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PASSIVE CONTROL OF BASE DRAG IN COMPRESSIBLE SUBSONIC FLOW USING MULTIPLE CAVITY

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ABSTRACT

Compressible flow in a suddenly expanded square duct was investigated experimentally to assess the effectiveness of the passive control in the form of the cavities. The flow parameters studied were the Mach number, nozzle pressure ratio, L/W ratio, and area ratio. The test were conducted for multiple cavities and without multiple cavities. From experimental results it is seen that the multiple cavity has a very good effect in reduction of base drag by decreasing the base suction and hence increasing the base pressure. From experimental investigation it is found that for all the L/W ratios the effect of multiple cavities are able to control the base pressure, further, it was seen that with the increase in the duct length control is becoming very effective. The wall pressure in the duct indicates that the passive control in the form of cavity do not disturb the flow field in the duct.

KEYWORDS: Wall Pressure, Base Flows, Cavity, Mach number & Square Duct

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Original Article

INTRODUCTION

The backward facing step (BFS) is one of the most fundamental configurations to study flow separation and following attachment which occurs due to the sudden expansion in the flow passage. The existence of flow separation and reattachment plays an important role in many engineering applications such as combustors, diffuser, electronic and turbine blade cooling as well as in external flows such as aircraft. For this reason, several studies on the flow separation and reattachment of the BFS geometry have been presented numerically and experimentally by many researchers in the past decades. Among these studies, the effect of Reynolds number, step height, aspect ratio has been reported for the 2D and 3D flows, which brought to insight for understanding the flow characteristics of the BFS configuration. Their attachment point spreads within a certain span along the streamwise distance, which is referred to as the reattachment zone. These three regions in whole, comprise the important features of a BFSX flow that can be altered or controlled to achieve desired outcome, such as, enhanced mixing characteristics and reduced drag, noise and vibrations. Hence it is essential to understand these flow features to control the parameter of interest to study the wake characteristics of a BFS flow. With the advancement in technology and the recent discovery of the coherent structures in the shear layers more research has shifted their interests to studying these turbulent structures. Suddenly expanded flows occur when a body moving with a certain speed subjected to suddenly expanded flows on the external force of the body, flow circulation, reattachment and operation of flow may take place. When a flowing fluid over a body detached it forms a region between the fluid and a body, this region with low pressure behind the body, this region with low pressure behind the body in which a separated streamline strikes the body then it is called as reattachment point.

The model is designed by using solid edge as a design tool. The Nozzle used in experiments is a square nozzle which can attain Mach=1. All the ducts are designed with the same width and height, which is 25×25mm the lengths of ducts are 4W, 6W and 8W. A plate having three cavities on the same side at a distance of 7.5mm is placed between one side of the nozzle and the duct. Figure 1 shows the dimension of Nozzle, duct and control plate.

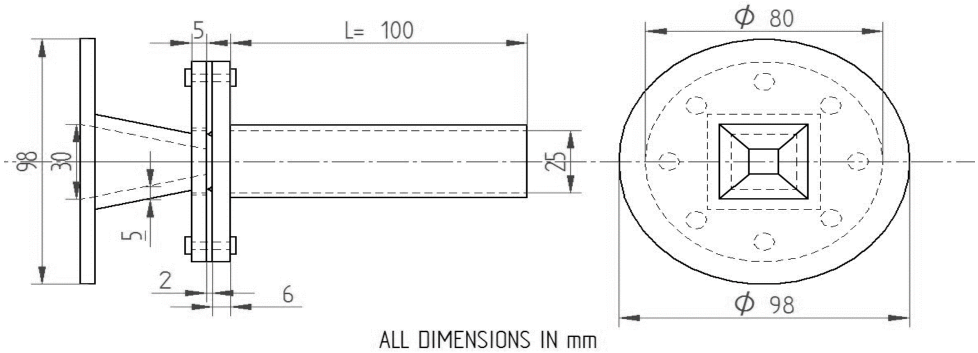

Figure 1: Design and Dimensions of Nozzle and Duct

LITERATURE REVIEW

Anderson et al., worked on base pressure and noise produced by the sudden expansion of air. The base pressure was having minimum value, with an attached flow, which depends solely on area ratio and on the geometry of the nozzle. The results have shown that for overall noise was lowest at a jet pressure nearly equal to that essential for generating minimum base pressure [1]. The e□ectiveness of passive devices for axisymmetric base drag reduction at Mach 2was studied by Viswanathet al., the devices examined included primarily base cavities and ventilated cavities. Their results showed that the ventilated cavities o□ered significant base-drag reduction. They found 50 per cent increase in base pressure and 3 to5 per cent net drag reduction in supersonic Mach numbers for a body of revolution [3]. Ramamurthy studied cavitation effects on the flow past backward facing steps. He concluded cavities an effective passive control but could not explain about the nature and type of cavity [4]. Khan et al., experimentally examined the effectiveness of micro jets for over, under, and correct expansion to control the base pressure in suddenly expanded ducts at moderate and high supersonic speeds. The result thus produced showed that the maximum gain in the base pressure is 152 percent of Mach number 2.58. The result also indicated that the micro jets do not augment the wall pressure field. They showed that micro jets can function as an effective controller raising the base suction to almost zero level in some special cases. Further, it was concluded that the nozzle pressure ratio has a major role to play in fixing the base pressure with and without control[8].

Martin analyzed the drag reduction induced by the addition of a multiple cavity at the base of a bluff body. The multiple cavities, placed at the base of a bluff body. The multiple cavities, placed at the base of the body have a beneficial effect on body drag reduction and wake randomness. When compared with single cavity, original body and multiple cavity. It is seen that in both cases co-efficient decreases by adding a cavity at the body base, presenting an asymptotic behavior with the cavity depth. Shorter cavity depth is needed to achieve the same drag co-efficient in the case of the multiple cavity [9]. Ratha reported that the Armaly has explained the existence of three recirculation regions, two at the bottom wall and one at the top wall downstream of the step[10]. Guo investigated numerical study of active flow control over a Hypersonic backward facing step using supersonic jet in near space. He studied the influence of altitude and active flow control on BFS flow. He used boundary layer thickness, recirculation region length, and lean angle of the primary recirculation region to evaluate the flow characteristics [11]. Pearce studied ventilated cavity flow over a Backward-facing step, Tasmania 7250, Australia. Cavity length was found to be linearly dependent on ventilation rate and to decrease with increasing boundary layer thickness/Reynolds number[12]. Aradayfrom the studies, it can be concluded that active control is not as effective as passive control techniques since it only performs around 5db of decrease in pressure fluctuation. However the active control has an inherent advantage of being able to adapt to changing conditions, whereas passive control is more effective, but they are not adjusted. Once implemented cannot be changed. From the above review, we can clearly see that much work has been done to understand the physics of flow over a BFS problem, but very few investigations are done to my understanding with passive controls. With this objective we are controlling the base pressure with passive control using multiple cavities in high speed flow regimes [13].

The aim of this paper is to determine the effect of multiple cavities on base pressure because of variations in Mach number, length/width ratio for compressible subsonic flow and transonic flow, and also, the effect of multiple cavity as a passive control device on the flow development in the base area and its effect on base drag in compressible subsonic flow and transonic flow.

EXPERIMENTAL SETUP

Figure 2 shows the experimental setup used for present study. At the exit periphery of the nozzle there are four holes for measuring base pressure (P_b). Control of base pressure was achieved by using dimple. Wall pressure taps were provided on the duct to measure wall pressure distribution. First five holes were made at an interval of 5 mm each and remaining was made at an interval 10mm and20mm each. Data acquisition system consists of sensors, DAQ measurement hardware, and a computer with programmable software. Compared to traditional measurement systems, PC-based DAQ systems exploit the processing power, productivity, display, and connectivity capabilities of industry-standard computers providing a more powerful, flexible, and cost-effective measurement solution.

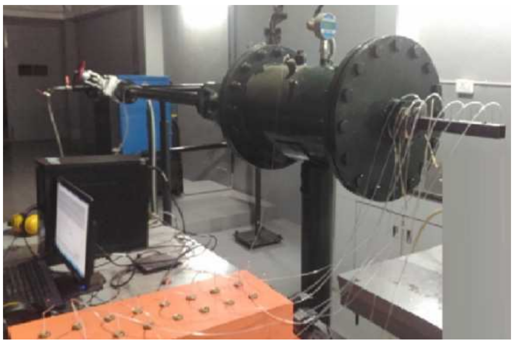

Figure 2: Experimental Setup

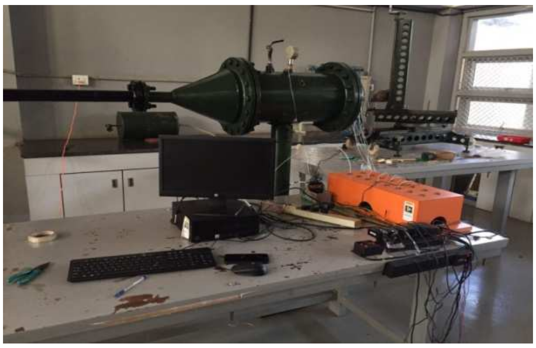

Figure 3: DAS

Dimension of the Plate and Ducts

The cavities which have been made on the plate of 80mm in diameter of thickness 2mm, with a square duct of 10×10mm. It also consists of a measuring hole of 2mm at a distance of 23mm from the center. The cavities are 1.5mm in diameter and are at a distance of 7.5mm from the center, with 0.5mm away from each other. Holes of 4mm diameter, which are equidistant from each other at 70mm diameter. The ducts which have been used are of various lengths 4W, 6W, and 8W which consists of pins at various intervals to find the wall pressure in the duct of 25×25mm.

RESULTS AND DISCUSIONS

Effect of Mach Number on Base Pressure at Different L/W at Fixed Area Ratio

The figure 4-6 shows that, Mach number strongly impacts the base pressure and also influences the control. For higher Mach number the base pressure is low, i.e. high drag and control are very effective. For low Mach number the base pressure is high i.e. low drag and control are not effective at all for L=4W.

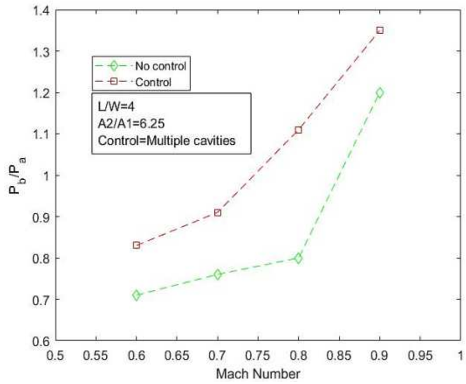

Figure 4: Base Pressure v/s Mach Number Plot for Duct L=4W

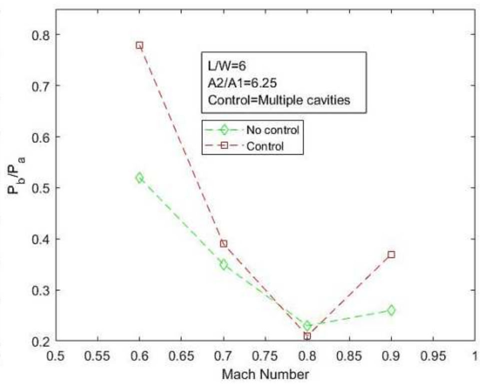

Figure 5: Base Pressure v/s Mach Number Plot for Duct L=6W

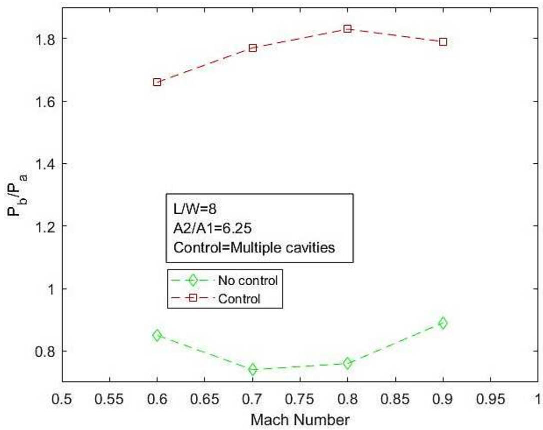

Figure 6: Base Pressure v/s Mach Number Plot for Duct L=8W

Wall Pressure Results

After sudden expansion behind backward facing step, the flow field might become oscillatory shown by wall pressure distribution in enlarged duct. So, it becomes very important to see that our control is not enhancing these oscillations.

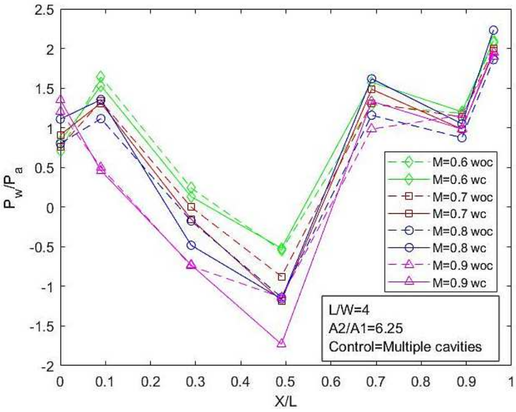

Figure 7: Wall pressure v/s X/L Plot for Duct L=4W

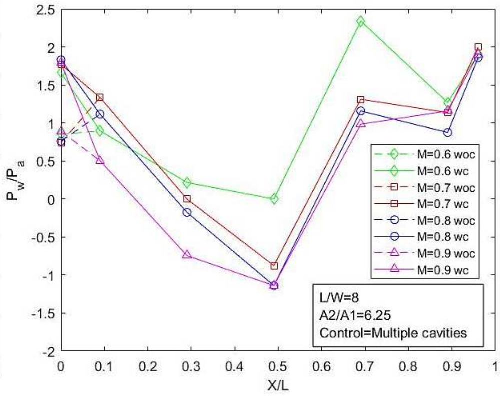

Figure 8: Wall pressure v/s X/L Plot for Duct L=8W

CONCLUSIONS

Compressible flow over a backward facing step was investigated experimentally; flow is studied for a wide range of Mach number and L/W ratio for multiple cavities and without multiple cavities situation. The following conclusions can be drawn. From experimental results the multiple cavity has a very good effect in reduction of base drag by controlling base pressure and observed for all L/W ratios 4W, 6W and 8W that the effect of multiple cavities in controlling base pressure is positive in nature. As the length of the duct increases gradually, the control is getting very effective. From figure 7 and 8, the wall pressure is not getting affected by the use of multiple cavities for 6W and 8W. The fluctuation in 4W duct wall pressure is unpredictable. From this at a low L/W ratio the wall pressure gets affected by using multiple cavities. The base pressure is strongly influenced by geometric parameters such as L/W ratio. For a given Mach number one can identify the optimum enlargement length to width ratio, which will result in a maximum increase/decrease of base pressure.

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