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Design and Thermal Analysis of Ramjet Engine for Supersonic Speeds

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ABSTRACT:

In this project, flow through the Ramjet's convergent divergent nozzle study is carried out by using FLUENT analysis. The nozzle geometry modeling and mesh generation has been done using CATIAV5 R20 and ANSYS 16.0 software. Here, the Ramjet's convergent divergent nozzle is designed for different supersonic speeds 1.6, 1.8 and 2.0.From the analysis, it is clearly observed that as the velocity and mass flow rate of air increases before the diffuser the speed of the jet also increases.The maximum temperature obtained at the end of the nozzle and at the throat section, we can observe the variation of temperature, pressure and velocity contours.

Key words:

Convergent Divergent Nozzle, CatiaV5R20, Ansys16.0, Fluent, Ramjet, Combustion chamber and diffuser.

1. INTRODUCTION

1.1 Ramjet

A ramjet, sometimes mentioned to as a flying an athodyd (an aero thermo dynamic duct), is a form of air breathing jet engine that uses the engine's forward motion to compress incoming air lacking an axial compressor. Ramjets cannot create thrust at zero air speed, they cannot move an aircraft from a standstill. For example a rocket assist to accelerate it to a speed where it initiates to produce thrust. Ramjets work most efficiently at supersonic speeds.

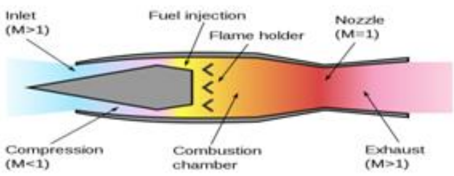

Fig 1.1: Process Diagram for Ramjet Engine

Ramjets can be mainly useful in applications calling for a small and simple mechanism for high-speed use, such as missiles. Weapon creators are looking to use ramjet equipment in weaponry shells to give added range; a 120 mm mortar shell, if helped by a ramjet, is thought to be able to attain a range of 35 km (22 mi). They have also been used successfully, though not efficiently, as tip jets on the end of helicopter rotors.

1.2EXHAUST GAS VELOCITY

As the gas enters a nozzle, it is moving at subsonic velocities. As the throat contracts, the gas is forced to accelerate until at the nozzle throat, where the cross-sectional area is the smallest, the axial velocity becomes sonic. From the throat the cross-sectional area then increases, the gas expands and the axial velocity becomes progressively more supersonic.

The linear velocity of the exiting exhaust gases can be calculated using the following equation:

$$v_e = \sqrt{\frac{TR}{M} \cdot \frac{2\gamma}{\gamma - 1} \cdot \left[1 - \left(\frac{p_e}{p}\right)^{\frac{\gamma-1}{\gamma}}\right]},$$

where:

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v_e = exhaust velocity at nozzle exit,

T = absolute temperature of inlet gas,

R = universal gas law constant,

M = the gas molecular mass (also known as the molecular weight)

$\gamma = \frac{c_p}{c_v}$ = isentropic expansion factor

(c_p and c_v are specific heats of the gas at constant pressure and constant volume respectively),

p_e = absolute pressure of exhaust gas at nozzle exit,

p = absolute pressure of inlet gas.

1.3 Convergent-divergent (C-D) nozzle

1.3.1Convergent nozzle:

Convergent nozzles are used on many jet engines. If the nozzle pressure ratio is above the critical value (about 1.8:1) a convergent nozzle will choke, resulting in some of the expansion to atmospheric pressure taking place downstream of the throat (i.e. smallest flow area), in the jet wake. Although jet momentum still produces much of the gross thrust, the imbalance between the throat static pressure and atmospheric pressure still generates some (pressure) thrust.

1.3.2 Divergent nozzle:

The supersonic speed of the air flowing into a scramjet allows the use of a simple divergent nozzle. Engines capable of supersonic flight have convergent-divergent exhaust duct features to generate supersonic flow. Rocket engines the extreme case they accommodated their distinctive shape to the very high area ratios of their nozzles. When the pressure ratio across a convergent nozzle exceeds a critical value the pressure of the exhaust exiting the engine exceeds the pressure of the surrounding air. This reduces the thrust producing efficiency of the nozzle by causing much of the expansion to take place downstream of the nozzle itself. Consequently, rocket engines and jet engines for supersonic flight incorporate a C-D nozzle which licenses further growth against the inside of the nozzle.

1.3.3 OBJECTIVE:

For all users the C-D nozzle inlet, throat, outlet values or may take the values from reference journals. But we are modelling the C-D nozzle inlet ,throat, outlet values are from analytically, based on the supersonic speeds Based on values of inlet, throat, and outlet so, we are design the convergent- divergent nozzle in CATIA v5 software and by changing the designs of convergent –divergent nozzle areas so that the design is too imported for future case. After, we will do the fluent analysis in the area of convergent-divergent portions of the ramjet engine for supersonic speed of Mach number 1.6 and plot the velocity and pressure graphs.

So that we are increasing the mass flow rate at inlet and also it increases mass flow rate and velocity automatically exhaust at outlet that is at divergent portion of the nozzle. After all Mach numbers was compared that the Mach number which were suitable for experimental analysis by changing different materials for future analysis. And for going on increasing Mach number velocity , pressure and temperature distribution also increases at divergent portion

2. DESGIN:

The main design in ramjet engine is body structure which contains three major parts is Diffuser, Combustion Chamber, Nozzle. These parts design calculated based on Mach numbers and formulae’s are taken from thermodynamics by y.cengel's m. boles'stext book and calculations are explained in detail

ρ= density of the fluid

P= pressure of the fluid

Q=stream rate through exhaust fan

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A= area

V= velocity

Flow rate through exhaust fan = $200m^3/min$ (given specification)

Q = AV

Density of air at inlet of the fan (ρ_1)=$\frac{P_1}{RT_1}$

Mass stream rate at inlet (m) = $\rho_1 A_1 V_1$

We are designing for Mach numbers are 1.6, 1.8 and 2

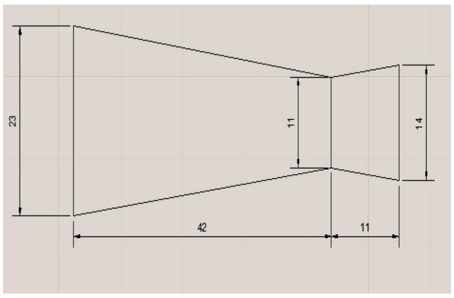

Fig 3.4: Total dimensions of the convergent – divergent nozzle of a ramjet engine in centimeters

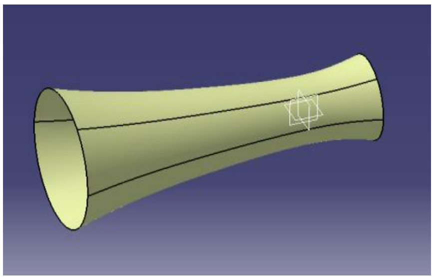

Fig 3.5: Design model in catia v5 software for Mach number1.6

The exhaust Mach number, M_e =1.8

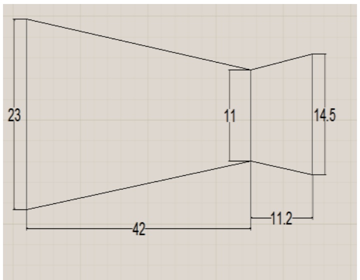

Fig 3.6: Total dimensions of the convergent – divergent nozzle of a ramjet engine in centimeters

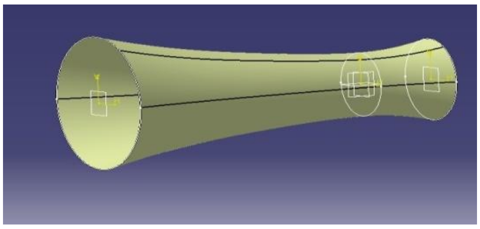

Fig3.7: Design model in catia v5 software for Mach number1.8

The exhaust Mach number, M_e =2.0

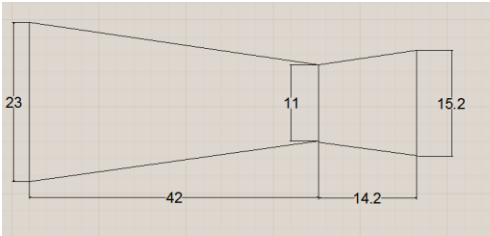

Fig 3.8: Total dimensions of the convergent – divergent nozzle of a ramjet engine in centimeters

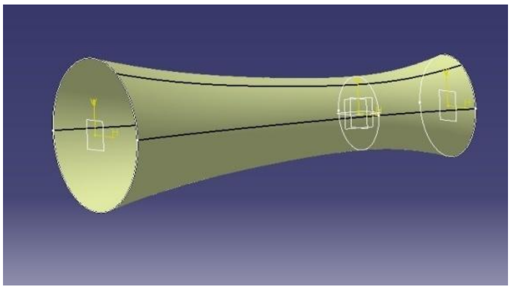

Fig3.9: Design model in catia v5 software for Mach number 2.0

3. COMPARING THEORETICAL AND ANALYTICAL RESULTS

According to the concept each type of engine has its maximum efficiency in a fairly slight range of Mach number M .This typical is most essential for air-feed jet engines. The major component of their propulsive mass is atmospheric air, and its parameters p and T, hence the parameters p *, and T *, at the air intake entry, depend in essence on the velocity and altitude of the aircraft's motion along the flight path. Analyzed in ANSYS fluent workbench 16.0 for supersonic speeds of 1.6, 1.8, 2.0and plotted the pressure, velocity and temperature as shown in figures below

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3.1 PRESSURE CONTOURS:

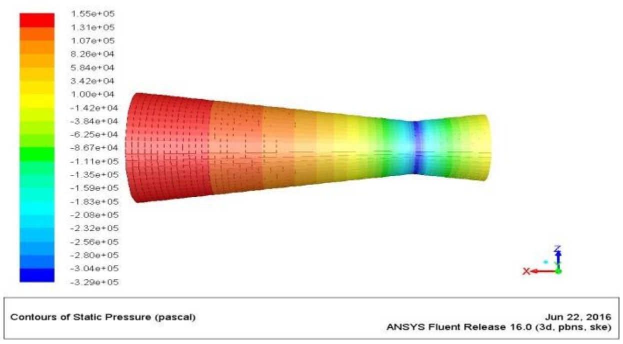


Fig 3.1: Pressure contour for Mach number 1.6

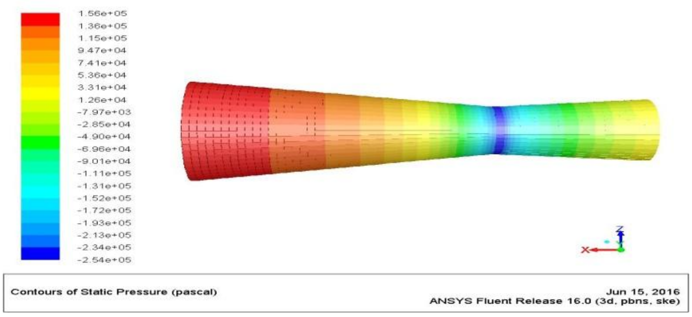


Fig 3.2: Pressure contour for Mach number 1.8

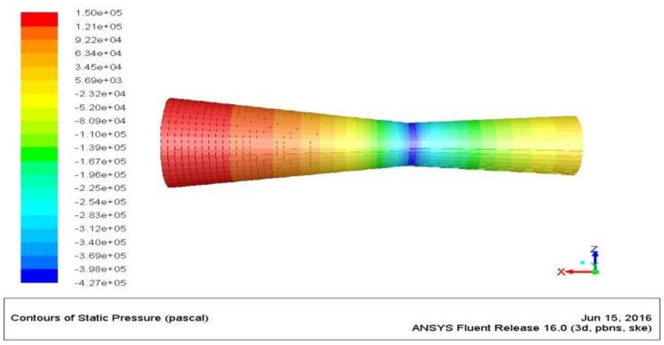
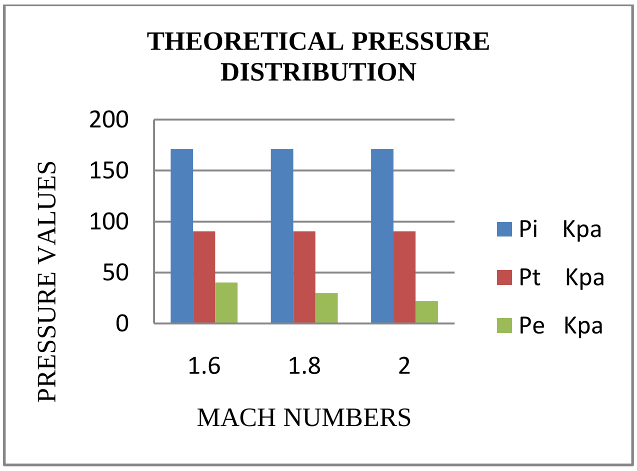
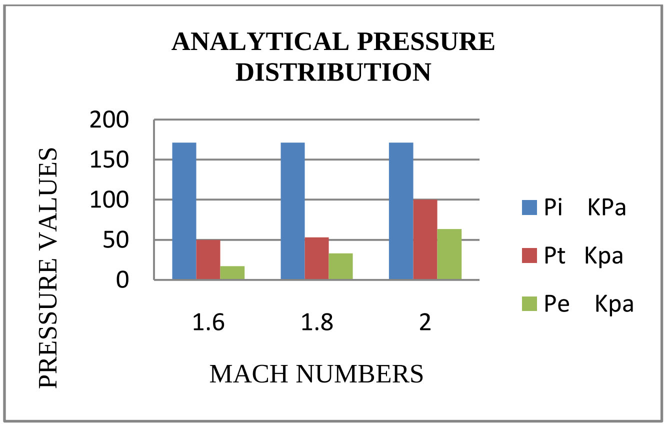


Fig 3.3: Pressure contour for Mach number 2.0

Table 3.1: Tabular form and Graphical representation of pressure distribution:

Mach numbers	theoretical values			analytical values		
	P_i	P_t	P_e	P_i	P_t	P_e
1.6	171.08	90.38	40.27	171.08	50	17.2
1.8	171.08	90.38	29.76	171.08	53	33
2.0	171.08	90.38	21.86	171.08	100	63.4





The bar chart represented that theoretical and analytical pressure distribution. If constant mass flow rate 5.89 kg per second is flows through the convergent and divergent nozzle area. If the pressures P_i,P_t,$P_e$reprensence the inlet , throat , and outlet as shown in fig. At inlet the pressure P_i maximum and at throat and outlet are changes because the nozzle shape is varies ,thermally design created was changes from throat section to outlet for Mach number 1.6 as shown in figure. Similarly, we done the Mach numbers at 1.8, 2.0. So that pressure is decreases gradually from inlet to outlet. As shown in figure.

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3.2 VELOCITY CONTOURS:

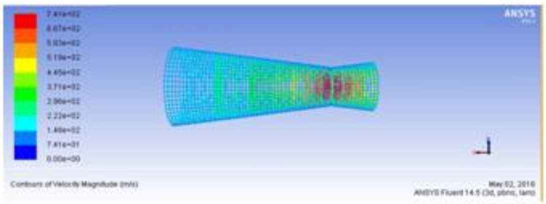


Fig3.4: VELOCITY contour for Mach number 1.6

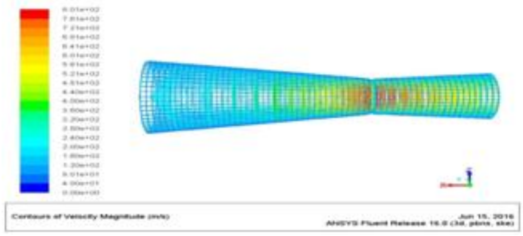


Fig3.5: velocity contour for Mach number 1.8

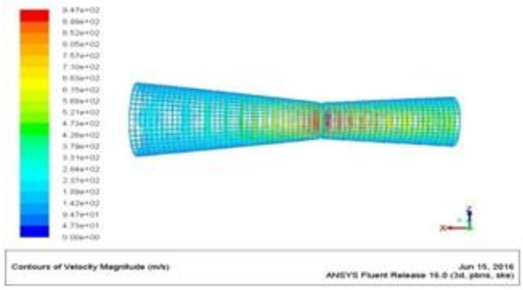
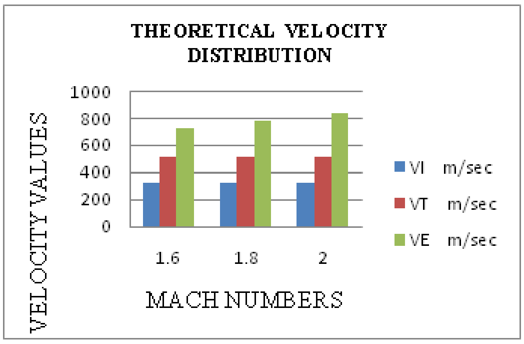
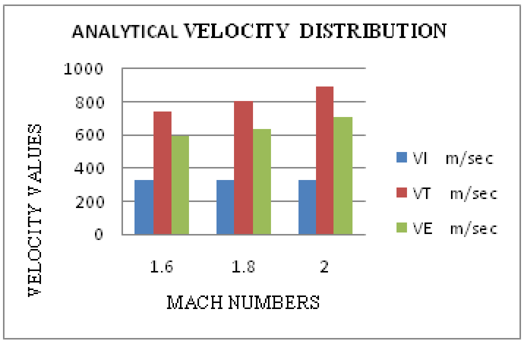


Fig5.6: velocity contour for Mach number 2.0

Table.3.2: Tabular form and graphical representation of velocity distribution

mach numbers	theoretical values			analytical values		
	V_I	V_T	V_E	V_I	V_T	V_E
1.6	326.24	508.73	725.16	326.24	741	593
1.8	326.24	508.73	781.24	326.24	801	641
2.0	326.24	508.73	830.81	326.24	890	710





The bar chart represented that theoretical and analytical velocity distribution. If constant mass flow rate 5.89 kg per second is flows through the convergent and divergent nozzle area. If the velocities V_i,V_t,$V_e$reprensence the inlet , throat , and outlet as shown in fig. the velocity is varies at the inlet ,throat and outlet because thermally design created was changes from throat section to outlet for Mach number 1.6 as shown in figure. Similarly, we done the Mach numbers at 1.8, 2.0. So that Mach number 2.0 obtain maximum velocity distribution at throat section as shown in figure

3.3 TEMPERATURE CONTOURS:

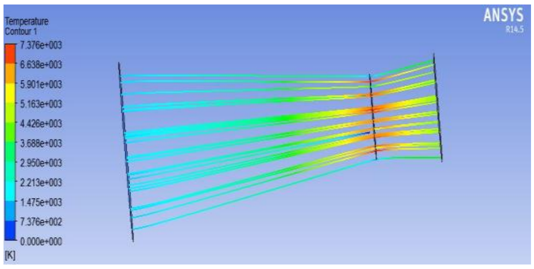


Fig3.7: temperature contour for Mach number 1.6

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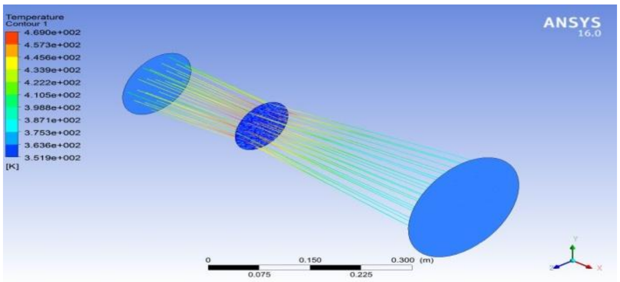


Fig3.8: temperature contour for Mach number 1.8

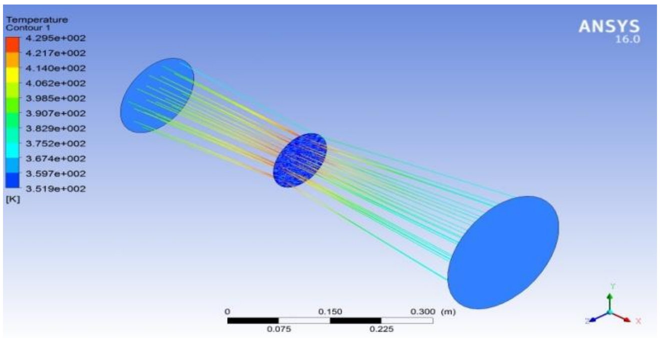
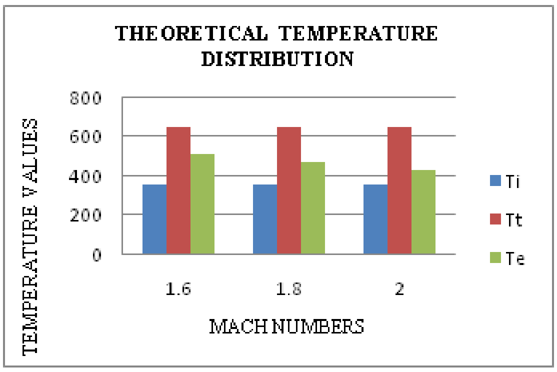
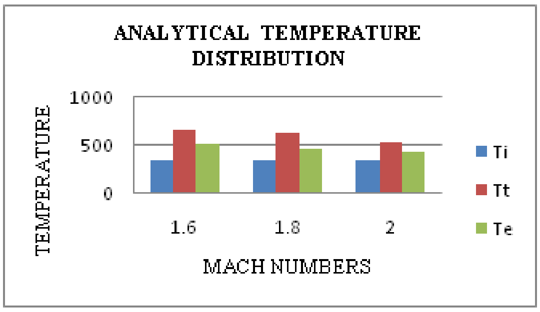


Fig5.9: temperature contour for Mach number 2.0

Table5.3: Tabular form and Graphical representation of temperature distribution

Mach numbers	theoretical values in ^{0}c			analytical values in ^{0}c		
	T_i	T_t	T_e	T_i	T_t	T_e
1.6	351.92	644.14	511.26	351.92	633.8	516.3
1.8	351.92	644.14	469.05	351.92	620	457
2.0	351.92	644.14	429.47	351.92	530	421.7





The bar chart represented that theoretical and analytical temperature distribution. If constant mass flow rate 5.89 kg per second is flows through the convergent and divergent nozzle area. If the temperatures T_i,T_t,$T_e$reprensence the inlet , throat , and outlet as shown in fig. At inlet the temperature T_i is constant (assumed 500^0c) and at throat and exhaust are changes because thermally design created was changes from throat section to outlet for Mach number 1.6 as shown in figure. Similarly, we done the Mach numbers at 1.8, 2.0. So that Mach number 2.0 obtain maximum temperature distribution at throat section as shown in figure.

4. CONCLUSION

After successfully completing this analysation of a design created, the decisions were finally confined into the following points. FLUENT analysis has been done on Convergent-Divergent nozzles of Ram Jet engine by using ANSYS 16.0 In figure 1 to 3, 4 to 6 and 7 to 9 shows the pressure, temperature and velocity distribution respectively. As the velocity and mass flow rate of air increases before the diffuser the speed of the jet also increases It is clearly seen the velocity is increasing along with the length of the nozzle. Due to shocking in the nozzle, the velocity decreased for a while but later began to increase as the fluid expanded through the divergent portion. Pressure gradually decreased along the length of the nozzle except a slight rise during the shocking. However, the rise was not significant comparing to the total fall in pressure. According to Bernoulli’s equation, pressure decrease as velocity increase along expansion zone.

We observed the temperature distribution in C-D nozzle of Ram Jet engine. Here, the maximum

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temperature obtained at the end of the nozzle and at the throat section we can observe the variation of temperature. From the velocity contours, the maximum velocity developed at the throat section. As the Mach number increases the velocity will get the maximum. From the pressure contours, the maximum pressure will get after the combustion chamber i.e. convergent portion. As Mach number increases pressure distribution is decreased. So observer that at Mach number 2.0 gets maximum velocity, based on thermally design created on Mach number

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