Technical Paper

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Computational steady-thrust vector control-supersonic secondary flow injection

Abstract

This paper presents the Computational study of flow through the Rocket Nozzle in order to manoeuvre the Rocket by means of Supersonic Secondary Injection of Hot gases. Well-designed nozzles can accelerate these gases to speeds of thousands of meters per second. In addition to accelerating the gases, nozzles are often responsible for steering (or "vectoring") the flow in order to control the rocket's direction of flight. Due to continuous secondary injection of hot gases, the strong unsteady effects like Shear Layers, Intervention of Shockwaves with the Core fluid flow, Biased Wall Shear, etc., has to be studied precisely to appraise/evaluate the effectiveness of Nozzle contribution in role of steering the Rocket. Numerical Technique/Computational Analysis has been carried out to provide tons of insight about the meticulous behavior of Fluid particles while they interact with secondary flow. Comparative study on Supersonic Fluid Flow and the intervention of Secondary Injection of Hot gases has been carried at different angle of injection and at different injecting Pressure in order to find its optimum injection angle and optimum Injecting Pressure. It has been observed that Steering of Rocket drives well by Secondary Injection when its injecting angle becomes tangential to fluid flow direction and Injecting Pressure favors to steer the rocket when it increases its magnitude.

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Introduction

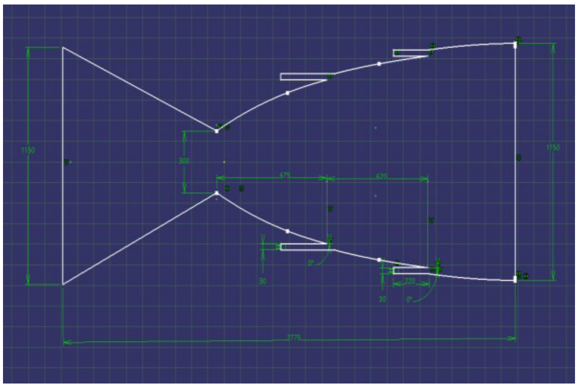
The supersonic nozzle is responsible for converting the thermal energy of the hot combustion gases into kinetic energy that can be used to propel the rocket. Understanding of supersonic nozzle starting is important for the design and optimization of new nozzles and analysis of their performance under different operational conditions. The nozzle starting process is complex and highly non- stationary. Behind the primary transmitting shock wave, the transient flow field is formed, which contains, in particular, a back-facing, so-called secondary shock–one of the main features of the process. The secondary shock interacts with the wall boundary layers, resulting in the shock bifurcation and formation of separation bubbles. Choking of flow is an important consideration in internal compressible flows. It is the critical point at which the flow within the duct becomes independent of downstream changes in conditions of the flow, and any further change would require either an adjustment of the upstream conditions or the formation of shocks within the duct. This point is usually attained when the flow becomes exactly sonic. The inability of pressure waves to travel in all directions after the flow achieves sonic velocity brings about the choking condition. Choking can be brought about by area change, friction, heat addition; also by any combination of them. A converging duct accelerates a subsonic flow only to the extent of the critical area or throat where the Mach number becomes unity; further decrease in area is impossible without altering the upstream or mass flow. A converging duct decelerates a supersonic flow until the choking point; any further reduction in area would be accompanied by the formation of a shock within the duct. In case of frictional choking, because of the growing boundary layers, which simulate a variable area duct for the inviscid core, the length of the duct is the limiting variable and for cases of heat addition; amount of heat that can be added is limited by choking.[1-9]

Problem description

The primary objective is to determine the Optimum angle of Injection of Hot gases and it's Injecting Pressure. Comparative study has been carried out on Secondary injection of hot gases into the core of Nozzle to appraise the effectiveness against each other.

CAD development

The CAD Model is developed in CATIA V5 and the angle of Injection is varied from 40 degree to 0 degree while the Area ratio is kept identical as 8. The Schematic diagram of Convergent–Divergent Nozzle is furnished below The geometry of Nozzle is remain unaltered for every Computational Flow Analysis and so the angle of injection is varying entity as like 40 degree, 30 degree, 20 degree, 10 degree and 0 degree.



Method of solution

The basic governing equations that govern the fluid flow are described below along with the transport equation for appropriate turbulence model. These equations predict the aerodynamic behavior of the system. The equations are,

Conservation of mass:

$$\frac{\partial \rho}{\partial t} + div(\rho u) = 0$$

Conservation of X momentum:

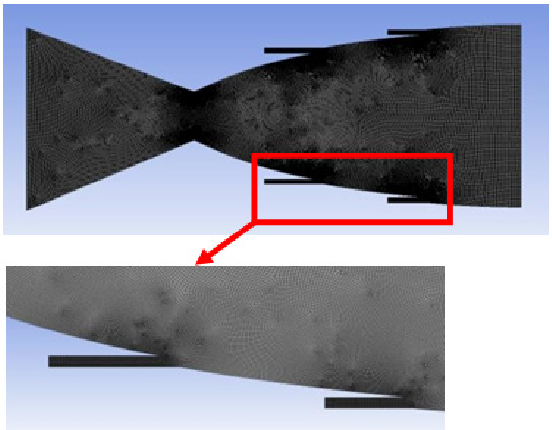
$$\frac{\partial(\rho u)}{\partial t}+div(\rho uu)=-\frac{\partial(p)}{\partial x}+div(\mu\, gradu)+SM_x$$

Conservation of Y momentum:

$$\frac{\partial(\rho v)}{\partial t}+div(\rho vu)=-\frac{\partial(p)}{\partial y}+div(\mu\, gradv)+SM_y$$

Conservation of Z momentum:

$$\frac{\partial(\rho w)}{\partial t}+div(\rho wu)=-\frac{\partial(p)}{\partial z}+div(\mu\, gradw)+SM_z$$



Meshing

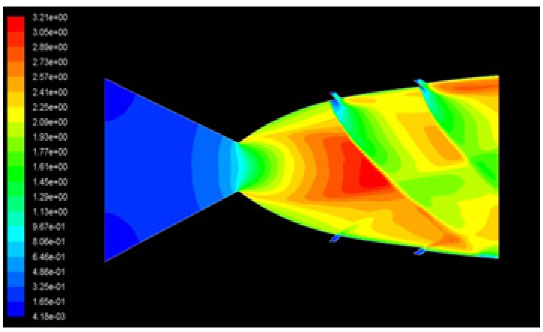
The surface of the geometry is discretised by Quad Elements and the Skewness of Quad Elements is maintained at 0.4. The Schematic diagram of Discretised Convergent–Divergent Nozzle is furnished below

Boundary condition

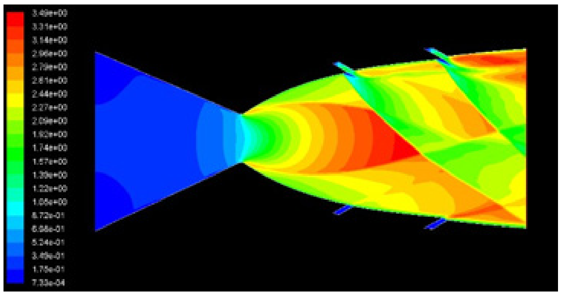
Pressure inlet	: 800MPa
Temperature inlet-primary	: 500k
Temperature inlet-secondary	: 1000k
Operating pressure	: 38KPa
Pressure ratio	: 1.05
Hot gas used	: hydrogen fluoride

Contour of mach number–single sided injection

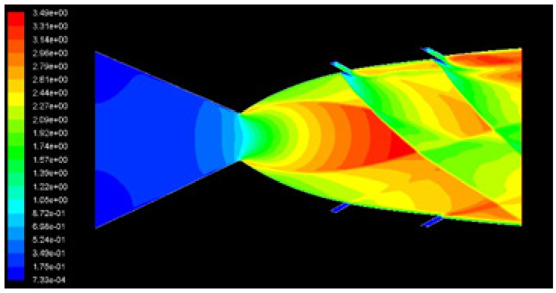
Angle 40 degree



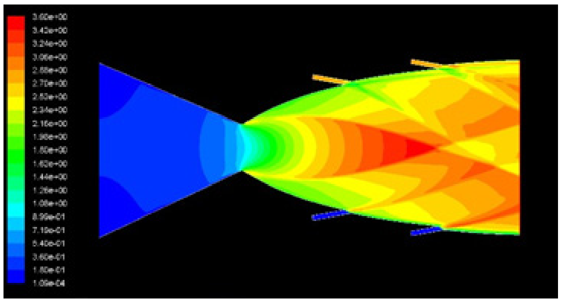
Angle 30 degree



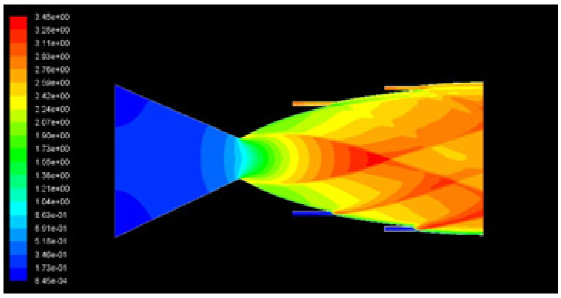
Angle 20 degree



Angle 10 degree



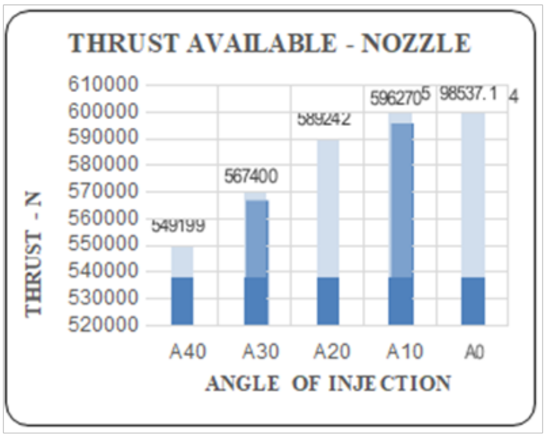
Angle 0 degree

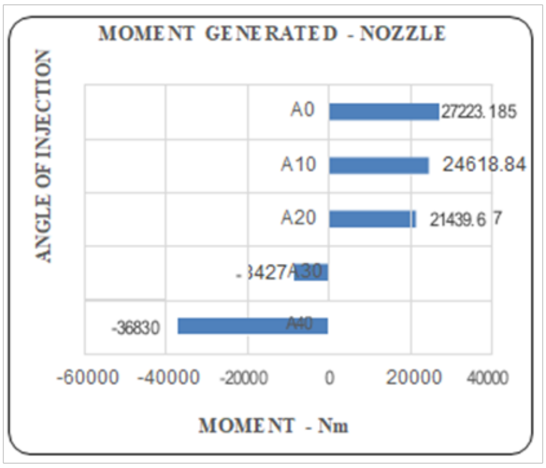


From the above graph of Moment Generation, it is evident that Intervention of Secondary Flow into Primary flow becomes unfavorable in role of steering the Rocket in desired direction, when the angle of Injection increases. For example, when the secondary flow is injected at an angle of 40 degree, it behaves as a barricade to Primary flow field, which results in formation of Bow shock kind and it generates the Clockwise Moment about Centre of its Mass, where desired direction is Counter Clockwise direction. When the angle of injection reduces, the Bow shock tends to lose strength thereby intervention of secondary flow favors to generating the required Moment in desired direction.

Angle of injection	Moment generated	Thrust available
A40	-36830	549199
A30	-8427	5674400
A20	21439.67	589242
A10	24618.84	596270
A0	27223.19	598537.1

Computational Flow Analysis on Nozzle has been carried out on one side injector mode (say, Top Mounted Slot) to evaluate the Thrust generated and the Moment generated by the Nozzle about its Centre of Mass due to Secondary injection of Hot Gases. The above furnished Contours of Mach Number dictates some of the physicals facts, which are enlightened in both graphical and data interpolation manner. From the graph of Thrust Available, it implies that the Thrust Available increases drastically as the angle of injection reduces, due to fact that the Shock wave tends to lose its potential hereby reducing the interference drag due to intervention of Secondary flow.



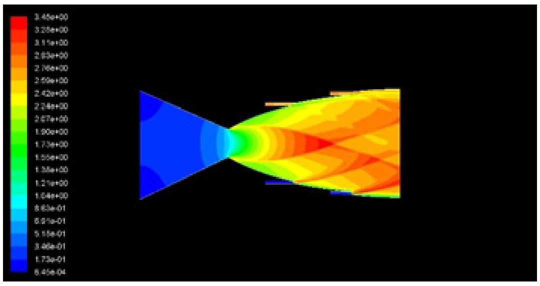


Sensitivity of zero degree angled slot–injecting pressure–singled sided injection

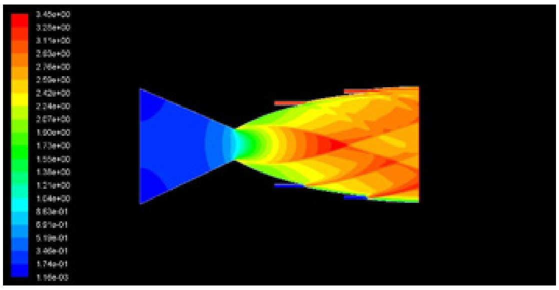
The comparative study on Injecting Pressure of Hot gases has been carried out to observe the sensitivity of Thrust of the Rocket with respect to Injecting Pressure. The below furnished graphs and tabulation signify the variation of Thrust generated and Moment created, when the Injecting Pressure is increased from 1MPa to 4MPa.

It has been observed that Injecting Pressure of Hot gases is directly proportional to Moment generation of Nozzle, while the Thrust reduces its magnitude when the injecting Pressure increases due to contribution of Moment generation, which favors the Maneuvering ability of Rocket i.e., better response in controlling/steering of Rocket.

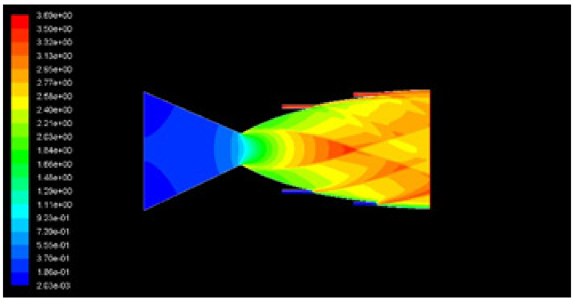
Pressure 1MPa



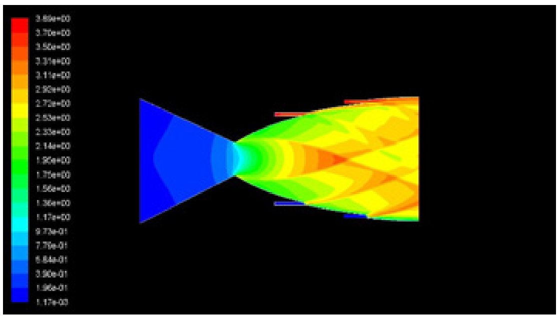
Pressure 2MPa



Pressure3MPa



Pressure 4MPa



Injection pressure	Moment generated	Thrust available
1MPa	27223	598537
2MPa	27915.18	596847
3MPa	28974	597029
4MPa	29224.9	597209

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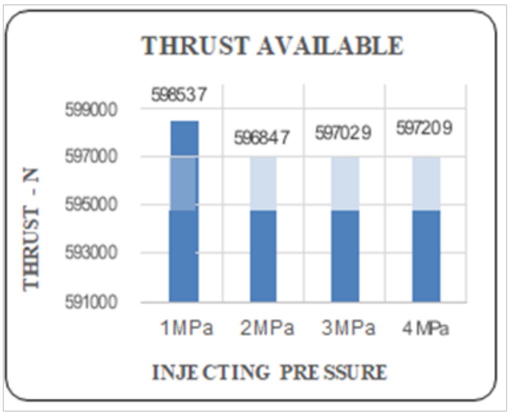

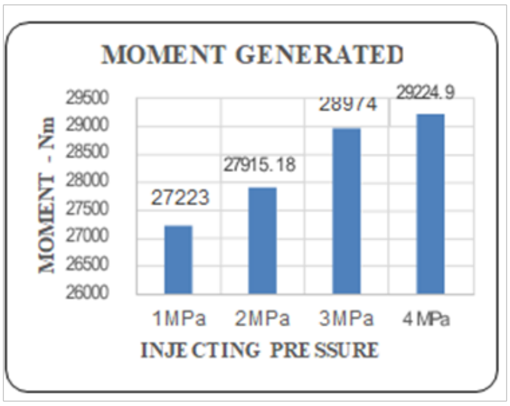

Conclusion

Computational Analysis is carried out to appraise the effectiveness of Secondary injection of hot gases into the Primary flow at different angle of injection. Tangential slotted injection of hot gas is found to have better steering ability and better response in controllability of Rocket than the partial tangential slotted injection. Injecting Pressure plays a significant role in Maneuvering of Rocket, in the way of increasing the Injection Pressure appreciates the responding ability of rocket to steer its direction vector by means of reducing the magnitude of Thrust partially in order to appreciate the magnitude of Moment generated effectively.

Acknowledgments

None.

Conflicts of interest

Author declares that there is no conflict of interest.

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