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Investigation of the Flowfield At Sonic and Supersonic Mach Numbers with Sudden Expansion

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Abstract: ***This paper presents the results of an experimental investigation conducted at sonic and supersonic Mach number. The objective of the study was to measure the base pressure, the flow development in the suddenly expanded duct, and the pressure loss at the two points in the flow network (i.e., from settling chamber to the exit of the duct). Experiments were conducted for converging and converging-diverging nozzle at Mach 1 and 1.2. The area ratio of the study is 7.84 for a fixed L/D ratio of 8. The results indicate that there is a continuous decrease in the base pressure despite jet being highly under-expanded the base pressure continue to decrease due to the large area ratio. The pressure loss is 30 % for lower Mach number, but it is around 80 % at NPR 7. The wall pressure assumes the lowest values for NPR 7 and the highest values at NPR 1.5.***

I. INTRODUCTION

The boundary layer flow was first discovered and reported by the Ludwig Prandtl in the early twentieth century. From then many researchers have performed research on the separated flow. Application of separated flow is found in many applications such as aircraft wing, combustors, diffusers, suddenly expanded pipes and turbines. The separated layer has been an area of interest by many researchers. The study can be applied to automobiles and aircraft industries. Here in these industries, there is a need to reduce the consumption of fossil fuels in order to have a green environment and conserve these sources of energy for a future generation. In order to achieve this objective, there is a need to reduce the drag. As it is considered the primary reason behind ineffectual fuel use. Therefore, in order to reduce the drag, the foremost requirement is to reduce the base drag as it contributes to the two-thirds of the total drag.

The separation of the flow forms a backward facing step. This backward facing step has three central regions namely the recirculation region, the shear layer, and reattachment point. This shear layer is made up of small coherent structures as shown in figure 1 below. The recirculation region formed at the base is due to the low base pressure region created at the base. Due to this wake region the coherent structures of the shear layer mixes with this primary vortex and forms the more massive coherent structure. Also, the flow which meets at the reattachment point and again starts to grow from this point. It is imperative to understand the mechanism behind this three regions of turbulent flow namely recirculation region, the shear layer and reattachment point in order to achieve the desired objective that is either enhancing the mixing of fuels or reduce the drag or reduce noise and vibrations.

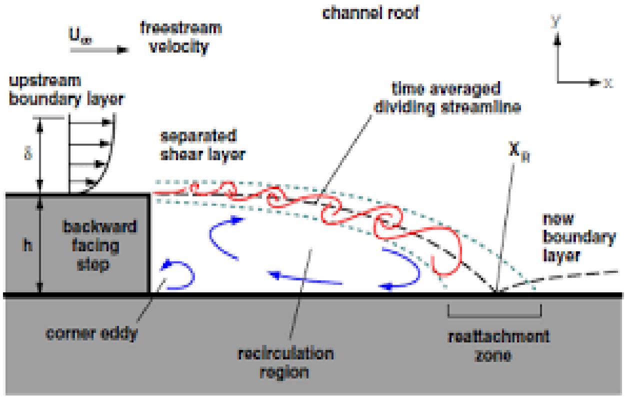

Figure 1. Backward facing step (Driver et.al.[1])

From a very long time, the industries of automobiles and aircraft are working towards the reduction of drag in order to save non-renewable sources of energy like fossil fuels and to avoid greenhouse gas emission.

II. LITERATURE SURVEY

The subject of control of base pressure has been of interest from past many decades. Many researchers have tried to control the base pressure by employing both active and passive control techniques. In the past, the researchers have used the passive control techniques in the form of after boat tailing [2, 3] base bleed [4-6] and many other vortex suppression [5, 7-9] devices are used to control the base pressure in missiles, projectiles or fighter planes. In order to control the base pressure, it is essential to break the vortex generated at the base of the missiles, projectiles or automobiles. Reviews of techniques for reducing base drag in the context of two-dimensional flows are contained in the papers by Nash [7] and Tanner [5]. Also Mauri [10], Tanner [5] and Murthy [11, 12] have written the review papers on axisymmetric base drag reduction techniques in the past.

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As explained by Wicks[13] a recirculation zone will be formed at the base of missiles, projectiles or automobiles which can be said as the vortex. There will be ejection of mass via the shear layer, and again the shear layer will hit the wall of the duct. The point where it hits the wall is known as the reattachment point. The base pressure will increase with the increase in the reattachment length. The wick[13] explained the main reason behind the vortex generation and the ejection of the mass which leads to the backflow. The idea of the boundary layer is the source of two fluids one being the recirculation zone other being the backflow from the expanded section of the wall as formulated by Wicks[13], many researchers researched the techniques of breaking the recirculation zone formed at the base and eventually controlling the base pressure.

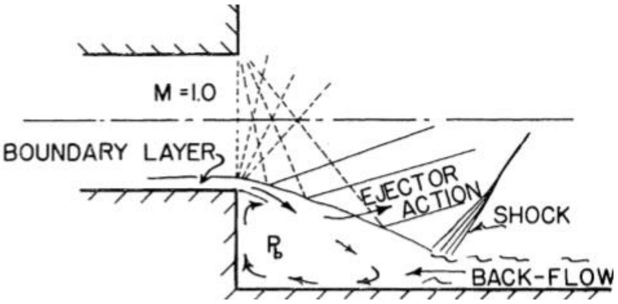

Figure 2. Jet-Pump action by wicks

As explained by the wicks the above figure shows his first formulated jet-pump action in which he explains about the boundary layer entrainment, backflow and ejection action.

There are two types of control techniques in order to control the base pressure. One is the active control and other being the passive control technique. In the active control technique, there will be the use of blowing or suction of air by which one can control the base pressure. For this, the one has to employ external control methods like microjets which can be an expensive affair.

Whereas the passive control technique is of two types- one is in the form of ribs and other in the form of a cavity. Employing passive control techniques is inexpensive when compared to active control techniques.

III. EXPERIMENTAL SET-UP

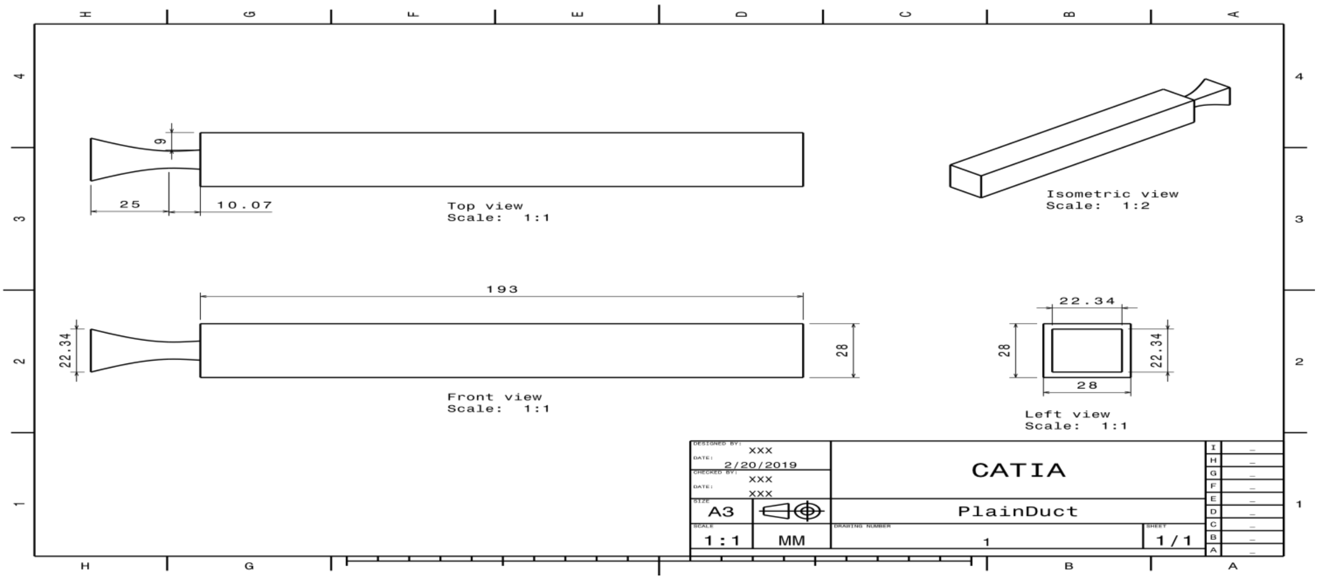

Fig. 3 converging-diverging nozzle of the square cross-section along with the enlarged

Fig. 3 shows a view of the converging-diverging nozzle of the square cross-section along with the enlarged square duct of the side 28 mm. Figure 2 shows a view of the nozzle assembly along with the enlarged duct mounted on the experimental setup indicating the settling chamber with other attachment and accessories being used during the experimentation. Figure 3 presents a view of the converging-diverging nozzle attached with the suddenly expanded square duct of side 28 mm indicating the base pressure as well as the wall pressure tappings.

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Fig. 4 A view of the Nozzle along with the duct attached with the settling chamber of the open jet facility

Fig. 5 A view of the Nozzle and the duct assembly

IV. RESULTS AND DISCUSSION

This investigation focuses attention on the base pressure, the flow development in the enlarged duct, and the total pressure loss between the two locations. This pressure loss in the stagnation pressure was calculated based on the one point is at the main settling chamber and the other at the exit plane of the suddenly expanded ducts of area ratio 7.84 with square cross-section and diameter ratio 2.8, to investigate the base pressure variations at various NPR and the Mach numbers. The parameters considered in the present study are the area ratio of the duct, L/W ratio of the duct was fixed at 8, the jet Mach numbers were M = 1 and 1.2. The tests were conducted at different NPR. The measured base pressures have been made non-dimensional by dividing them by the ambient atmospheric pressure to which the flow from the enlarged duct was discharged.

In Fig. 6, it is seen that the base pressures decrease with the increase of NPR and this trend continues for all the NPR. The increase in NPR values is unable to influence the base pressure values, even though the Jets are experiencing a favorable pressure gradient. In the normal conditions once the jets are under-expanded the trends in the base pressure are altogether different. The physics behind this trend may be when relief effect due to an increase of the area ratio is beyond some limit, the flow from the converging or converging-diverging nozzle discharged into the enlarged duct tend to attach with reattachment length other than the optimum for a strong vortex at the base. This process makes the NPR effect on base pressure to become insignificant for higher area ratio.

The wall pressure along the duct is shown in Fig. 7. When NPR values are from 3 to 7 the jet exiting from the converging nozzle is under-expanded. Due to jets being under expanded an expansion fan will be located at the nozzle exit. When the jets are coming out will undergo expansion resulting in lower values of the base pressure. It is also seen that at x/D = 0, the base pressure assumes minimal values later in the downstream there is an increase in the wall pressure by more than 100 %, and this trend continues till it attains the value equal to the ambient pressure. However, at NPR 1.5 the flow has not choked, and hence the Mach number at the nozzle exit will be less than the sonic Mach number. Hence, at NPR = 1.5 the wall pressure values remain steady, but later the recovery of the flow takes place and attains the ambient pressure. When NPR = 2, at this NPR the flow will attain sonic Mach number at the exit of the nozzle. At the exit, the flow attains 80 % of the atmospheric pressure and progressively attains the ambient conditions.

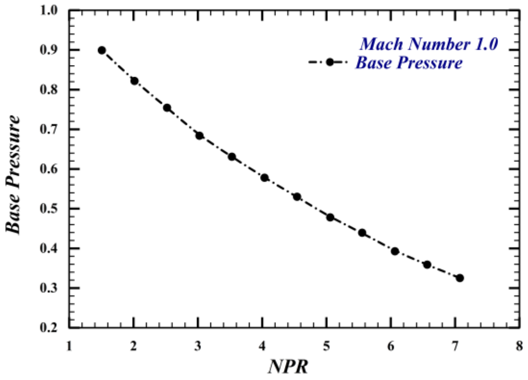

Fig. 6 Base pressure variation with NPR

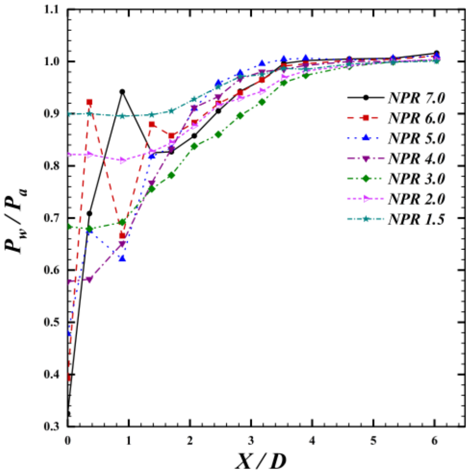

Fig. 7 wall pressure distribution along the duct wall at Mach M = 1

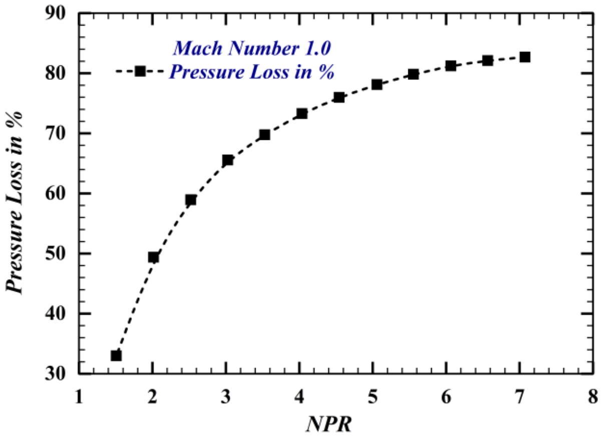

Fig. 8 Percentage Pressure loss variation with NPR

Fig. 8 shows the pressure loss at various NPR. From the figure, it is seen that at lower NPR's the loss in total pressure is as low as 30 %, and at NPR 7 it is around 80 %. This trend in the behavior of the results was expected at these Mach numbers.

The base pressure, wall pressure, and the pressure loss results at Mach 1.2 are shown Figs. 9 to 11.

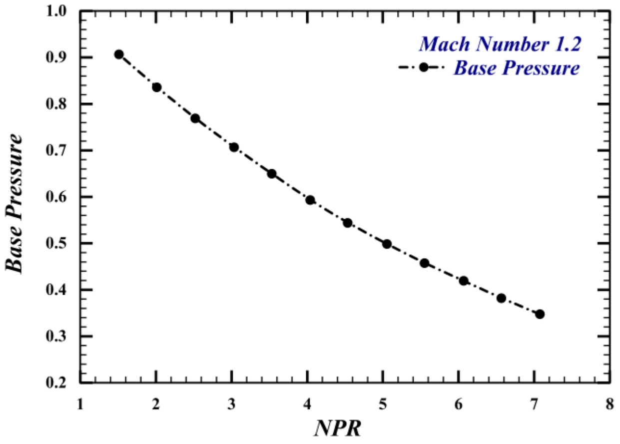

Fig. 9 Base pressure variation with NPR

Fig. 9 presents the base pressure results for Mach 1.2. These results are in no way different from Mach 1. This may be due to the Mach number range. Hence the under-expanded jets are unable to influence the base flow when the area ratio is very high.

The wall pressure and flow development are shown in Fig. 10. The wall pressure is very much similar with the exception that its magnitude is being changed due to the increase in the Mach number. The percentage pressure loss at Mach 1.2 is shown in Fig. 11. The pressure also is almost the same as was observed at Mach 1.

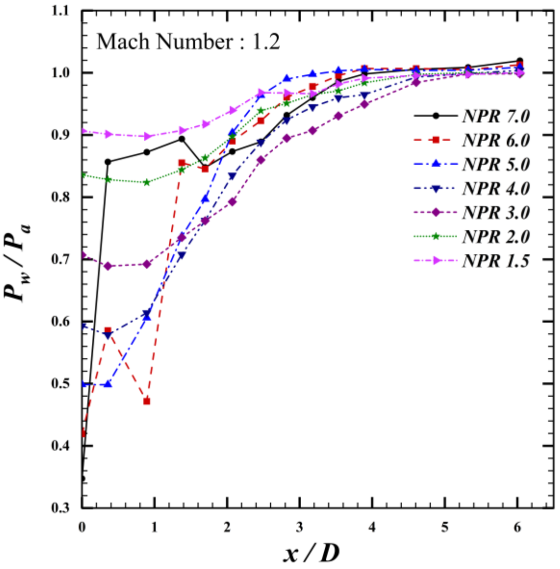

Fig. 10 wall pressure distribution along the duct wall

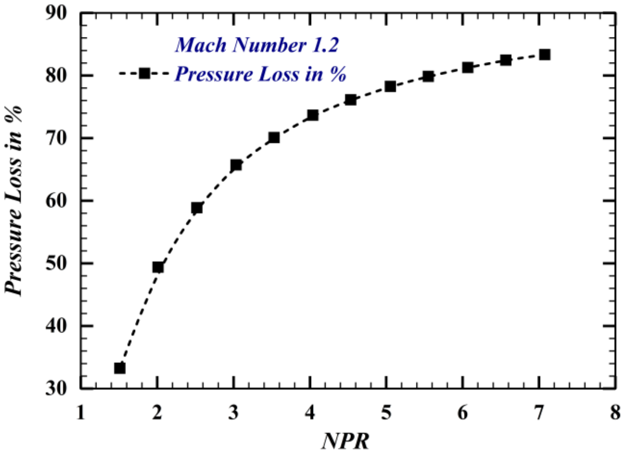

Fig. 11 Percentage Pressure loss variation with NPR

CONCLUSIONS:

Base on the above discussion we may draw the following conclusions:

- The base pressure continues to decrease even though the level of under expansion is very high.
- It may be concluded that whenever the area ratio of a suddenly expanded duct is beyond a certain limit the jets under the influence of the favorable pressure gradient do not yield desired results as they attached with the duct with much larger reattachment length.
- The large reattachment becomes very influential parameter, and the level of under expansion is unable to make an impact on the base pressure.
- The percentage pressure loss is the highest at the largest NPR and the minimum at the lowest NPR.
- The wall pressure assumes minimal values for highly under-expanded jets. However, at lowest NPR the wall pressure is closed ambient pressure.
- The data obtained will be a handy database for the future design of the aerospace vehicles.

REFERENCES:

1. D. M. Driver, H. L. Seegmiller, and J. G. Marvin, "Time-dependent behavior of a reattaching shear layer," *AIAA Journal*, vol. 25, pp. 914-919, 1987.
2. W. Mair, "Reduction of base drag by boat-tailed afterbodies in low-speed flow," *The Aeronautical Quarterly*, vol. 20, pp. 307-320, 1969.
3. D. Maull and B. Hoole, "The effect of boat-tailing on the flow around a two-dimensional blunt-based aerofoil at zero incidences," *The Aeronautical Journal*, vol. 71, pp. 854-858, 1967.
4. P. Bearman, "The effect of base bleed on the flow behind a two-dimensional model with a blunt trailing edge," *The Aeronautical Quarterly*, vol. 18, pp. 207-224, 1967.
5. M. Tanner, "Reduction of base drag," *Progress in Aerospace Sciences*, vol. 16, pp. 369-384, 1975.
6. C. Wood, "Visualization of an incompressible wake with base bleed," *Journal of Fluid Mechanics*, vol. 29, pp. 259-272, 1967.
7. J. Nash, "A Discussion of Two-Dimensional Turbulent Base Flows. NPL Aero Rep. 1162," *British ARC, July*, vol. 20, 1965.
8. J. F. Nash, V. Quincey, and J. Callinan, *Experiments on the two-dimensional base flow at subsonic and transonic speeds*: HM Stationery Office, 1963.
9. N. Pollock, *Some effects of base geometry on two-dimensional base drag at subsonic and transonic speeds*: Department of Supply, Australian Defence Scientific Service, Aeronautical …, 1969.
10. T. Morel, "The effect of base slant on the flow pattern and drag of three-dimensional bodies with blunt ends," in *Aerodynamic Drag Mechanisms of Bluff Bodies and Road Vehicles*, ed: Springer, 1978, pp. 191-226.
11. S. Murthy, *Aerodynamics of base combustion: technical papers from the Workshop on Aerodynamics of Base Combustion, May 1974, subsequently revised for this volume* vol. 40: American Institute of Aeronautics and Astronautics, 1976.
12. S. Murthy and J. Osborn, "Base flow phenomena with and without injection- Experimental results, theories, and bibliography," *Aerodynamics of base combustion. (A 76-37230 18-02) New York, American Institute of Aeronautics and Astronautics, Inc.*, pp. 7-210, 1976.
13. R. S. Wick, "The effect of the boundary layer on sonic flow through an abrupt cross-sectional area change," *Journal of the Aeronautical Sciences*, vol. 20, pp. 675-682, 1953.