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DESIGN OPTIMIZATION AND ANALYTICAL INVESTIGATIONS OF SCRAMJET ENGINE INLET

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ABSTRACT:

An improved modification to the Ramjet engine gave the design of the scramjet engine. Ramjet works on the principle of ramification of the incoming supersonic flow to subsonic regime, thereby compressing the fluid eliminating the use of compressor. Without reducing the flow to subsonic region scramjet works on the same ram pressure principle. The functioning of scramjet happens in the hypersonic regime. It cannot self start, so other propulsion devices such as jet engine is used till the vehicle reaches the required functional regime. In this paper, a computational study is done on the scramjet engine with two different inlets; namely single and double ramp. A jet engine can reach up to a mach number of 3-4. Hence the computational study is done to optimize the performance when the operational mach number lies over a range. The mach number considered are 3,5,7,9. Scramjet models are designed in CREO parametric software for the optimized models of single ramp and double ramp with different ramp angles (10^0 & 12^0). CFD analysis is done to determine the pressure, Mach number , static temperature and density at different Mach numbers 3,5,7,9 and at different models(single and double with different angles). CFD analysis is done in ANSYS fluent software.

Keywords: Scramjet engine, inlet, ANSYS Fluent, Hypersonic, Supersonic.

I. Introduction:

Globalization is intrinsically dependent on the communication technology offered by the satellites. Launching of satellite is an expensive affair die to one time use of launch vehicles. A combination of oxidizer along with the fuel is carried by these Launch vehicles for combustion. Launch vehicles designed so are expensive less efficient due reason they can carry only 2-4% of their lift-off mass to orbit. Oxidizer carried in the Propulsion system of the Launch vehicle take up to 70% of the total propellant. Hence, next generation technology of the Launch vehicles propulsion system are being researched as to use atmospheric oxygen during their flight through the atmosphere, thereby having a reduction in the amount of the total propellant mass required. Re-useable vehicle or launch vehicle with high payload to structural mass is favoured. Worldwide efforts are done on these concepts due to their potential to bring a breakthrough in the launch vehicle design optimization. Ramjet, Scramjet and Dual Mode Ramjet (DMRJ) are the three concepts of air-breathing engines which are being developed by various space agencies.

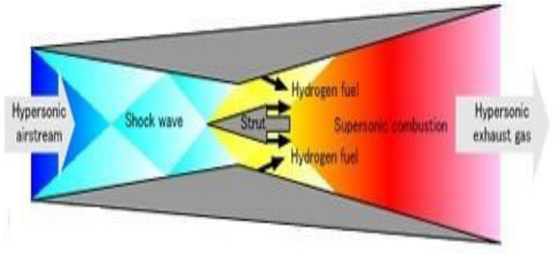


Fig 1: scramjet engine

An innovative Design proposed is the dual mode ramjet (DMRJ) where a ramjet transforms into scramjet over operating Mach 4-8 regime this can efficiently operate both in subsonic and supersonic combustion modes. On august 28,2016, ISRO proposed Air Breathing Propulsion Project (ABPP), which was the successful flight testing of its Scramjet. This first experimental mission of ISRO’s Scramjet Engine was successfully conducted from Satish Dhawan Space Centre SHAR, Srihari Kota. Figure 2 showthe configuration of an isolator, with a constant area duct. The length of the duct is determined by the length of the shock train formed and it has to be greater in order to successfully contain the shock train.

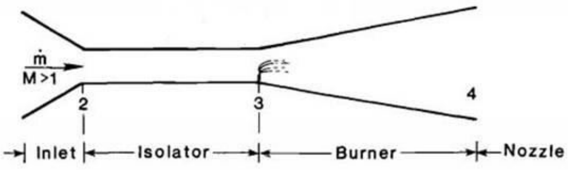


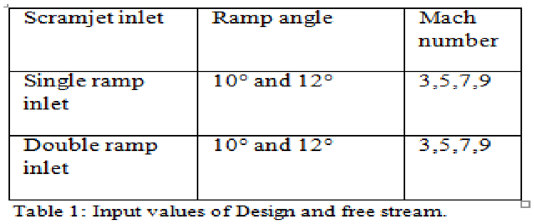
Figure 2: Station designations of the components of a dual-mode scramjet engine.

Ramjets and Scramjets

The Hyper-X program aims to demonstrate ramjet/scramjet engine design tools and methods for air-breathing hypersonic vehicles. Scramjet provides a solution to this subject. Ramjets work most efficiently at supersonic speeds around operational Mach 3 up to Mach 6. However, the efficiency of the ramjet engine starts to drop when the vehicle reaches hypersonic speeds that is above 6 mach number. An improved modification to the Ramjet engine gave the design of the scramjet engine as it efficiently operates at hypersonic speeds and allows supersonic combustion.

II. **Literature Review**: Atulya Sethi [1] work on the design and analysis of air breathing Supersonic Combustion Ramjet Engine inlet to achieve maximum static pressure at the exit of the inlet. SukantaRoga [2] has done computational analysis of Scramjet Engine Combustion Chamber for a Diamond-Shaped Strut Injector at operating Flight Mach 4.5, the design based on species transport combustor which is standard k-epsilon turbulence model. Devendra Sen[3] has done work on the idea that a combined cycle engine be used as scramjet compression system in hypersonic air transport vehicle so as to achieve a sustained flight at mach 8.

III. **Problem description and Methodology:**Not much data is available in regards to scramjet engine. This is because the functioning regime lies in the hypersonic or supersonic conditions. Though conceptually efficient, the starting of the engine and structural properties of the engine machine poses a ceiling to the scramjet engine design. A jet engine can bring the free stream flow to mach 3-4 range. Computational analysis from this mach number can give us the behavior of various parameters of the fluid inside the engine such as mach number, pressure, density through-out the length of the engine for varying design of inlets, such as single ramp and double ramp with varying angles of 10° and 12°.



Scramjet inlet	Ramp angle	Mach number
Single ramp inlet	10° and 12°	3,5,7,9
Double ramp inlet	10° and 12°	3,5,7,9

Table 1: Input values of Design and free stream.

Scramjet models are designed in CREO Parametric: Geometry creation in CREO is done with the required commands from the geometry creation tool pad. Contraction Ratio(CR), ramps, ramp angle, length of scramjet exists in geometry creation tool pad. We use it to design the four models of scramjet inlet with different specifications.

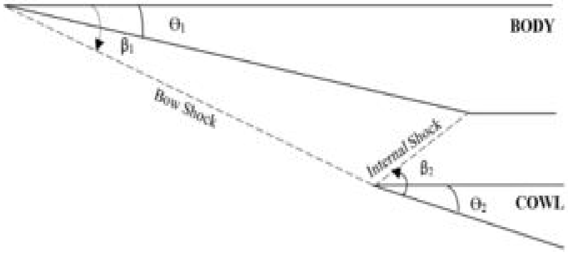


Figure 3: Single Ramp model with two shock waves at the inlet.

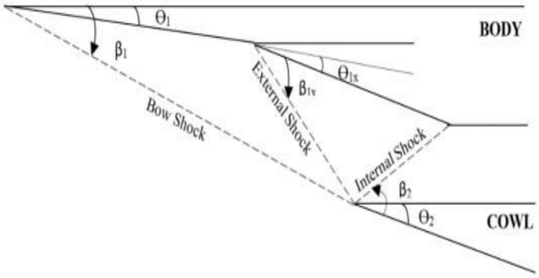


Figure 4: Double Ramp model with three shock waves at the inlet.

2-D design of scramjet inlet:

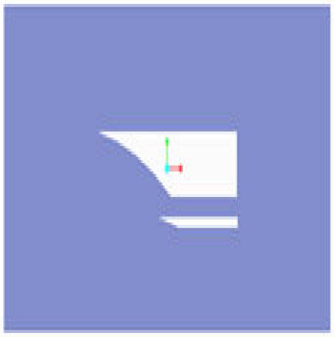


Fig 5 single ramp model

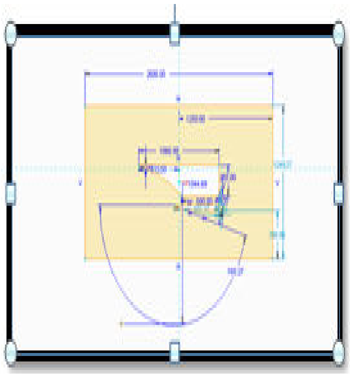


Fig 6 single ramp 2D model

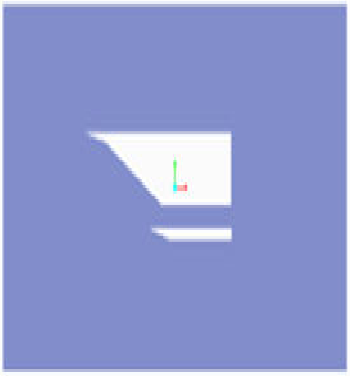


Fig 7 double ramp model

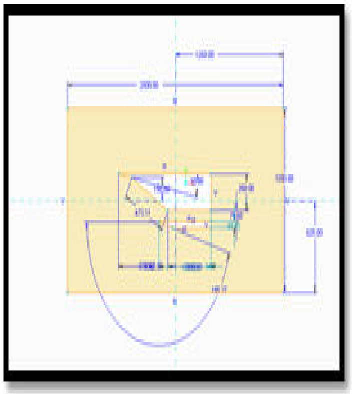


Fig 8 double ramp 2D model

CFD ANALYSIS OF SCRAMJET INLET: Meshing is integral to the computer-aided engineering (CAE) simulation. The mesh considered has affect on the accuracy, convergence of the solution and processing speed. This is a time taking process. Proceed meshing with diligence.The model is designed with the help of pro-e and then import on ANSYS for Meshing and analysis. CFD analysis is used to for calculating the pressure profile and temperature distribution and mach number throughout the length. For ease of meshing, the control volume is divided into as two connected volumes. The edges are meshed with 360 intervals. A tetrahedral mesh structure is used for analysis. So the total number of nodes and elements is 1919 and 1784. In ANSYS ICEM CFD Hexa consider object-oriented unstructured meshing technology. With no tedious up-front triangular surface meshing required providing well-balanced start meshes, ANSYS ICEM CFD Hexa works directly from the CAD surfaces and fills the volume with Hexahedral elements using the Octree approach. An algorithm provides the element quality. Options are available for automatically refine and coarsen the mesh both on geometry and within the volume. A Delauny algorithm is also included to create Hexas from surface mesh that already exists and also to give a smoother transition in the volume element size. The grid generated Scramjet inlet geometry has 88868 nodes and 448143 elements. The pre-processor serves for both the grid generation and also for the purpose of the mesh generation. The generated mesh in the model scramjet inlet is a structured with equally spaced faces and also nodes. After mesh generation in scramjet inlet model the boundary condition of each face is coded in the ICEM CFD software itself. For this simulation the faces are given the options of air inlet and the supersonic outflow outlet and remaining all the faces of the model scramjet inlet is set to be walls for the purpose of this simulation and further the mesh generated model is exported in to the solver for the purpose of simulation. For 2-D dimensional computations over the model, a structured grid of quadrilateral cells are made. The overall rectangular domain is made of several iterations were chosen for all models. Inlet exit was the part of the outlet boundary face whereas the model base was situated on the boundary which was assigned as wall boundary. The grid generation scheme is quad/tri type cells of volume meshing. For every inlet models grid with approximately 30000 cells is made. After meshing the initialize boundary condition for all the scramjet inlet models is coded.

Name	Type
Outlet	Pressure outlet
Upper boundary	Wall
Lower boundary	Wall
Fluid	Air

Table 2: Boundary conditions for all models

The grid for the scramjet inlet 2D models generated using the software ANSYS and the other specification discussed. Grid independence study results in formation of fine grids to obtained desired results. Separated domains was selected based on several iterations chosen. Accuracy of the solution is dependent on many parameters like size of the control volume, orientation of boundaries, discretization and its order of accuracy.

IV. Results Analysis:

Computational Results from ANSYS Fluent are taken as a case of mach number and pressure:

Two dimensional simulations of the flow field using FLUENT are to be made. Computations validated through a simulation of hypersonic inlet at desired Mach number. Boundary conditions and properties of the model defined as reference to the literature.

A. SINGLE RAMP INLET:

CASE 1: Single ramp with 10° ramp angle:

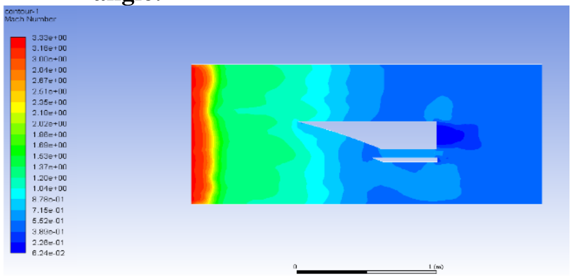


Fig 8: Mach number of single ramp angle 10^0 at Mach 3

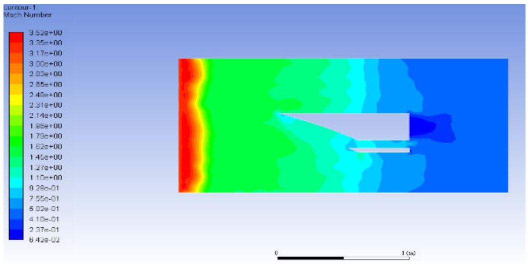


Fig 9: Mach number contour single ramp angle 10^0 at Mach 5

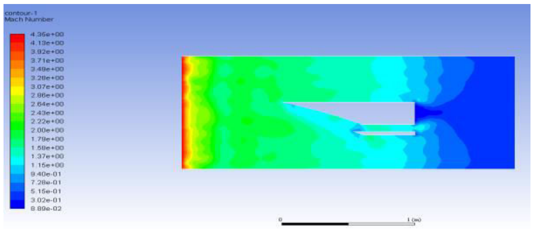


Fig 10: Mach number contour single ramp angle 10^0 at Mach 7

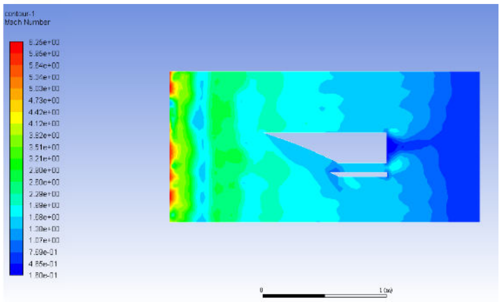


Fig 11: Mach number contour single ramp angle 10^0 at Mach 9

CASE 2: Single ramp with 12° ramp angle:

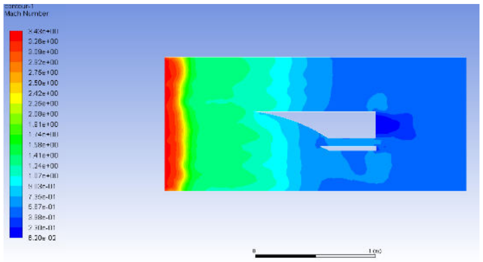


Fig 12: Mach number of single rampangle 12^0 at Mach 3

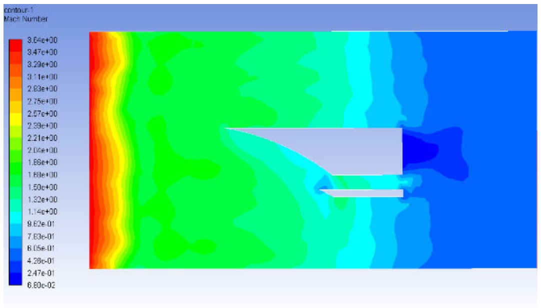


Fig 13: Mach number contour single ramp angle 12^0 at Mach 5

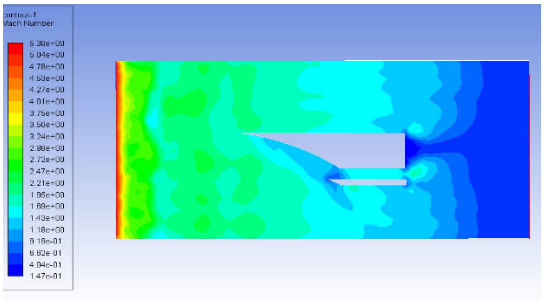


Fig 14: Mach number contour single rampangle 12^0 at Mach 7

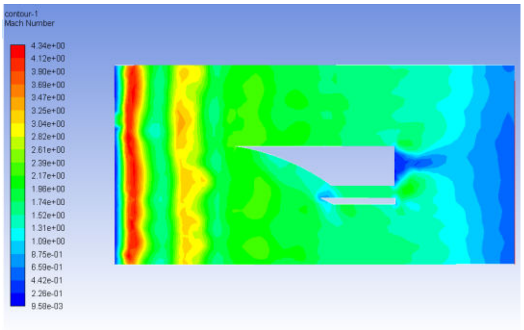


Fig 15: Mach number contour single ramp angle 12^0 at Mach 9

B. DOUBLE RAMP CONDITION:

CASE 1: Double ramp with 10° ramp angle:

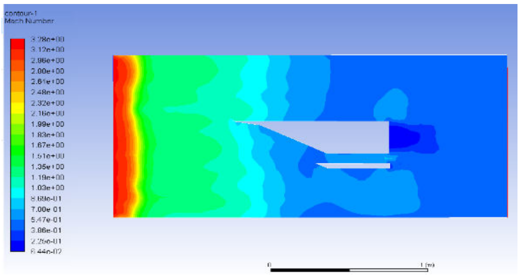


Fig 16: Mach number contour double ramp angle 10^0 at Mach 3

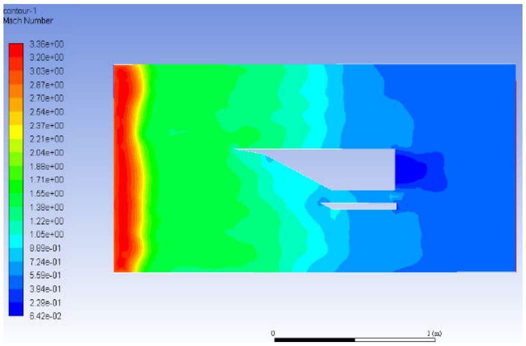


Fig 17: Mach number contour double ramp angle 10^0 at Mach 5

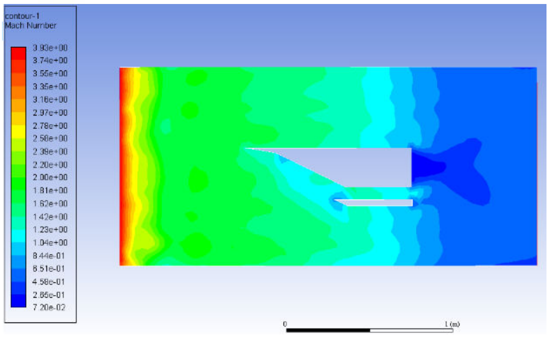


Fig 18: Mach number contour double ramp angle 10^0 at Mach 7

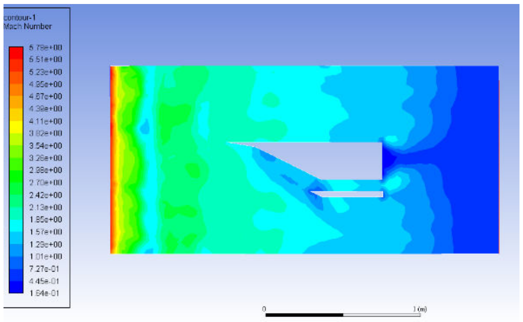


Fig 19: Mach number contour double ramp angle 10^0 at Mach 9

CASE 2: Double ramp inlet with 12°ramp angle:

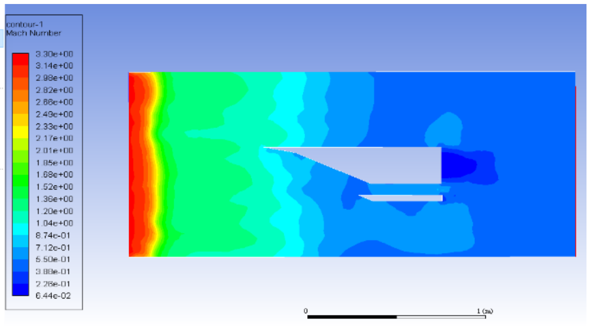


Fig 20: Mach number contour double angle 12^0 at Mach 3

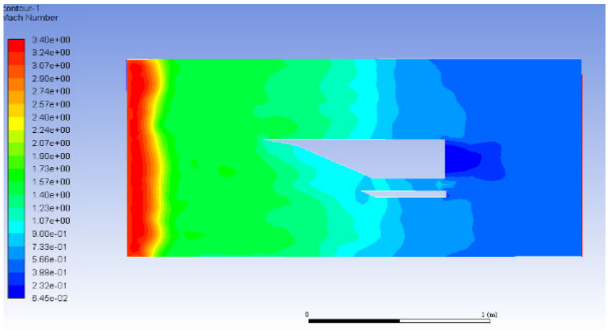


Fig 21: Mach number contour double ramp angle 12^0 at Mach 5

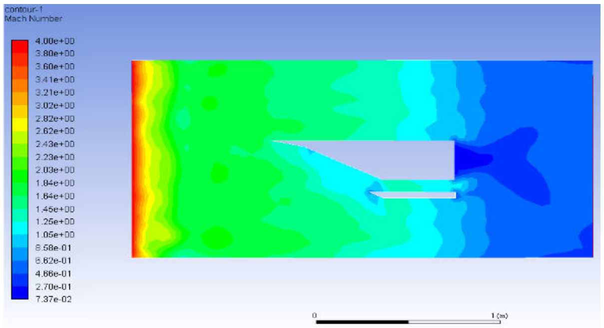


Fig 22: Mach number contour double ramp angle 12^0 at Mach 7

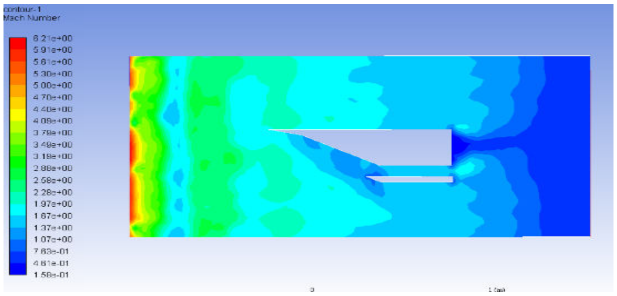


Fig 23: Mach number contour double angle 12° at Mach 5

This is analysis carried out for Mach number 3, 5, 7&9 forthe entire scramjet inlet models single and double ramp. The ramp angles are 10^0 and 12^0 .The simulation contours obeys the flow pattern which analyzed here as plots to compare the performance of the models with respect these designs. Here, is to compare the standard parameters such as Pressure, Mach numbers, temperature and density for Mach number 3, 5, 7&9 forthe entire scramjet inlet models single and double ramp. The ramp angles are 10° and 12°. From the computational analysis results Figure 8-23 gives the Mach number profile throughout the length of the scramjet inlet.

Ramp angle (°)	Free stream Mach number	Maximum Pressure (pa)	Exit nu
10	3	4.22E+05	
	5	2.32E+06	0
	7	6.10E+06	1
	9	9.37E+06	1
12	3	5.16E+05	1
	5	2.46E+06	1
	7	9.29E+06	1
	9	1.14E+07	2

Table 3: analysis results for single ramp condition

Ramp angle (°)	Free stream Mach number	Maximum Pressure (pa)
10	3	4.04E+05
	5	1.06E+06
	7	3.80E+06
	9	8.31E+06
12	3	4.13E+05
	5	1.29E+06
	7	3.76E+06
	9	9.02E+06

Table 4:analysis results for double ramp con

V. Conclusion:

The scramjet works on the principle of the ram pressure. Figure 8-23, shows mach profile, it can be inferred that the shock train of oblique shocks are formed. For high Mach number the profile shows discontinuous pattern, indicating high turbulence, shock waves in overexpansion. For our study the final aim to check which inlet and ramp angle gives us the supersonic condition and maximum pressure for combustion. This is due the reason that compressor is eliminated in the design of Scramjet. Table 3-4 gives out the data for the single ramp condition and double ramp condition respectively. From that it is inferred that single ramp condition for a ramp angle of 12° gives out the optimized values. In the optimized condition we observe that from operating mach 3(which can be achieved from jet engines) to a range of mach 9, the operation is supersonic throughout the length. It has also been observed that the pressure, temperature increases with ramp angle and Mach number, having highest values in the single ramp conditions. The results from this paper can only be applied to geometry similar to the design considered that is for the oswatitsch intake design. While this is theoretical, in practicality the structure of the scramjet also plays a role in final design consideration. This paper deals with only the aerodynamic quantities. Further study can be done on the structural aspect of the scramjet.

REFERENCES

[1] Hypersonic flow theory, Ph.D.thesisDr.NikosJ.Mourtos.

[2] Derek J. Dalle_, Sean M. Torrezy, and James F. Driscoll Performance Analysis of Variable-Geometry Scramjet Inlets Using a Low-Order Model 47th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, 31 July - 03 August2011, San Diego, California.

[3] Ramesh kolleru and Vijay Gopal Comparative Numerical Studies of Scramjet Inlet Performance using k-ε Turbulence Model with Adaptive Grids COMSOL conference Bangalore012.

[4] Kristen Nicole Roberts Analysis and Design of a hypersonic Scramjet engine with a starting Mach number of 4.00, Maters thesis, The university of Texas at Arlington, August 2008.

[5] AqheelMurutuzaSiddiquin and G.M. Sayeed Ahmed, Design and Analysis of a Scramjet engine Inlet International Journal of Scientific and Research Publications, Volume 3,Issue 1, January 2013 1 ISSN 2250-3153.

[6] M. Krause, B. Reinartz, J. Ballmann, "Numerical Computations for designing a Scramjet intake, 25thInternational conference of Aeronautical Sciences 2006.

[7] Michael K. Smart and Carl A. Trexler, Mach 4 Performance of a Fixed-Geometry Hypersonic Inlet with Rectangular-to-Elliptical Shape Transition, AIAA – 2003-0012.

[8] Donde Pratik Prakash, Hypersonic Intake studies, Master's Thesis, Indian Institute of technology, Bombay, July 2006.

[9] Amjad A. Pasha and Krishnendu Sinha, Simulation of Hypersonic Shock/Turbulent Boundary-Layer Interactions Using Shock-Unsteadiness Model, Journal of Propulsion and Power Vol. 28, No. 1, January–February 2012