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EXPERIMENTAL STUDY OF SINGLE EXPANSION RAMP NOZZLE (SERN) FLOWS WITH 22° RAMP ANGLE WITHOUT COWL

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Abstract—*The project deals with the experimental study of the velocity decay characteristics of Single Expansion Ramp Nozzle (SERN) flows at low supersonic speeds. The preliminary design is carried out for the SERN with a 22° rampanglewithout cowl and the model is fabricated. The experiment has carried out at lowNozzle Pressure Ratios (NPRs)ranging from3 to 6.The readings for total pressure are taken along the mutually perpendicular transverseaxes 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.*

Keywords: *Pitot tube, Traverse Mechanism, Pressure Scanner, Pressure Indicator.*

NOMENCLATURE

M	Jet Mach number
NPR	Nozzle Pressure Ratio
X	Jet axis parallel to the flow direction
Y & Z	Axes perpendicular to X axis
h	Throat height of the SERN
P_0	Stagnation/Total pressure
P_1	Static pressure
U	Local velocity of the jet
Um	Maximum velocity of the jet

1. INTRODUCTION

Nozzle is one of the most important components of the aircraft & rocket engines. So the attentions are focused to optimize the shape, length and contour of the nozzle to improve the performance of the vehicle. Nozzles have been designed, fabricated, tested and implanted starting from early converging nozzle in the subsonic aircrafts to the converging-diverging (C-D) nozzle in the supersonic vehicles. The research has been carriedout in the development of air breathing hypersonic vehicles for flying in the earth's atmosphere [1-10]. The Single Expansion Ramp Nozzle (SERN) is the suitable candidate for this application because of its less weight and reduction in base drag in comparison to C-D nozzle.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. Single expanded ramp nozzle is similar to CD nozzle but difference is that divergent portion cut is made such that the flat plate in divergent section is the ramp that can be placed in the exit of throat in upper portion. and the bottom portion of throat is the cowl.

2. EXPERIMENTAL SETUP

The experimental facility for supersonic free jet setup is shown in Fig. 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.

Fig. 1: Supersonic free jet facility at Rajalakshmi Engineering College

There are three perforated plates at the first half of the settling chamber which makes the flow laminar. The nozzles with desired geometries can be attached to the settling chamber for the study purposes.

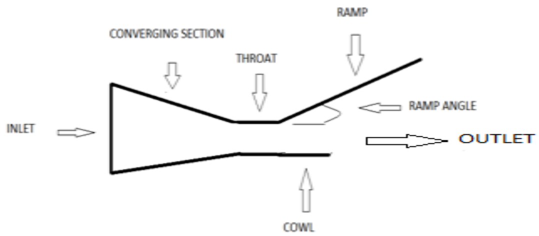

Fig. 2: SERN

3. EXPERIMENTAL PROCEDURE

A SERN (Fig. 2)consists of a rectangular converging nozzle and upper ramp with 22°angle and without cowl is designed and fabricated with stainless steel.The experiment is carried out for different NPRs ranging from 3 to 6.The required stagnation pressure can be maintained in the settling chamber by adjusting the pressure regulating valve. A metallic Pitot tube mounted with three- dimensional traverse mechanism was used to measure the total pressure along the three mutual perpendicular direction of the supersonic jet.The non-dimensionalised velocity is plotted along the Y & Z directions.The Pitot tube is connected with the pressure sensor and personal computer, where reading was taken. The pressure sensor and indicator was initially calibrated with the mercury manometer and it was 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].

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

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

4. RESULTS& DISCUSSIONS

The non dimensional velocity profile for SERN with ramp angle 22° without cowlare drawn at different NPRs ranging from 3 to 6.

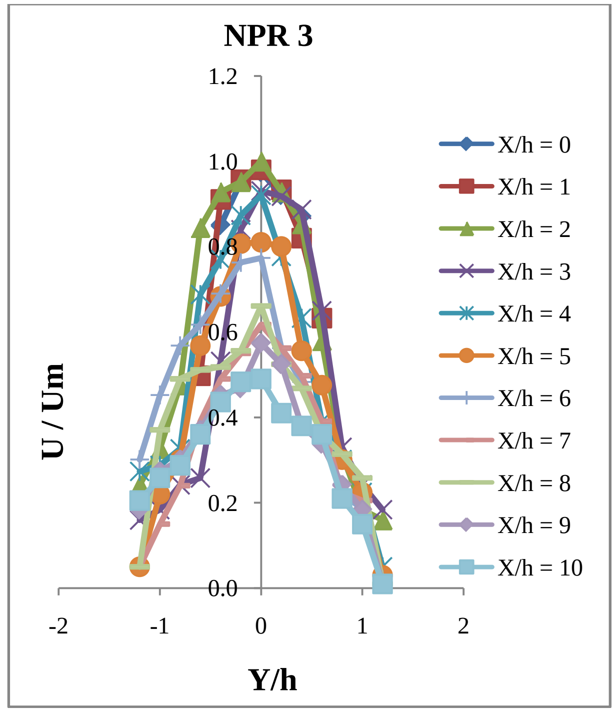

Fig. 3.a

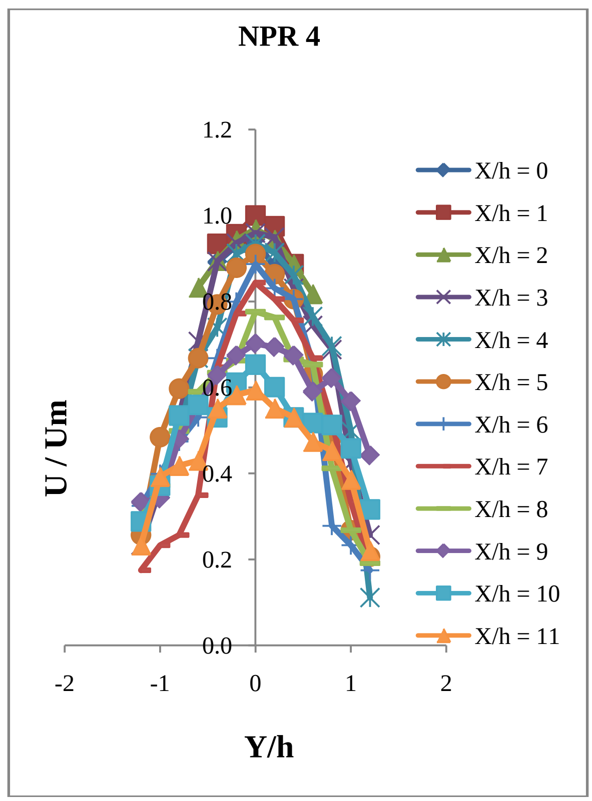

Fig. 3.b

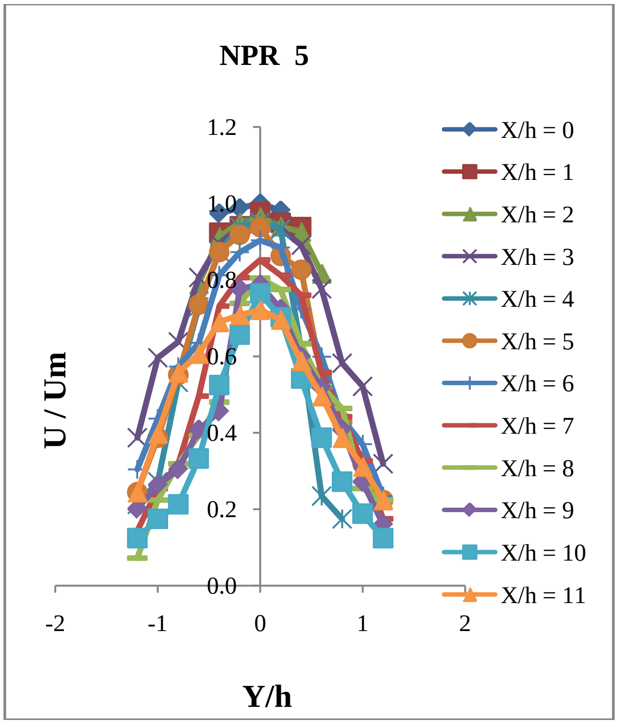

Fig. 3.c

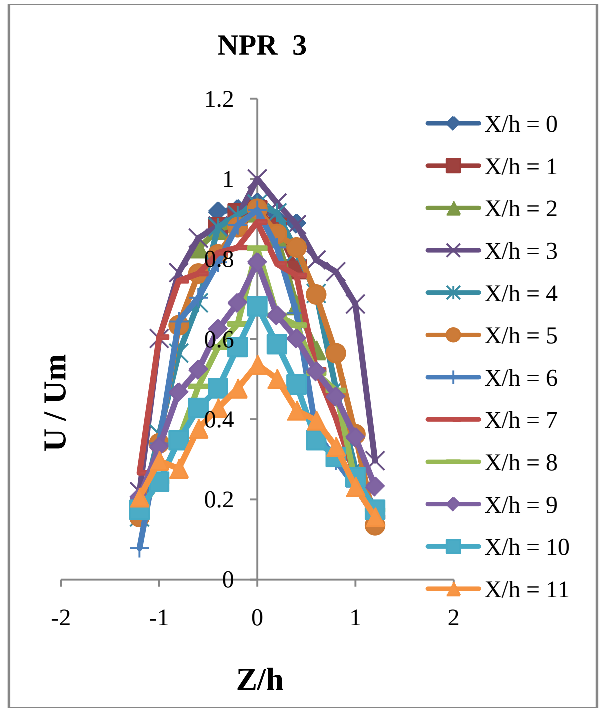

Fig. 3.e

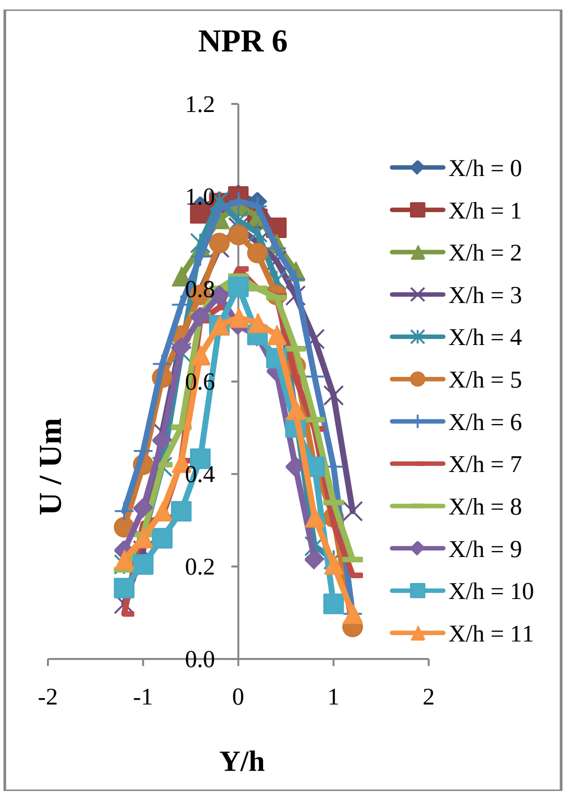

Fig. 3.d

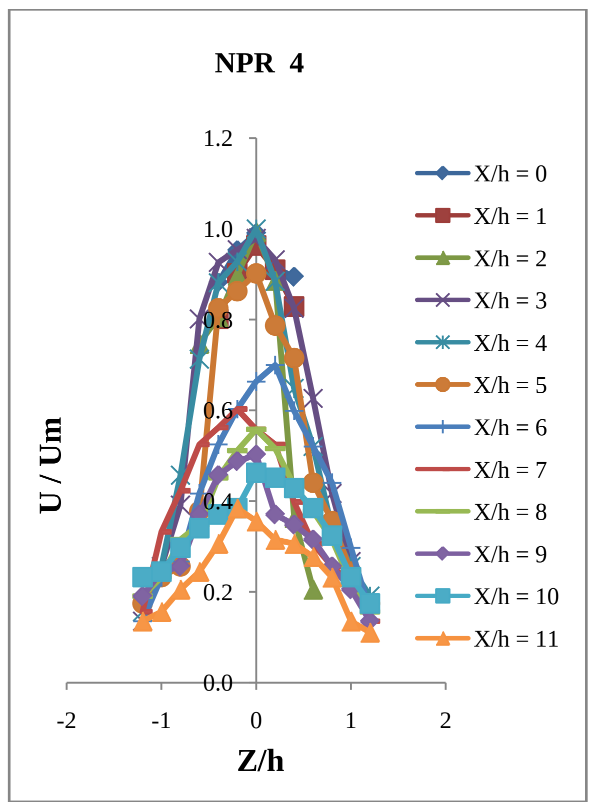

Fig. 3.f

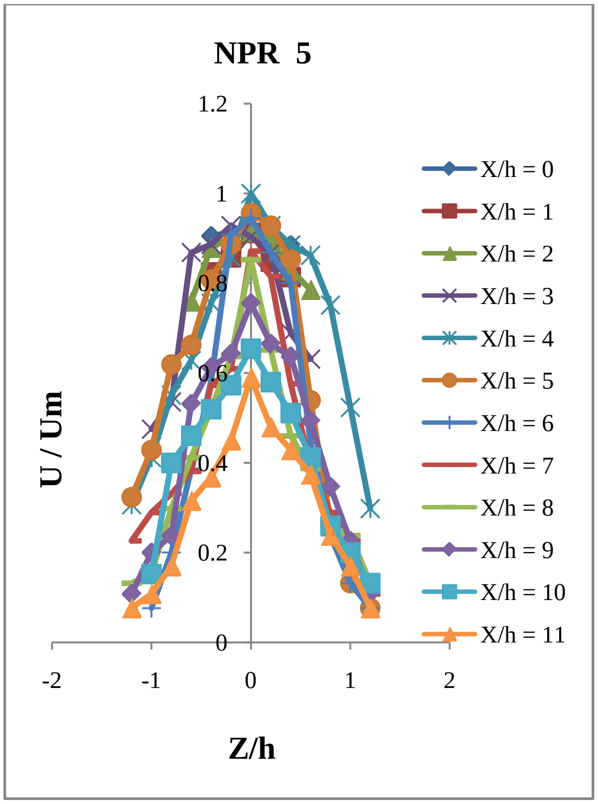

Fig. 3.g

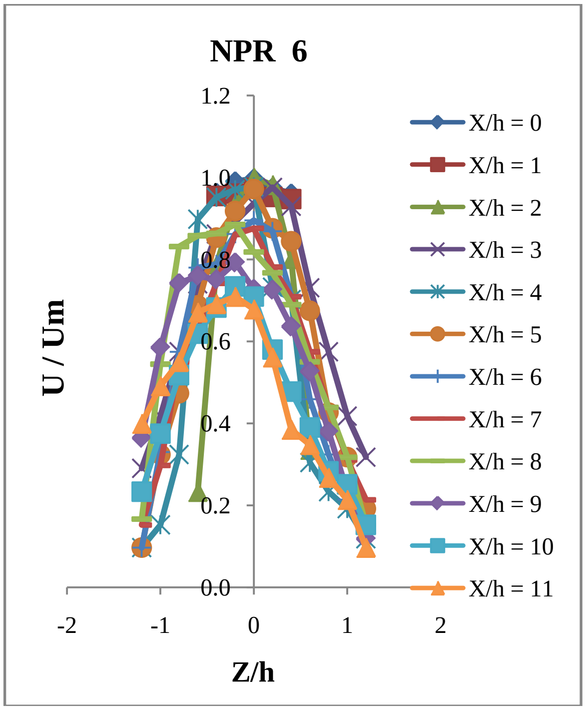

Fig. 3.h

Fig. 3: (a-h).Non dimensional velocity (U/Um) profile for SERN along Y & Z directions.

The Fig. s 3.a, b, c, d is the Y direction non-dimensionalisedvelocity profile of the SERN with 22° ramp angle and without cowl. From the center line of the nozzle throat, upward direction is considered as +Y direction and downward direction is considered as -Y direction.

As the NPR increases from 3 to 6, the velocity along +Y direction increases in comparison to the variation along the -Y directions, although the variation is minimal [9]. This concludes that the jet will follow the path of the ramp at hypersonic flow. The Fig. s 3.e, f, g, h is the Z direction non-dimensionalised velocity profile of the SERN with 22° ramp angle and without cowl. Clearly the velocity profile is similar to that of C-D nozzle as the SERN is symmetric about the Z axis.

5. CONCLUSIONS

The experimental results show that the flow velocity at the exit gradually increases and then decreases along the axial locations. The velocities are found to rise to the peak near the center of the nozzle.The velocity characteristics of the SERN for 22° and without cowl are studied along the three mutually perpendicular directions at different NPRs ranging from 3 to 6. The non-dimensionalised velocity profile is drawn along Y & Z directions.The graphs become steeper as pressure increases. At lower pressures the changes in the velocity is very less and only near the center location the change is more abrupt.It is concluded that the velocity profile is symmetric along the Z directions and asymmetric along the Y direction. The +Y directions have the higher velocity than the -Y directions which signifies the effect of ramp. It is also concluded that the static pressure gradually increases and decreases due to formation of oblique shocks, which was seen with the help of Shadowgraph system. There will be a pitch down moment because of the shape of the SERN. This moment has to be balanced by some means for better stability.

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