Effects of Secondary Injection in Rocket Nozzle at Various Conditions

M.S.Shamnas[1], S.R.Balakrishnan[2], S.Balaji[3]
PG scholar[1], Director /H.O.D[2], professor[3]
[1, 2,3]Department of Aeronautical Engineering, Nehru institute of engineering and technology

Abstract

Interest in fluidic thrust vectoring has promoted many numerical and experimental investigations to explore its validity in real world applications. The benefits of such technology are numerous making investigations into its effectiveness a valid and worthwhile exercise. From the comprehensive literature review , it was found that method of Shock Vector Control was potentially an appropriate method of fluidic vectoring suitable for adaption to investigate its suitability for use for thrust vectoring. Appropriate CFD program parameters were selected such as gambit fluent for the analysis and catia v5 for the design of the project. In my project I am doing varying injection mass flow rate , injector size and injector location would be altered to investigate its effect on the production of thrust in an axisymmetric converging diverging rocket nozzle. Flow patterns and contours of various parameters have been studied and reported. Among a number of ways by which the deflection can be accomplished, TVC through secondary injection of matter namely, secondary gas injection for thrust vector control (SITVC) into the thrust chamber nozzle has been successfully applied mainly to solid motors. In contrast, SITVC is controlled by flow regulation and requires no moving components.

Keywords- *Shock Vector Control, rocket nozzle, fluidic injection*

1. Introduction

Secondary fluid injection inside the nozzle is one method used for producing control force for space vehicles. This technique uses asymmetric wall forces caused by lateral injection of a fluid (gas or liquid) into the divergent portion of the supersonic exhaust nozzle. In addition to the usual jet reaction, local high pressures associated with an induced shock wave "amplify" the jet reaction. Experiments on secondary injection had been reported by Hausmann and they demonstrated that the shock-induced reaction associated with an air jet directed into supersonic air (both gases at ambient temperature) could be as large as the jet reaction. The nature of this shock-induced reaction and the way in which it depends upon the mainstream and injectant properties have since been the subject of considerable study, mostly experimental. Several experiments have been reported for jet-interference phenomena on simple aerodynamic surfaces . The initial studies of secondary injection used gases as the injected fluids .A preliminary work was done to study the secondary injection as an air into the main stream of fluid passing through the throat to the divergent section of the nozzle. Initially the study is focused to understand the phenomenon of secondary injection in the divergent section and flow behaviour before and aft the injection location. In the present CFD study, a shock wave is produced in cases of supersonic jet injections with flow separation. In these cases there is circulation of flow downstream of the point of injection causing redeflection of mainstream flow as well. Mach distributions along the plane of injection show that the major affect of injection is down stream of flow and a very little effect is on the upstream. This change in flow velocity downstream of the injection creates an asymmetric pressure distribution on the wall of the nozzle.

2. Thrust vector control

In a rocket, the rocket engine or motor not only provides the propulsive force but also the means of controlling its flight path by redirecting the thrust vector to provide directional control for the vehicle's flight path. This is known as thrust vector control (TVC). TVC can be divided into those systems for use with liquid engines and those for solid motors. When choosing a TVC method, we need to consider the characteristics of the engine/motor and its flight application and duration. Also, the maximum angular accelerations required or acceptable, the environment, the number of engines/motors on the rocket, available actuating power, and the weight and space limitations are all weighed against each other to produce a cost effective, yet appropriate, system of control. The effective loss of engine performance due to the use of a particular TVC method and the maximum thrust vector deflection required are major design considerations.

2.1 Secondary injection thrust vector control:

To steer a rocket over its trajectory, thrust vector control (TVC) is applied. Among a number of ways by which the deflection can be accomplished, TVC through secondary injection of matter namely, secondary gas injection for thrust vector control (SITVC) into the thrust chamber nozzle has been successfully applied mainly to solid motors. Mechanically operating TVC methods, such as gimbaled, jet vanes, and jet evator, require actuating components that work efficiently in the high temperature environment of the rocket exhaust and are invariably associated with axial thrust loss during vectoring. In contrast, SITVC is controlled by flow regulation and requires no moving components. With secondary injection, complex interaction between the primary and secondary jet streams is accompanied by a high pressure region on the primary nozzle wall near the secondary jet nozzle exit, which is the source of an interaction force that augments the thrust of the control jet. In addition, in a gimbald thrust chamber the side force is located at approximately the injector end. With an SITVC system, the applied side force is located downstream of the nozzle throat and at approximately the point of injection, resulting in an increased momentum arm, which decreases the required side force.

3.Thrust formulae used

Thrust is the sum of both pressure and momentum contributions using the following equation:

$$F = \dot{m}\,(C_j - C_a) + A_j\,(P_2 - P_3)$$

Where subscripts "j" and "a" are exhaust plane and ambient or free stream conditions relative to the rocket respectively. If the rocket were to be stationary such as if hovering, a notable potential application of this method of thrust modulation, the equation would therefore simplify to;

$$F = \dot{m}\,C_j + A_j\,(P_2 - P_3)$$

4. Geometrical configuration

The model is modelled in CATIA-v5-R20 and it is shown in figure 1. It consists of different geometries to analyse the flow properties.

4.1 Input parameters for design

The inlet boundary condition is applied to the inlet of the nozzle.

Parameters	Values
Inlet pressure	2MPa
Inlet temperature	616K
Initial Mach number	0.2
Mass flow rate,	5.62kg/s

Table.1 boundary condition values

Other conditions

Secondary injection mass flow rate is 2.4% of the main mass flow rate.

Location of the secondary injector port is 30mm from the throat area of the nozzle.

SA model turbulence model is used for the analysis.

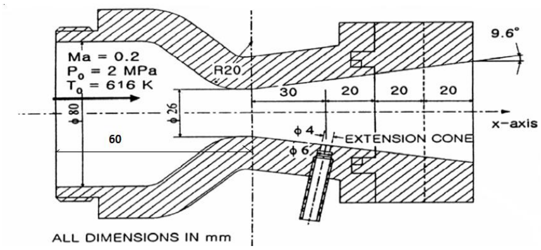

Figure 1. Nozzle geometry

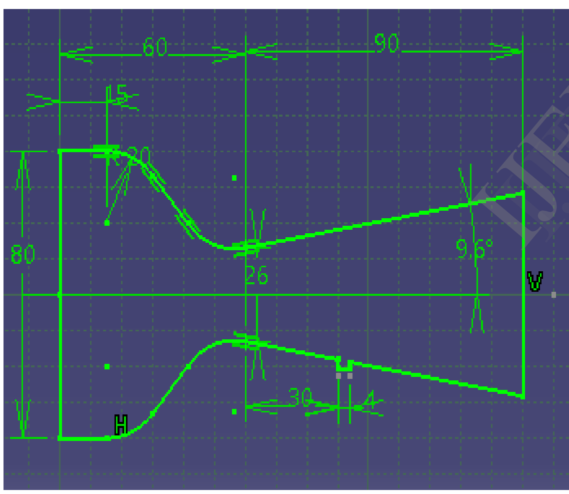

Figure 2. Catia model

4. Current work

There are other significant factors that strongly affect thrust such as the angle of the secondary injector port and as such the added mass flow. This relation can be very clearly indicated upon studying the thrust equation. The position of the used injector also has a dramatic and significant impact on the generation and alteration of thrust production particularly in the presence of a generated normal shock. If injection occurs too far upstream flow velocity recovers with expansion and hence the optimal reduction in flow velocity at the exit plane is not achieved. So the three cases are,

1.Varying the secondary injection port position(constant mass flow 2.4%,port angle 90)

2._Varying secondary injection mass flow rate(constant position 30mm, port angle 90)

3._Varying the secondary injection port angle(constant mass flow 2.4%,position 30mm)

The following will show the results of the above geometry conditions.

5. Computational Results

5.1. Results for varying the secondary injection port position

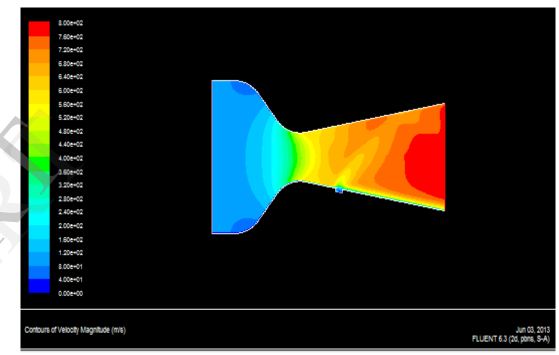

Figure 3.Port location change of 20mm

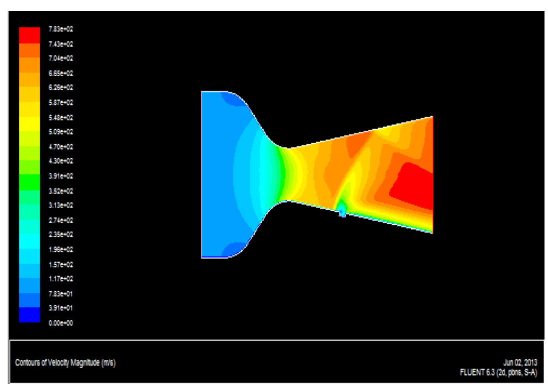

Figure 4.Port location change of 30mm

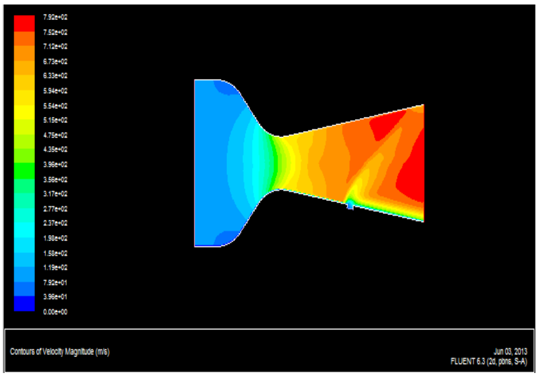

Figure 5.Port location change of 40mm

Sl Posi-tion, mm	outlet Mach number	Outlet Tempe-rature, K	Outlet Static pressure Pa	Exit Velocity m/s
20	2.29	370	1.04E+05	800.89
25	2.29	344	1.04E+05	800.38
30	2.19	383	1.04E+05	782
35	2.24	370	1.04E+05	791
40	2.28	344	1.04E+05	798

Table 2: parameter values for first case

5.2. Results for varying secondary injection mass flow rate

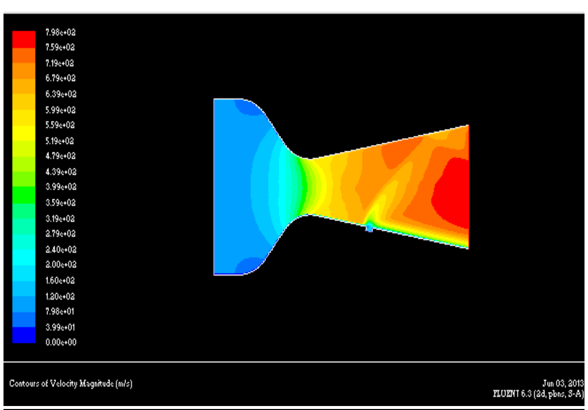

Figure 6.Velocity contour at 1.5% mass flow

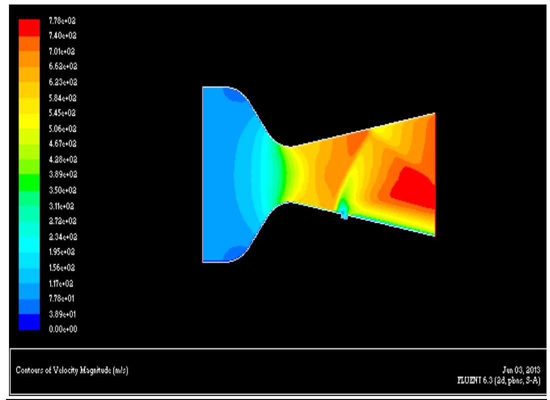

Figure 7.Velocity contour at 3% mass flow

mass flow, %	outlet mach number	Outlet pressure Pa	Outlet temper-ature,K	Velo city m/s
1.5	2.28	1.73E+05	390	798
1.9	2.26	1.70E+05	388	794
2.4	2.19	1.40E+05	383	782
2.7	2.17	1.31E+05	379	779
3	2.17	1.32E+05	378	778

Table 3: parameter values for second case

5.3. Results for varying the secondary injection port angle

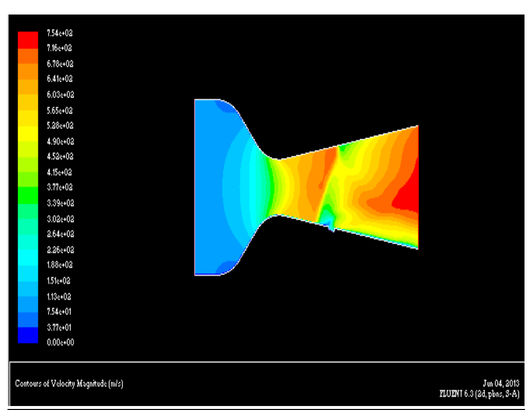

Figure 8.Velocity contour at 65 degree

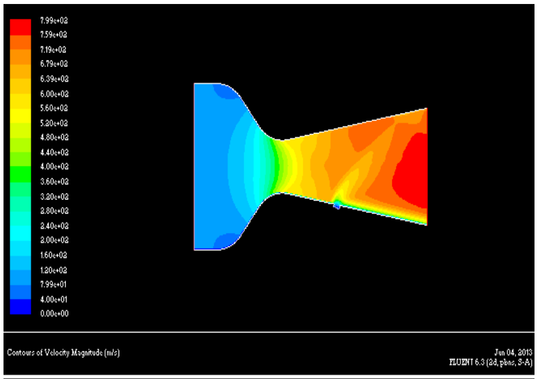

Figure 9.Velocity contour at 80 degree

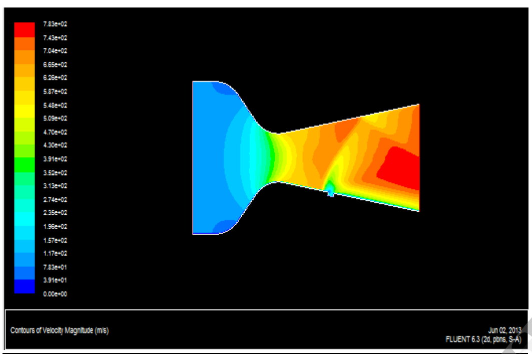

Figure 10.Velocity contour at 90 degree

Angle degree	outlet mach number	Outlet pressure , Pa	Outlet tempe-Rapture k	Velo-city m/s
65	2.2	2.5E+05	389	753
70	2.26	2.2E+05	388	754
75	2.28	2E+05	387	756
80	2.28	1.22E+05	370	799
85	2.28	1.2E+05	370	798
90	2.19	1.4E+05	383	782

Table 4: parameter values for third case

6. Conclusion

The net thrust and graph for the various conditions are given below,

6.1. Results for varying the secondary injection port position

SI position (mm)	momentum thrust(N)	pressure thrust(N)	net thrust(N)
20	4598	7.2	4505
25	4501	7.2	4508
30	4394	7.2	4401
35	4484	7.2	4491
40	4445	7.2	4452

Table 5: Net thrust for first case

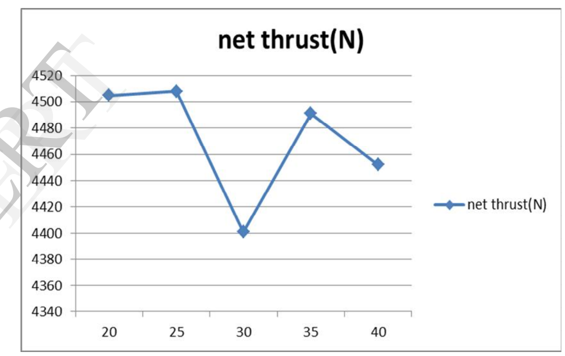

Figure 11. Net thrust graph for first case

6.2. Results for varying secondary injection mass flow rate

mass flow,%	momentum thrust(N)	pressure thrust(N)	net thrust(N)
1.5	4484	172	4656
1.9	4462	168	4630
2.4	4394	96	4490
2.7	4377	72	4449
3	4372	74	4446

Table 6: Net thrust for second case

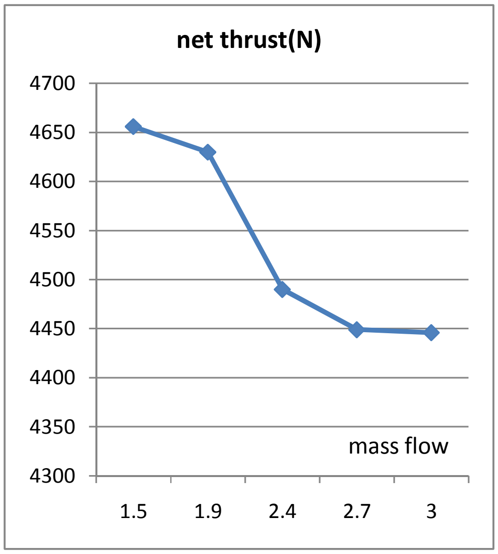

Figure 12. Net thrust graph for second case

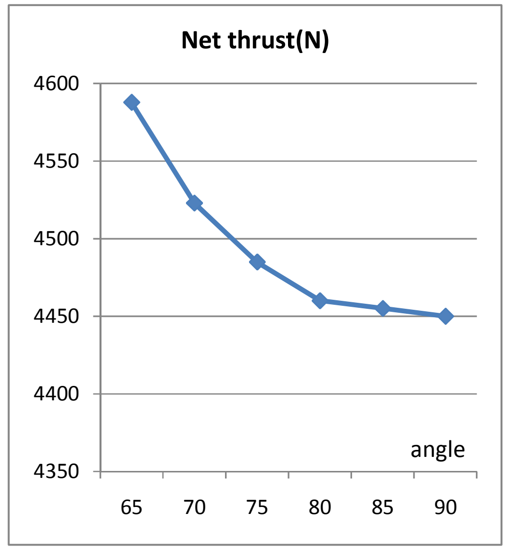

Figure 13. Net thrust graph for third case

6.3. Results for varying the secondary injection port angle

Angle Degree	momentum thrust(N)	pressure thrust(N)	net thrust(N)
65	4231	170	4588
70	4237	182	4523
75	4248	184	4485
80	4410	7.2	4460
85	4410	7.2	4455
90	4357	98	4450

Table 7: Net thrust for third case

The above tables and graph shows that how thrust varied for various conditions such as varying secondary injection port position, varying mass flow rate and varying secondary injection port angle ,so concluded that ,

1. For varying secondary injection port position the minimum thrust is obtained at 30mm position. So 30mm position is good for the thrust vectoring.
2. For varying the mass flow rate, the net thrust is decreased for increasing the mass flow rate. But 3% secondary injection is possible .
3. For varying secondary injection port angle ,the net thrust is decreased for the increasing the port angle.

7. References

[1] Horton T.R., and Meade, A.J., "Thrust Vector Control of Rockets by Gaseous Injection. Critical Appraisal of Theoretical Models," Rocket Propulsion Establishment, Rept. RPE/67/7, Westcott, England, U.K., July 1967

[2] Broad well, J.E., "Analysis of Fluid Mechanics of Secondary Injection for Thrust Vector Control," AIAA *Journal*, Vol.1, No, 10, 1963.pp.580-585.

[3] Dahm, T.J., "The Development of an Analogy to Blast Wave Theory for for Prediction of Interaction Force Associated with Gaseous Secondary Injection," VIDYA TN-9163 May 1964.

[4] Walker, R.E and shandor M., "Influence of Injectant Properties for Fluid Injection Thrust Vector Control ," *journal of spacecraft and rockets*, vol,1.no 4,1964,pp,409-413.

[5] Wu, J.M., Chapkis.R.L, and Mager, A., "Approximate Analysis of Thrust vector control by Fluid injection," ARS *Journal* Vol, 31, No.6, Dec, 1961, pp. 1677-1685.

[6] Dhinagaran.R., AND Bose, T, K, "comparison of Euler and Navier-Stokes Solution for nozzle flows with secondary injection," AIAA paper 96 -0453, Jan 1996.