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Combined Effect of Relief and Level of Expansion in a Suddenly Expanded Flow

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Abstract : *This paper presents the experimental results on the flow characteristics of a suddenly expanded flow from the convergent nozzle for subsonic, sonic and sonic under expanded flow. In the present study micro jets were used to investigate the effect of micro jets on base pressure flow field in the enlarged duct. Accordingly an active control in the form of four micro jets of 1 mm orifice diameter located at* 90^0 *intervals along a pitch circle diameter of 1.3 times the nozzle exit diameter in the base region was employed. The NPRs of the present study are 1.5, 2.0, 2.5 and 3.0 and the area ratio (ratio of area of suddenly expanded duct to nozzle exit area) studied were 2.4, 3.61, 4.84, and 6.25. The length-to-diameter (i.e. L/D) ratio of the sudden expansion duct was varied from 10 to 1. From the results, it is seen that the flow in the base region is dominated by the waves, the general perception what we have that correctly expanded flow will be from waves is proved to be wrong; also, it is found that for L/D in the range L/D = 4, 3 and 2 the flow remains oscillatory mostly for NPRs 2.5 and 3.0. However, these oscillations are suppressed either with the increase in the L/D ratio in the range from 3 to 10 or with decrease in the level of expansion NPRs from 2.5 to 1.5. The present study explicitly reveals that, the base pressure in a suddenly expanded axi-symmetric duct can be controlled by employing micro jets under the influence of favorable pressure gradient.*

Keywords: *Active control, Area ratio, Static pressure at base, L/D ratio, Micro jets*

I. Introduction

One of the most pressing problems that arise in aircraft, shells, air-craft bombs, Missiles, and space-rocket transportation systems the design is the task of reducing the base drag which; arises due to the low base pressure at the base due to the suction created at the base region. For at least the last so many years, a research of the flow in a cylindrical channel with the sudden flow expansion was used for simulation of the flows near the aircraft's base and in the propulsion system's nozzles. Among the many problems in gas dynamics, which are related to the interaction of supersonic jets with obstacles, the flow of supersonic jets in channels with a sudden expansion is of a special kind, related to the separated, and the problem itself, in a sense, is classic. Such flows are realized in various technical devices of space-rocket laser systems: in the launch tubes of the starting plants, nozzles with a break in generating line, diffusers of tall stands and technological processing plants (lances and blowing devices of metallurgic furnaces, gas fixtures and pipes of the chemical industry). Problem of studying the sonic and supersonic separation flow with sudden flow expansion in a cylindrical duct. A phenomenon of the turbulent separation, like any natural phenomenon, appears more complex in its properties, forms and manifestation as it becomes more deeply studied. However, from a practical point of view, the study of turbulent separation made undeniable progress, whereby a developed separation and its main properties can be predicted and properly considered in the design of technical devices. The variety of real turbulent separated flows, their complex physical nature and lack of general theories lead to the need of combining the physical experiment, calculated approximations and analytical studies to a greater extent than in other areas of gas dynamics. The problem of supersonic jets' propagation in channels with a sudden expansion is traditional for applied gas dynamics. Intensification of researches in this direction is due to the practice requirements to create new transport vehicles, as well such designed for supersonic flights.

Sudden enlargement flow field is a complex phenomenon which is followed by flow separation, flow re-circulation and reattachment. The point at which the dividing streamline strikes the wall is called the reattachment point. In such a case the shear layer divides such a flow in to two main regions, one being the re-circulation region and the other the main flow region (Fig. 1).

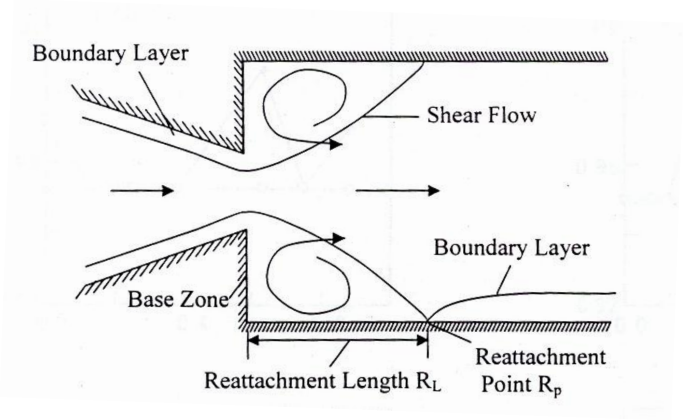

Figure 1: Sudden Expansion Flow Field

II. Literature Review

Flow through a rectangular Passage which is expanded suddenly into another rectangular duct of larger Cross-sectional area has been studied experimentally with stagnation Pressures from 3.5 atmospheres to 1.25 atmospheres by Rathakrishnan et al. [1]. The length to height ratio of the enlarged duct varied from 5.769 to 1.923 and three models with length to height ratios 5.769, 3.846, and 1.923 were studied. The influence of stagnation Pressures and length to height ratio of the enlarged duct on base pressure and flow field mean pressures in the enlarged duct is discussed. The results of the present investigation indicate that the oscillatory nature of the mean pressure flow field in the enlarged portion with rectangular cross-section is appreciably different from that for circular cross-section at similar flow conditions. Khan and Rathakrishnan [2-6] done experimental investigation to study the effectiveness of micro jets under the influence of Over, Under, and Correct expansion to control the base pressure in suddenly expanded axi-symmetric ducts. They found that the maximum increase in base pressure is 152 percent for Mach number 2.58. Also they found that the micro jets do not adversely influence the wall pressure distribution. They showed that micro jets can serve as an effective controller raising the base suction to almost zero level for some combination for parameters. Further, it was concluded that the nozzle pressure ratio has a definite role to play in fixing the base pressure with and without control. The effectiveness of micro jets to control the base pressure in suddenly expanded axi-symmetric ducts is studied experimentally by Ashfaq et al. [7-19]. From the experimental results, it was found that the micro jets can serve as active controllers for base pressure. From the wall pressure distribution in the duct it found that the micro jets do not disturb the flow field in the enlarged duct. They presented the results of experimental studies to control the base pressure from a convergent nozzle under the influence of favourable pressures gradient at sonic Mach number. The area ratio (ratio of area of suddenly expanded duct to nozzle exit area) studied are 2.4, 3.61, 4.84 and 6.25. The L/D ratio of the sudden expansion duct varies from 10 to 1. They concluded that, unlike passive controls the favourable pressure gradient does not ensure augmentation of the control effectiveness for active control in the form of micro jets. Wall pressure was measured and it is found that the micro jets do not disturb the flow field in the duct rather the quality of flow has improved due to the presence of micro jets in some cases.

III. Experimental Procedure

Fig. 2 shows the experimental setup used for the present study. At the exit periphery of the nozzle there are eight holes as shown in Fig. 2, 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 achieved by blowing through the control holes (c), using pressure from a settling chamber by employing a tube connecting the main settling chamber with the control 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 4 mm each and remaining was made at an interval 8 mm 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 are used in the present study, L/D ratios up to 10 have been employed.

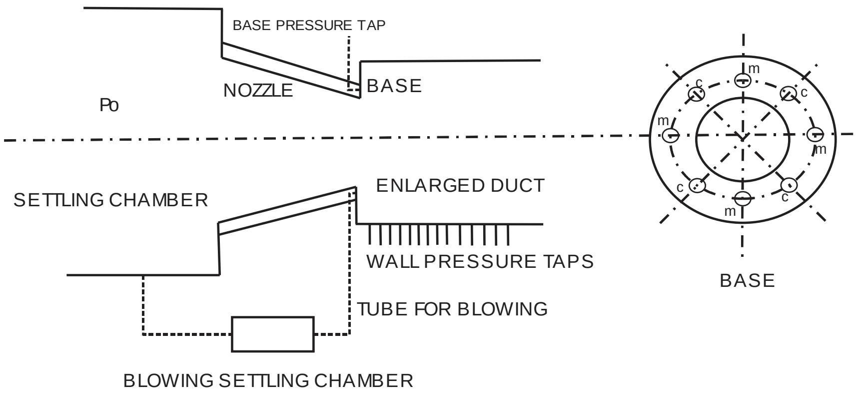

Figure 2: Experimental Setup

The experimental setup of the present study consisted of an axi-symmetric nozzle followed by a concentric axi-symmetric duct of larger cross-sectional area. The exit diameter of the nozzle was kept constant (i.e. 10 mm) and the area ratio of the model tested were 2.4, 3.61, 4.84, and 6.25 defined, as the ratio of the cross-sectional area of the enlarged duct to that of the nozzle exit. Different area ratios were achieved by changing the diameter of the enlarged duct. The suddenly expanded ducts were fabricated out of brass pipe. Model length was ten times the inlet diameter so that the duct has a maximum L/D = 10. The lower L/Ds were achieved by cutting the length after testing a particular L/D.

PSI model 9010 pressure transducer was used for measuring pressure at the base and the stagnation pressure in the settling chamber. It has 16 channels and pressure range is 0-300 psi. It averages 250 samples per second and displays the reading. The software provided by the manufacturer was used to interface the transducer with the computer. The user-friendly menu driven software acquires data and shows the pressure readings from all the 16 channels simultaneously in a window type display on the computer screen. The software can be used to choose the units of pressure from a list of available units, perform a re-zero/full calibration, etc. The trans-ducer also has a facility to choose the number of samples to be averaged, by means of dipswitch settings. It could be operated in temperatures ranging from -20° to +60° C and 95 per cent humidity.

IV. Results And Discussion

The measured data consists of static pressure at base (P_b); wall static pressure (P_w) along the duct and the nozzle pressure ratio (NPR) defined as the ratio of stagnation pressure (P_0) to the back pressure (P_{atm}). All the measured pressures will be non-dimensionalized by dividing them with the ambient pressure (i.e. the back pressure). In the present study the pressure in the control chamber will be the same as the NPR of the respective runs since we have drawn the air from the main settling chamber.

To study the combined effect of the level of expansion and area ratio on static pressure at base some plots of static pressure at base variation vs. L/D for different area ratios and Nozzle pressure ratio at sonic flow conditions are revealed in Figs. 3 to 10. NPRs considered are 1.5, 2, 2.5 and 3 are for different combinations of length to dia. ratio, area ratios. From the Fig. it is observed that, level of static pressure at the base just gets reversed when the NPR is changed in the range from 1.5 to 3. For a given inertia level and the level of expansion nozzle (NPR) which controls the expansion level has a strong effect on the control mechanism usefulness of the control mechanism by the micro jets. Also, it is observed that with the increment in the level of expansion, the control mechanism becomes more pronounce and tends to increase the static pressure at the base.

Results indicate that one need to identify the optimum parameters of Mach number, NPR, L /D, and area ratio to achieve desired static pressure at the base with and without control.

Results for L /D = 10 are shown in Fig. 3 and it is evident from the Fig. that for lower NPRs the base pressure assumes very high values for all the area ratio, however; with increase in NPR level of expansion changes and the pressure is progressively decreases. At NPR 3, control mechanism gives the maximum increase in the base pressure value. This could be due the presence of pressure gradient which; happens to be favorable to the flow. From literature, it observed that either active or passive control they become effective in the presence of favorable pressure gradient.

Results for duct length to diameter ratio of L /D = 8 are presented in Fig. 4; they too exhibit the similar results with the exception that the magnitude of static pressure at the base has increased, even though the trend remains the same.

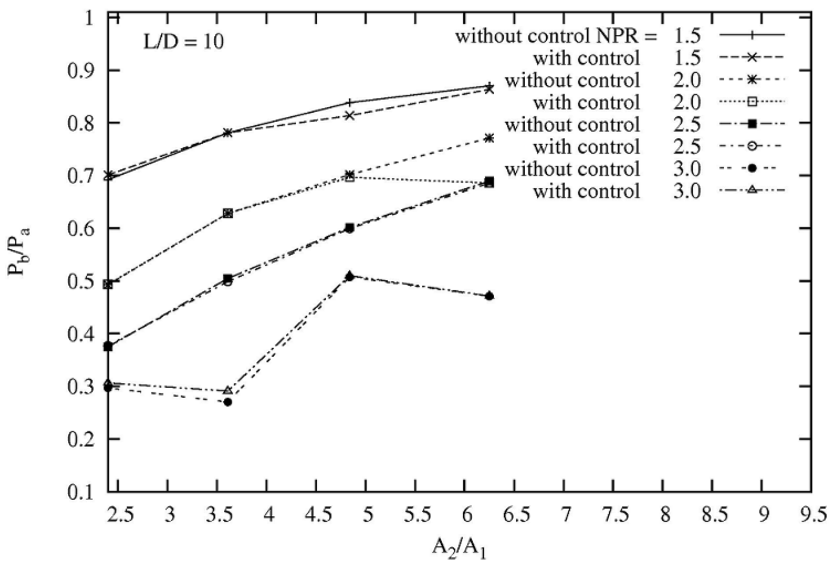

Figure 3: P_b/P_aVariation vs. Area Ratio

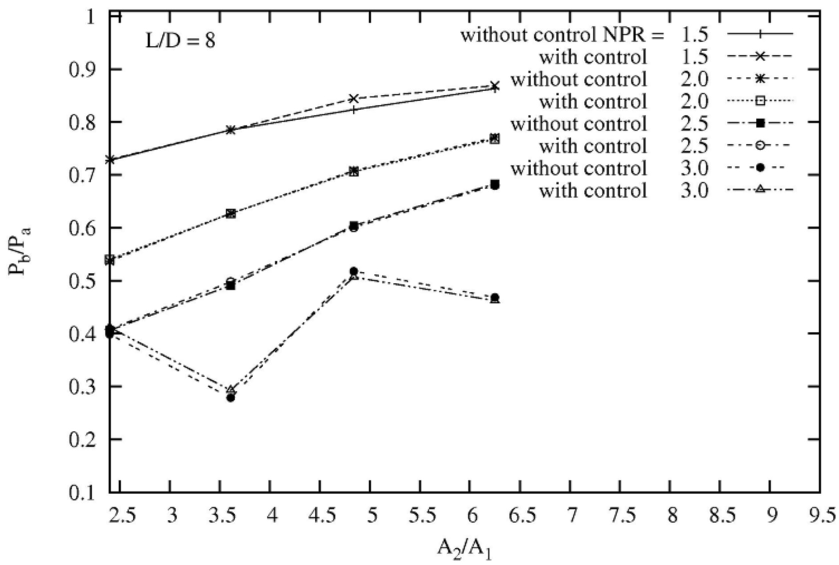

Figure 4: P_b/P_aVariation vs. Area Ratio

The reasons for the increase in static pressure at the base may be due to decreased duct length and also, the effect of the back pressure which; will influencing the flow field.

Fig. 5 presents the base pressure results for L/D = 6. From the Fig. it is found that with increase in the Nozzle Pressure ratio the base pressure value decreases continuously at the same time for a given fixed level of expansion with the increase in relief the base pressure increases progressively. However, at the highest level of NPR of the present study the base pressure results are oscillatory in nature; this peculiar trend is due to the presence waves when the jets are under expanded and formation of these waves will continue till the base pressure attains the value nearly closed to the back pressure. Fig. 6 shows base pressure results for L/D = 5, the trend is on the similar lines.

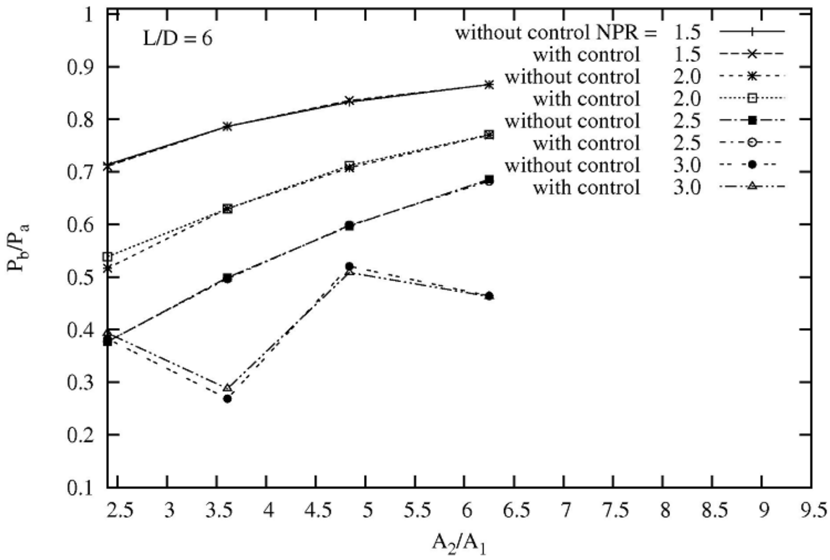

Figure 5: P_b/P_a Variation vs. Area Ratio

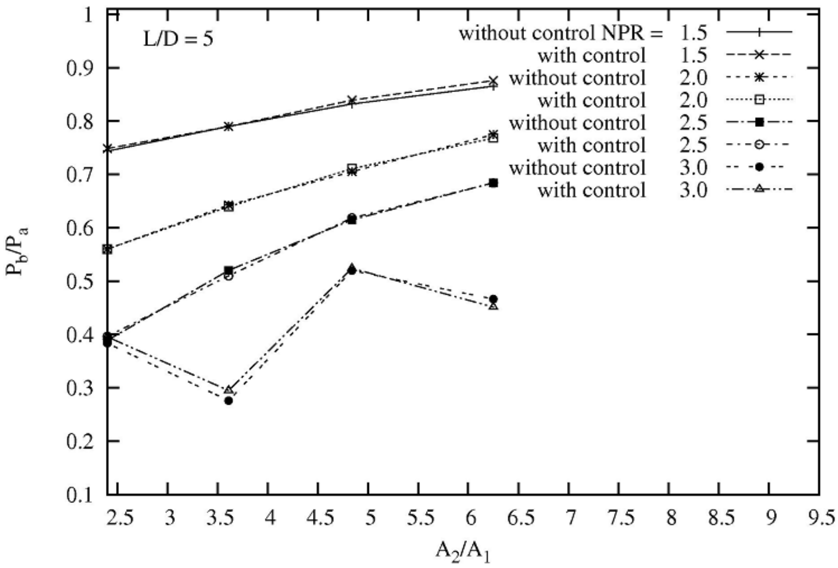

Figure 6: P_b/P_a Variation vs. Area Ratio

Fig. 7 shows results for L/D = 4. From the Fig. it is seen that results for NPRs 1.5 and 2 are on the similar lines as it was observed for higher L/Ds. However, for NPR 2.5 and 3 the trend is different, this may due the combined effect of the short length of the enlarged duct and the influence of the back pressure which has made flow oscillatory for NPR = 2.5.

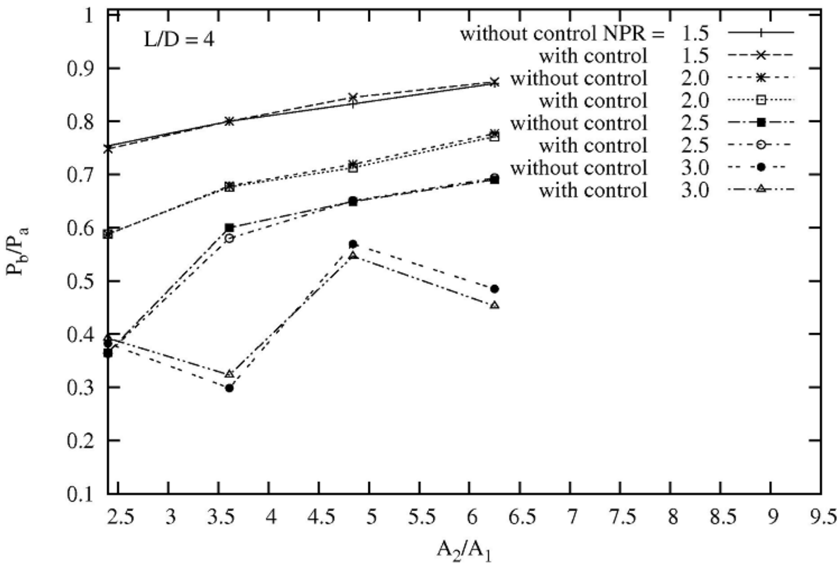

Figure 7: P_b/P_a Variation vs. Area Ratio

Results for L /D = 3 are shown in Fig. 8. At lower NPRs ranging 1.5 to 2, static pressure at base has got high values as compared to the similar results for high L/D ratios, it may be due the combined effect of the presence of the waves in the flow field, variation in relief, and the effect of the back pressure. However, for NPRs in the range 2.5 and 3.0 for lowest area ratio namely area ratio 2.4 static pressure at base has got lowest value, later with increase in the area ratio, the reattachment length will increase, since; the level of inertia is the same, hence the vortex positioned at the base will remain the same, and increase in area ratio will result in increase of relief available to the flow, which; in turn will increase static pressure at the base, as the base vortex cannot generate the suction in the base region which; it could do for lower area ratios. These are the possible reasons for this trend. L/D = 3 seems to be lowest pipe length needed for flow to remained attached with pipe wall for area ratios 4.84 and 6.25, never the less for the area ratios 2.4 and 3.61 the lowest duct length needed is L/D = 2 as shown in Fig. 9. Results for L /D = 1 are shown in Fig. 10, as seen from the Fig. that duct length is not enough for the jet to be remain attached to the wall and it behaves like a free jet without getting influenced by the base region.

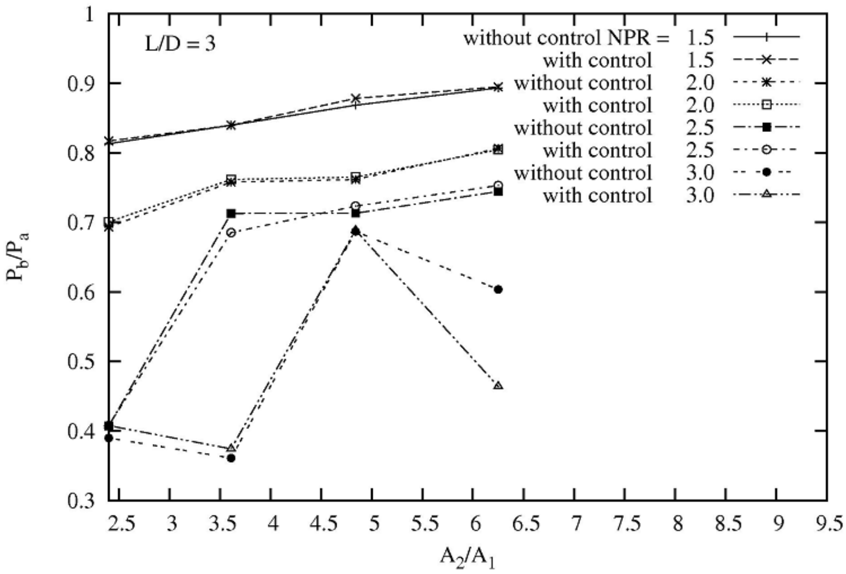

Figure 8: P_b/P_a Variation vs. area ratio

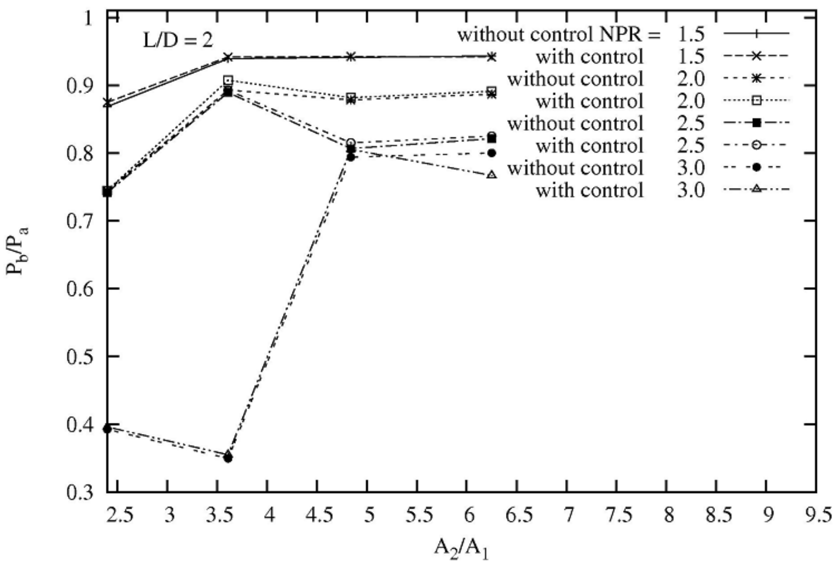

Figure 9: P_b/P_aVariation vs. Area Ratio

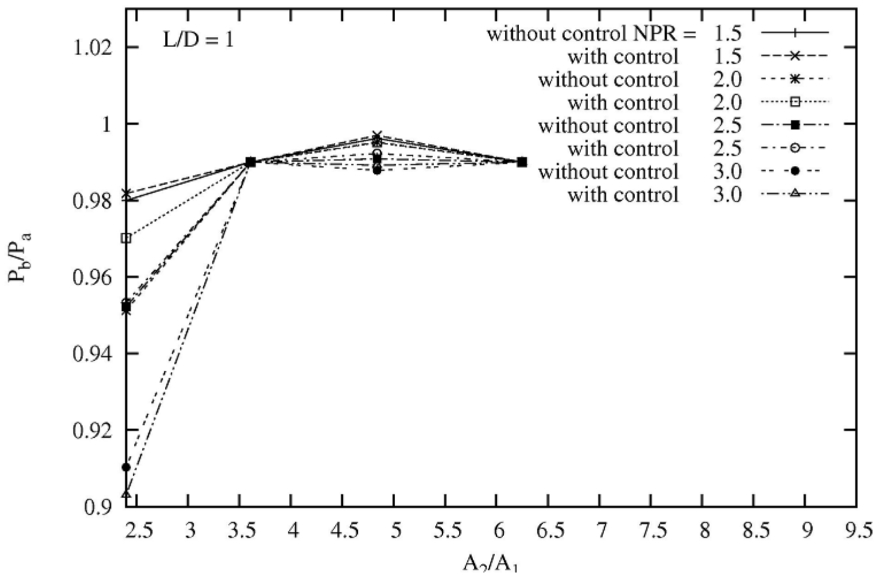

Figure 10: P_b/P_aVariation vs. Area Ratio

V. Conclusion

From the above results we can draw the following conclusions:

- The flow field in the wall duct is dominated by the presence of waves, reflection from the wall, recompression and recombination's.
- The flow from the nozzle with correct expansion is not free from the waves as it can be seen from the base pressure flow field for NPRs 2.5 and 3.
- The flow field is oscillatory within the base region and beyond the reattachment points the development of the flow and the base pressure recovery is very smooth. This happens for L/D = 10, 8, 6, 5 and 4 only.
- With increase in the Nozzle Pressure Ratio which; results in decrease in base pressure and also results in increase of base pressure progressively with increase in area ratio from 2.4 to 6.25.
- The minimum duct length requirement seems to be L/D = 2 for the Lower NPRs namely 1.5 and 2.0, however, L/D = 3 seems to be the minimum duct length required for all the parameters of the present study.

References

[1] E. Rathakrishnan, T. J. Ignatius and Channa Raju, An experimental study of Suddenly Expanded Flow field, Mechanics Research Communications, Vol. 18(1), 1991 pp. 1-9.

[2] S. A. Khan and E. Rathakrishnan, Active Control of Suddenly Expanded Flows from Over expanded Nozzles, International Journal of Turbo and Jet Engines (IJT), Vol. 19, No. 1-2, 2002, pp. 119-126.

[3] S. A. Khan and E. Rathakrishnan, Control of Suddenly Expanded Flows with Micro Jets, International Journal of Turbo and Jet Engines (IJT), Vol. 20, No.2, 2003, pp. 63-81.

[4] S. A. Khan and E. Rathakrishnan, Active Control of Suddenly Expanded Flow from Under Expanded Nozzles, International Journal of Turbo and Jet Engines, (IJT), Vol. 21, No. 4, 2004, pp. 233-253.

[5] S. A. Khan and E. Rathakrishnan, Control of Suddenly Expanded Flow from Correctly Expanded Nozzles, International Journal of Turbo and Jet Engines (IJT), Vol. 21, No. 4, 2004, pp. 255-278.

[6] S. A. Khan and E. Rathakrishnan, Control of Suddenly Expanded Flow, Aircraft Engineering and Aerospace Technology: An International Journal, Vol. 78, No. 4, 2006, pp. 293-309.

[7] Syed Ashfaq, S. A. Khan and E. Rathakrishnan, Active Control of Flow through the Nozzles at Sonic Mach Number, International Journal of Emerging Trends in Engineering and Development, Vol. 2, Issue-3, 2013, pp. 73–82.

[8] Syed Ashfaq and S. A. Khan, Sonic Under Expanded Flow Control with Micro Jets, International Journal of Engineering Research and Applications, Vol. 3, Issue-6, 2013, pp. 1482-1488.

[9] Syed Ashfaq, S. A. Khan and E. Rathakrishnan, Control of suddenly expanded flow for area ratio 3.61, International Journal of Advanced Scientific and Technical Research, Issue 3 volume 6, Nov.-Dec. 2013, pp. 798-807.

[10] Syed Ashfaq and S. A. Khan, Experimental Studies on Low Speed Converging Nozzle Flow with Sudden Expansion, International Journal of Emerging Technology and Advanced Engineering, Volume 4, Issue 1, 2014, pp. 532-540.

[11] Syed Ashfaq and S. A. Khan, Effect of Mach number on Wall Pressure Flow Field for Area Ratio 2.56 , IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Vol. 11, Issue 2, 2014, pp. 56-64.

[12] Syed Ashfaq, S. A. Khan, E. Rathakrishnan, Control of Base Pressure with Micro Jets for Area Ratio 2.4, International Review of Mechanical Engineering (IREME), Vol. 8, N. 1, 2014, pp. 1-10.

[13] Syed Ashfaq, S. A. Khan, Studies on Flow from Convergent Nozzle with Sudden Expansion and Control Effectiveness under the Influence of Micro Jets, International Journal of Research in Mechanical Engineering and Technology (IJRMET), Vol. 4, Issue 1, 2014, pp. 76-87.

[14] Syed Ashfaq, S. A. Khan, Influence of Micro Jets on Wall Pressure for Area Ratio 3.24, International Journal of Emerging Technology and Advanced Engineering, Vol. 4, Issue 2, 2014, pp. 872-880.

[15] Syed Ashfaq, S. A. Khan, Experimental Investigation of Flow through Convergent Nozzle and Influence of Micro Jets on the Enlarged Duct Flow Field, IPASJ International Journal of Mechanical Engineering (IIJME), Vol. 2, Issue 3, 2014, pp. 7-14.

[16] Syed Ashfaq and S. A. Khan, Studies on Flow from Converging Nozzle and the Effect of Nozzle Pressure Ratio for Area Ratio of 6.25, International Journal of Engineering & Advanced Technology (IJESAT), Volume 4, Issue 1, 2014, pp. 49-60.

[17] Syed Ashfaq and S. A. Khan, Studies on Wall Pressure Flow Control by Micro Jets for High Area Ratio, International Journal of Engineering & Advanced Technology (IJESAT), Volume 4, Issue 1, 2014, pp. 664-672.

[18] Syed Ashfaq and S. A. Khan, Studies on Wall Pressure of Sonic Flow through the Converging Nozzles for Different Area Ratios, International Journal of Emerging trends in Engineering and Development, (IJETED), Issue 4, Volume 2, 2014, pp. 125-137.

[19] Syed Ashfaq and S. A. Khan, The Effect of Micro Jets on Wall Pressure for Sonic under expanded Flow, International Journal of Engineering Research and Applications (IJERA), Volume 4, Issue 3, 2014, pp. 32-38.