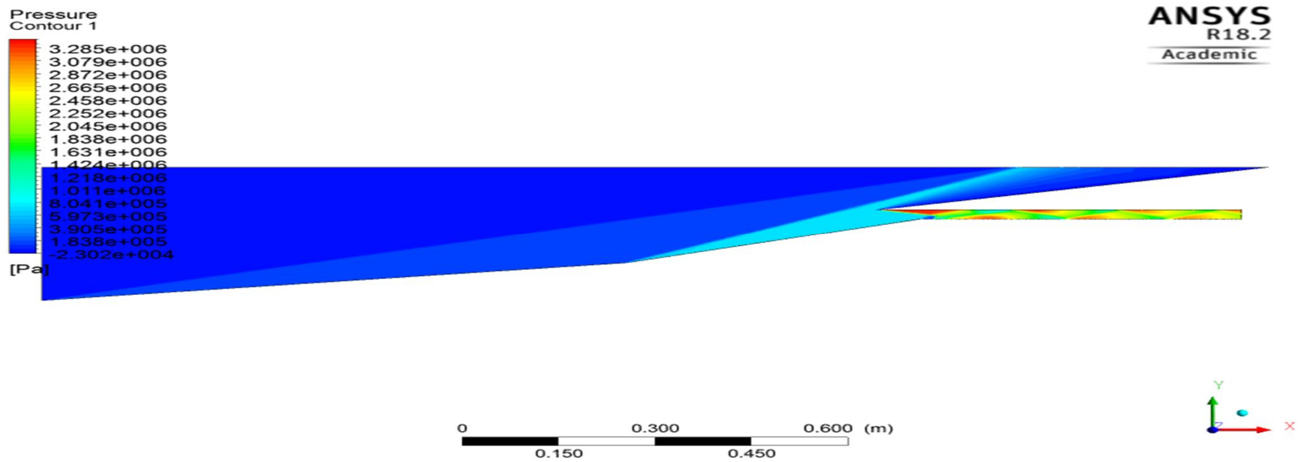
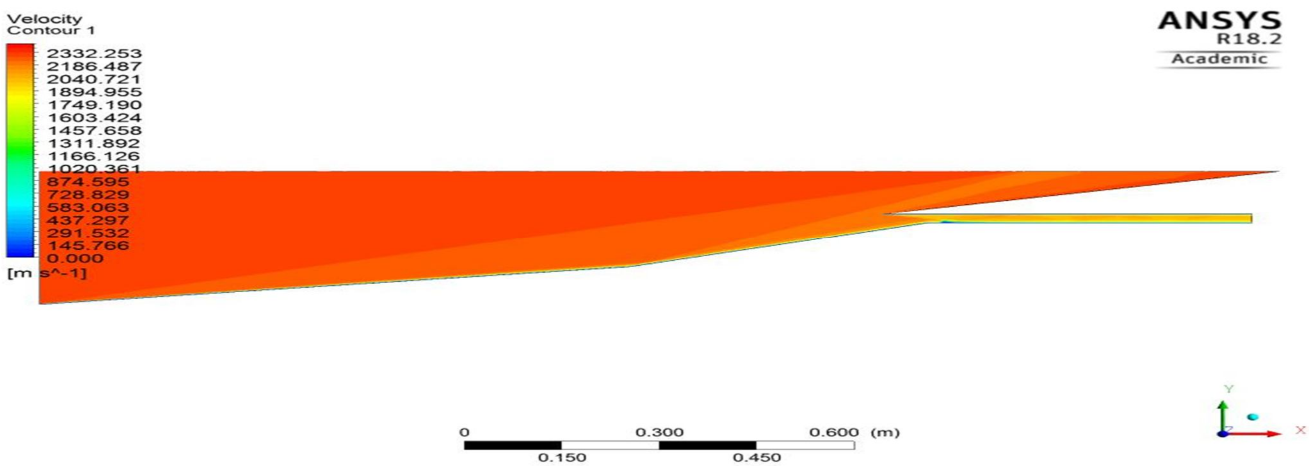
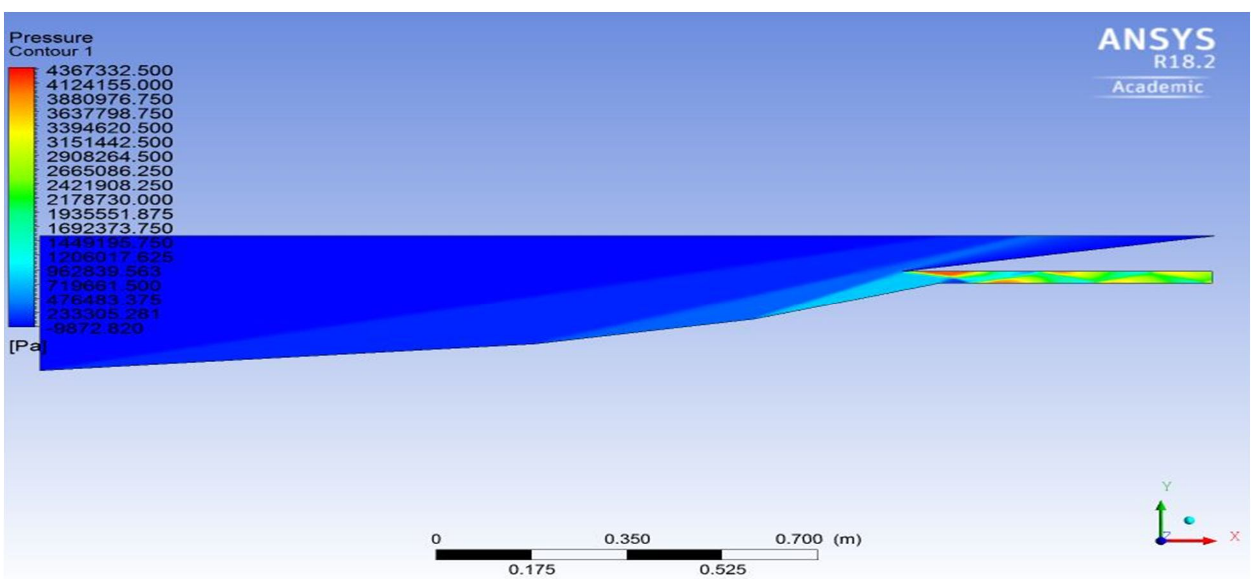


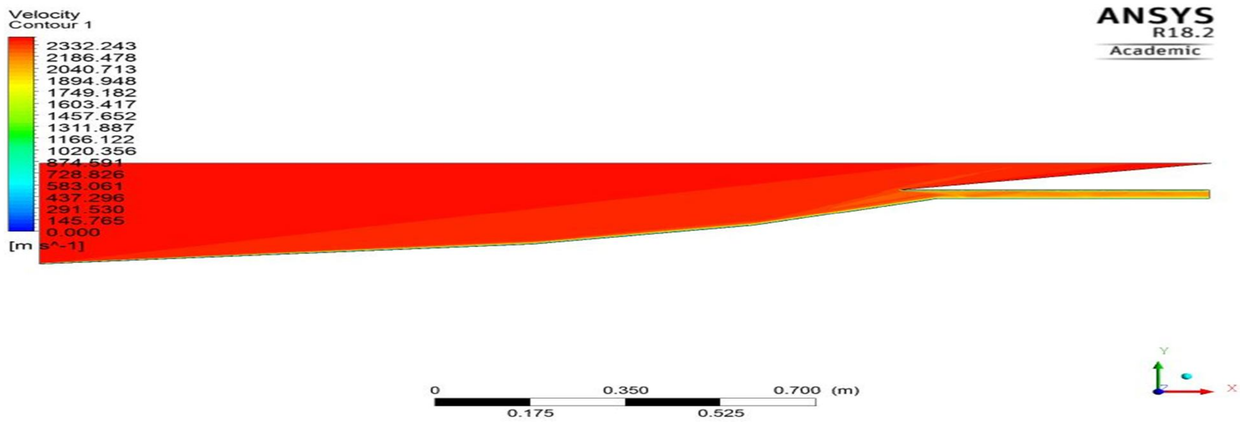
Pressure counters of 2-ramp inlet geometry Mach 7



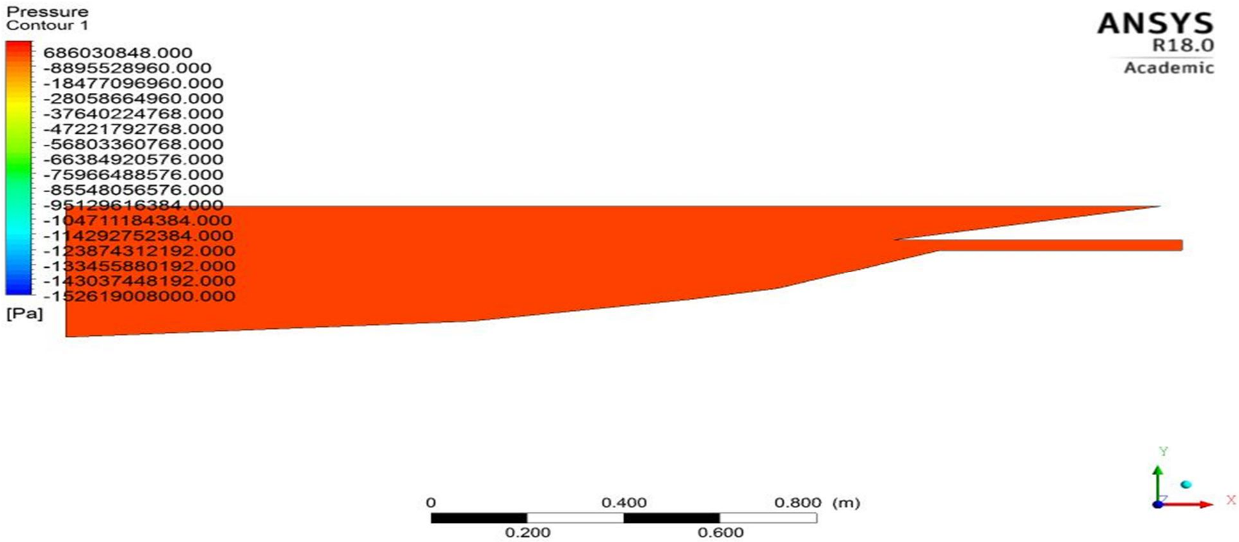
Velocity counters of 2-ramp inlet geometry using Mach 7



Pressure counters of 3-ramp inlet geometry Mach 7

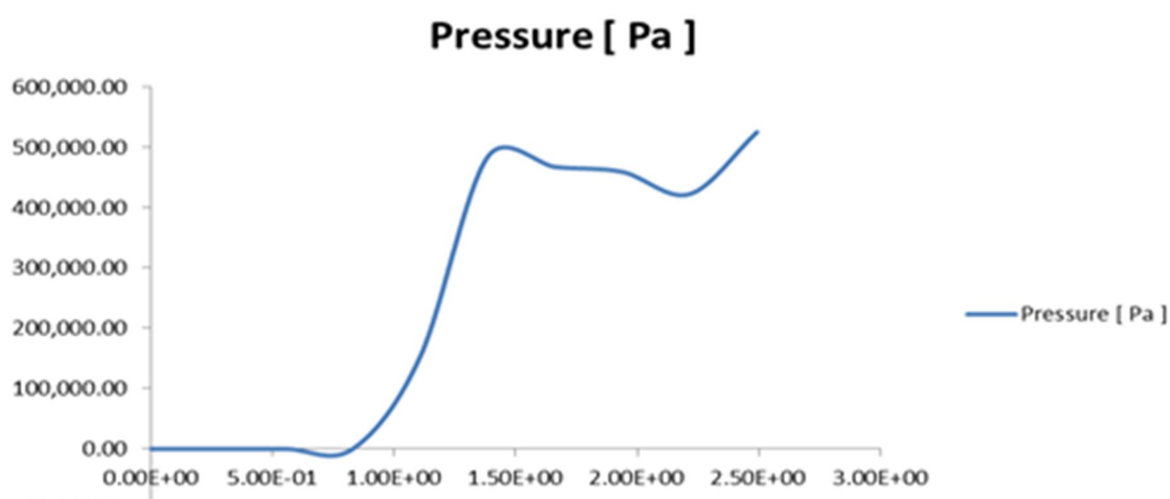


Velocity counters of 3-ramp inlet geometry Mach 7

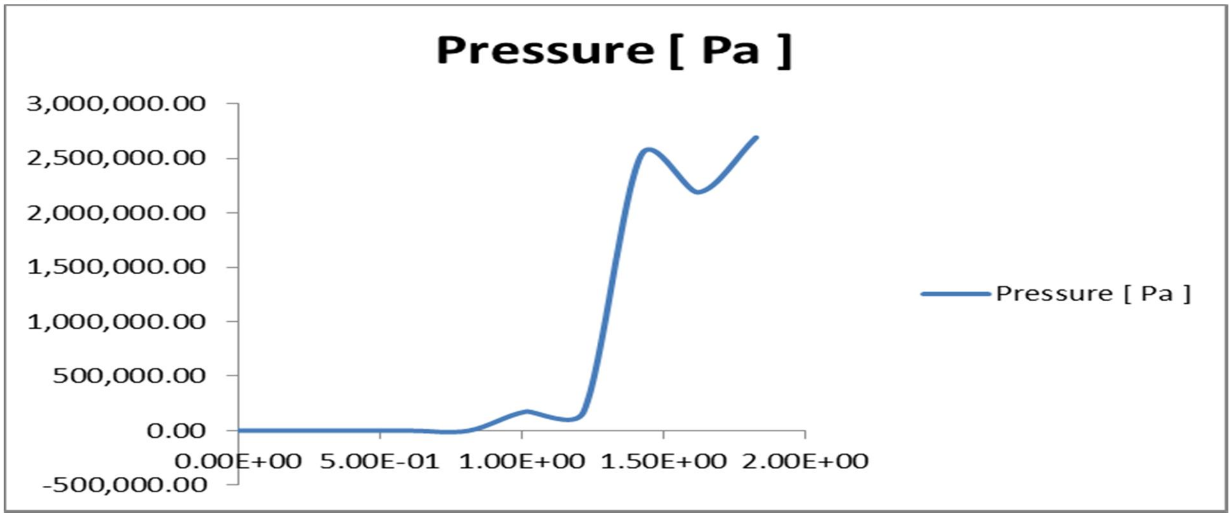


Pressure counters of 3-ramp inlet geometry Mach 7

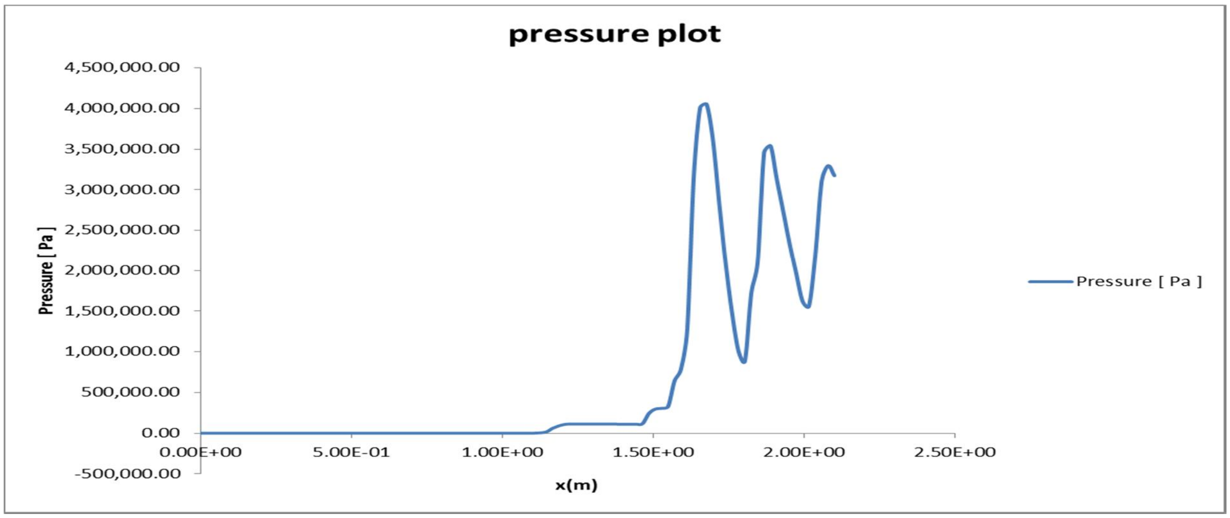
Using 4 ramp geometry there is no self starting of the hypersonic scramjet engine, so we neglecting the 4 ramp stimulation



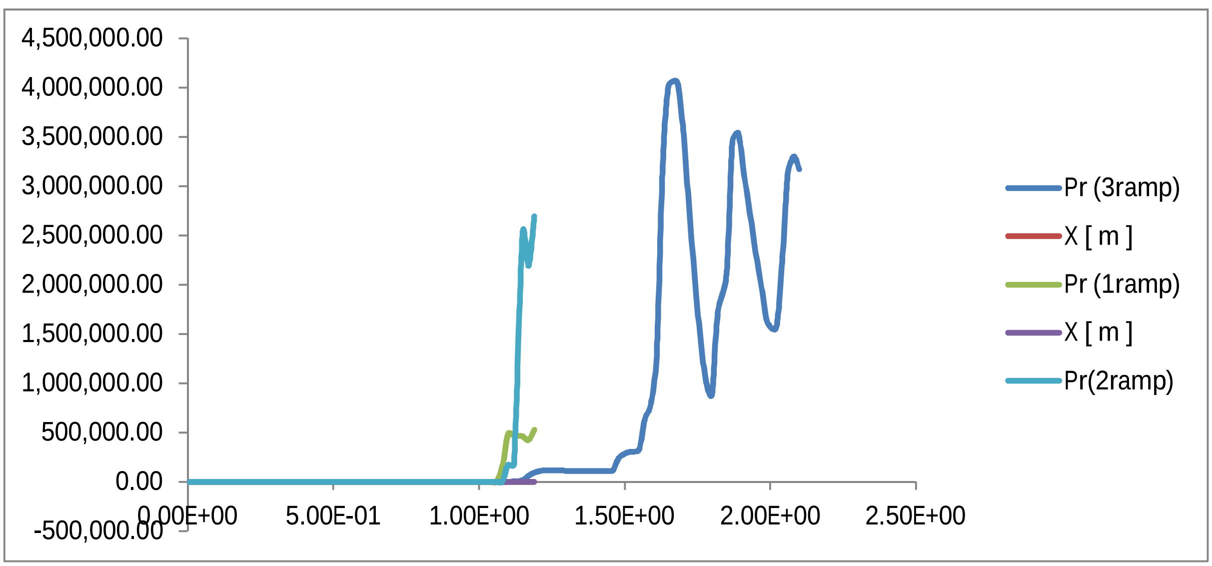
Pressure plot of 1-ramp inlet geometry Mach 7



Pressure plot of 2-ramp inlet geometry Mach 7



Pressure plot of 3-ramp inlet geometry Mach 7



Compare Pressure recovery of 1-2-3-ramp inlet geometry Mach 7

IV. CONCLUSION

In conclusion based on this all geometrical models of different ramps i.e. one, two, three ramps inlet geometry traveling at Mach 7 with the recovery pressure at the end of each outlet we can say 3 ramps is best suitable inlet geometry for maximum pressure recovery to get rapid combustion of fuel.

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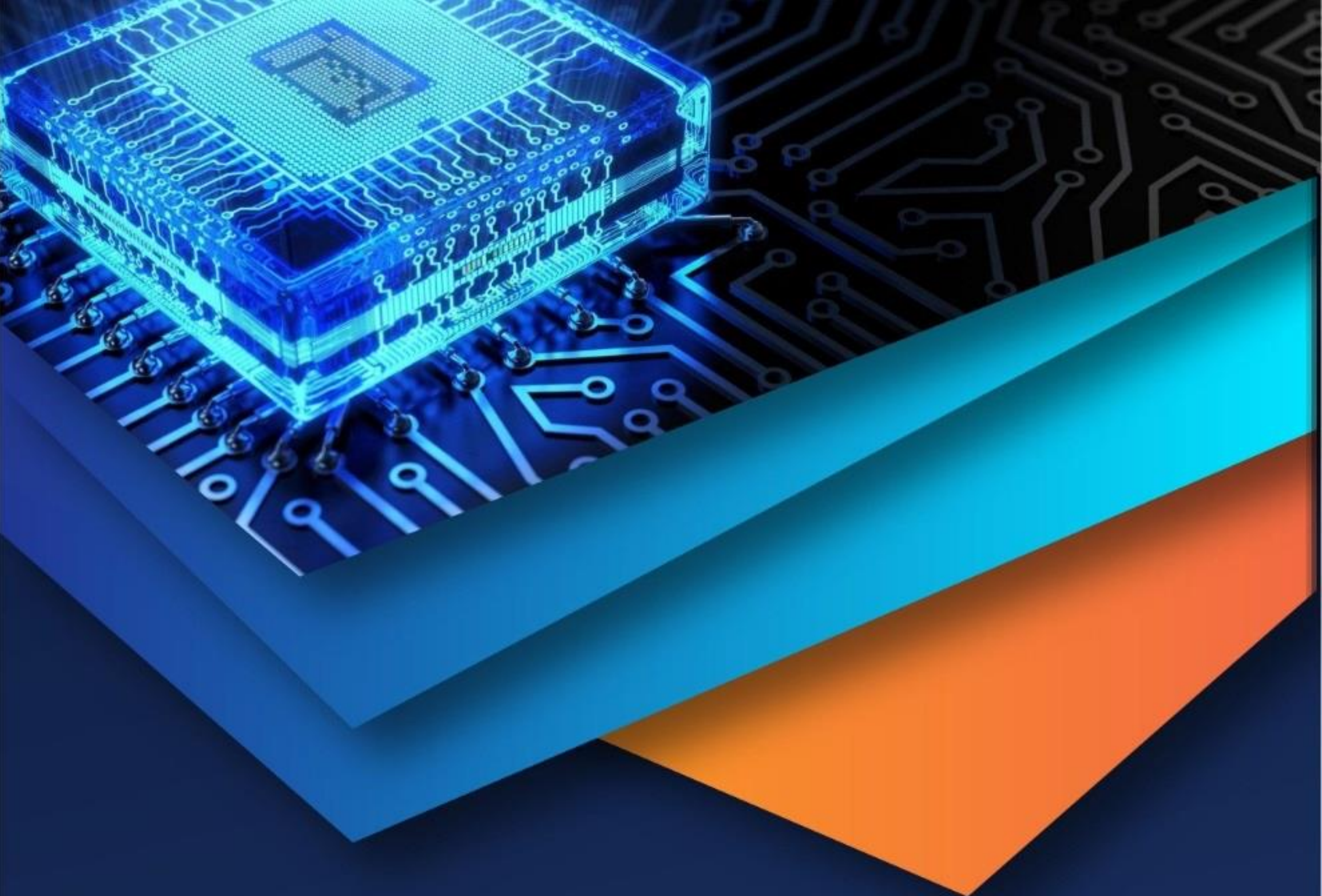

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