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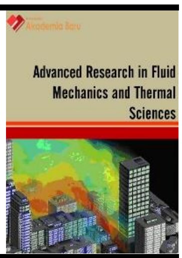

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Threaded Spikes for Bluff Body Base Flow Control

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ABSTRACT

Although the demand for rockets and missiles has increased exponentially but the problems of the gas dynamics related to these vehicles remains to be a challenge. The main problem is high-pressure associated with the shock wave in front and low-pressure recirculation bubble attached behind the vehicle at the blunt base. This barrier of wave drag due to the shock waves and the drag due to the bubble leads to a huge amount of the fuel consumption and high fluctuations in the flow field of the enlarged duct. This paper focuses mainly on the base drag and experimentally investigated the effect of the passive control in the form of the threaded spikes for bluff bodies as the base flow controller. Two threaded spikes of length 40 mm opposite to each other and attached to a control plate of diameter 80 mm and thickness 1 mm are at pitch circular diameter of 23 mm and slot of 10 mm X 10 mm at the center, placed between the nozzle and the duct to act as the passive controller. The Mach numbers considered for the investigation in the subsonic regime were 0.6, 0.7 and in the transonic regime were 0.8, 0.9 for the enlarged duct cross-sectional area of 625 mm2 and the exit area of the nozzle considered was 100 mm2. The lengths of the enlarged duct were 100 mm, 150 mm and 200 mm. The passive control and regulating the base pressure by threaded spikes were found very efficient without any adverse effect on the flow field of the enlarged duct.

Keywords:
Base flows, threaded spikes, wall pressure, Mach number

1. Introduction

Separation for high-speed vehicles starts after the sudden expansion at the edge of the blunt base when the streamlines nearest to the wall surface has no support. Thus, the boundary layer separates and falls downstream to a point known as reattachment point. Between separation and reattachment, a zone with the viscous and rotational flow field associated with huge loss of energy is formed. This zone is known as low pressure zone or recirculation zone resulting in huge amount of the base drag. The low pressure behind the vehicles can amount to as high as 50 % of the total drag when the jet engine is not fired [1]. To decrease the fuel consumption and to increase the vehicles

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range, an effective base drag controller is needed. In this study an attempt has been made by experimental investigation to manipulate the base pressure by passive control in the form of threaded spike.

1.1 Background about Base Flows behind Bluff Bodies

Base flows are characterized behind bluff bodies as the low pressure recirculation zone, the reversed flow due to the boundary layer and the vortex shedding [2]. The bluff bodies are non-aerodynamic bodies and are found in the internal as well as in the external flow applications [3] as shown in Figure 1. Some of bluff bodies are cylinders [4], bricks and aero foils etc. at high angle of attack because behind these bodies drag is dominated by the pressure component at high Reynolds number.

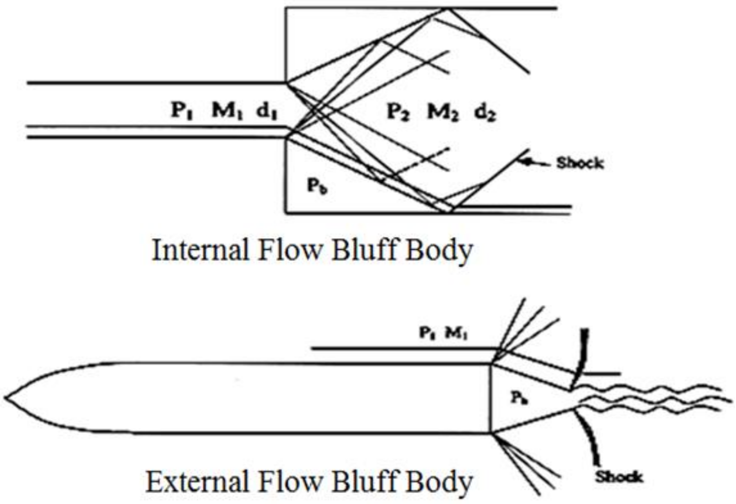

Fig. 1. Internal and External Flow Bluff Body

Thus, to control these flow separation, vortex shedding, vibration, reverse flow leading to the instability an effective controller is needed.

1.2 Background about Controls

To suppress these instabilities a control method can be generalized in the two main categories. The passive methods which is fixed and can be achieved by the geometrical changes and does not require any extra source of energy. Whereas, the active control which can be implemented on demand, but it requires additional source of energy. The instabilities after the flow separation leads to a very complex flow phenomenon, flow structure and the flow pattern in the enlarged duct [5]. Passive control by the static cylinder [6], the splitter plate [7], and the cavities [8] etc. to reduce the base drag for the bluff bodies has been used. Also, the aero spikes traditionally were used to control the wave drag but for the first time in this study is used by Khan *et al*., [9] to control the base pressure behind bluff bodies. The active control such blowing from the micro jets [10], and the dynamic cylinder etc. have been used. A part from the experimental investigation, researchers have used numerical methods and the CFD analysis to correlate the base drag with flow Mach numbers [11], geometric parameters [12] for high-speed compressible flows and CFD simulation also been used to analyses the Mach number and flow parameter for supersonic regimes [13,14]. Some researcher used both passive [15] and active [16] controller depending on the flow regime. So, by increasing the base pressure we decrease the base drag by either with passive or active control methods. The literature is available for flow behind bluff bodies but threaded spikes to control the low- pressure zone at the base at high Mach numbers has never been studied. We propose to use threaded spikes for the case of the bluff bodies to control the base drag.

2. Experimental Arrangement

This work is extension of aero spike Khan *et al*., [9] used to control the base drag behind the bluff bodies. The objective of the present work is to control the base drag by acquiring base pressure data at different Mach numbers and employing the passive control mechanism to control it. Also, the wall pressure readings are equally important to check the influence of the control mechanism on the flow field of the enlarged duct.

2.1 Requirement

The experimental setup requires an internal flow apparatus consisting of the settling chamber, the storage tank, the nozzle, the enlarged duct, and the pressure sensors. Data Acquisition system is used data reading (DAQ) and the LabVIEW software. Compressed dry air from the storage tank is vented to the settling chamber using a pressure regulator valve and in to the nozzle. Further expansion takes place through the area ratio of the enlarged duct of area ratio of 6.25 mm^2. The flow inside the settling chamber reaches in equilibrium and the pressure reaches stagnation conditions. The various parts of the experimental setup have been shown in Figure 2 and the flow chart in Figure 3 describes the schematic.

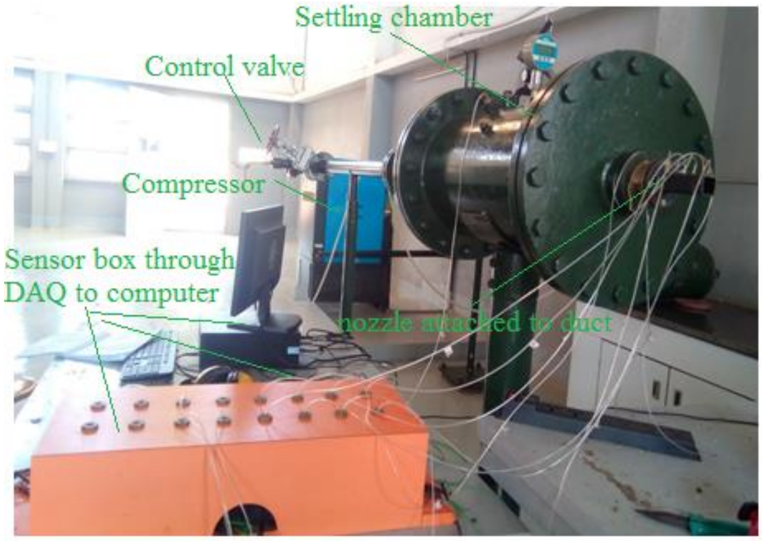

Fig. 2. Experimental Setup

The Mach number varied are from 0.6, to 0.7 for the case of the subsonic flows and 0.8, 0.9 for the transonic flows for a fixed length of the duct as 100 mm, 150 mm, and 200 mm. Threaded spikes are used as the control mechanism and was tested for all the ducts length and for all the Mach number regimes. DAQ PSI model 9205 is used for measuring the base pressure, wall pressure and the stagnation pressure in the settling chamber. It has 16 channels and pressure range is approximately 0-150 psi. It averages 250 samples per seconds and displays pressure readings from all the channels simultaneously on the computer screen. Virtual instrumentation software is used as an interface between the DAQ, the Sensors and the computer. Our focus is mainly on the base pressure variation with the increase in the Mach number for with and without control cases.

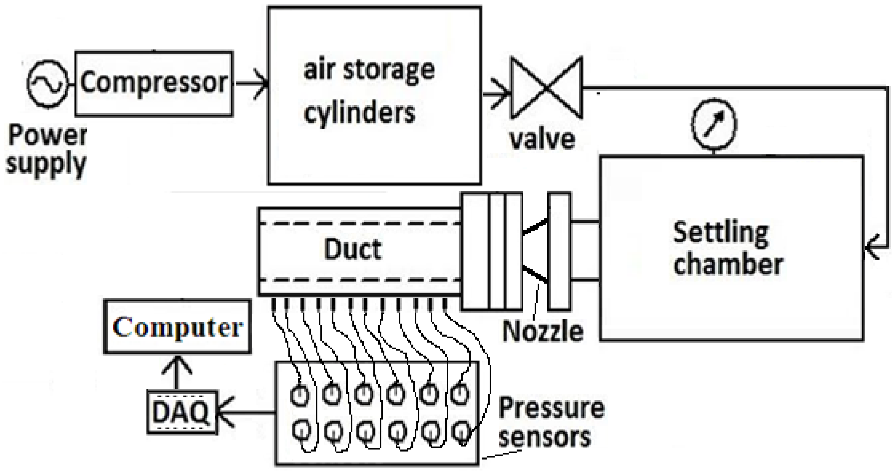

Fig. 3. Schematic description of experimental Setup

2.2 Fabricated Models

In the present study, the converging nozzle is fabricated from the brass. Ducts used were of low-grade steel pipe and the area ratio of square duct to the square nozzle (Figure 4) is 6.25.

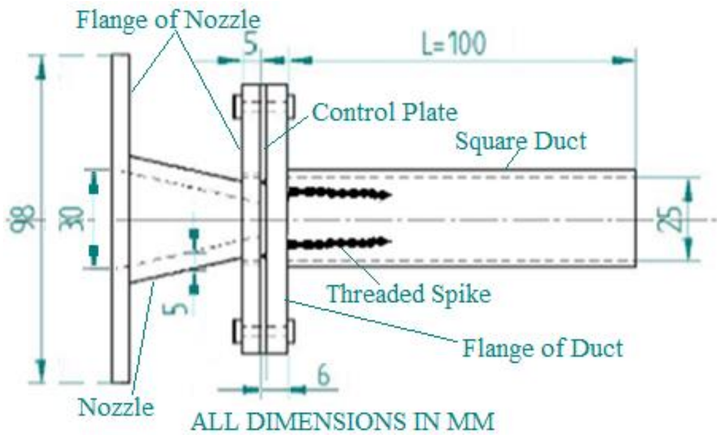

Fig. 4. Square nozzle and threaded control plate

Two threaded spikes have been shown and the diameter of the spike is 3 mm and the length is 40 mm. Figure 5 shows the geometry of the passive control used in the present study in the form of threaded spikes. It is seen that two threaded spikes are placed diameterly opposite to each other. Two pressure sensors are used for the base pressure measurement and they were placed inside a circular hole of 1 mm. The passive control used in the present investigation brazed with the control plate/flange.

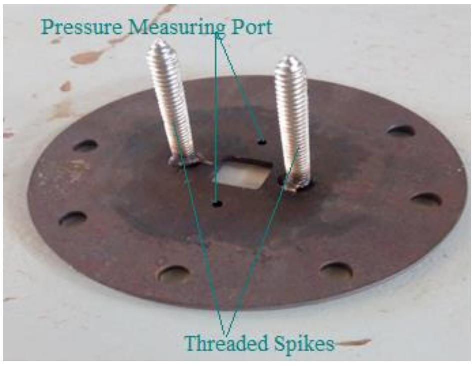

Fig. 5. Control plate with threaded spike

Table 1 describes the technical details and the specification of the passive control mechanism. Nozzle was fabricated out of the solid brass rod. The suddenly enlarged duct was made up of low-grade steel. Threaded spikes were made of hardened steel. Control plate was fabricated from mild steel having 1mm thickness. Length and diameter of the spikes were 40 mm and 3 mm respectively. The passive control in the form of the threaded spikes was located with an inward angle of two degrees. The suddenly expanded duct was having square cross-section of side 25 mm and the cross-sectional area of 625 mm^2 with area ratio of 6.25.

Table 1
Technical Specification of Control Mechanism

No	Design Feature	Specification
1	Nozzle Material	Brass
2	Duct Material	Low-grade Steel
3	Spike Material	Hardened Steel
4	Control Plate	Threaded Spike
5	Length of Spike	40 mm
6	Diameter of Spike	3 mm
7	Inward angle of Spike	2^o
8	Nozzle Exit Area	100 mm^2
9	Duct Area	625 mm^2
10	Bluff Angle	15 ^{o}
11	Control Plate Thickness	1 mm
12	Measuring Port Diameter	1 mm

Figure 6 shows 4 sensing point on the nozzle to measure the base pressure. Further it is attached with a locking mechanism as shown in green to the settling chamber.

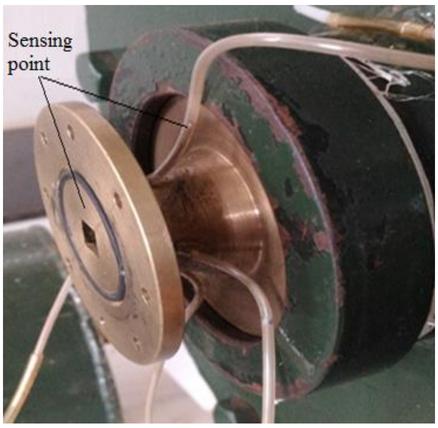

Fig. 6. Control plate with spike plate

Figure 7 displays the enlarged ducts of length 100 mm, 150 mm, and 200 mm respectively along with pressure tabs. The wall pressures are measured for the lengths of duct and at different tab positions.

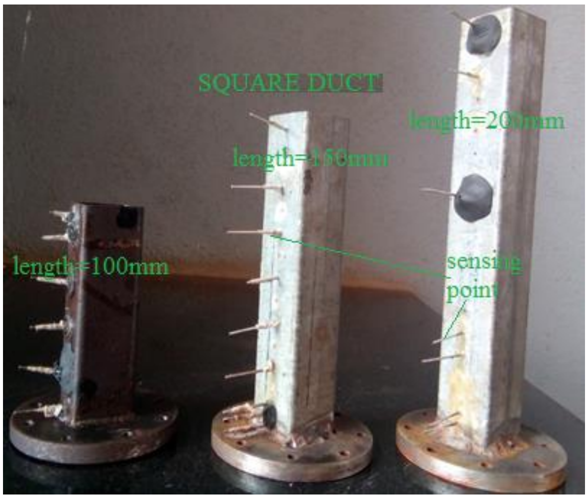

Fig. 7. Different L/W ratio ducts

3. Results

3.1 Base Pressure Measurement

The base pressure variation with the Mach number for different L/W = 4 are shown in Figure 8 For L/W = 4, the trend of graph shows that, the base pressure is dependent on the Mach number.

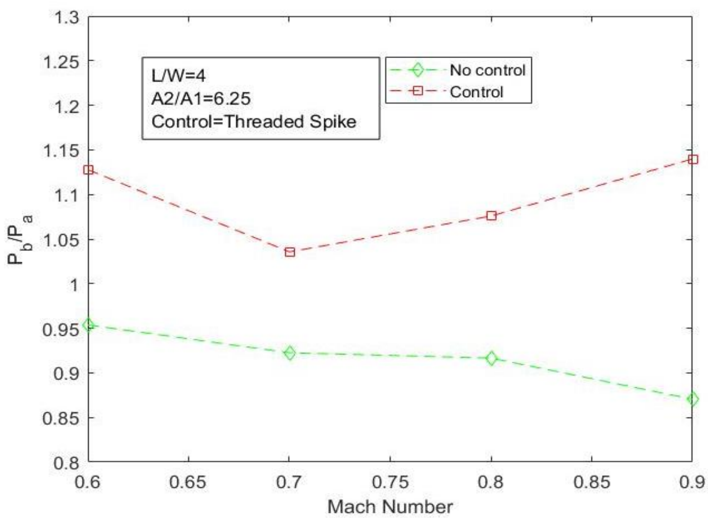

Fig. 8. Variation of Base Pressure against Mach number for L/W = 4

For higher Mach number the base pressure values without control are low but when the control is employed the magnitude of the base pressure assumes higher values. Which implies that at higher Mach number when the base pressure is low, that leads to higher drag, under these conditions when the control is introduced it becomes very effective. For Mach 0.6 to 0.7 the control is not that marginally effective but after 0.7 to 0.9 the control shows substantial increase in the base pressure.

The trend of the base pressure for L = 6W, are shown in Figure 9 which shows the usual trend of decrease in base pressure with increase in Mach number without controls but with controls the base pressure assumes very high value which is more than the ambient pressure right from the Mach 0.6 and at Mach 0.9 the base pressure value is 30 % more than the atmospheric pressure. These results will be useful as at these transonic Mach number the base drag is maximum.

Figure 10 too shows the similar trends as discussed earlier that the base pressure decreases with the increase in the Mach number. However, when the passive control in the form of treaded spikes were used the base pressure increases with increase in Mach number. Once again it is found that it assumes a large value at the beginning itself and finally results in 30 % more than the ambient atmospheric pressure. Hence, as the Mach number increases, the drag increases, so the requirement for the control too increases and in this case the control has been very effective to increase the base pressure, thus reducing the base drag.

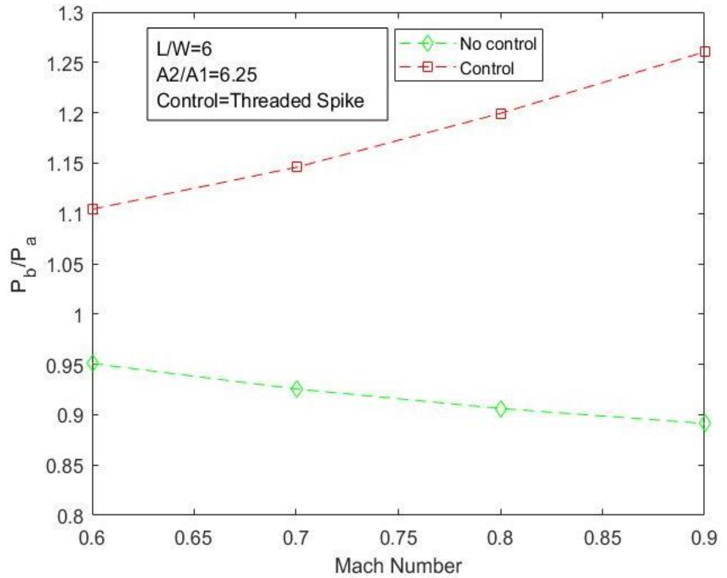

Fig. 9. Variation of Base Pressure against Mach number for L/W = 6

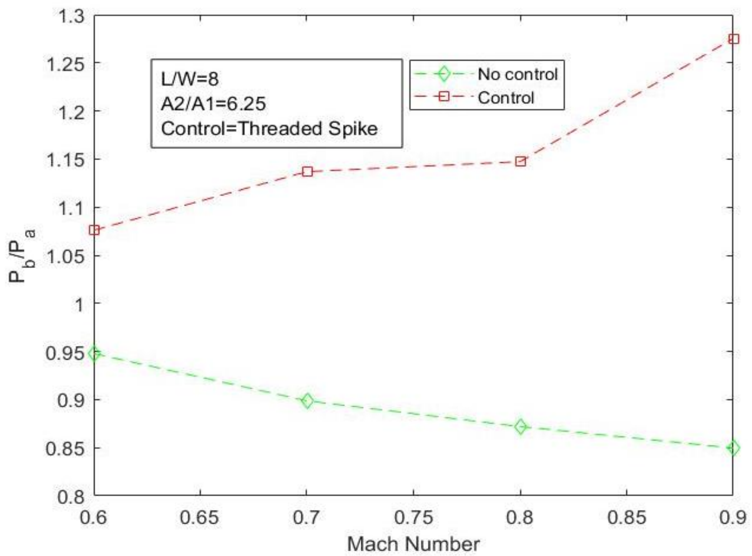

Fig. 10. Variation of Base Pressure against Mach number for L/W = 8

3.2 Wall Pressure Measurement

After abrupt change in the area of the bluff bodies, the flow field might become oscillatory as shown by the wall pressure flow nature in the duct.

So, it becomes very important to study these fluctuations in the duct flow field. It is seen from the Figure 11 that for a duct of area ratio of 6.25, L/W = 4 at different Mach number the passive control near dead zone is marginally oscillatory in nature but later in the downstream once it crossed the reattachment length the oscillatory nature has come down. This is due to a very effective increase in base pressure but at X/L = 0.89 the base pressure/wall pressure with control and without control for all Mach numbers are nearly same except for Mach no. 0.7 as shown in the red colour. Thus, shows there are no adverse effect on the main field of the jet for all the Mach numbers. So qualitatively the flow field is quite stable for all the Mach numbers of the present investigations.

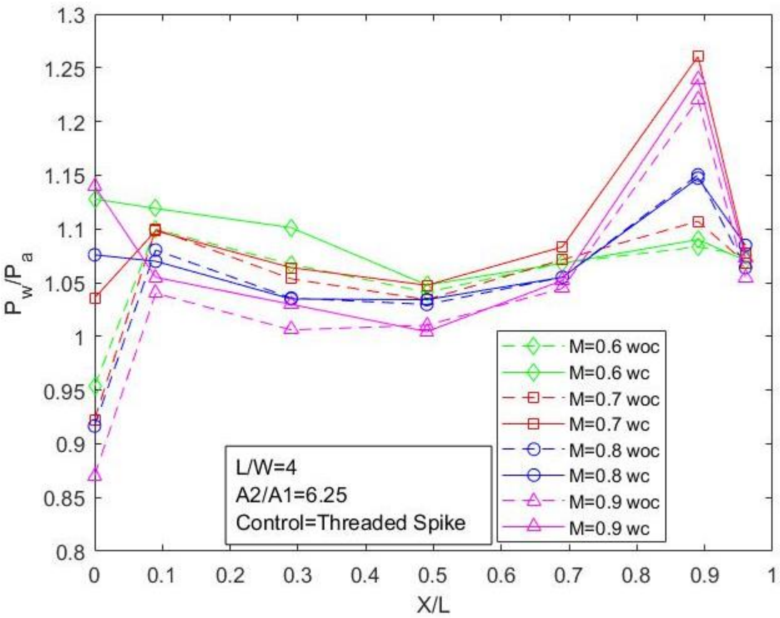

Fig. 11. Wall pressure variation at different regimes for L=4W

Figure 12 shows that for a duct of area ratio 6.25, L/W = 6 and different Mach numbers the oscillations damped out and the passive control in the form of the threaded screw does not adversely influence the base pressure. At X/L = 0.7, the trend with and without control are different for Mach number 0.6. For all the other cases the difference is negligible.

Thus, shows that there is no adverse effect on flow field but at higher Mach number such as 0.7, 0.8 and 0.9 some oscillations are observed, and this may be due to the inertia level at these Mach numbers.

From Figure 13 for a duct of area ratio 6.25 and L/W = 8 the trend of the wall pressure along the duct length for all Mach number are nearly same with and without control but for Mach 0.6 at X/L = 0.3, 0.5 and 0.7 are oscillatory in nature. The control reversal takes place at X/L = 0.45. All other curves except at Mach 0.6 and 0.7 which has the highest variation at X/L = 0.7. Thus, our passive control with threaded spike is working very well without disturbing the main flow.

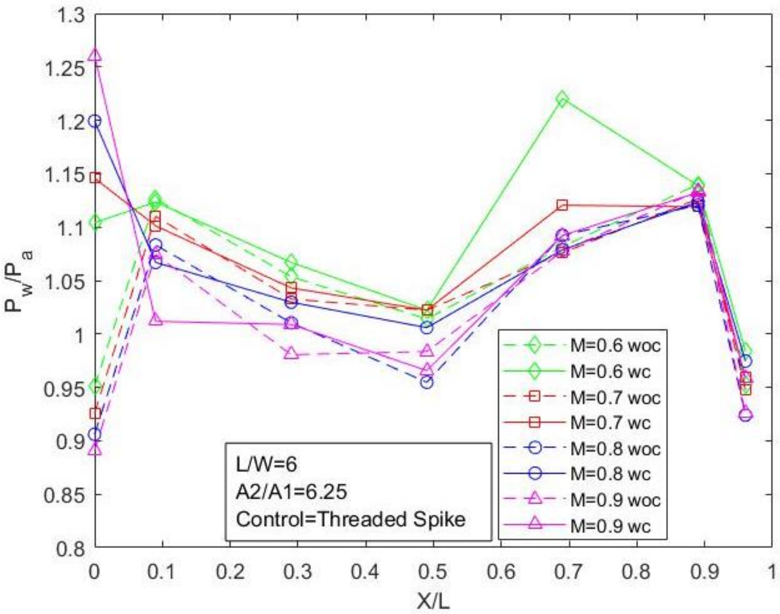

Fig. 12. Wall pressure distribution for L = 6W

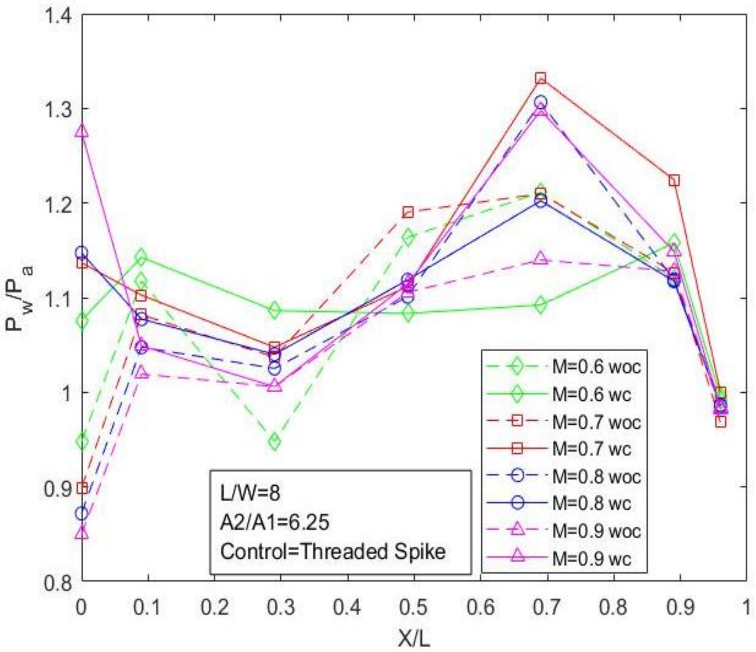

Fig. 13. Wall pressure variation at different regimes for L = 8W

4. Conclusions

From the above discussion, we conclude that for wide range of L/W ratio for different Mach numbers at constant area ratio the base pressure is strongly influenced by the flow parameters such as Mach number, Duct area ratio, and the nozzle pressure ratio. The threaded spike was very efficient in regulating the Base pressure and hence the base drag. This could be attributed to the increase in skin friction due to threads on spike which broke the large and small eddies in to very weak and small eddies, thus increasing the base pressure very effectively even in transonic regimes. The data obtained in this investigation shows the dependency of base pressure on Mach number. For wall pressure distribution, we can clearly indicate that it does not adversely affect the flow field with and without control.

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