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DESIGN AND ANALYSIS OF ROCKET ENGINE NOZZLE BY USING CFD AND OPTIMIZATION OF NOZZLE PARAMETERS

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ABSTRACT

A rocket engine nozzle has been conducted to understand the supersonic flow through its various parameters like as convergent angle divergent angle and throat radius along with using CFD analysis. A two dimensional model is used for the analysis of finite-volume method in Ansys Fluent software. In the various configurations of nozzle parameters for the static pressure, mach number are being analysis and satisfy the thrust requirements for the rocket by optimum parameters values. In the optimal values obtained from using optimization technique of taguchi design and analysis method in DOE. In this method governing for 3 levels and 3 factors involving in the analysis of configurations of design by optimal parameter.

Keywords – divergent angle, convergent angle, throat radius, mach number, supersonic.

INTRODUCTION

In the current work objectives of determine an optimal convergent angle, divergent angle and throat radius of the nozzle which would give the maximum outlet velocity and meet the thrust requirements. Computational fluid dynamics (CFD) is engineering tool that access experimentation. An engineering problems to solve by using various method like analytical method, experimental methods using prototypes. The analytical method is very complicated and difficult. The experimental methods are very costly. Prototype testing has to be error detected from design to made another prototype. So, time and cost consuming are high. Thus the difficulties rectified by using CFD. In the CFD a problem is simulated in software and transport equation associated with the problem is mathematically solved along with computer assistance. The CFD proves for efficient tool and also analysis of various flow parameters.

METHODOLOGY:

Geometrical Parameters of Nozzle 2D Model

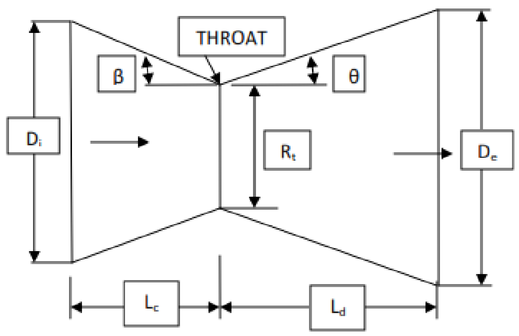


Table I: DESIGN PARAMETERS

Inlet Diameter(m)	1
Throat Diameter(m)	0.3
Exit Diameter(m)	0.8
Total Pressure(bar)	44.1 & 50
Total temperature (K)	3400

Table II: PROCESS PARAMETERS

Level	Convergent Angle (β) in Degree	Divergent Angle (θ) in Degree	Throat Radius (R_t) mm
I	30	7.5	0
II	45	15	125
III	60	30	228

TAGUCHI DESIGN:

Computational fluid dynamics analysis involving in the three factors (θ, β, R_t) configuration design for 3 levels of values along by attain taguchi design. In the design involving in nine configuration of nozzle analysis consist of altered parameters. Also the nine configurations of nozzle analysis conduct from 44.1e5Pa and 50e6Pa of inlet pressure.

Table III: TAGUCHI 3×3 DESIGN

S. No	Convergent Angle (β) in degree	Divergent Angle (θ) in degree	Throat Radius (Rt)mm
1	30	7.5	0
2	30	15.0	125
3	30	30.0	228
4	45	7.5	125
5	45	15.0	228
6	45	30.0	0
7	60	7.5	228
8	60	15.0	0
9	60	30.0	125

Table IV: ANALYSIS PROCEDURE

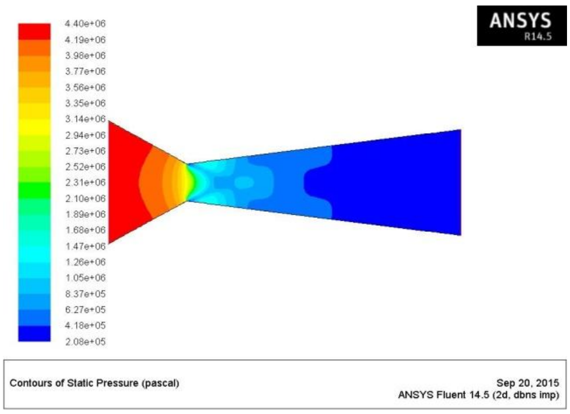
PROCEDURE	DETAILS
Solution Setup-General	Type: Density Based, Velocity formation: Absolute, Time: Steady, 2D Space: Planar.
Models	Energy: on, Viscous: Inviscid.
Materials	Fluid: Air, Density: Ideal gas
Cell Zone Condition	Operating Condition= 0Pa
Boundary Condition	Inlet-Pressure inlet = 44.1e5Pa (I), 50e6 Pa (II), Temperature=3400K.
Solution	Solution Controls – Courant Number=5. Solution Initialization – Standard – Compute – Inlet. Run Calculation: Enter the Number of iteration (1000), Click calculation.
	(Till Solution is converged).
Results	Graphics and animations – Contours-mach number static pressure contour. Plots - XY plot – mach number Vs position, Static pressure Vs Position

In this procedure is conduct for various configurations of nozzle.

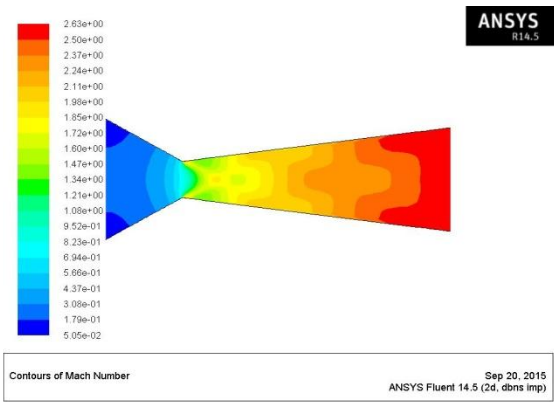
RESULTS:

1. Inlet Pressure At 44.1e5 Pa Based:

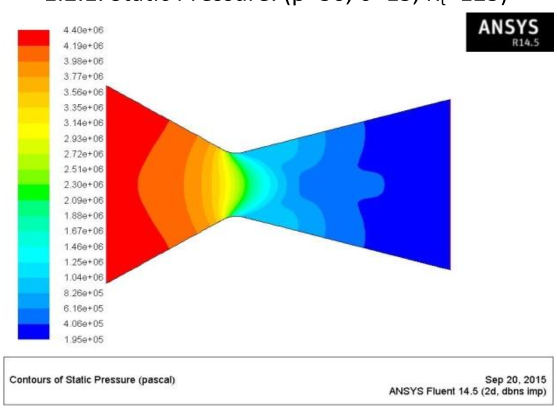
1.1.1. Static Pressure:(β=30, θ=7.5, R_t=0)



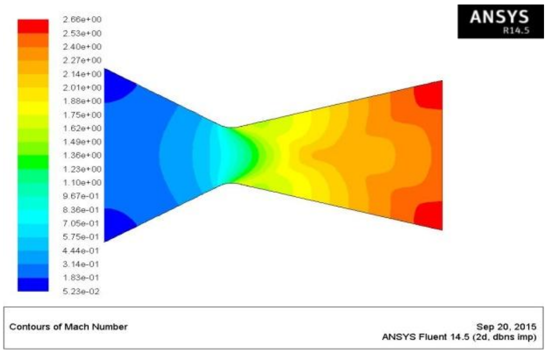
1.1.2. Mach Number:(β=30, θ=7.5, R_t=0)



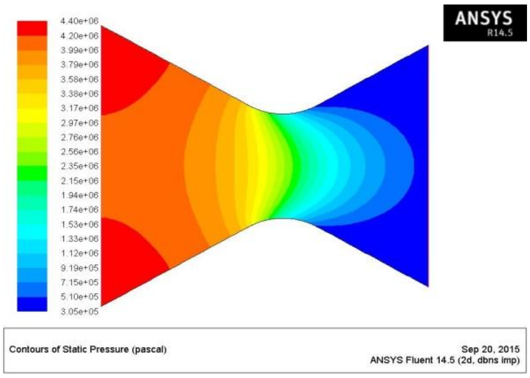
1.2.1. Static Pressure: (β=30, θ=15, R_t=125)



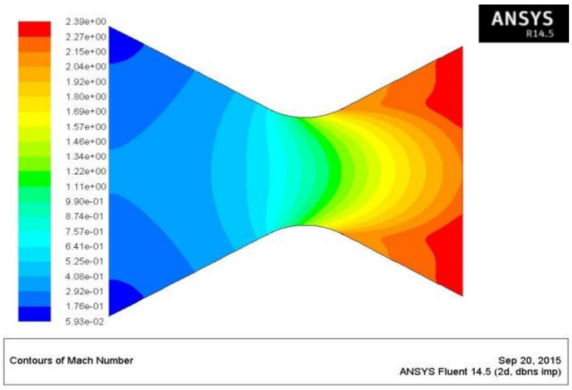
1.2.2. Mach Number: (β=30, θ=15, R_t=125)



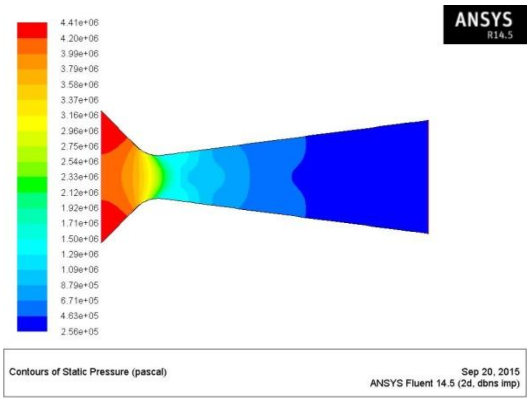
1.3.1. Static Pressure: (β=30, θ=30, R_t=228)



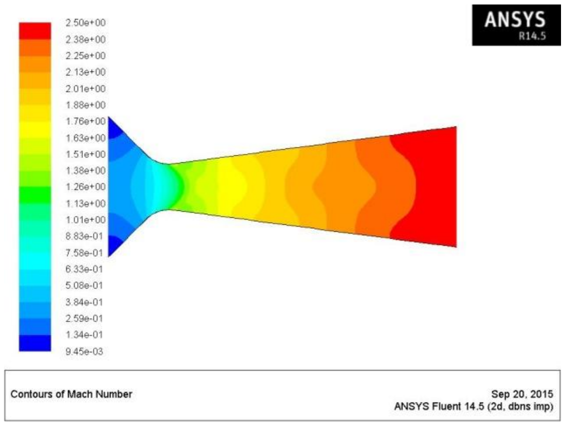
1.3.2. Mach Number: (β=30, θ=30, R_t=228)



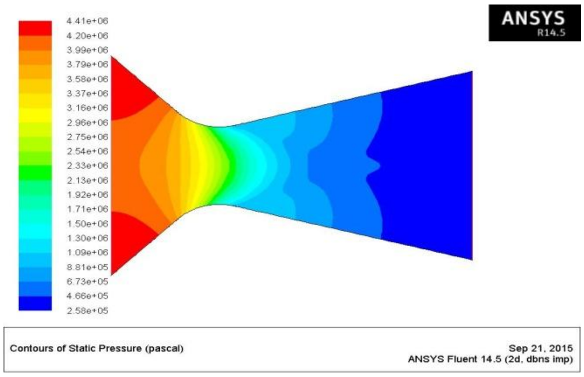
1.4.1. Static Pressure: (β=45, θ=7.5, R_t=125)



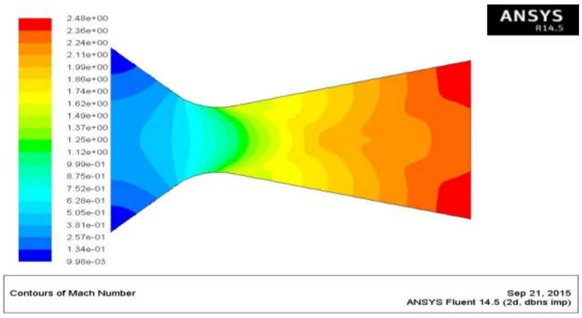
1.4.2. Mach Number: (β=45, θ=7.5, R_t=125)



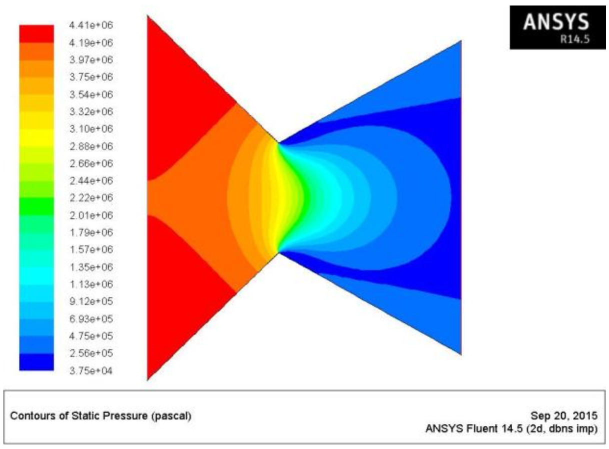
1.5.1. Static Pressure: (β=45, θ=15, R_t=228)



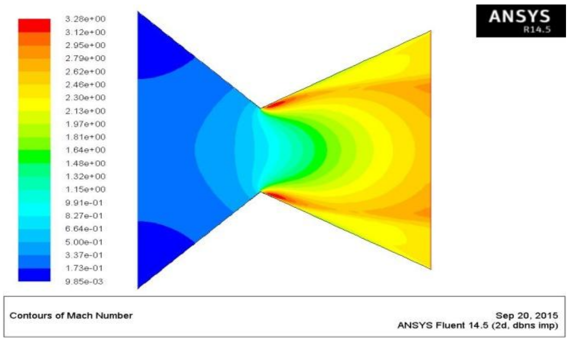
1.5.2. Mach Number: (β=45, θ=15, R_t=228)



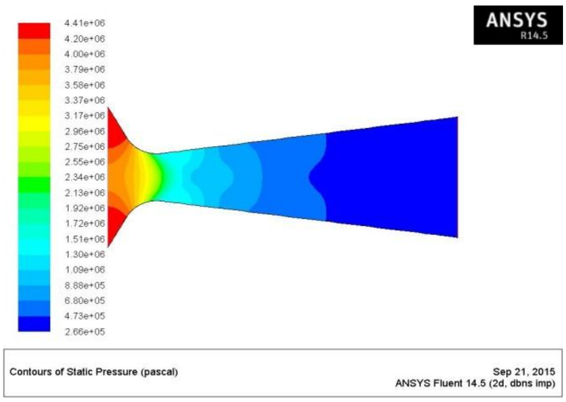
1.6.1. Static Pressure: (β=45, θ=30, R_t=0)



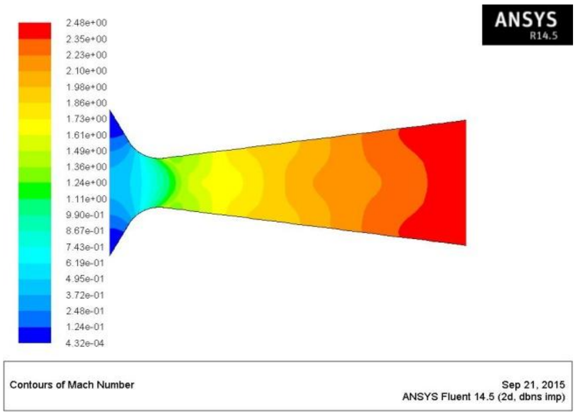
1.6.2. Mach Number: (β=45, θ=30, R_t=0)



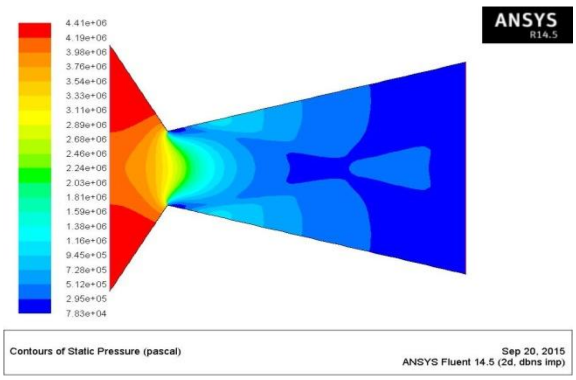
1.7.1. Static Pressure: (β=60, θ=7.5, R_t=228)



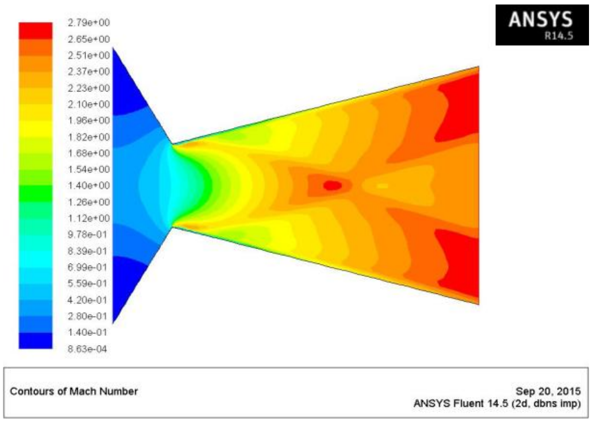
1.7.2. Mach Number: (β=60, θ=7.5, R_t=228)



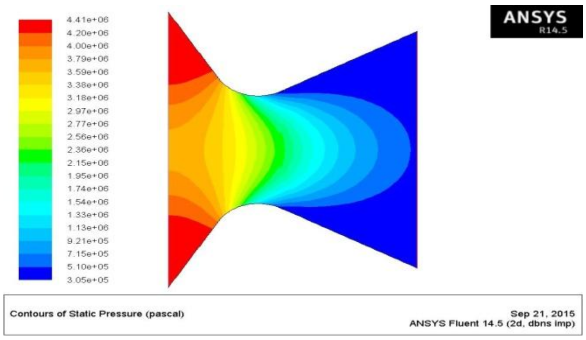
1.8.1. Static Pressure: (β=60, θ=15, R_t=0)



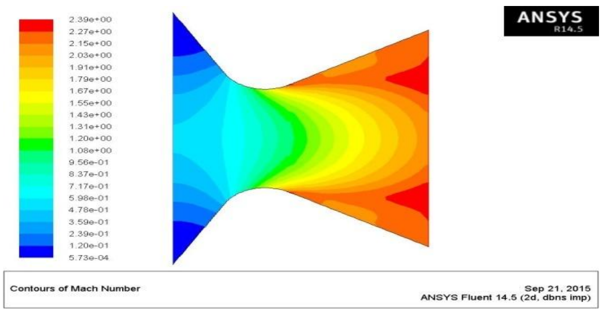
1.8.2. Mach Number: (β=60, θ=15, R_t=0)



1.9.1. Static Pressure: (β=60, θ=30, R_t=125)

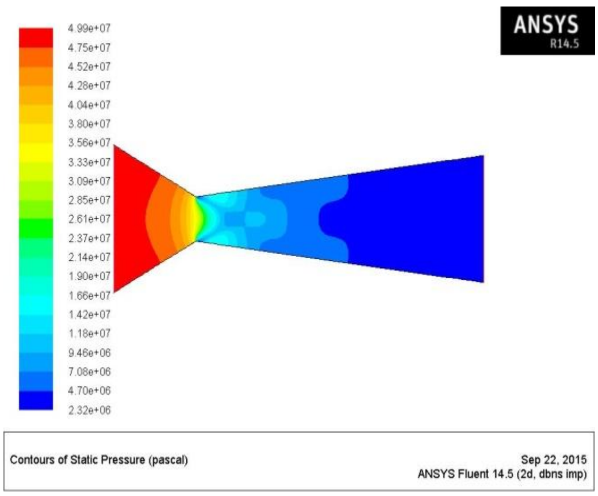


1.9.2. Mach Number: (β=60, θ=30, R_t=125)

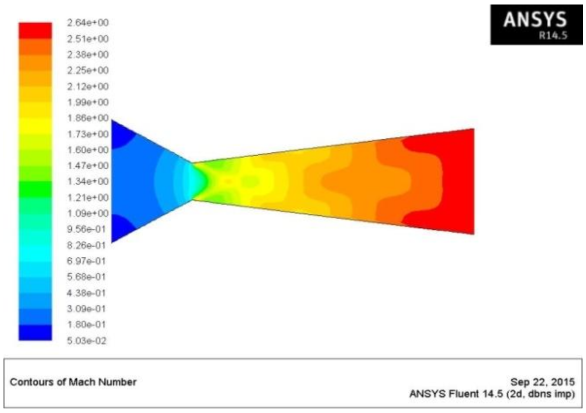


2. Inlet Pressure At 50e6 Pa Based:

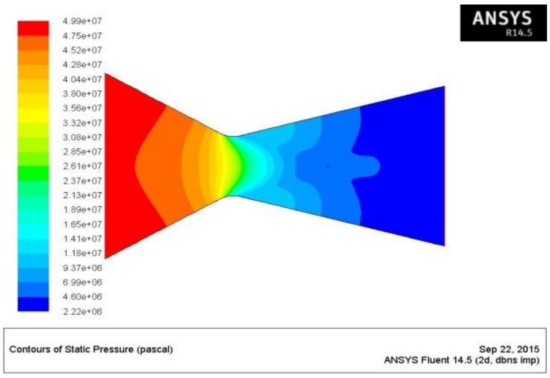
2.1.1. Static Pressure: (β=30, θ=7.5, R_t=0)



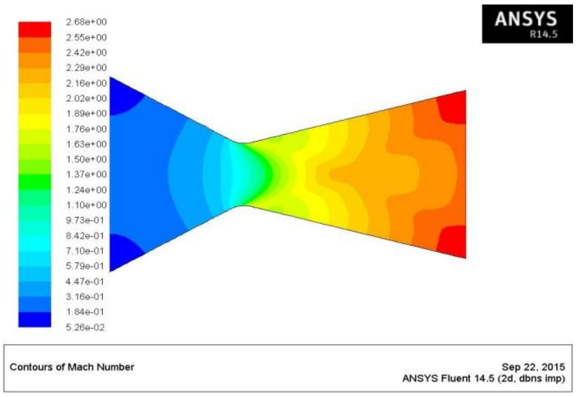
2.1.2. Mach Number: (β=30, θ=7.5, R_t=0)



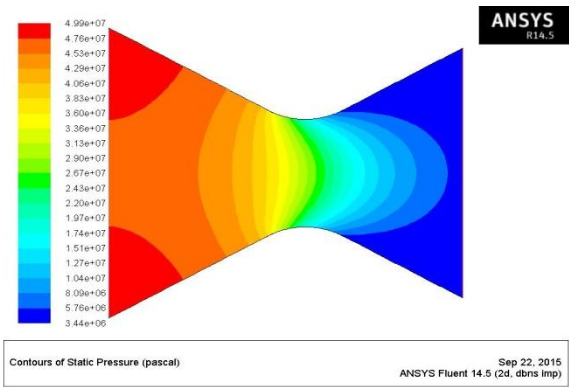
2.2.1. Static Pressure: (β=30, θ=15, R_t=125)



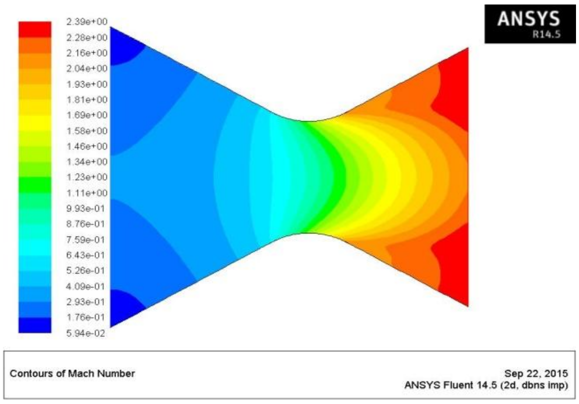
2.2.2. Mach Number: (β=30, θ=15, R_t=125)



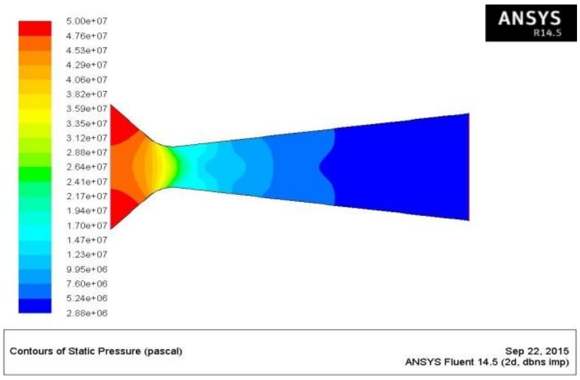
2.3.1. Static Pressure: (β=30, θ=30, R_t=228)



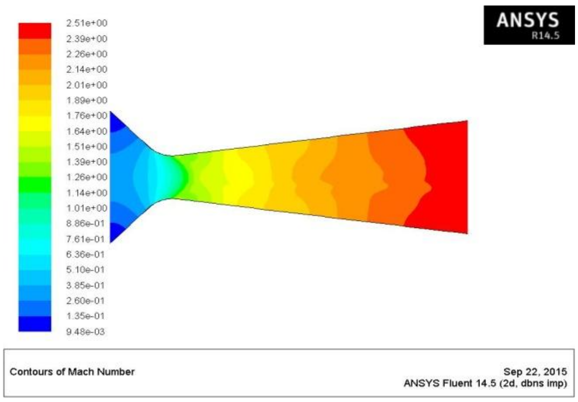
2.3.2. Mach Number: (β=30, θ=30, R_t=228)



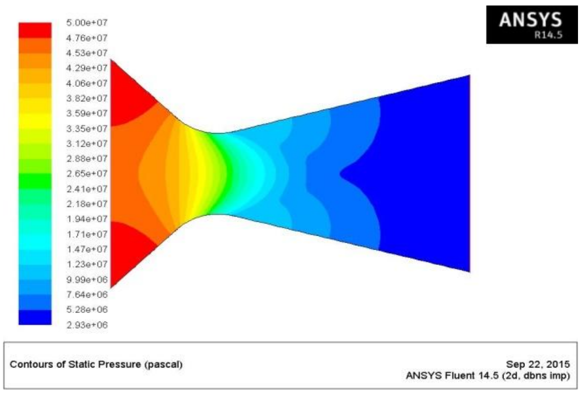
2.4.1. Static Pressure: (β=45, θ=7.5, R_t=125)



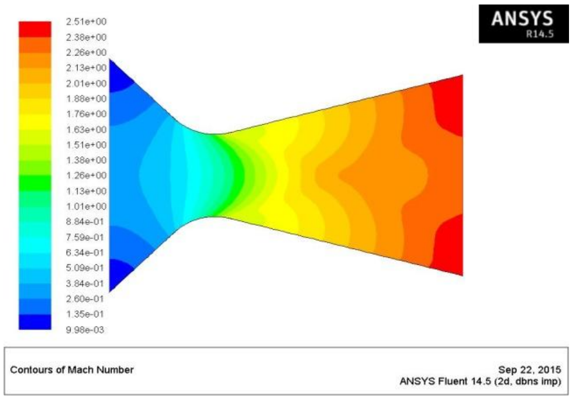
2.4.2. Mach Number: (β=45, θ=7.5, R_t=125)



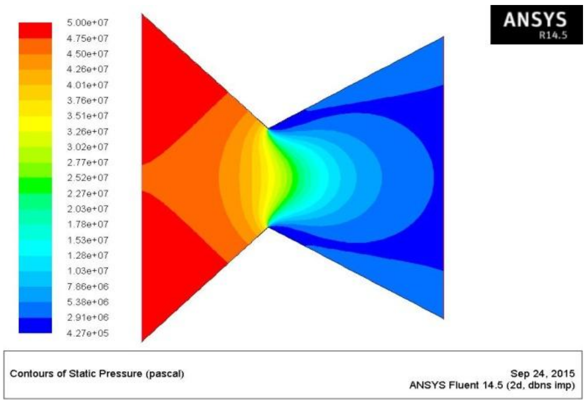
2.5.1. Static Pressure: (β=45, θ=15, R_t=228)



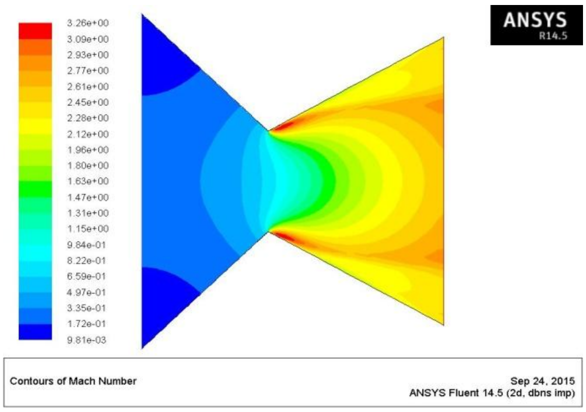
2.5.2. Mach Number: (β=45, θ=15, R_t=228)



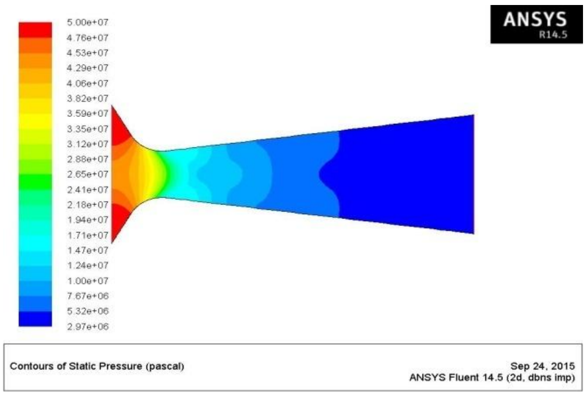
2.6.1. Static Pressure: (β=45, θ=30, R_t=0)



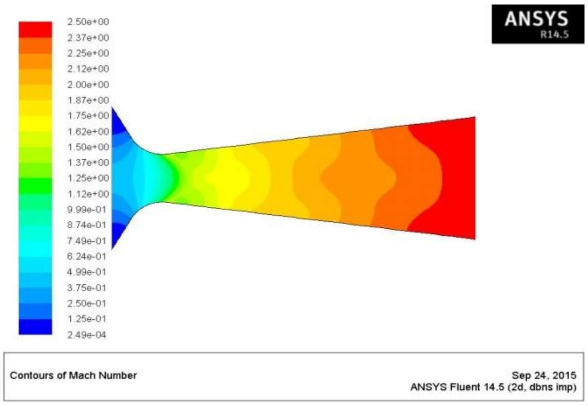
2.6.2. Mach Number: (β=45, θ=30, R_t=0)



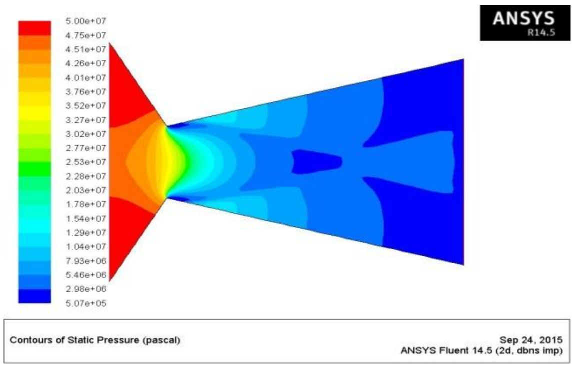
2.7.1. Static Pressure: (β=60, θ=7.5, R_t=228)



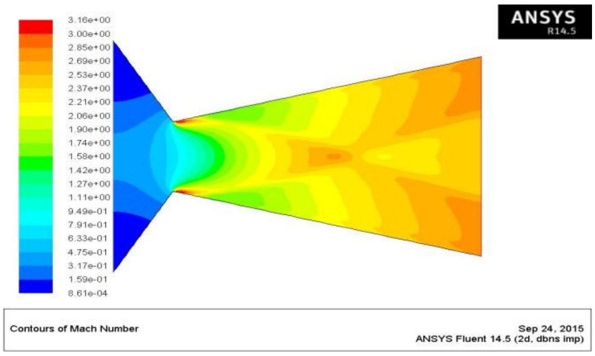
2.7.2. Mach Number: (β=60, θ=7.5, R_t=228)



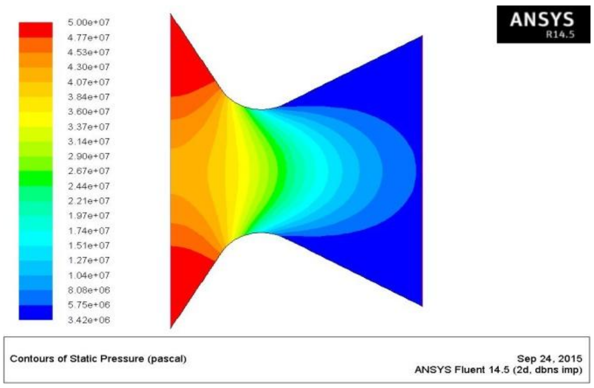
2.8.1. Static Pressure: (β=60, θ=15, R_t=0)



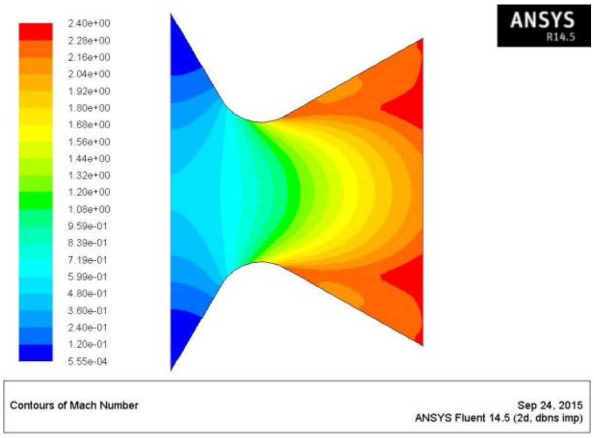
2.8.2. Mach Number: (β=60, θ=15, R_t=0)



2.9.1. Static Pressure: (β=60, θ=30, R_t=125)



2.9.2. Mach Number: (β=60, θ=30, R_t=125)



DISCUSSION ABOUT CONTOURS RESULT

In the nozzle exit section of analysis results produce by the static pressure and mach number contour of the CFD has to be corresponding design parameters. Such, as the result based values along by optimal values of nozzle design parameters obtained from following optimization technique. Here with consider the factors of convergent angle, divergent angle and throat radius. Also response of static pressure and mach number values of CFD analysis in two types of inlet pressure value applied for optimal parameters of nozzle attained.

In the static pressure at exit section will be smaller is better value of the S/N ratio obtained result in static pressure reduction. Here 6th row series of S/N ratio has to be a optimum parameters value (-109.632).

Table V: OPTIMIZATION OF STATIC PRESSURE

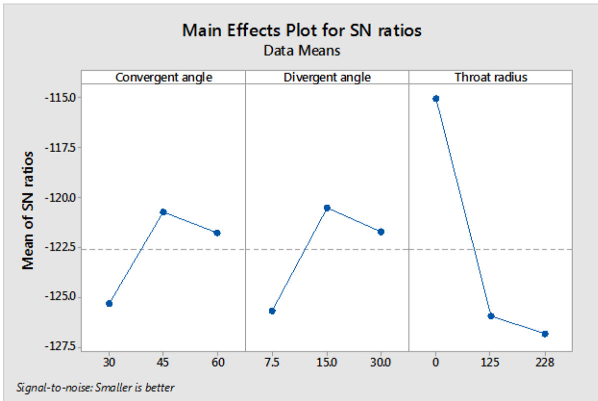
S. No	Static Pressure (44.1Pa)	Static Pressure (50Pa)	S/N Ratio for Static Pressure	Mean for Static Pressure
1	2.08e+05	2.32e+06	-124.334	1264000
2	1.95e+05	2.22e+06	-123.95	1207500
3	3.05e+05	3.44e+06	-127.755	1872500
4	2.56e+05	2.88e+06	-126.212	1568000
5	2.58e+05	2.93e+06	-126.361	1594000
6	3.75e+04	4.27e+05	-109.632	232250
7	2.66e+05	2.97e+06	-126.48	1618000
8	7.83e+04	5.07e+05	-111.192	292650
9	3.05e+05	3.42e+06	-127.705	1862500

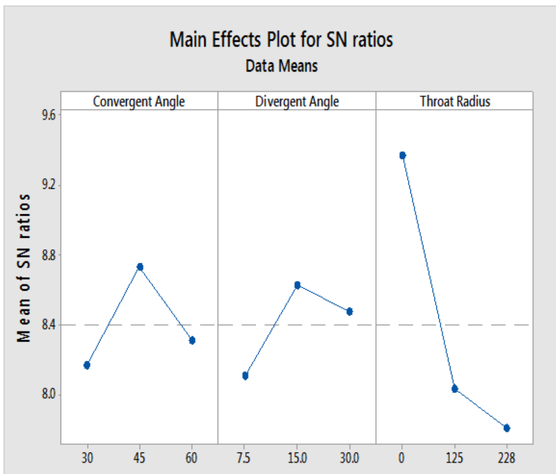
In the mach number at exit section will be larger is better value of the S/N ratio obtained result of increase in mach number. Here 6th row series of S/N ratio has to be a maximum value is optimum (10.29083).

Table VI:OPTIMIZATION OF MACH NUMBER

S. No	Mach Number (44.1Pa)	Mach Number (50Pa)	S/N Ratio for Mach Number	Mean for Mach Number
1	2.63e+00	2.64e+00	8.415565	2.635
2	2.66e+00	2.68e+00	8.530042	2.67
3	2.39e+00	2.39e+00	7.567958	2.39
4	2.50e+00	2.51e+00	7.976103	2.505
5	2.48e+00	2.51e+00	7.94094	2.495
6	3.28e+00	3.26e+00	10.29083	3.27
7	2.48e+00	2.50e+00	7.923777	2.49
8	2.79e+00	3.16e+00	9.419325	2.975
9	2.39e+00	2.40e+00	7.586054	2.395

Mean of SN Ratio:





CONCLUSION

The rocket nozzle analysis with the help of CFD and parameters optimization obtained from the taguchi analysis of DOE. The following observations were found in the rocket nozzle of 9(design)×2(inlet pressure) = 18 times different configuration values of analysis results.

Mach Number: The optimal mach number at the exit section is found to be 3.28e+00 (44.1e5 Pa) and 3.26e+00 (50e6 Pa) mach value (supersonic) consist of S/N ratio based values in the convergent angle (β) 45^{o}(2), divergent angle (θ) 30^{o}(3) and throat radius (R_t) 0(1). Also, graph based values of β=45^{o} (2), θ=15^{o} (2), R_t = 0(1) for optimum parameters.

Static Pressure: The optimal static pressure at the exit section is found to be 3.75e+04 (44.1e5 Pa) and 4.27e+05 (50e6 Pa) static pressure value consist of S/N ratio value based the convergent angle (β) 45^{o}(2), divergent angle (θ) 30^{o}(3) and throat radius (R_t) 0(1). Also, graph based values of β=45^{o}(2), θ=15^{o}(2), R_t = 0(1) for comes to optimum parameters. In the static pressure and mach number values at β=45^{o}(2), and R_t = 0(1) by optimal for two different inlet pressure condition. Also S/N ratio of value based result only limited range of available for configurations of nozzle in θ=30^{o}(3) angle of optimal value. But, graph based values provide the optimal divergent is 15^{o}(2) angle.

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