Experimental Studyof Single Expansion Ramp Nozzle Flows (SERN) at Low Supersonic Speeds

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***Abstract*-- The project deals with the experimental study of Single Expansion Ramp Nozzle (SERN) flows at low supersonic speeds. The preliminary design is carried out for three different ramp angles of 18°, 20° & 22° and the model is fabricated. The study includes the effect of cowl length such as 0h, 1h, 2h,3h &4h (Where h is the height of the nozzle throat) on the performance of SERN. The experiment has carried out at lowNozzle Pressure Ratios (NPRs)ranging from 2 to 6.The readings for total pressure is taken along the axis of the nozzle. The Pitot tube fitted with three dimensional traverse mechanisms is used to take the total pressure reading at different X/h locations of the nozzle. A pressure scanner and pressure indicator connected to Pitot tube is used to measure the total pressure.**

***Index Term*-- Pitot tube, Traverse Mechanism, Ramp angle, Cowl length**

NOMENCLATURE

h	height of the throat of the nozzle
M	Jet Mach number
NPR	Nozzle Pressure Ratio
X	Jet axis parallel to the flow direction
P_0	Stagnation/Total pressure
P_1	Static pressure
L	Length of the nozzle = 4h

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.

Stepping into yet another avenue, one such nozzle designs for hypersonic applications is the SERN. 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. Experiment has been carried out in the nineties forthe SERN with hypersonic vehicles [1-4] with or without combustions. There have been several papers dealing with the numerical simulation[6-20]either with their own code or commercial packages dealing with 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 Convergent Divergent (CD) 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.

II. EXPERIMENTAL SETUP

Fig. 1. Supersonic free jet facility
Rajalakshmi Engineering College, Chennai

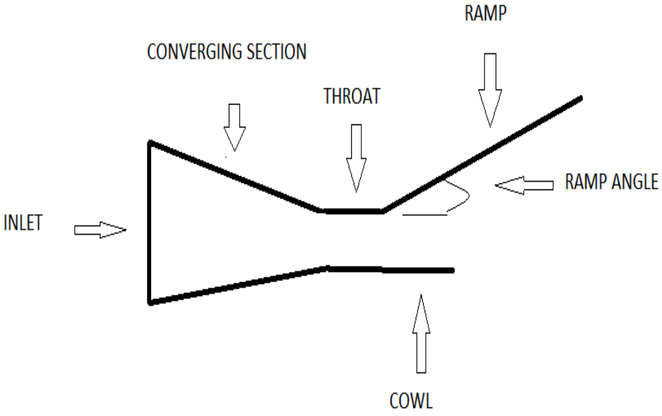


Fig. 2. SERN

The experimental facility for supersonic free jet setup is shown in figure 1. It consists of two 15 hp compressors with 100 cfs capacity each. The compressed air is allowed to pass through an air dryer which removes the moisture available in the atmospheric air to the 5000 L metallic storage tank. The storage tank is cylindrical in shape and has automatic pressure control monitoring system and a drainage valve at the bottom. The gases from the storage tank are allowed to pass to the settling chamber via diffuser through the control valve. There are three perforated plates at the first half of the settling chamber which makes the flow laminar. There is pressure dial gauze in the settling chamber to monitor the stagnation pressure. The nozzles with desired geometries can be attached to the settling chamber for the study purposes.

III. EXPERIMENTAL PROCEDURE

A SERN (Figure 2) is designed and fabricated for low supersonic speeds with stainless steel. It consists of a rectangular converging nozzle and flexible attachable and detachable upper ramp with 18°, 20°& 22° angles and the lower cowl of 0h,1h, 2h, 3h and 4h, Where 'h' is the height of the throat. The required stagnation pressure can be maintained in the settling chamber by adjusting the pressure regulating valve. The stagnant air from the settling chamber was allowed to expand through a SERN. The SERN was fixed to the end of the settling chamber with a 'O' ring sealing to avoid leakage. Required pressure is maintained in the settling chamber for the desired NPRs. A metallic Pitot tube mounted with three-dimensional traverse mechanisms was used to measure the total pressure along the supersonic jet. The Pitot tube is connected pressure sensor and pressure indicator, where reading was taken. The pressure sensor and indicator initially calibrated with the mercury manometer and it is found that the error is within the limit.

The Pitot pressure (P_0) is used to measure the Mach number M_1 (equation 1) in case of subsonic flow. In the case of supersonic flow (equation 2), a shock forms in front of the probe, and P_0 is equal to the total pressure behind the shock. Wherever the flow is subsonic, there is no shock ahead of the probe. The static pressure P_1 can be assumed to be constant and equal to the ambient static pressure everywhere within the jet [5].

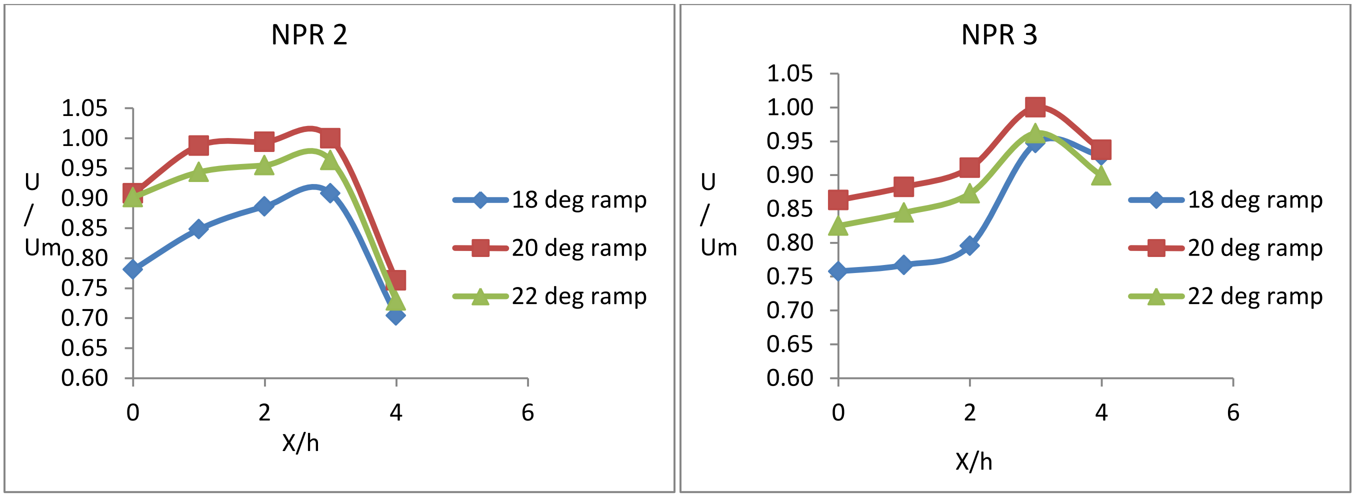
$$\frac{P_0}{P_1} = \left[1+\frac{\gamma}{\gamma-1}M_1^2\right]^{\frac{\gamma}{\gamma-1}} \qquad (1)$$

$$\frac{P_0}{P_1} = \left[\frac{(\gamma+1)M_1^2}{(\gamma-1)M_1^2+2}\right]^{\frac{\gamma}{\gamma-1}}\left[\frac{\gamma+1}{2\gamma M_1^2-(\gamma-1)}\right]^{\frac{1}{\gamma-1}} \qquad (2)$$

IV. RESULTS& DISCUSSIONS

A. Effect of Ramp Angle:

The non dimensional velocity profile for three different ramp angles are drawn at different NPRs ranging from 2 to 6.



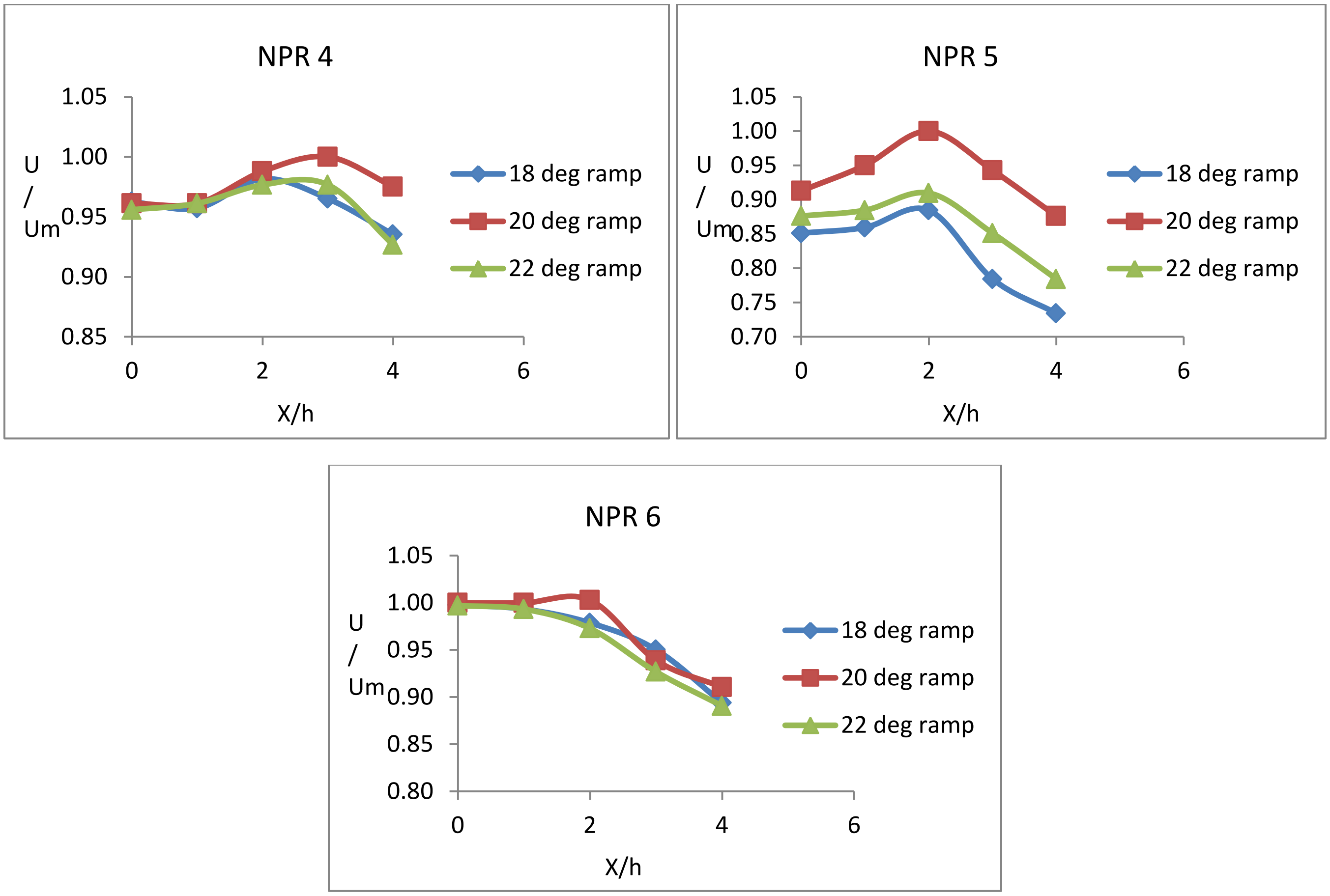


Fig. 3. Axial velocity distribution on the nozzle for different NPRs (No cowl)

All the above figures are drawn for the SERN without cowl. At NPR 2, expansion takes place upto X/h = 1 and velocity remains constant upto X/h = 3 and then sharply decreases. This is the trend followed by all the three ramp angle configurations. At NPR 3 & 4, expansion takes place upto X/h =3 and then the velocity decreases. At NPR 5 & 6, velocity increases upto X/h =2 and then decreases. In all the figures ramp angle 20° has the higher peaks which shows the thrust is optimum in case of SERN with ramp angle 20° in compared to other two configurations.

Table I
Effect of ramp angle on nozzle thrust without cowl

Cowl Length	**NPR**	**% Change in axial thrust by changing ramp angle from 18° to 20°**	**% Change in axial thrust by changing ramp angle from 22° to 20°**
0h	2	9.18	3.48
	3	5.69	3.79
	4	1.71	2.28
	5	15.00	15.00
	6	0.33	0.33
1h	2	3.59	5.09
	3	3.60	5.04
	4	0.76	-1.71
	5	1.00	2.67
	6	1.14	1.63
2h	2	12.64	2.25
	3	2.56	2.78
	4	2.99	4.86
	5	0.52	2.98
	6	0.65	0.97
3h	2	1.51	0.30
	3	4.63	-2.20
	4	1.15	-2.87
	5	0.67	0.67
	6	9.01	3.95
4h	2	20.53	9.03
	3	15.94	13.09
	4	4.67	6.91
	5	7.54	0.00
	6	5.71	2.06

The above table shows the variation of axial thrust for SERN (without cowl) with 20° ramp angle in comparison to SERN with 18° & 22° ramp angles. In all the cases the performance of SERN with 20° ramp is the better than the SERN with 18° & 22° ramp angles.

B. Effect of Cowl Length:

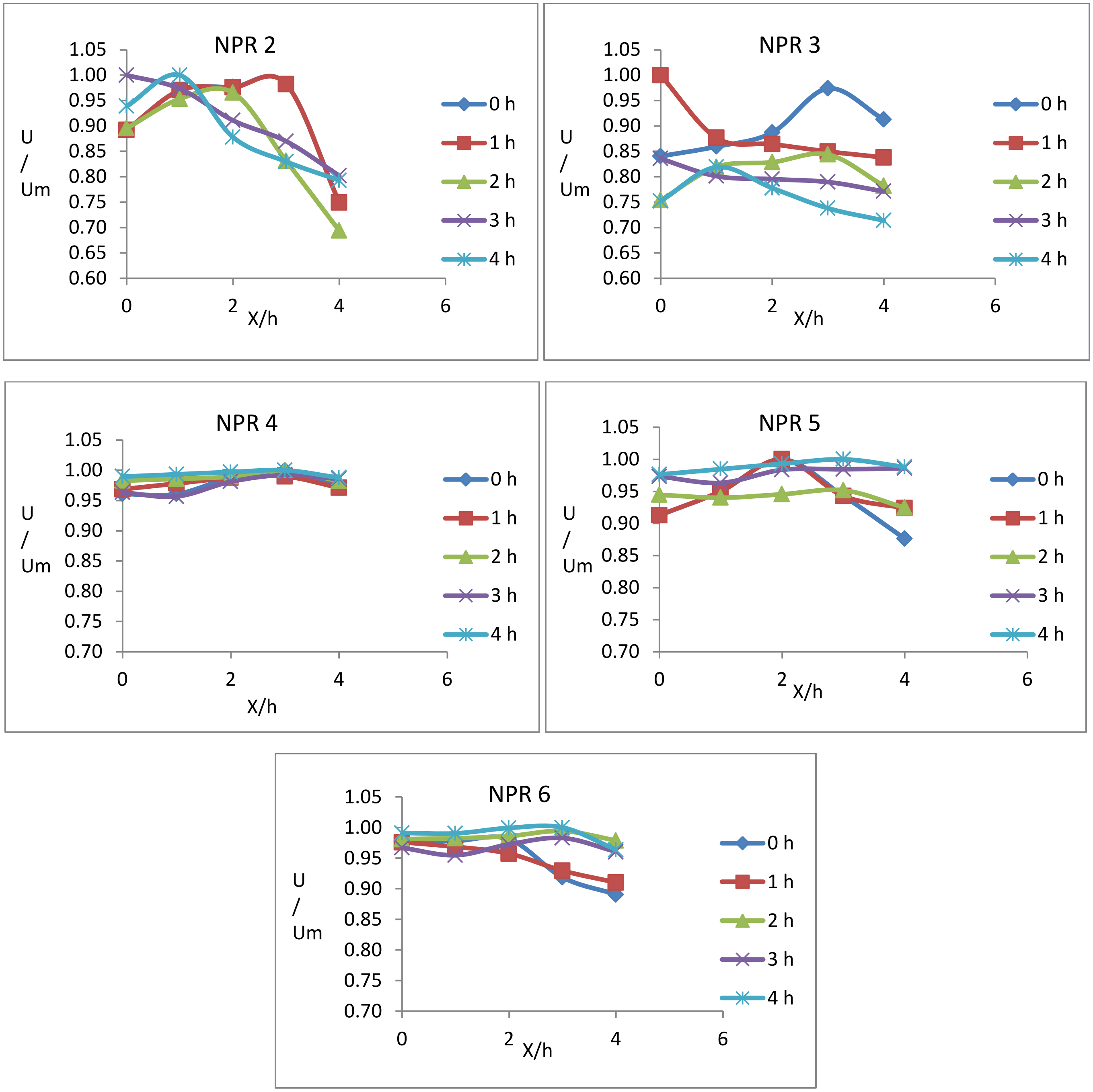


Fig. 4. Axial velocity distribution on the nozzle for different NPRs

At low Nozzle pressure ratios (NPR 2), effect of cowl is least significant. SERN without cowl and 3h have maximum velocity at throat location and further expansion doesn't take place in the diverging section of the nozzle. The flow velocity gradually decreases afterwards. Whereas for 2h& 4h configurations expansion goes on upto X/h = 2 i.e. upto middle of the diverging section of the nozzle so as the velocity increases. After X/h = 2 the velocity profile linearly decreases for all configurations. At NPR 3 maximum velocity occurs at X/h = 0 for SERN with 1h cowl configurations. Expansion keeps on going for 0h & 2h configurations for X/h = 3 and for 3h & 4h it is upto X/h = 1. After the exit section of the ramp, the flow velocity gradually decreases. At NPR 4, all configurations have maximum velocity at X/h = 3&4. At NPR 5& 6, for SERN with 4h cowl have better performance than the SERN with other configurations.

V. CONCLUSIONS

Single expansion ramp nozzle performance is studied by varying the nozzle pressure ratios, ramp angles, cowl lengths. It is concluded that:

- Effect of ramp angle is negligible at low supersonic speeds; however SERN with ramp angle 20° has better performance than SERN with 18° and 22°.
- Extension of nozzle cowl length has least significant at low NPRs; effect of cowl length has beneficial effect on nozzle velocity so as nozzle thrust at higher NPRs.
- SERN with ramp angle 20° & 4h cowl has better performance than the other configurations.

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