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2D Hypersonic Scramjet Inlet Geometry 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 work gives a report on the design, analysis of optimal 2D scramjet engine inlet operating at Mach 7 without use of movable geometry. A computational study for scramjet inlet with different ramp angles is carried out. Several cases are considered to compress the air by rounding leading edge without moving the whole cowl up and down, by fixing the cowl lip and assuming axisymmetric inlet with rounded edge. The numerical tests are conducted to obtain maximum total pressure recovery, drag force and outlet Mach number for given flight condition. Two dimensional effects are studied with Navier-strokes approach to compute the pressure and Mach number at a different location. Oblique shock waves, expansion waves and shock wave interactions are primarily focused. Computational Fluid Dynamics (CFD) solver is used; steady flow simulations are carried out for inlet geometries with one, two, three and four ramps. Geometrical shape is redesigned based on oblique shock wave analysis. The corrected model is tested on Fluent with boundary layer considerations 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 with contraction ratio 10. It had been observed that two ramp scramjet inlet model has been preferred to use which has optimum pressure recovery and lower drag.*

Keywords— scramjet, CFD, oblique shockwave, hypersonic

I. INTRODUCTION

The primary part of a scramjet motor is the channel. It is in charge of providing a supersonic stream with reasonable weight, temperature and mass stream rate to the combustor for productive ignition of fuel. Consequently, the bay is a basic part which influences incredibly the general effectiveness of the entire scramjet motor. For example, the quantity of inclines and the points between each pair of contiguous slopes, the undeniable answer for a scramjet motor to work a Mach number is to change these parameters and in this manner change the geometry of the delta. This examination plans to handle this test and obtain a structure a channel working geometry of Mach 7.

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In this study, the Sideways shockwave connection fills in as the hypothetical base for delta investigation. CFD disturbance displaying in Fluent will be studied and used for further applications. India has effectively propelled the main practice run of its Hypersonic Technology Demonstrator Vehicle (HSTDV) from Abdul Kalam Island in Odissa. The rocket is a piece of India's endeavours to build up a scramjet motor, which is the viewed as the following booster for future rocket, flying machine and shuttle innovation. The practice run of the HSTDV was directed by the Defence Research and Development Organization (DRDO), which has been building up the scramjet engine.

A scramjet motor comprises of four noteworthy parts: bay, isolator, combustor and spout. All through this paper, the scramjet motor is isolated to various areas by the stations as depicted [1]. Various projects expecting to create flying machines equipped for hypersonic flight initially showed up in the late 1950's and mid 1960's and have grown from that point onward [2]. It has been discovered that rocket pushed vehicles were not a useful alternative for hypersonic trip because of the need of installed oxidizer tank, bringing about overwhelming burden conveying [3]. An all the more encouraging decision is an air breathing impetus framework and the best reasonable air breathing motor cycle for hypersonic flight is scramjet supersonic ignition ramjet [4].

As air going through the motor channel, it is packed by shockwave and backed off to a subsonic speed before entering the combustor where fuel is infused and consumed. Air is then quickened through a spout to make push [5]. Ramjet motor can just work effectively up to Mach 6 as at flight Mach number over 6, to accomplish subsonic stream to the combustor, the pressure proportion needs to increment to an incentive at which stun misfortunes become unfavorably significant and the wind stream temperature is high to such an extent that separation starts to happen in the spout, henceforth, less vitality is removed in type of push [20].

II. GOVERNING EQUATIONS

I. Continuity Equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

II. Momentum Equation (Navier-stokes Equation)

X-Momentum equation

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)$$

Y-Momentum equation:

$$\rho\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)$$

Z- Momentum equation:

$$\rho\left(u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)$$
$$=-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)$$

III. Energy Equation

$$\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)=\frac{1}{\alpha}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)$$

IV. 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 is 10 from inlet to outlet.

III. METHODOLOGY

i. Basic Geometry and meshing

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 two orders 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.

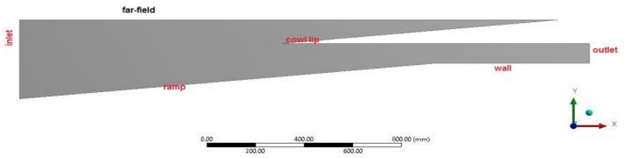

Fig-1 Basic structure of inlet geometry:

Dimensions:

Number of RAMPS	1ST RAMP ANGLE	2ND RAMP ANGLE	3RD RAMP ANGLE	INLET LENGTH	OULET LENGTH	TOTAL WIDTH
1	6	-	-	300	30	2010
2	5.2	15	-	250	25	2136
3	4.3	9	15.3	250	25	2386

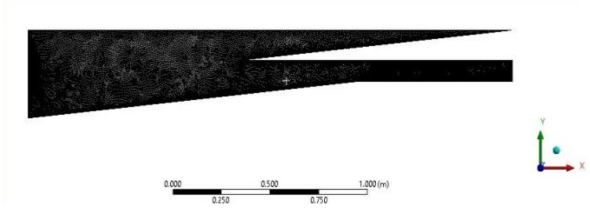

Fig-2 Basic geometry

IV. RESULTS AND DISCUSSION

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

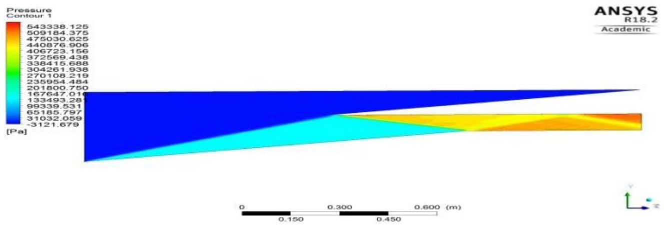

Fig-3 Pressure counters of 1-ramp inlet geometry Mach 7

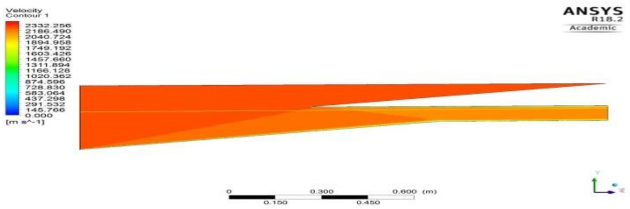

Fig-4 Velocity counters of 1-ramp inlet geometry Mach 7

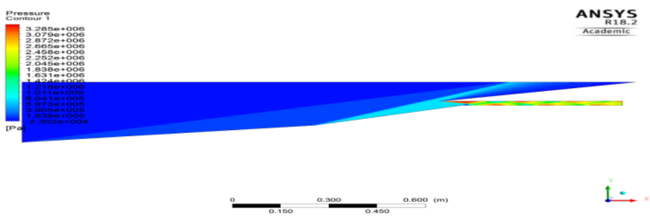

Fig-5 Pressure counters of 2-ramp inlet geometry Mach 7

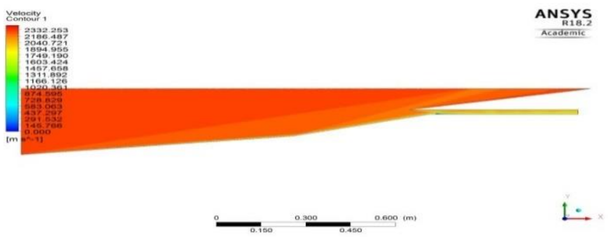

Fig-6 Velocity counters of 2-ramp inlet geometry using Mach 7

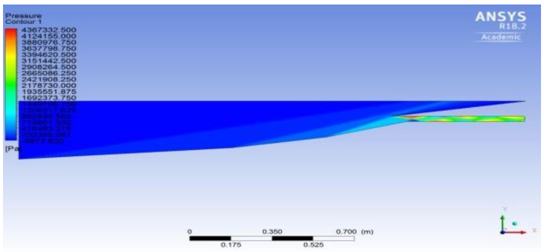

Fig-7 Pressure counters of 3-ramp inlet geometry Mach 7

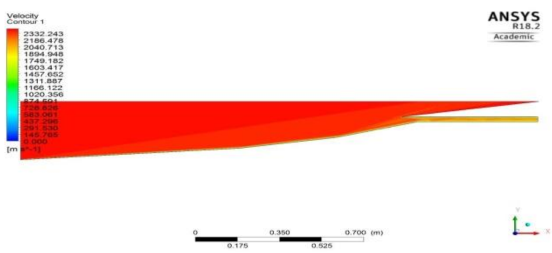

Fig-7 Velocity counters of 3-ramp inlet geometry Mach 7

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

4.1 Pressure Analysis

Number of ramps		Absolute pressure(bar)	Total pressure(bar)
1 ramp	Inlet	1.01325	4667
	Outlet	5.8311	3070
2 ramp	Inlet	1.01325	4665
	Outlet	25.4386	1690
3 ramp	Inlet	1.01325	6238
	Outlet	26.7346	1860

Table: 1 Absolute and Total pressures of different ramps

One ramp inlet Geometry: Table 1 represents the various pressures of different ramp geometry we can say that the pressure increase with increase of ramps which is produced by oblique shock waves. Represents the maximum pressure outlet of 5 bar, when one ramp inlet geometry is used. This is far less than the two ramp inlet geometry as shown below.

Two ramps inlet Geometry: The maximum pressure outlet of 25 bar when two ramps inlet geometry is used. The shockwave produced by Mach 7 inlets.

Three ramps inlet Geometry: The maximum pressure outlet of 26 bar when three ramps inlet geometry is used. The shockwave produced by Mach 7 inlets. The comparison of all the three inlet geometry in a pressure. Here the contraction ratio is 10 i.e. to inlet and outlet. Four ramp geometry there is no self-starting of the hypersonic scramjet engine, so we neglecting the 4 ramp stimulation, because there will not be generation of shock wave therefore the overlapping the shockwave deflects more than what it is designed. Hence the 4 ramp inlet geometry is not used in this analysis.

4.2 Drag Force and Drag Coefficient

Number of ramps	Drag Force(KN)	Drag coefficient
1 ramp	47.484	77525.249
2 ramp	42.565	69866.755
3 ramp	132.737	216714.91

Table: 2 Drag forces and drag coefficients

The drag force and drag coefficient is calculated in order to get the optimized inlet geometry for the hypersonic scramjet inlet. The obtained values show that one and three ramp are having heavy drag forces and drag coefficient are obtained, but for the two ramp inlet geometry ramp is lesser than the other one and three ramps geometry. So here two ramps is suggested.

4.3 Mach Number Analysis

Number of ramps	Mach number	
	Inlet	Outlet
1 ramp	7	4.46
2 ramp	7	2.97
3 ramp	7	3.12

The Mach number for all the inlet geometries is 7, where outlet of the each inlet geometry is varied with different Mach number. In this case minimum the Mach number higher the pressure will be so here two ramps inlet geometry is suggested with outlet of Mach 2.97.

V.CONCLUSION

In this work, CFD analysis were performed, and provided the fundamental understanding of the uniform flow and analysis of shock wave by using a ramp. The pressure and velocity variation under different geometric variations and also variation of pressure has been investigated and tabulated. Based on this results following conclusion were made:

For one ramp inlet geometry the maximum pressure recovery is 5 bar when outlet width is about 30mm and inlet is 300mm with drag force 47.484 KN is and Mach number is 4.14.
For two ramps inlet geometry the maximum pressure recovery is 25 bar when outlet width is about 25mm and inlet is 250mm with drag force 42.565 KN and Mach number is 2.97. For three ramps inlet geometry the maximum pressure recovery is 26 bar when outlet width is about 25mm and inlet is 250mm with Drag force 132.737 KN and Mach number 3.12 therefore three ramp geometry is preferred, but while considering drag force and Mach numbers at outlet this geometry not considered. As we discussed above using of 4 ramp inlet there will be no self-starting of the hypersonic scramjet engine so neglecting the four ramp inlet geometry.

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