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# COMPUTATIONAL STUDY OF THE EFFECT OF GEOMETRIC PARAMETERS ON THE PERFORMANCE OF SINGLE EXPANSION RAMP NOZZLE FLOWS

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**Abstract** - The present work deals with the computational study of the single expansion ramp nozzle (SERN) flows for the supersonic regime. Theoretical calculations are carried out for different geometries with certain assumptions. Based on the initial calculation and with the help of Method of Characteristics, nozzle configuration with similar axisymmetric convergent portion and distinct non-axisymmetric divergent portions are drafted. Commercial CFD software ANSYS 12 with Navier Stokes code is used for the computational studies. The study begins with a simple upper flat ramp at different angles with a very small lower cowl at fixed angles. The divergent section of a conventional three-dimensional nozzle is used as the upper ramp of the SERN. The study includes the variation of the ramp at different angles ranging from 16 deg. to 24 deg. with 2 deg. intervals, the cowl angle ranging from 0 deg. to 6 deg. with 2 deg. intervals and the length of the cowl varying from 0.2, 0.4, 0.6, 0.8 and 1.0 times the length of the ramp. The performance parameters like Thrust, Normal force and Mach Variation for these different contours are analyzed and compared. The various parameters used are nozzle length, cowl length, cowl angle, ramp-angle, and ramp length. The shape of the SERN is optimized for the design parameters. The grid sensitivity computational analysis is also performed before finalizing the grid for study.

**Keywords** - Single Expansion Ramp Nozzle, convergent-divergent nozzle, cowl angle, ramp angle, cowl length, ramp length, methods of characteristics.

## I. INTRODUCTION

Nozzles have always been an indispensable component in aircrafts as far as the amount of guile and skill employed to design them is concerned. The extent to which an effectively designed nozzle influences the performance of flight can never be under estimated owing to the wide range of flight velocities and altitudes to which it makes the aircraft susceptible to. Over the years highly intensive research work has consistently been carried out to bring out more and more improvement in the performance of nozzles by coming out with several new designs. These varieties of nozzles range from a simple convergent and divergent duct which was used in the beginning of the supersonic era to the most novel designs such as the non axis-symmetric nozzles that have currently been a major breakthrough in hypersonic flights and are also promising candidates for achieving further increase in the flight velocities up to hypersonic regimes.

Stepping into yet another avenue, one such nozzle designs which has recently been proposed primarily for hypersonic applications is the SERN. The conventional convergent divergent (C-D) nozzle will not be suitable for the hypersonic applications because bottom wall of the divergent portion will be exposed to the external flow, which gives rise to a very high drag. SERN have been one of the major breakthroughs as far as hypersonic vehicles are concerned mainly owing to their phenomenal weight

and base drag reduction characteristics. Research has been carried out for the parametric optimization of the geometric characteristics of SERN, but all of these have been confined only to the hypersonic regime as is the case and have proved to be remarkably worthwhile. Now through this paper it is intended to use this non axis-symmetric nozzle in case of the supersonic vehicles as well. By establishing that the use of the SERN in lieu of the conventional C-D nozzle gives a substantial reduction in weight and drag with only a marginal compensation of thrust, it can be put forth as an appropriate replacement to the conventional nozzles for the supersonic regime. The main aim of this study is to find variables for an optimized geometry. The study focuses the variation of the cowl angle at fixed upper ramp angle and the variation of the cowl length at fixed upper ramp length and angle.

## II. SERN GEOMETRY

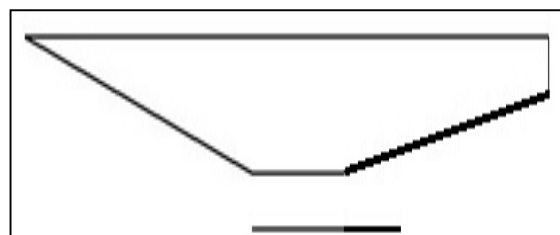


Fig. 1: A hypersonic vehicle with SERN

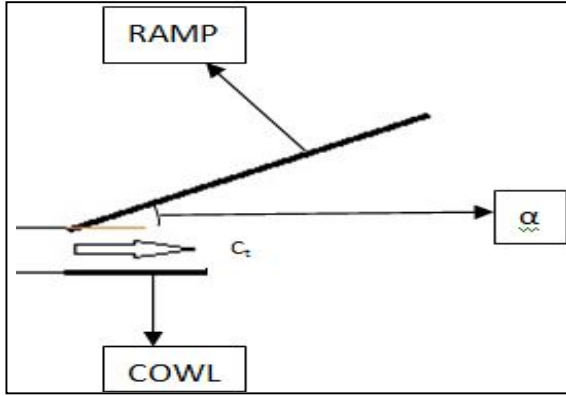


Fig. 2 : SERN Geometry

**III. COMPUTATIONAL STUDY**

Computational studies are carried out by using Ansys 12 software. Different computation strategy such as different types of mesh, turbulence models and convergence criteria were employed to obtain better convergence of results.

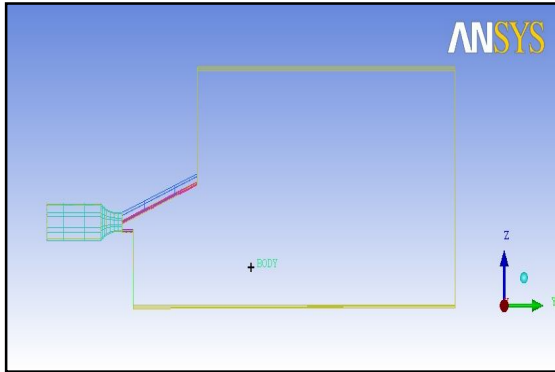


Fig. 3 : Computational domain

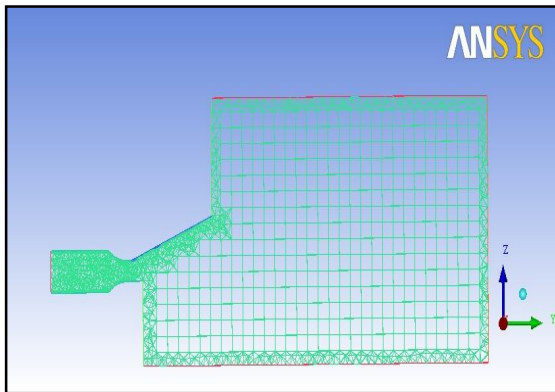


Fig. 4 : Mesh on the computational domain

Table1. Computaional domain

Meshing strategy	Tetrahedron with Prism at walls and hexahedron core.
Number of elements	0.2-0.3 millions
Scheme	High resolution
Turbulence Model	k epsilon
Heat transfer	Total Energy

Model	
Convergence	Converged with order of $10^{-5}$

**IV. RESULTS & DISCUSSIONS**

The Mach number variation is plotted along the axis of the nozzle in the figure5 for the ramp angle of 16 degree. The Mach number increases gradually & it reaches Mach 1 at the throat. After the throat the Mach number increases upto  $X/L = 0.46$  and beyond that there is a rapid decline of the Mach number from  $X/L= 0.46$  to  $X/L = 0.62$  because of the formation of oblique shock waves. At exit the Mach number is higher for cowl angle 0 degree & least for cowl angle 6 degree. The decrease in Mach number at the exit is because of the decrease in area at the divergent section of the nozzle. This variation of Mach number holds good as it is predicted by S.K.Damira et al. <sup>8</sup>.

The figure6-9 shows the variations of Mach number for ramp angles 18 degree to 24 degree & cowl angle 0 degree to 6 degree. The variation of Mach number shows the general trend. For constant ramp angle, it increases from cowl angle 6 degree to 0 degree.

The static pressure variation is non-dimensionalised by dividing it with the maximum pressure and the variation along the axis of the nozzle is plotted in the figure 11 to figure 15. In all the figures it shows a general trend, it gradually decreases upto  $X/L= 0.46$  and then increases and decreases. The increase in static pressure is because of the formation of oblique shocks as mentioned earlier in that region. All the pressure plots show a general trend.

The variation of cowl length with exit velocity is plotted in figure 16. It is concluded that when cowl length is equal to the ramp length, the velocity is maximum and so as the thrust.

Table2. Cowl angle, Ramp angle and Maximum Mach Number

Cowl angle $\beta$	Ramp angle $\alpha$	Maximum Mach Number
0 degree	16 degree	1.88
	18 degree	1.90
	20 degree	1.92
	22 degree	1.88
	24 degree	1.85

2 degree	16 degree	1.87
	18 degree	1.89
	20 degree	1.91
	22 degree	1.87
	24 degree	1.83
4 degree	16 degree	1.86
	18 degree	1.86
	20 degree	1.90
	22 degree	1.86
	24 degree	1.82
6 degree	16 degree	1.85
	18 degree	1.86
	20 degree	1.89
	22 degree	1.85
	24 degree	1.81

## V. CONCLUSION

Simulation has been carried out for SERN at ramp angles ranging from 16 degree to 24 degree at 2 deg. intervals & the different cowl angle ranging from 0 degree to 6 degree at 2 deg. intervals with the help of commercial software Ansys 12. The parameters such as Mach number vs. the nozzle axis, Thrust vs. nozzle axis & static pressure vs. nozzle axis are plotted.

The Mach number gradually increases & then slightly decreases because of the formation of shock waves & remains constant in all the cases. The variation of thrust increases from ramp angle 16 degree to 20 degree & then decreases. The static pressure

gradually decreases then increases and decreases because of the formation of the oblique shocks.

From the above it is concluded that the SERN with 20 degree ramp angle & 0 degree cowl angle gives higher thrust than the other configurations.

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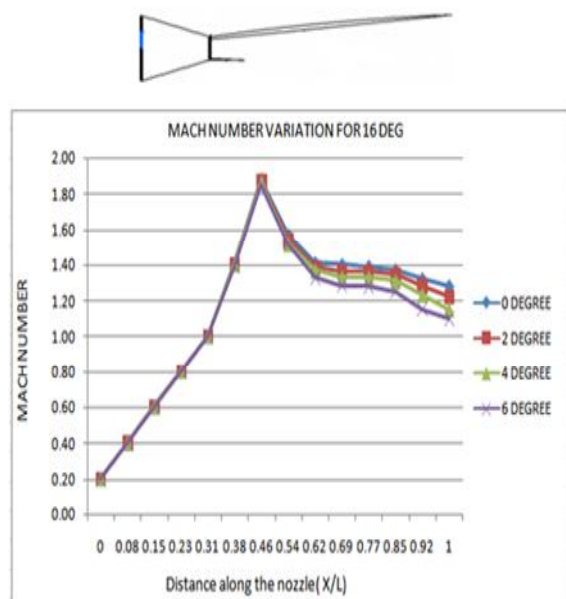


Fig. 5 : Mach number variation along the nozzle axis (for ramp angle 16 degree)

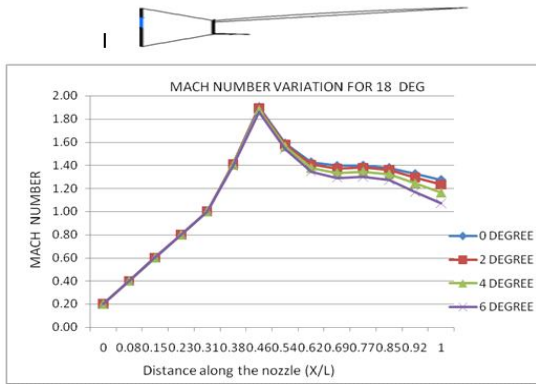


Fig. 6 : Mach number variation along the nozzle axis (for ramp angle 18 degree)

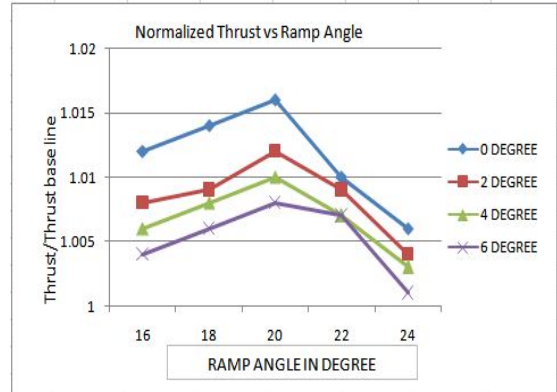


Fig. 10 : Variation of Thrust with Ramp angle.

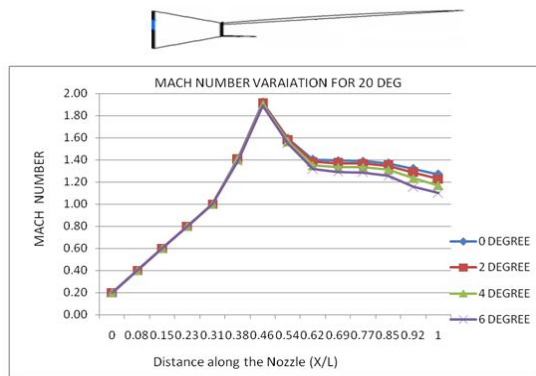


Fig. 7 : Mach number variation along the nozzle axis (for ramp angle 20 degree)

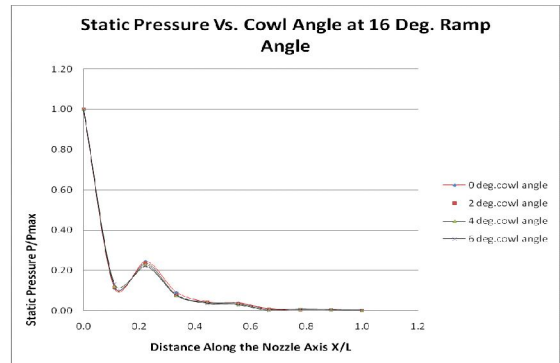


Fig. 11 : Static Pressure variation along the nozzle axis for 16 deg.ramp angle.

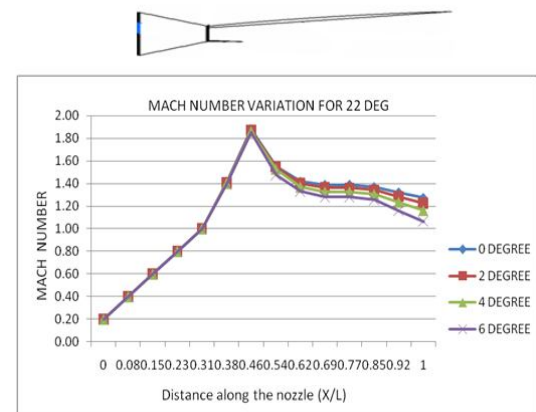


Fig. 8 : Mach number variation along the nozzle axis (for ramp angle 22 degree)

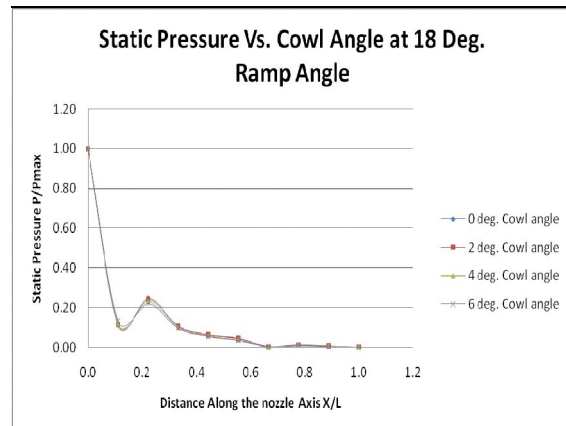


Fig. 12 : Static Pressure variation along the nozzle axis for 18 deg.ramp angle.

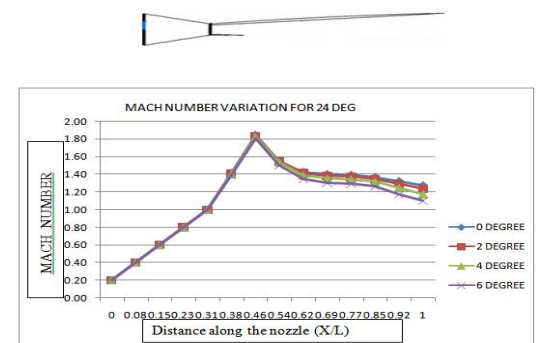


Fig. 9 : Mach number variation along the nozzle axis (for ramp angle 24 degree)

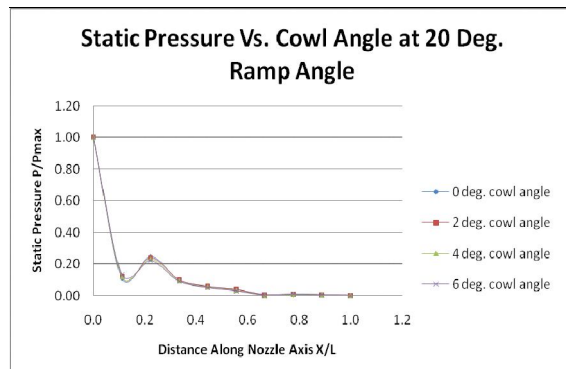


Fig. 13 : Static Pressure variation along the nozzle axis for 20 deg.ramp angle.

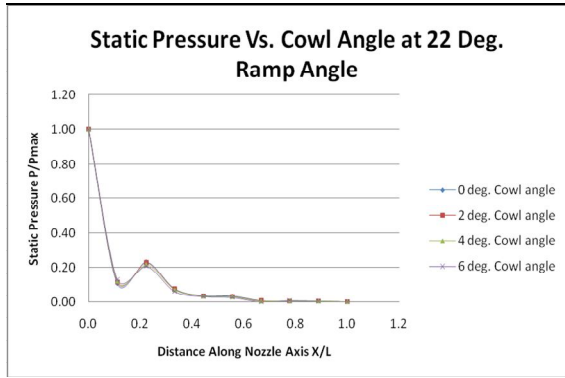


Fig. 14 : Static Pressure variation along the nozzle axis for 22 deg.ramp anlje.

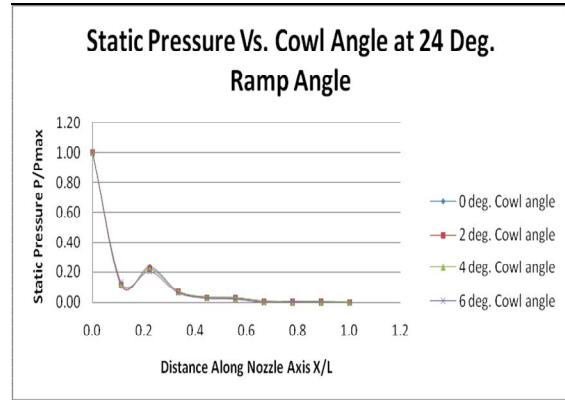


Fig. 15 : Static Pressure variation along the nozzle axis for 24 deg.ramp anlje.

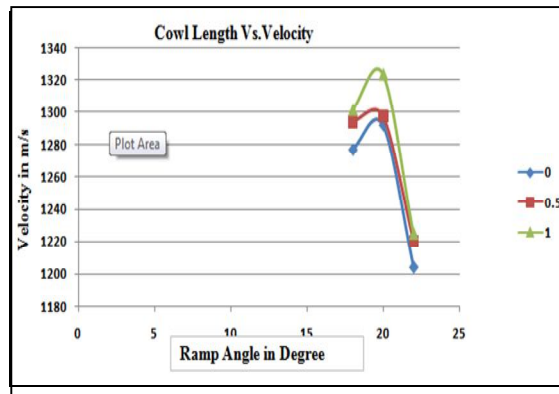


Fig. 16 : Variation of velocity with cowl angle.

