DESIGN AND COMPUTATIONAL ANALYSIS OF INLET CONE SECTION OF ARTILLERY RAMJET

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Abstract : In the past few decades many research and studies have been done on the ramjet engines to analysis the inlet section of ramjet artillery. Here the study focuses on the Pseudo Vacuum trajectory which is the one where the thrust is always balancing the drag. This trajectory can be achieved by controlling the mass flow rate through by-pass control of inlet air or by a regression rate control of fuel. The standards of development and activity of a solid-fuel ramjet propelled artillery shell or a projectile are also provided. The study talks about different parameters such as Pressure, Temperature, Eddy viscosity and Velocity with different cross-sectional area.

According to 1 dimensional consideration, the primary design of the propulsion system for a solid fuel ramjet was used and different methods were introduced in order to calculate the control requirements. By using this method, the solid fuel ramjet which was okay for 155 mm gun launched projectiles were monitored at various angles this implies that the control requirements by any of the methods will be minimal and hence demonstrating the self-throttling characteristics of solid fuel ramjet engine**.**

***IndexTerms* - SFRJ, LFRJ, Inlet area, Mach, Pressure, Velocity, Eddy Viscosity, Temperature, Mesh, Artillery ramjet.**

I. INTRODUCTION

Ramjet commonly known as the aero thermodynamic duct, is an air breathing engine which uses its forward motion to compress the incoming air without the use of any compressor (nor axial neither centrifugal). At zero airspeeds ramjets cannot produce thrust and hence they cannot move the aircraft from the still position which results in ramjet has the assisted take-offs and it can be used in the rockets to accelerate the speed where it actually begins to produce the thrust. The efficiency of ramjet can be closely observed at high mac numbers. Ramjet works and gives the desired output when it is subjected to use around the Mach 3, which is approx. 2300mph. Ramjets can be operated till up to the Mach 6 i.e. 4600mph. [2]

Ramjets can be widely used for the mechanisms such as missiles. Many countries US, Canada, and UK are using ramjet mechanism in the field of defense and also uses it on the large scale during the time of war. Now a day's ramjet technologies are more likely to use in the artillery shell in order to obtain a range of about 35km. Many experiments and research is done on the artillery shell so that the desired output can be obtained which will be helpful all over.

There are two ramjet types; Solid fuel ramjet engine (SFRJ) and Liquid fuel ramjet engine (LFRJ). Solid fuel ramjet engine has some moving components but it is simple and easy to understand (SFRJ) as compared to Liquid fuel ramjet. [3]

The construction of an SFRJ can be described in a certain way as follows: it consists of two parts; the diameter of the inlet is little less than the diameter of the gun barrel. The inlet is covered by a diaphragm shape structure. The rear part is considered as the outer diameter which could be less in comparison than the frontal part and the engine is formed where the fuel grain can be stored.

The principle of operating the SFRJ assisted gun projectile is as follows; when the gun is fired, combustion gases in the gun propellant fills the annular gap which is there between the gun barrel and the rear part. On applying force, the high pressure gas tends to form the projectile into the atmosphere at the supersonics Mach number (2 or more). After the projectile is subjected to the atmosphere, the intake opens as the diaphragm releases and the passes through the SFRJ and has very quick successions.

When the air flows the stagnation temperature is around 540 K or it can high. Being introduced to very high temperature and the high pressure gases the surface automatically get ignited and releases its combustion products. And hence the products released are moved through the nozzle with the where momentum rate is greater than the inlet value, which results in the production of thrust. [4]

At conditions when the SFRJ flies at the lower altitude, it adds large amount of air mass flow rate which has very high mass flux, pressure, and temperature values in the combustion chamber which also demands the high fuel rate for large mass flow rate. Whereas, at the conditions when the SFRJ flies at the high altitudes, it adds small amount of air mass flow rate which has very low mass flux, pressure and temperature values in the combustion chamber which demands the reduced fuel rate and this condition can be achieved by the regression rate dependency. These characteristics of SFRJ tends to increase its performance at high altitudes.

The scope of these ramjets is really high in the fields of military or aerospace sector. The only problem one faces if he wishes to use these ramjets is that, Ramjets are not independent they need some external source that can provide them enough speed so that ramjets become sustainable i.e. we can't start a ramjet from rest (Velocity=0). To overcome this problem these ramjets are now mounted on artillery shells. These special artilleries are powerful enough to provide there shell a speed of 1M or one mach. After the shell reaches a speed of one Mach the ramjet take overs the fight and increases the range. Artillery shells or projectiles themselves are able to take out the target at a maximum distance of 24km but if ramjets will be introduced with ordinary artillery shells then the maximum range will be no less than 150km.

II. PROPELLANT DEVELOPMENT

In artillery shell of 155mm, the propulsion is by using the fuel rich propellant in Ramjet. The propellants consisting of Aluminium, ammonium perchlorate and polybutadiene with no hydrogen were studied and their properties were observed so that it can be used in appropriate manner as a fuel in the Ramjet engine. Several trails were made in order to find the burn rates of different propellants at minimum pressure requirements in the combustor of ramjet. It is observed that reducing the Ammonium Perchlorate (AP) content in the propellant results in the reduction of burn rate of solid composites of propellants. Contents of AP burns till certain level. Here, different ways are discussed to improve the burn rate of fuel rich composite (propellant). [5, 6]

Following methods can help to increase the burn rate of the fuel.

- Pyral can be used
- Ammonium perchlorate can be used for (Recrystallization)
- Addition of catalyst into the propellant using various methods
- AC (activated charcoal) with moisture can also be added

Pyral is used as a metal fuel which results in the propellant with high burning rate and their density varies (decreases). Fine sized AP are used to reduce the density variation. Further, AC along with moisture is added in the propellants which also increases the burn rate. At 70 bar the highest burn rate is achieved ie.3.8mm/s. [5,7] The result showed that ammonium perchlorate (35%) along with iron oxide (1%) on it, aluminium (activated) with polytetrafluoroethylene (10%), and hydroxyl terminated polybutadiene (25%) were the accurate proportions for the fuel. Further study of the fuel mixture (propellants) depicts that its Young's modulus is 1.73Mpa whereas its tensile strength is 0.24Mpa. [8]

III. PSEUDO VACUUM TRAJECTORY

Pseudo Vacuum trajectory is the one where the thrust is always balancing the drag. Along with the increase in velocity and range this pseudo vacuum trajectory gives accurate results (stable). Further advantages which are described below;

1. Its accurate and the stable results (which are predicted) for the trajectories.
2. The inability to respond to the external barriers which can affect the trajectory motion.

Cross wind exerts the force on the center of pressure of the projectile which tends to deviate the direction of motion (for the projectile) by the use of the pseudo vacuum trajectories. The result and wind direction coincides with the axis of the projectile which comes under the angle of actual trajectories, which results in the increase of drag. As the relative wind velocity increases the thrust is also generated and maintain itself on the pseudo vacuum trajectories. Similarly, the head wings and the tail wings will be by Thrust is equal to drag. Also the spin is given around it so that the there is no case of asymmetry and in addition it produces small drift of the trajectory. [1, 4].

IV. CONTROL FOR PSEUDO VACUUM TRAJECTORIES

The projectile moat has an inlet of a symmetric axis with body center of cone angle as 450. The launch angle design has the maximum Mach number. Variable wing conditions affects the drag of projectile and also the inlet operations such as the mass flow rate, stagnation pressure ratio. The changes observed in the inlet operating conditions as an effect of variable wing conditions which also reduces the maximum launch angle.

The analysis shows that the launch angle (lower) which is due to high drag requires larger quantity of fuel. It can also be said that the launch angle (higher) can also be achieved by using the large value of the throat diameter. Overall it is estimated that the annular gap of 6.5mm is for engine with bypass co troll of inlet air. Overall observations were made and it was found that the on the results obtained for different launch angles and the annular gaps the actual value which was observed in the literature of HTPB is 8.5*. For wider launch angles the maximum possible values is of 82mm. [1, 4]

V. LAUNCH ANGLE CAPABILITY

By using the control procedures, the maximum launch angle can be achieved, as Launch angles directly proportional to the range. The main obstacle for higher launch angle is because of the operations on the inlet in the critical conditions at its respective peak altitude. Mainly the ramjet engines are operated at its suitable margin which does not support the working of inlet at its critical conditions. If the inlets are operated during its critical conditions, then the chances of damaging the inlet cross section increases rapidly.

If it happens then the combustion system blows out. By control systems cannot be operated under such critical mode and hence the all the performances and the experiments must be only carried out only when it satisfies all the required conditions. [4]

VI. CFD

The CFD is done using ANSYS software this software was chosen because of its high accuracy. In order to achieve precession, four different models of ramjet with different outlet were designed using Catia V5 software. Of all 4 models (Say A, B, C and D) 4 sub models were made with different cross-sectional area (For example for model A model A:1, A:2, A:3 and A:4 were made). The analysis was done in 2d mode on ANSYS workbench. The study was to check the change in Velocity, Pressure, Temperature and Eddy Viscosity. Sub models of each model were made with different inlet areas. Hence 64 results were achieved. The results were really discrete.

6.1 Design

All the designs were made using Wire Frame and Surface Design of Mechanical design of Catia software. A scaling of 12.31135 Is preformed; that is in order to convert the model made in Catia into actual seized model mutilation is to be done between the lengths and scaling factor (12.31135). Designs were made 2d and accessible in Ansys software by fill command. The file that was used while analysis was in ".stp" format. The average length of the part (Ramjet) was taken 113.97275mm with an average diameter of 22.6925mm. But for the ease of Analysis the vertical length was divided by its symmetry. In each sub model the variation of 10mm was done.

Table 1- Inlet values

	A	B	C	D	E
1	Part	Upper Distance(mm)	Real Upper Value (mm)	Lower Distance (mm)	Inlet Area (mm2)
2	Try23				
3	-1	8.13674138	100.174271	1.189mm	203.208
4	1	8.949	110.174271	1.189mm	247.151
5	2	9.7612586	120.174271	1.189mm	294.88
6	3	10.5735172	130.174271	1.189mm	346.752
7	Try25				
8	-1	8.06874136	99.337099	1.189mm	200.053
9	1	8.881	109.337099	1.189mm	243.342
10	2	9.6932586	119.337099	1.189mm	290.724
11	3	10.5055172	129.337099	1.189mm	342.282
12	Try26				
13	-1	8.13674138	100.174271	1.189mm	203.55
14	1	8.949	110.174271	1.189mm	247.151
15	2	9.7612586	120.174271	1.189mm	294.88
16	3	10.5735172	130.174271	1.189mm	346.752
17	Try27				
18	-1	10.5887414	130.361701	2.001mm	339.611
19	-2	9.7764828	120.361701	2.813mm	275.383
20	1	11.401	140.361701	1.189mm	403.911
21	2	12.2132586	150.361701	0.376mm	468.14
22					

Figure 1-Try 25

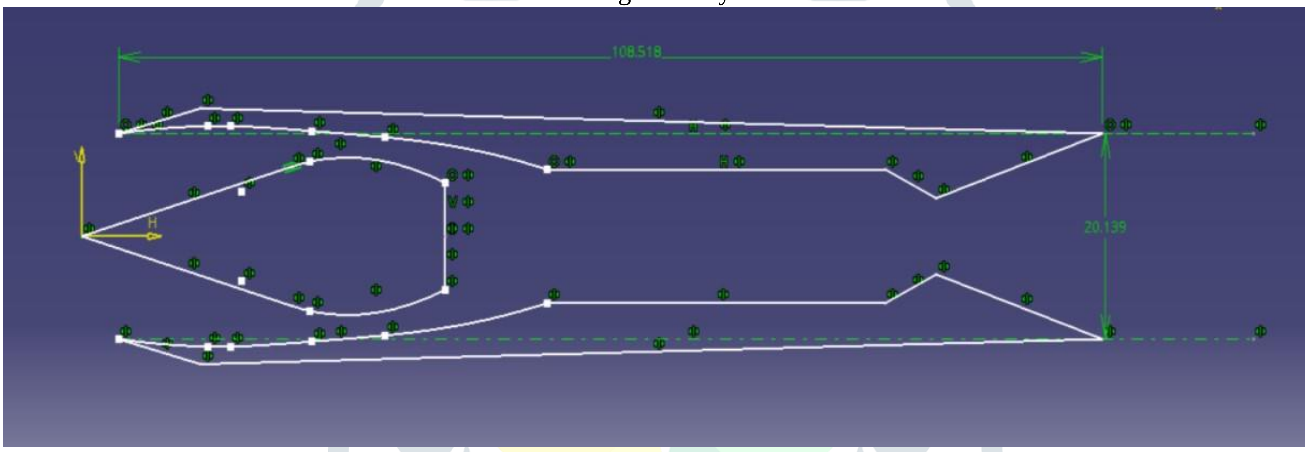


Figure 2- Try 26

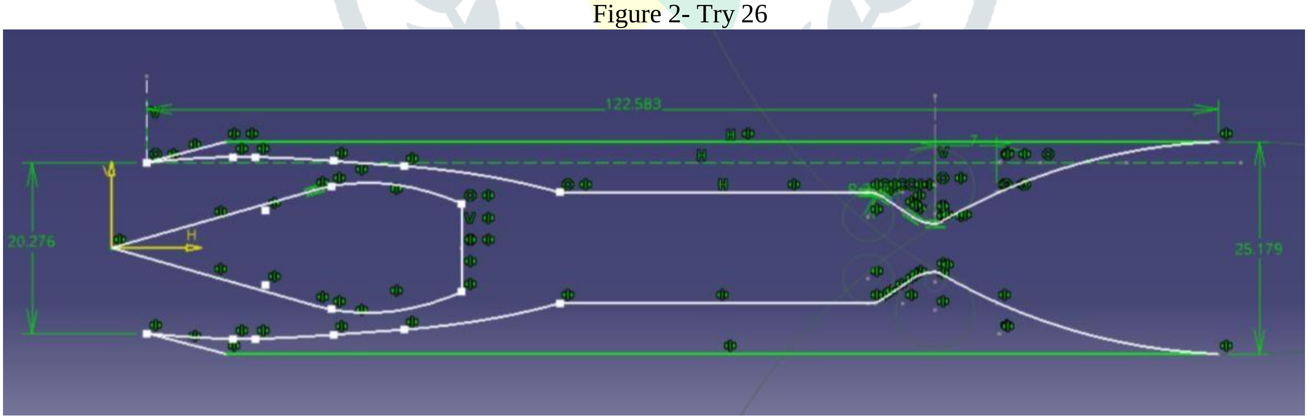


Figure 3- Try 27

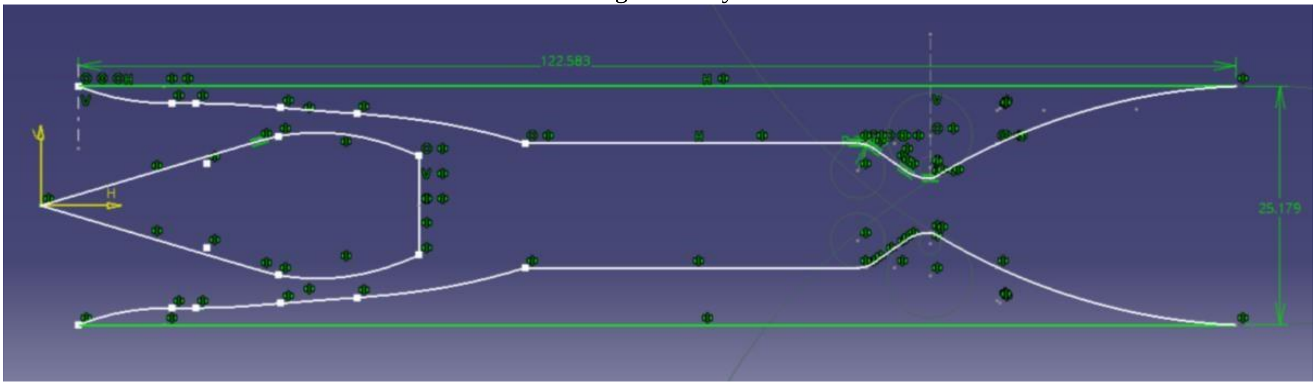
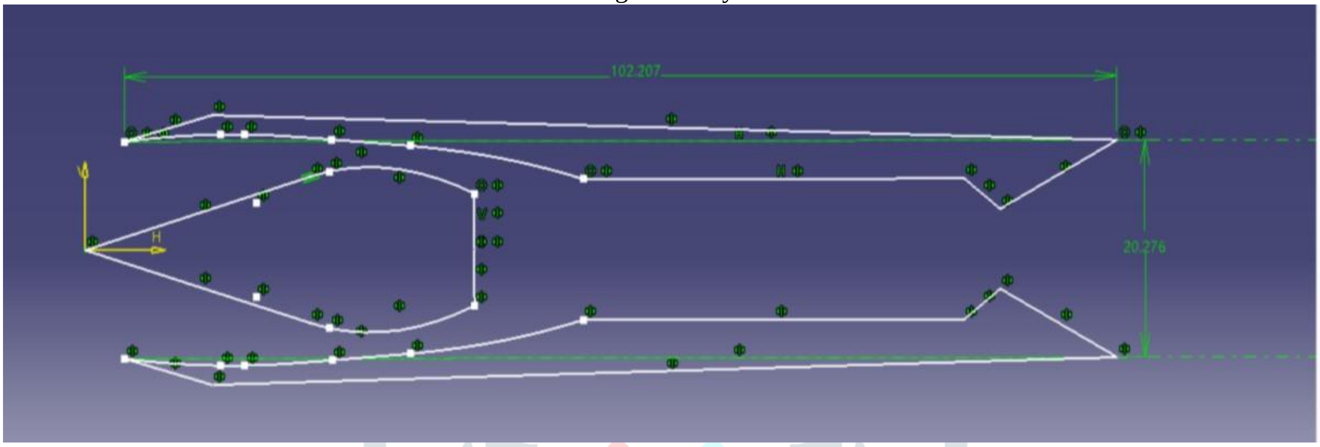


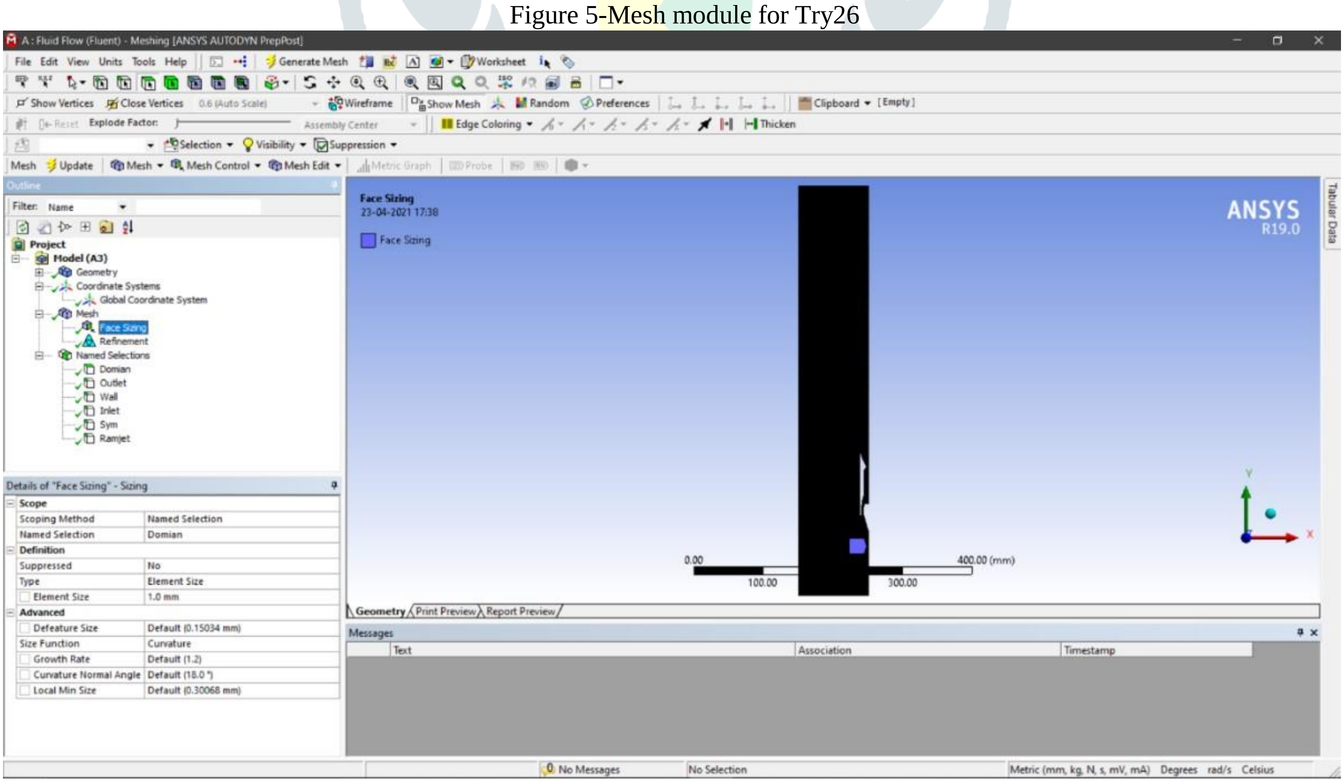
Figure 4- Try 23



6.2 ANSYS

All the analysis was done in Fluid flow (Fluent). The physics were chosen of CFD and the solver Was Fluent. The domain is having a height of 100 mm from the horizontal axis or symmetrical axis and is having a total length of 593mm. In Face sizing, Element size mesh definition was performed with an element size of 1mm. Curvature size function was chosen which gave defaulter size of 0.15034mm. Refinement was preformed over the ramjet with no suppressed definition. There were a total 61304 nodes and 60346 Elements. In Inflation of Mesh Inflation Option of Smooth Transition was chosen with a maximum of 2 layers' growth rate 1.2 with pre Inflation Algorithm.

Figure 5-Mesh module for Try26



In Setup and Solution solver type was taken pressure base, velocity function was chosen as absolute, time was taken as steady and 2D space was planer. In modules the energy equation was taken along with spalart-allmaras (1equation) in which viscous heating was taken in action. In materials the fluid was taken as air with a constant density of 1.225Kg/m3, Specific heat of 1006.43j/Kg-k, thermal conductivity of 0.0242Kg/m-s and sturland viscosity of three coefficient method was chosen with reference viscosity of 0.00001716Kg/m-s, reference temperature of 273.11K and effective temperature of 110.56K. Boundary condition in inlet were defined as velocity-inlet type. In which magnitude of velocity was taken as 1029m/s, Supersonic/Internal Gauge pressure was taken as 529420500Pascal, turbulent viscosity ratio was taken as 10 and temperature was taken as 321.65K. All reference values are taken from inlet. In solution method coupled scheme was chosen along with pseudo transient. After solution initializing in hybrid initializing, 1000 iteration were chosen along with 1 reporting interval in run calculation tab. All the results were taken on Contour section. Those result were in term of velocity, eddy viscosity, pressure and temperature. Number of Contour were 11 for easy differentiation in colours or range of values.

6.3 Result

For the analysis of all the different models and sub models of different inlet area we can say that inlet area is directly proportional to eddy viscosity and velocity. Whereas inlet area is inversely proportional to pressure. However, temperature is more related to the change in area than it is related to inlet area only. Heat is generated adversely on surface at compared to the area of flow. The heat is generated due to the compression of molecules. One more thing is noted that there is relation between temperature and pressure. As in pressure we talk about the compression and relaxation of molecules. Figure 6, Figure 7 Figure8 and Figure 9 represents various contours of model try 26-1 (Refer Table 1 for Try26:1). All graphs are made from a certain distance before the inlet, which is kept constant in all graphs. Only the points of variation are represented in the graphs. As per the analysis in ANSYS software a maximum value of pressure of 780500pa is achieved in Try27:2(Refer Table 1) of all the sub models. However, the minimum pressure is noted is Try26:1(Refer Table 1) of -1542000pa. Talking of Eddy viscosity, it is more inclined over the outlet area or the shape of nozzle. The maximum value of eddy viscosity obtained was 0.4651 which was obtained in model Try27:2(Refer Table 1). The maximum value of Velocity was 1989m/s in model Try27:1 (Refer Table 1). Taking of temperature, the maximum value was 2496K in model Try26:3(Refer Table 1) and minimum value of Temperature was 286.4k seen in model try25: -1. All of the graphs attached below speaks about the variation of eddy viscosity, velocity, temperature and pressure with respect to distance of air flow in x direction for model each model. It is to be noted that overall maximum or minimum values may not lie in that region of air flow.

Figure 6- Velocity Contour for model Try26

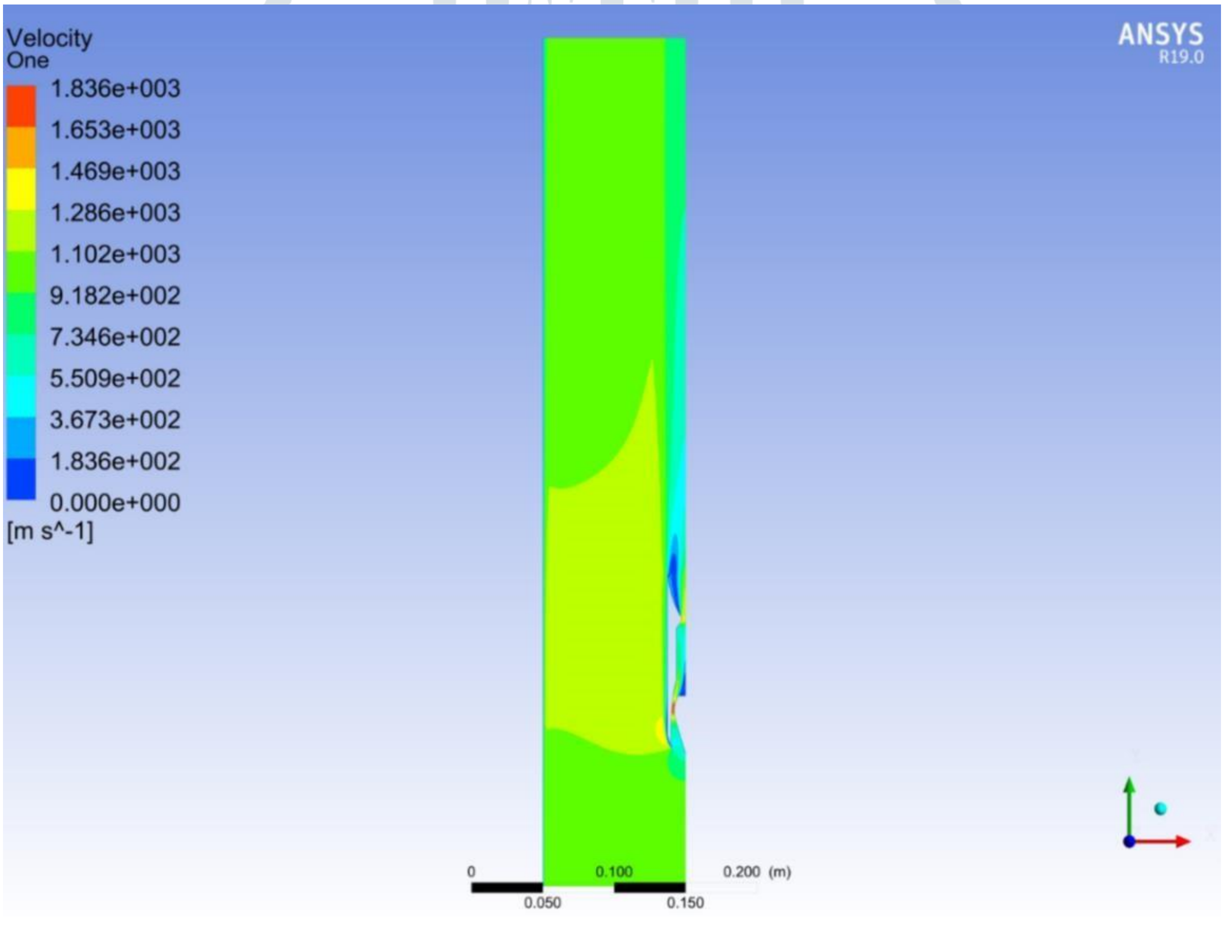


Figure 7- Temperature Contour for model Try26

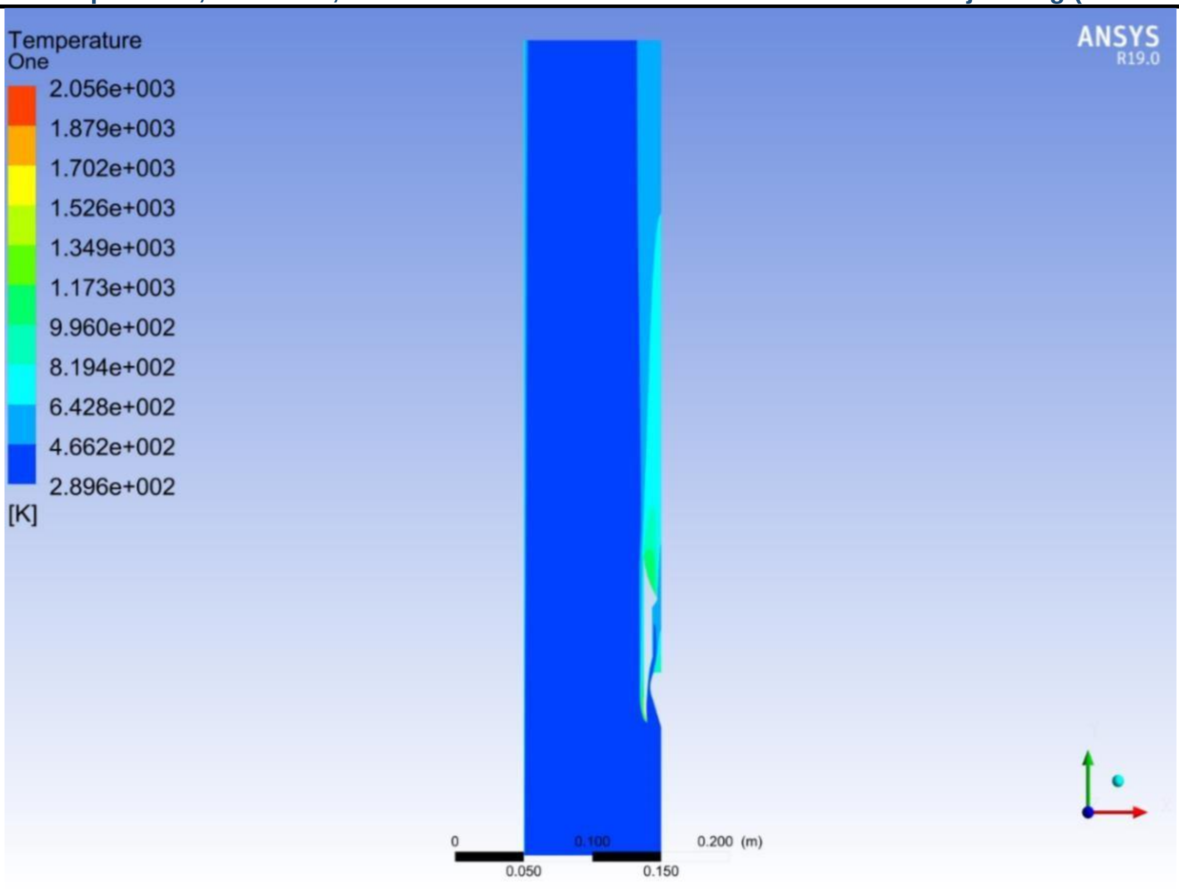


Figure 8- Pressure Contour for model Try26

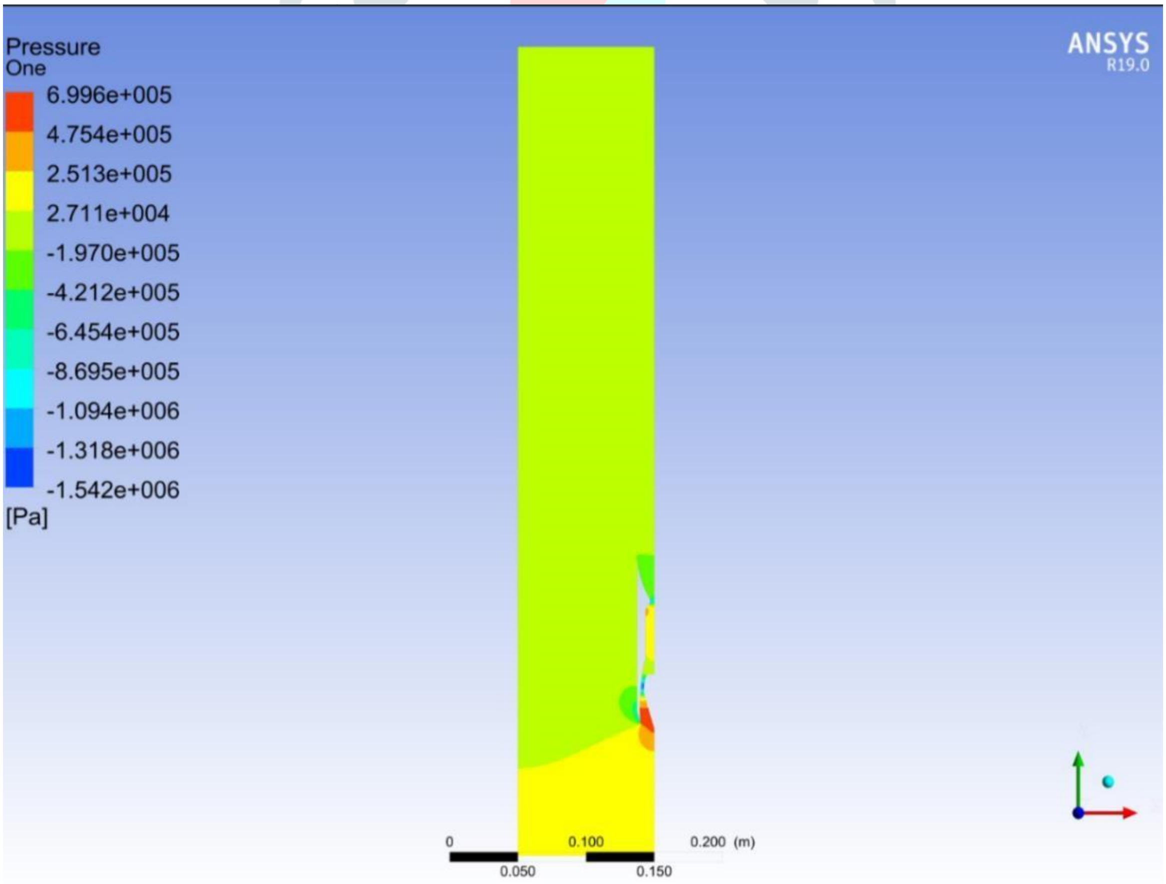
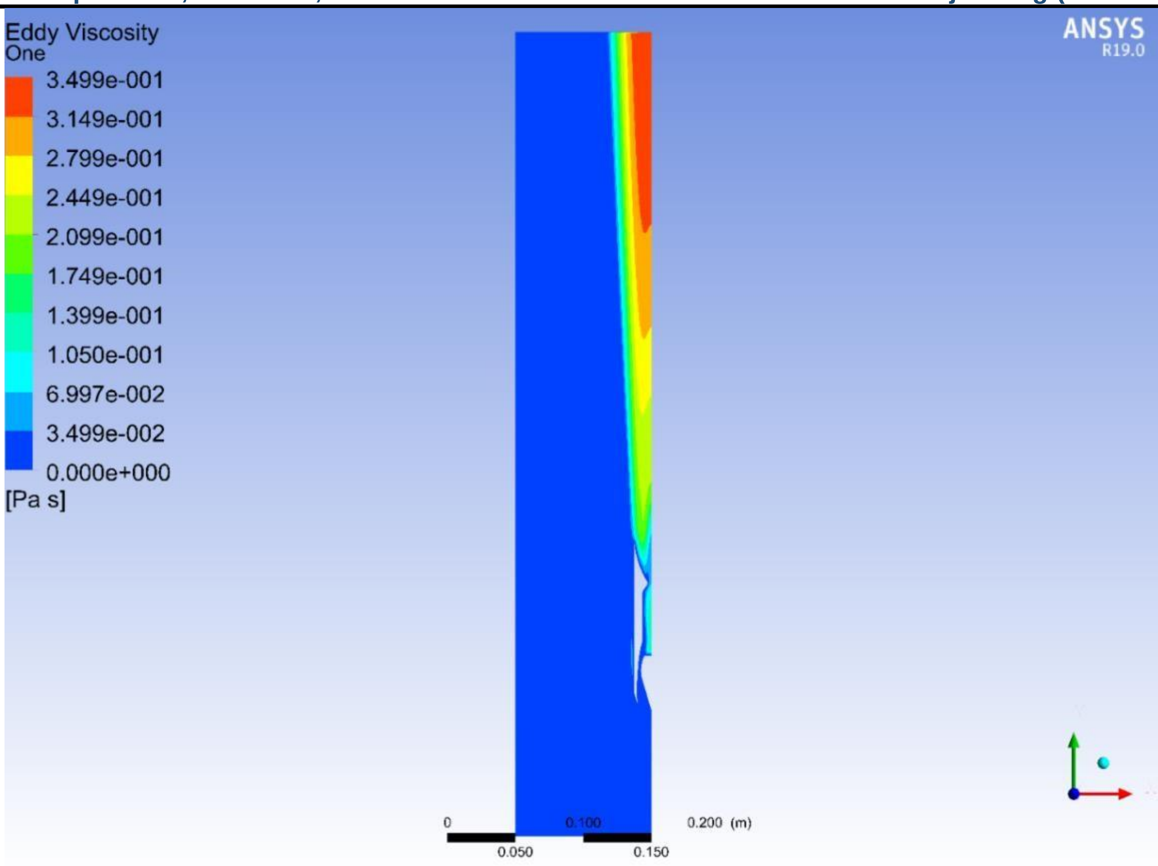
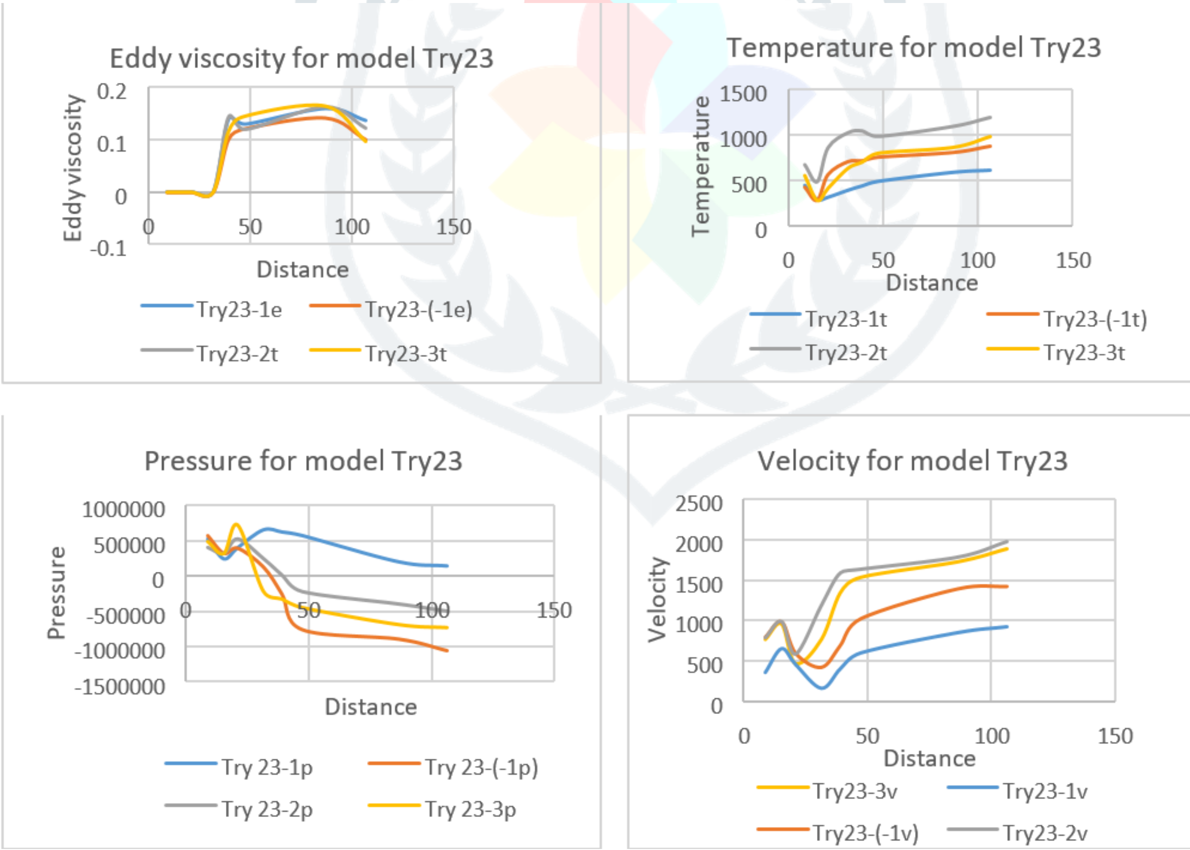


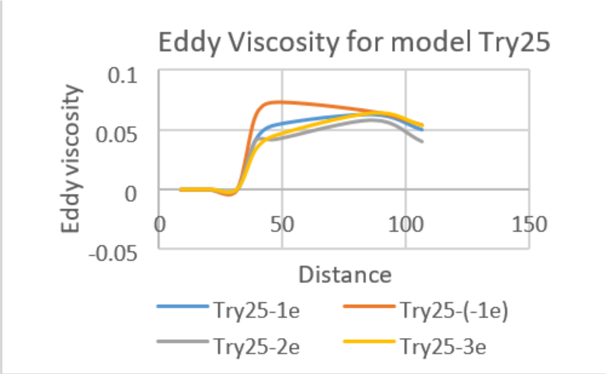
Figure 9- Eddy Viscosity contour for model Try26

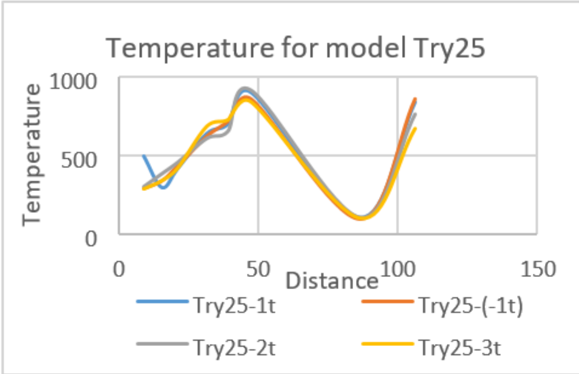


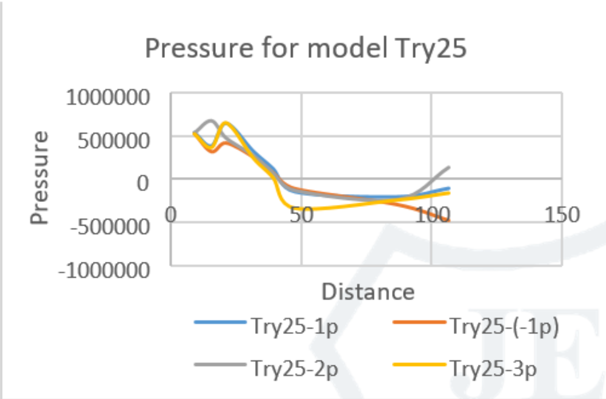
Graph set 1- the variation of eddy viscosity, velocity, temperature and pressure with respect to distance of air flow in x direction for model Try23

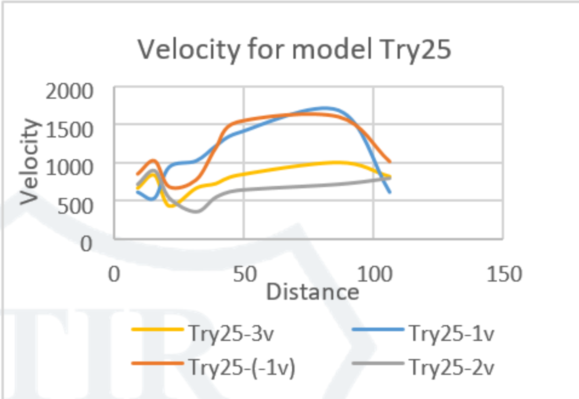


Graph set 2- the variation of eddy viscosity, velocity, temperature and pressure with respect to distance of air flow in x direction for model Try25

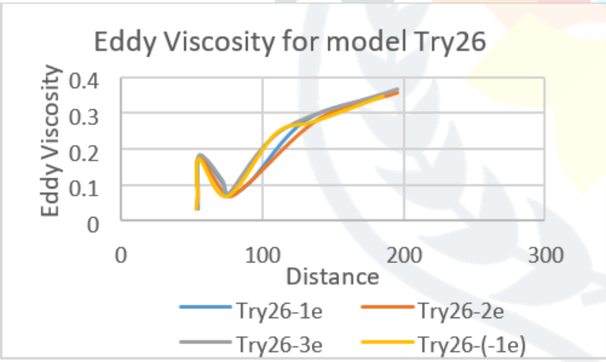


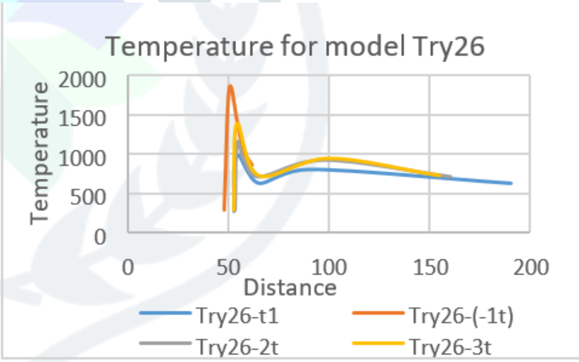


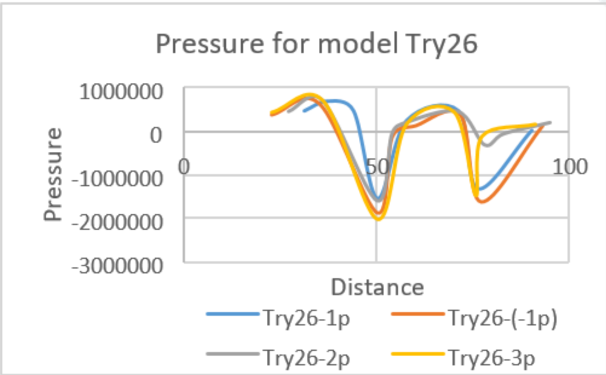


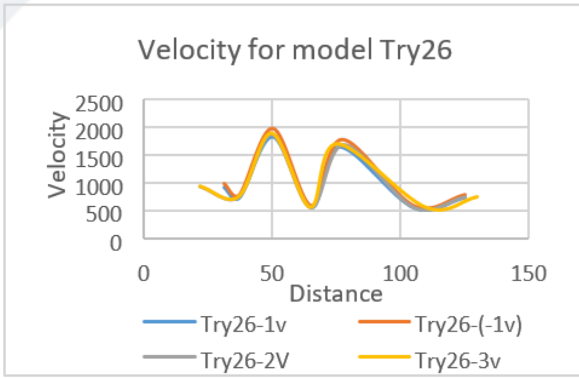


Graph set 3- the variation of eddy viscosity, velocity, temperature and pressure with respect to distance of air flow in x direction for model Try26

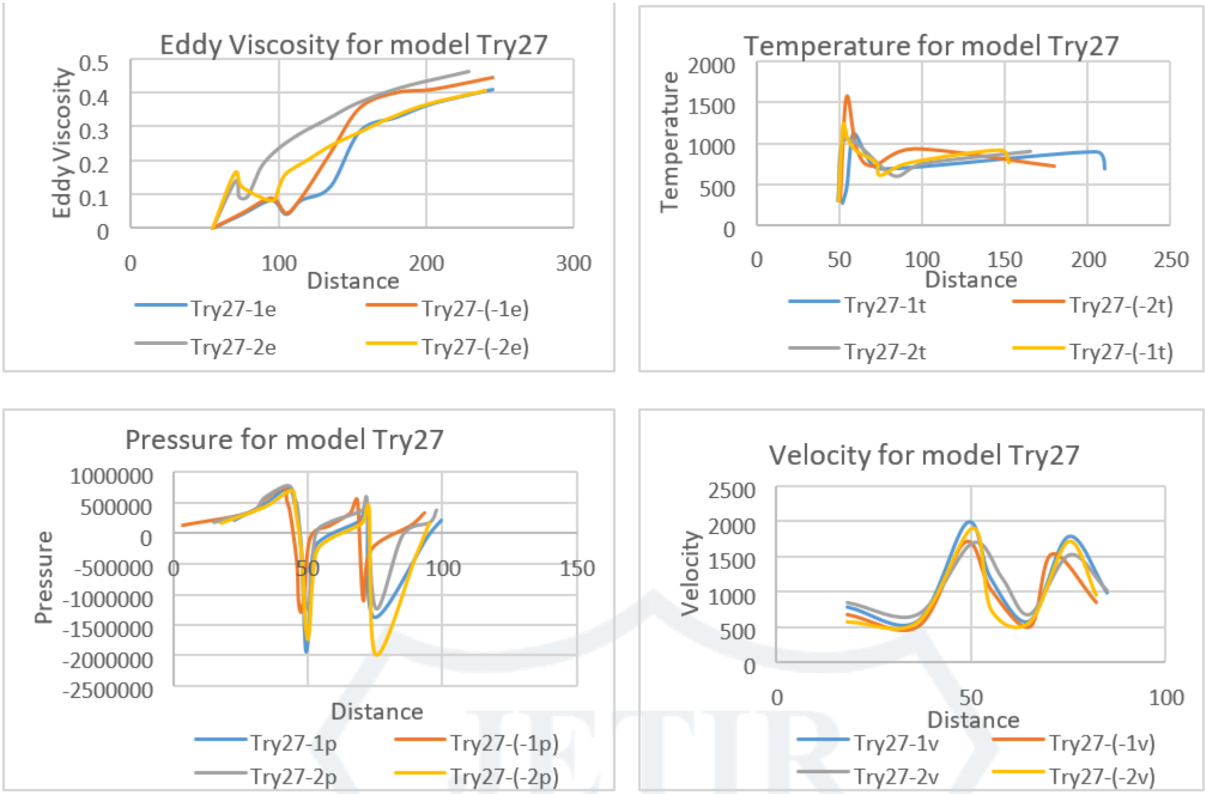








Graph set 4- the variation of eddy viscosity, velocity, temperature and pressure with respect to distance of air flow in x direction for model Try27



VII. Conclusion

Solid fuel ramjet is one of the most suitable method which can be used when the main objective is to get the maximum range for the Mach number. Also, the use of SFRJ is now widely used in the defence sector for the protection purposes. Many countries are contributing towards the research of the new technologies which can be used in order to get the maximum output from the newly presented idea.

Taking of inlet area, more the inlet area more will be the velocity. More the velocity less will be the pressure as pressure and velocity are inversely proportional. One more thing is to be taken in consideration that is the angle at which air strikes the body. If the angle will be huge so will be the pressure but this rule is followed till some angle only, that angle varies from one object to another. Increase inlet area increases the eddy current but eddy current is more of a function of shape of outlet duct. Temperature and inlet area are not linked as strong as other parameters but change in inlet area or any area is having considerable effect on temperature. If the body is converging, then there will be rise in temperature and vice-versa. Most of the temperature that comes on play is because of the friction between air and the surface in contact. For the regular 155-mm firearm dispatched projectiles, following pseudo-vacuum trajectories of solid fuel ramjets, the most extreme reach is discovered to be more than 20 km. however with ramjets the range changes to 150km

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