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EFFECT OF NOZZLE PRESSURE RATIO IN A SUDDENLY EXPANDED FLOW

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ABSTRACT

This paper presents an experimental investigation to study the effectiveness of micro jets to control base pressure in suddenly axi-symmetric ducts. Four micro jets of 1mm orifice diameter located at 90 °intervals along a pitch circle diameter of 1.3 times the nozzle exit diameter in the base region was employed as active controls. The Mach numbers of the suddenly expanded flows were 1.25, 1.3, 1.48, 1.6, 1.8, 2.0, 2.5 and 3.0. The jets were expanded suddenly into an axi-symmetric tube with cross-sectional area 2.56, 3.24, 4.84 and 6.25 times that of nozzle exit area. The length-to-diameter ratio of the sudden expansion tube was varied from 10 to 1. The wall pressure distribution in the suddenly enlarged duct was also measured. It is found that the micro jets can serve as active controllers for base pressure. Also, the micro jets do not adversely influence the wall pressure distribution. From the present investigation it is evident that for a given Mach number and area ratio one can identify the enlargement length to diameter ratio that will result in maximum increase/decrease of base pressure.

Keywords: Base pressure, Wall Pressure, and Nozzle Pressure Ratio

1. INTRODUCTION

The subject of base flows at high Reynolds numbers has been and continues to be an important area of research in view of its relevance in external aerodynamics. Base drag arising from flow separation at the blunt base of a body, can be sizeable fraction of total drag in the context of projectiles, missiles and after bodies of fighter aircraft; for example, the base drag component can be as high as 50 percent of the total drag for a missile with power off (i.e. with no jet flow at the base). Large-scale flow unsteadiness, often associated with a turbulent separated flow, can cause additional problems like base buffeting which are undesirable.

Because of its vide applicability, suddenly expanded flows have studied extensively. Many researchers attempted to control the base pressure with passive and some of the works relevant to the present study are reviewed in the section to follow. However, to the best of the author’s knowledge there is no work reported with active control of base pressure. Therefore, in the present study an attempt is made to investigate the base pressure control with active control in the form of micro jets.

2. LITERATURE REVIEW

Flow field of abrupt axi-symmetric expansion is a complex phenomenon characterized by flow separation, flow re-circulation and reattachment. A shear layer into two main regions may divide such a flow field, one being the flow recirculation region and the other the main flow region. The point at which the dividing streamline (Fig. 1). Strikes the wall is called the reattachment point. The effect of boundary layer on sonic flow through an abrupt cross-sectional area was studied experimentally Wicks [1953]. He observed that the base pressure in the expansion corner. was principally the same and base pressure phenomenon in external flow could be studied relatively easily by experiments with internal flowing?

Korst [1956] investigated the problem of base pressure in transonic and supersonic flow for cases in which the flow approaching the base is sonic or supersonic after the wake. He devised a physical flow model based on the concepts of interaction between the dissipative shear flow and the adjacent free stream and the conservation of mass in the wake.

Anderson and Williams [1968] worked on base pressure and noise produced by the abrupt expansion of air in duct. With an attached flow the base pressure was having minimum value, which depends mainly on the duct to nozzle area ratio and on the geometry of the nozzle. The plot for overall noise showed a minimum at a jet pressure approximately equal to that required producing minimum base pressure.

Rathakrishnan and Sreekanth [1984] studied flows in pipe with sudden enlargement. They concluded that the non-dimensional base pressure is a strong function of the expansion area ratios, the overall pressure ratios and the duct length-to-diameter ratios. They showed that for a given overall pressure ratio and a given area ratio, it is possible to identify an optimal length-to-diameter ratio of the enlargement that will result in maximum exit plane total pressure at the nozzle exit on the symmetry axis (i.e. minimum pressure loss in the nozzle) and in a minimum base pressure at the sudden enlargement plane. The separation and reattachment seemed to be strongly dependent on the area ratio of the inlet to enlargement. For a given nozzle and duct area ratio, the duct length must exceed a definite minimum value for minimum base pressure. For an optimum performance of flow through pipes with sudden expansion, it is not sufficient if the base pressure minimization alone is considered.

The effectiveness of passive devices for axi-symmetric base drag reduction at Mach 2 was studied by Vishwanath and Patil [1990]. The devices examined included primarily base cavities and ventilated cavities. Their results indicated that the ventilated cavities offered significant base drag reduction. They found 50 per cent increase in base pressure and 3 to 5 per cent net drag reduction at supersonic Mach numbers for body of revolution.

Kruiswyk and Dutton [1990] experimentally investigated the effects of the base cavity on the near wake flow field of slender two-dimensional body in subsonic speed range. Three basic configurations were investigated and compared; they are a blunt base, a shallow rectangular cavity of base of depth equal to one half of the base height. Schlierene photographs revealed that the base qualitative structure of the vortex sheet was unmodified by the presence of base cavity. The weaker vortex street yielded higher pressures in the near wake for the cavity bases, and increase in the base pressure coefficients of the order of 10 to 14 per cent. And increase in the shedding frequencies of the order of 4 to 6 per cent relative to the blunt based configuration.

[Mathur and Dutton 1996] studied the effect of base bleed on the near wake flow field of a cylindrical after body at Mach 2.5. They found that with increasing bleed flow rate, the average base pressure increases initially, attains a peak value and then decreases.

Suddenly expanded flow with control seems to be of interest with many applications. Further, there seems to be complete vacuum as far as active control of base pressure field is concerned. Therefore, it is proposed to investigate the control of base pressure field with active control in the form of blowing.

3. EXPERIMENTAL SETUP

Figure 2 shows the experimental setup used for the present study. At the exit periphery of the nozzle there are eight holes as shown in figure, four of which are (marked c) were used for blowing and the remaining four (marked m) were used for base pressure (P_b) measurement. Control of base pressure was done by blowing through the control holes (c), using pressure from a settling chamber by employing a tube connecting the settling chamber and the control holes (c). Wall pressure taps were provided on the duct to measure wall pressure distribution. First nine holes were made at an interval of 3mm each and remaining was made at an interval 5mm each. From literature it is found that, the typical L/D (as shown in Fig. 2) resulting in P_b maximum is usually from 3 to 5 without controls. Since active controls were used in the present study, L/D ratios up to 10 have been employed. For each Mach number, and L/D ratios used were 10, 8, 6, 5, 4, 3, 2, and 1 and for each value of L/D ratio nozzle pressure ratio (NPR) were 3, 5, 7, 9, and 11. PSI system 2000 Pressure transducer was used for measuring pressure at the base. It has 16 channels and pressure range 0-300 psi. It averages 250 samples per seconds and displays the reading. Mercury manometer was used for the measurement of wall pressure distribution in the duct.

4. RESULTS AND DISCUSSION

The measured data consists of base pressure (P_b); wall static pressure (P_w) along the duct and the nozzle pressure ratio (NPR) defined as the ratio of the ratio of stagnation pressure (P_0) to the back pressure (P_{atm}). All the measured pressures were non-dimensional zed by dividing them with the ambient pressure (i.e. the back pressure). In the present study the blow pressure is the same as the NPR of the respective runs. To get an insight into the effect of NPR on base at different Mach numbers and L/Ds, base pressure as a function of NPR, area ratio, Mach number and L/D is analyzed. The base pressure variation with NPR for L/D = 10 at different Mach numbers are presented in Figs. 3 to 4. The results for M = 1.25 shown in Fig. 3(a), shows that, the combination of NPR and area ratio very strongly influence the base pressure as well as control effectiveness. This may be because as the NPR increases the level of over expansion comes down, hence the oblique shock at the nozzle exit becomes weaker than those at lower NPRs. Therefore, the turning away tendency of incoming flow comes down leaving the vortex almost intact. At this situation when the micro jets are introduced they may propagate without any deflecting tendency, thereby entraining some mass from the standing vortex and convicting it away from the base pressure to assume higher values. For the largest area ratio (i.e. 6.25) the base vortex becomes progressively stronger with increase of area ratio and exhibits very low base pressure at NPR 7. After that the base pressure shows an increasing trend with NPR. This simply suggests that for a given area ratio there is specific NPR at which the reattachment length is such that the vortex at the base assumes maximum strength, causing base pressure to take low value. For lower area ratio, namely 4.84 and 3.24 some similar results are seen but the NPR at which the base pressure starts increasing is at NPR 5. Whereas, for area ratio 2.56 the base pressure increases with increase of NPR continuously. This may be because of non-availability of the required relaxing space to the expanding shear layer from the nozzle exit to attach at the optimum reattachment point to result in a strong vortex at the base.

The results for M = 1.3 are shown in Fig. 3(b). Here again we see that the area ratio and level of expansion dictates the base pressure level, also control becomes more effective with increase of favorable pressure gradient. Results for M = 1.48, 1.6, 1.8, 2.0, 2.5, and 3.0 are presented in Figs. 3(c) to 3(d) and Fig. 4. we see that up to Mach number 2, the results exhibit similar results as discussed above. Whereas for Mach numbers 2.5 and

3.0, the base pressure decreases continuously even beyond NPR 7 for all the area ratios excepting area ratio 2.56. This is because these jets are over expanded in the range of NPR of the present study.

5. CONCLUSIONS

Active Control in the form of micro jets to control base pressure has been demonstrated. The micro jets serve as an effective active controller, raising the base suction to almost zero level for some combination of parameters. There is no adverse effect of the active control on the duct flow field. The nozzle pressure ratio has a definite role to play in fixing the level of base pressure with and without control, in the supersonic jet Mach number regime too. For lower Mach numbers there is significant increase of base pressure for most of the cases, but it should be emphasized that some combination of parameters results in decrease of base pressure when control is employed. Therefore, one has to identify the proper combination of parameters to achieve the desired results.

6. REFERENCES

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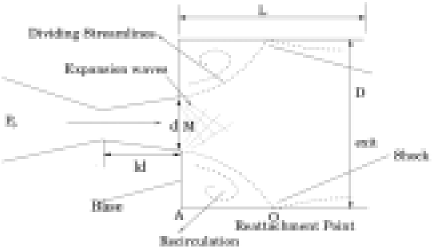

Fig.1 Sudden Expansion Flow Field

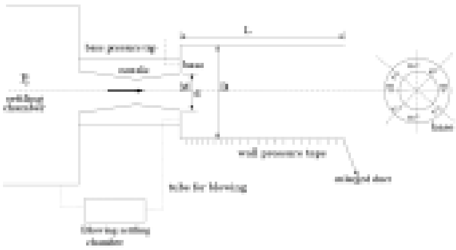

Fig.2. Experimental Setup

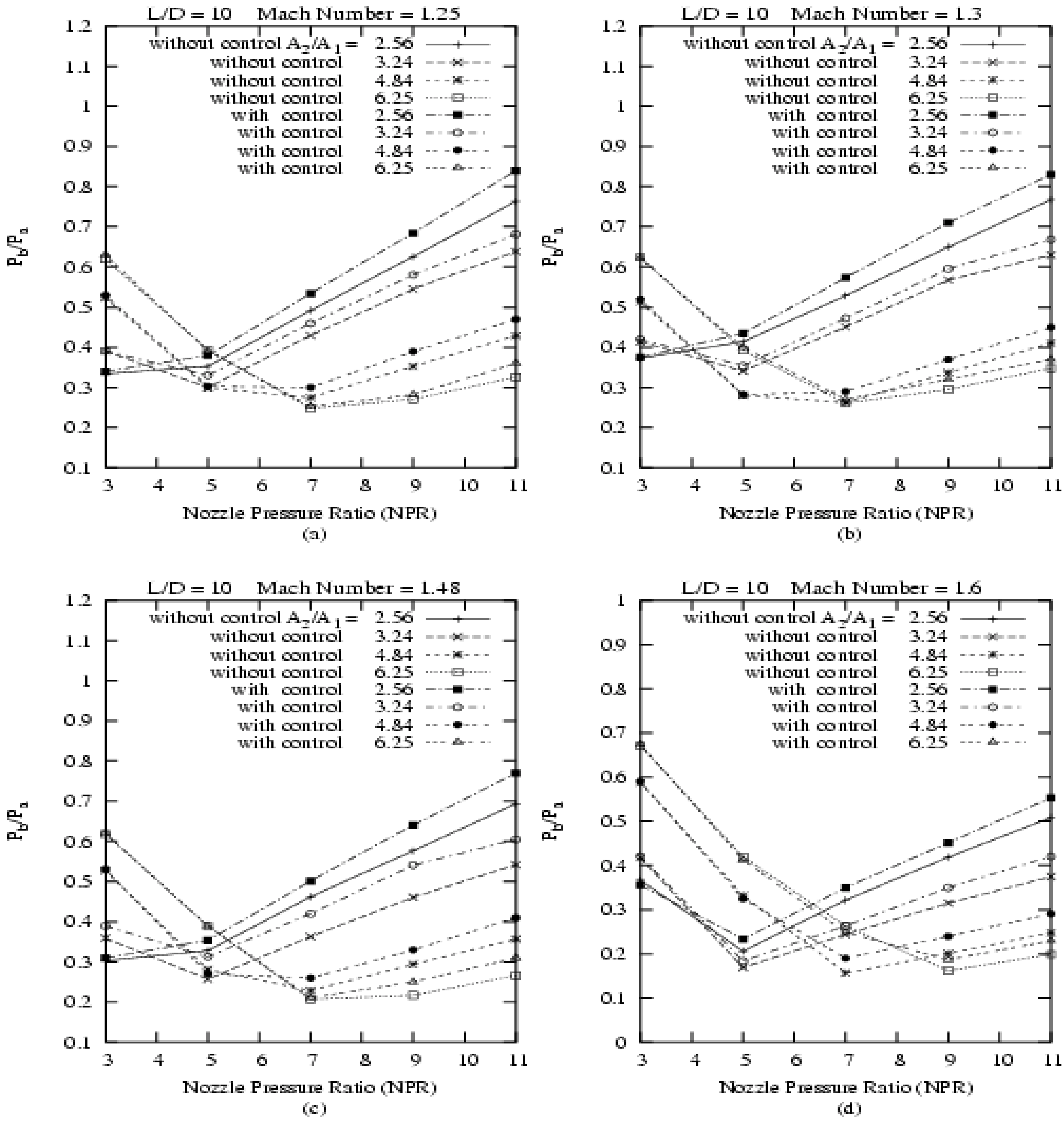

Fig. 3 Base Pressure Variation with Nozzle Pressure Ratio (NPR)

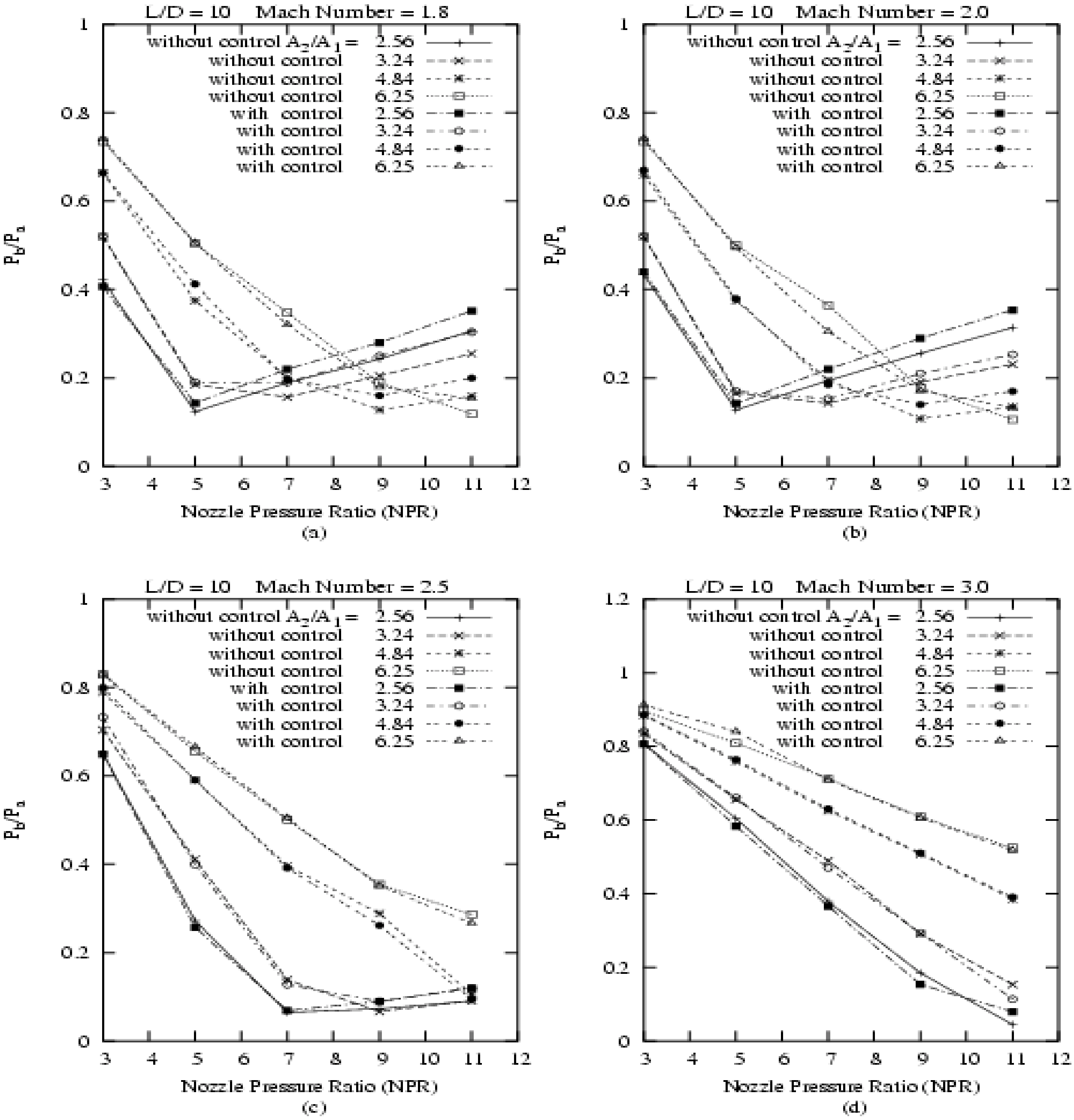

Fig. 4 Base Pressure Variation with Nozzle Pressure Ratio (NPR)