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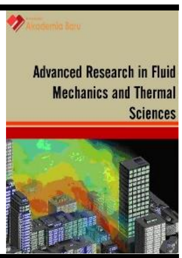

Grooved Cavity as a Passive Controller behind Backward Facing Step

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ABSTRACT

A semicircular grooved cavity is designed for controlling the base pressure and hence the base drag in case of a backward facing step. This paper presents the effect of the continuous grooved cavity to control the base pressure for various compressible subsonic flow to minimize the base drag. Grooved cavity of 1.5 mm radius at 45o along pitch circular diameter of 23 mm in the base region is employed as passive controller. The test is conducted for Mach 0.6, 0.7, 0.8 and 0.9. The square nozzle of side 10 mm with an angle of incidence as 150 on all four side from which the flow suddenly expands to a square duct of side 25 mm acts as backward facing step model. The experimental investigation is carried out for three ducts of length equivalent to 4, 6 and 8 times width. The results of this investigation provide grooved cavity at 45o as a very effective passive control mechanism to regulate the base flows, further at higher Mach numbers it may be associated with minor effect on the main flow field.

1. Introduction

The decrease of high pressure at nose and increase of low pressure at base was investigated using breathing blunt-nose concept in supersonic speeds [3]. The high pressure drag is wave drag and low pressure drag is base drag. We in our investigation have focused only on low pressure drag at the base. The low pressure behind the high speed objects can result in more than 50 % of the total drag in no-jet condition [4]. Thus, making effective control to reduce base drag becomes demand of today's world for high speed vehicles. This base drag is due to the low pressure in the base corner is a depressed recirculation zone which can be best studied using backward facing step. In our investigation, an attempt has been made to study the gas dynamic problem of recirculation zone in the vicinity of recirculation zone for compressed flows with internal flow apparatus.

1.1 Previous Study about Cavities

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Cavities of different shapes and sizes have been studied by many researchers with a purpose to reduce drag. Some have worked on passive cavities while others on active cavities. Others have worked on discontinuous cavities and yet another on continuous cavities. Effect of solid and ventilated base cavities on drag was investigated by varying the depth of cavities and the results were positive and negative depending on the depth [5]. So it means that the geometric parameters play a vital role. Research shows reduction of drag by using single and multiple cavities at base of D-shaped body [6]. Also cavities are known to reduce skin friction drag [7] but skin friction is not always favorable for base drag. So, it becomes very important for researcher to investigate on different shapes and sizes which results in increase or decrease of the drag. However, most of the previous studies were mainly focused on the reduction of skin friction drag but a few literature to the authors knowledge focus on base drag reduction with the cavities. Therefore, in the present work, a new type of grooved cavity at 45° is used as passive controller for the case of a backward facing step to reduce the base drag. The aim of the present study is to reduce the reattachment length so as to stabilize the flow field of the separated shear layer. The results reveal that the semi-circular lobes enhance the turbulent mixing and the shear layer growth rate downstream of the backward facing step and hence, they significantly reduce the reattachment length by about 75 percent [8].

1.2 Previous Study about Base Drag behind BFS

The Instabilities in separated flows make it very complex and researchers used passive means by fixing rib, fence, splitter plate, cavities etc. to reduce the base drag in the case of the backward-facing steps [9]. Some researchers used active methods such as periodic suction and injection [10], counter flow blowing [11], micro jets [12], plasma actuator [13]. Passive and active methods for drag reduction behind the bluff bodies for incompressible subsonic flow was studied by [14]. CFD analysis on effect of geometric [15] and flow parameters [16] was investigated for supersonic flows as well. Yet again some used both active [17] and passive controller [18] depending on the flow regime.

So, by controlling the base pressure by either passive or active control we reduce the base drag. Thus, enormous literature can be found regarding the base drag reduction for flow in a backward facing step but nowhere can we find the use of grooved cavities in low pressure zone at high Mach numbers. We propose to use semicircular grooved cavities for the case of the backward facing step to control the base drag as shown in Figure 1.

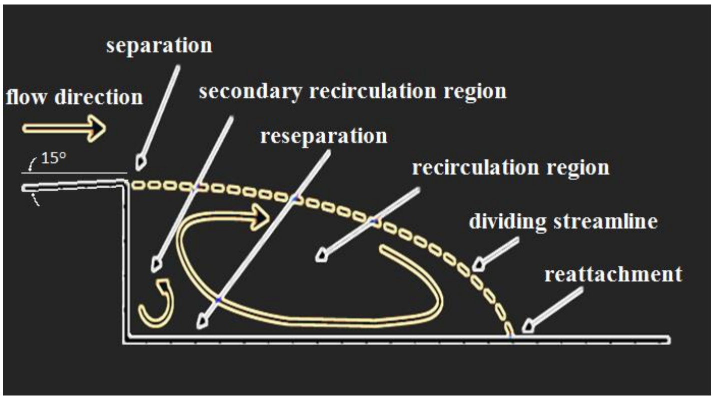

Fig. 1. Mixed flow field behind Backward Facing Step

2. Experimental Setup

To find correlation between Mach number and the base pressure for different geometric length and area, the measurement of the pressure at base and stream wise direction is necessary. The current experimental setup consists of internal flow apparatus, storage tank, compressor, nozzle, duct pressure sensors etc. Readings using (Data Acquisition System) DAQ and LabVIEW software are recorded.

2.1 Internal Flow Apparatus

Compressed dry air from storage tank is channelled through settling chamber using a control valve in to the nozzle. Further expansion takes place through the nozzles of dimensions (10mm x 10mm) to the enlarged cross-section of (25mm x 25mm). The flow is in equilibrium inside the settling chamber and the pressure is the stagnation pressure. The various parts have been shown in Figure 2 and the flow chart in Figure 3. describes the overall schematic.

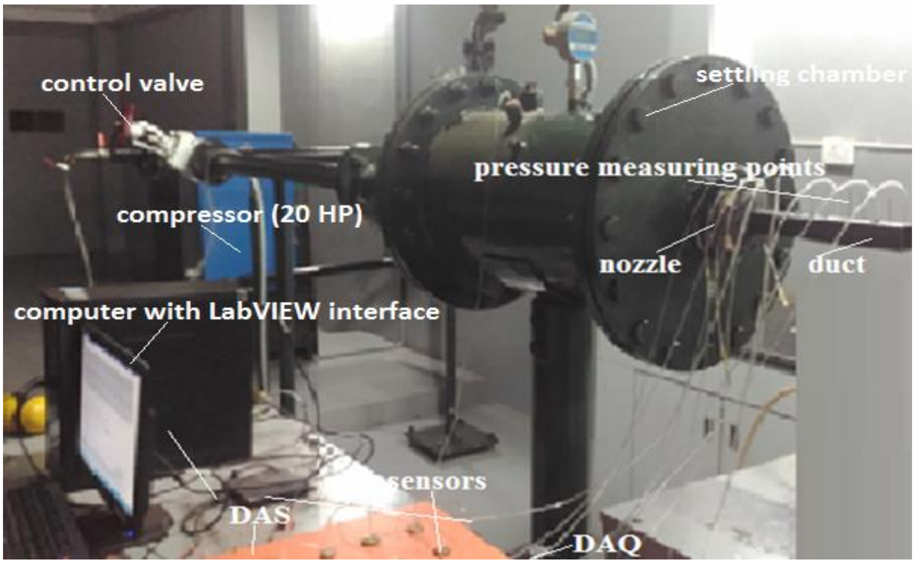

Fig. 2. Experimental Setup

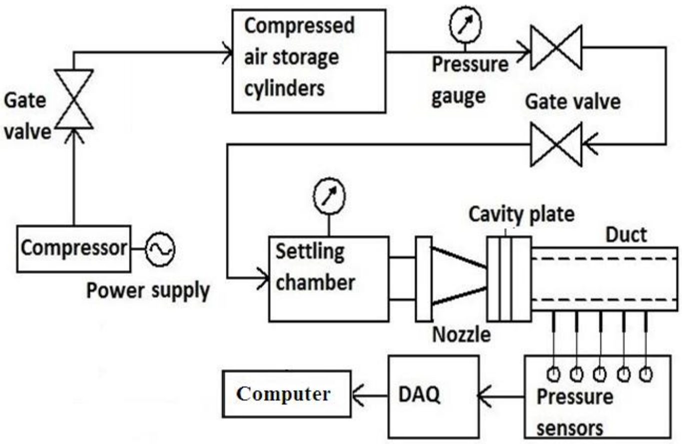

Fig. 3. Schematic description of experimental Setup

The Mach number varied are 0.6, 0.7, 0.8 and 0.9 for fixed length as 4W, 6W and 8W. Grooved cavity is used as the control mechanism and was tested for all ducts from 4W to 8W and for all Mach numbers from 0.6 to 0.9. Pressure transducer 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 in a window type display on the computer screen. LabVIEW software is used as an interface between DAQ, Sensors and computer. Our focus is mainly on how the flow parameter (Mach number) influences the base pressure.

2.2 Fabricated Models

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

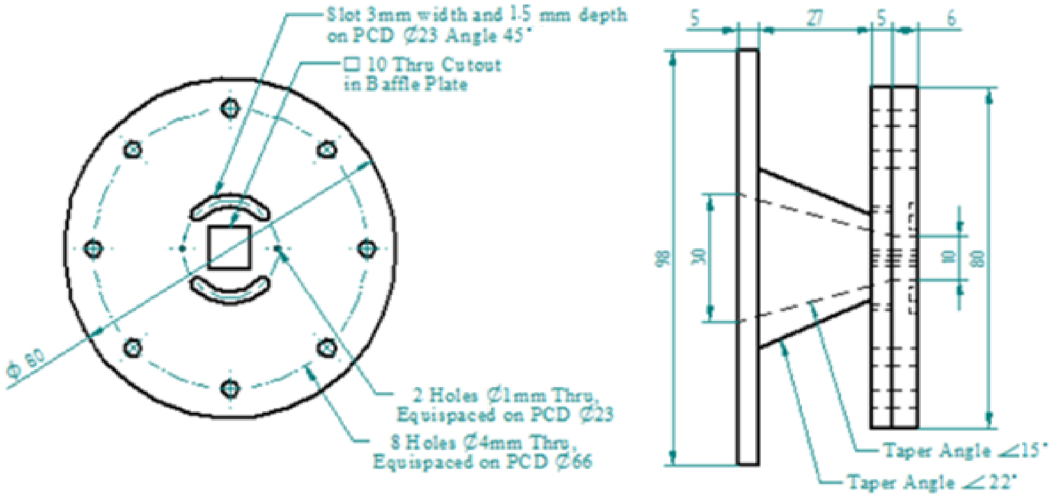

Fig. 4. Square nozzle and grooved control plate

Also, two grooved cavities have been shown. The diameter of the cavity is 3 mm and length is 4W to 8W. In the centre of control plate there is a slot of cross-section equal to nozzle exit. Figure 5 displays the ducts of 4W, 6W, and 8W respectively along with pressure tabs for measuring wall pressure. Pressures are measured for various L/W ratio at different tab positions on the duct.

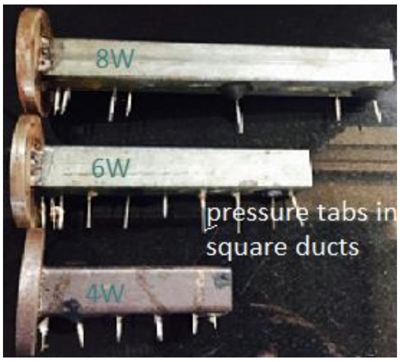

Fig. 5. Different L/W ratio ducts

3. Results

3.1 Base Pressure Measurement

The objective of this study is to determine the effect of grooved cavities on manipulating the base pressure as a result of variation in Mach number at particular L/W ratio for high speed compressible flows.

From the above Figure 6, it is evident that base pressure has been enhanced considerably, and shows its dependency on flow parameter such as Mach number at fixed L/W ratio. Also, the base pressure is marginally larger than the ambient pressure. The effect of grooved cavities on increasing base pressure is quite high.

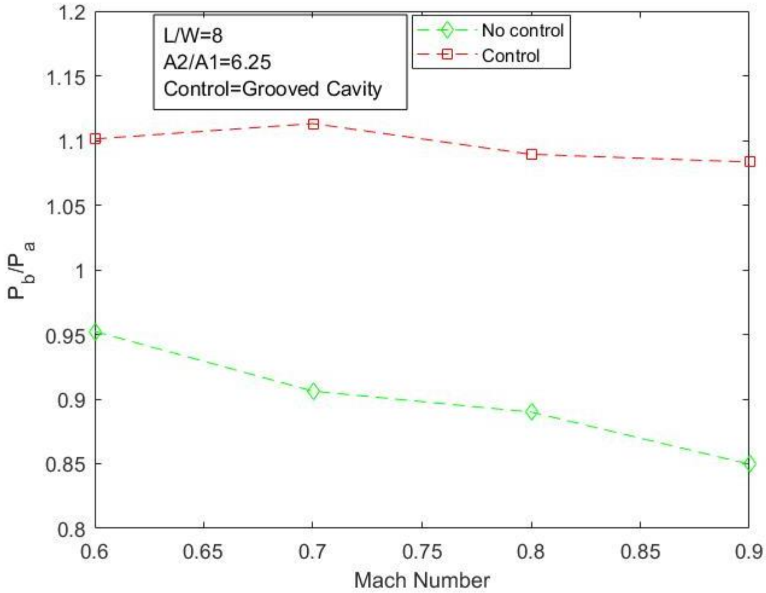

Fig. 6. Variation of Base Pressure against Mach number for L/W = 8

Thus, leading to the base drag reduction for all Mach numbers considered of the present investigation. This effectiveness may be contributed to the increase in the skin friction, which is inversely proportional to the base drag. Decreasing the depression and reducing the overall size of recirculation zone. Figure 6 to Figure 8 shows a decreasing trend of the base pressure with the increasing Mach number without control for L = 8W, 6W, and 4W. The trend of the graph shows the strong impact of the control on the base pressure while the Mach number is increasing. The percentage increase in the base pressure at higher Mach numbers in transonic zone as 0.8 and 0.9 is quite high and at subsonic regime (0.6 and 0.7) too, the control is quite effective.

3.2 Wall Pressure Measurement

After the sudden expansion behind the backward facing step, the flow field might become oscillatory as shown by the wall pressure flow field in the enlarged ducts. Hence, it is extremely important to see that out control does aggravate the flow field. It is seen from Figure 9 that at X/L = 0 the variation for each Mach number is quite high and from X/L from 0.1 to 0.9 it has been wonderfully under control. For lower Mach numbers the wall pressure is marginally above the ambient atmospheric pressure.

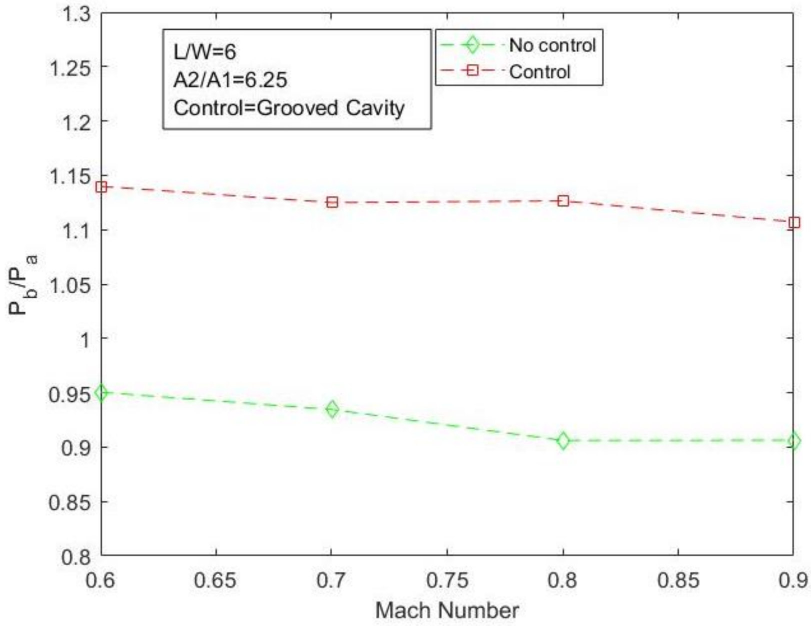

Fig. 7. Variation of Base Pressure against Mach number for L/W=6

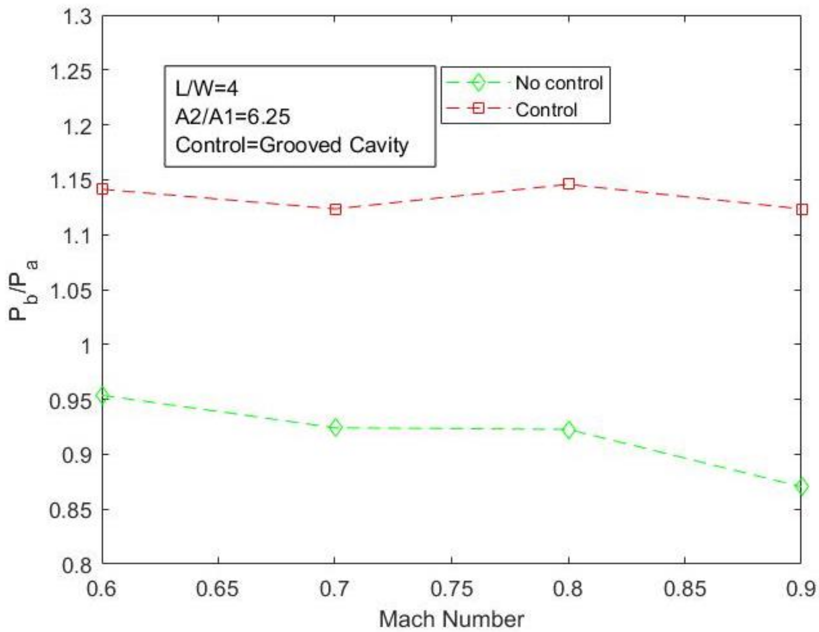

Fig. 8. Variation of Base Pressure against Mach number for L/W=4

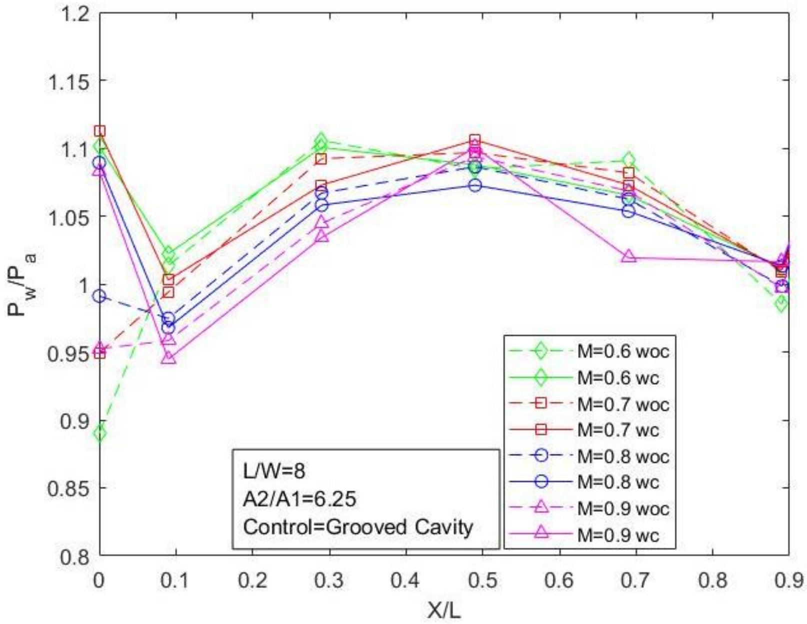

Fig. 9. Wall pressure distribution for L=8W

Figure 10 shows the results for L/W = 6, these results show the trend with and without control are nearly same, thus making our control very effective and having negligible adverse effect on the flow field in the duct.

Wall pressure results for duct length L/W = 4 are shown in Figure 11. From the results it is evident that there are some oscillations in the duct flow field, this may be due to the small duct length, as well as due to the influence of the back pressure. Except Mach 0.6 for all Mach numbers, the wall pressure readings are nearly same before and after the control is employed.

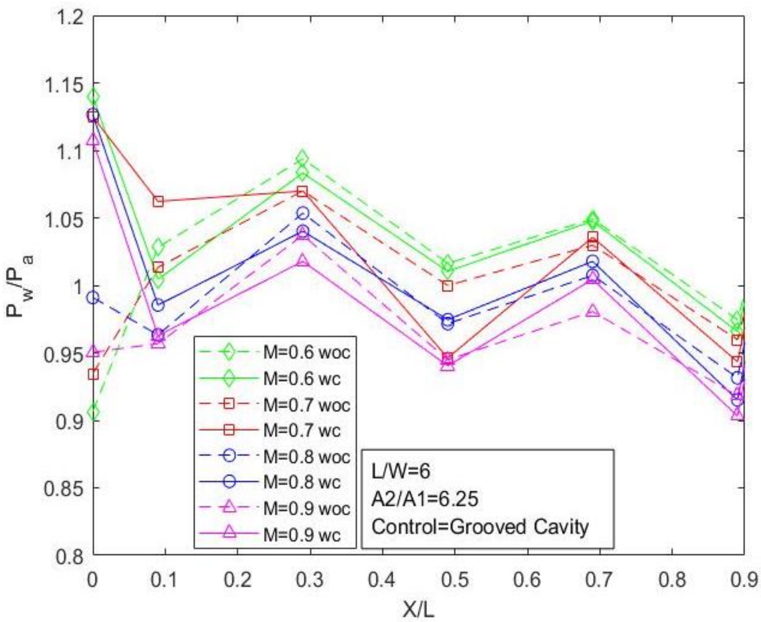

Fig. 10. Wall pressure distribution for L = 6W

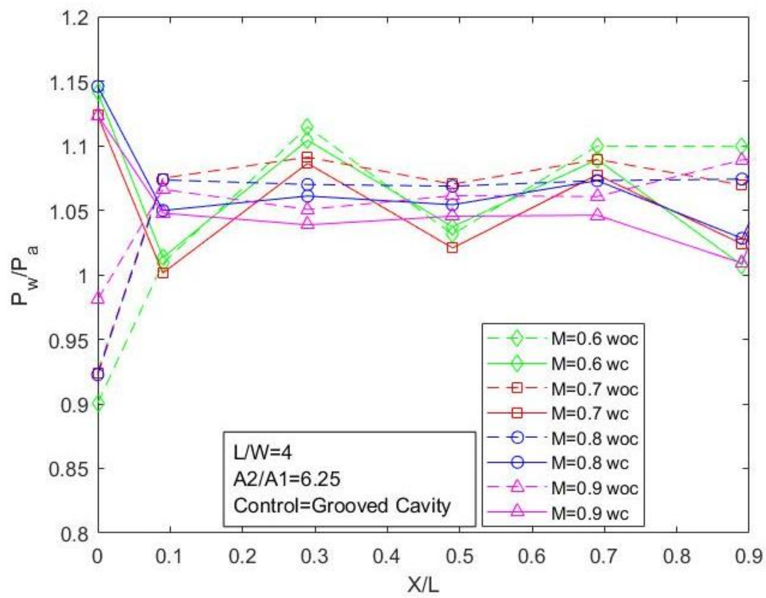

Fig. 11. Wall pressure distribution for L = 4W

4. Conclusions

Hence the compressible flow over a backward facing step is experimentally investigated and the base flow control in the form of grooved cavity is demonstrated as an effective controller of the base pressure, where it is found that the Passive control results in increase of the base pressure, thus decreasing the depression in the base corner. It is also observed that for all the Mach numbers from 0.6 to 0.7 at a fixed duct length of 4W, 6W, and 8W, the control was found to be very effective in controlling the base pressure. The best results were for duct of length 8W for all the Mach numbers. Also, from the static wall pressure distribution we can clearly say that the wall pressure is getting marginally affected using the grooved cavities for 6W and 8W as the control mechanism, however, we can see some adverse effect for 4W duct at Mach 0.6 as it exceeds X/L > 0.7.

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References

[1] Vashishtha, Ashish, and E. Rathakrishnan. "Breathing blunt-nose concept for drag reduction in supersonic flow." *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering* 223, no. 1 (2009): 31-38.

[2] Viswanath, P. R. "Flow management techniques for base and afterbody drag reduction." *Progress in Aerospace Sciences*32, no. 2-3 (1996): 79-129.

[3] Morel, Thomas. "Effect of base cavities on the aerodynamic drag of an axisymmetric cylinder." *The Aeronautical Quarterly*30, no. 2 (1979): 400-412.

[4] Martín-Alcántara, A., E. Sanmiguel-Rojas, C. Gutiérrez-Montes, and C. Martínez-Bazán. "Drag reduction induced by the addition of a multi-cavity at the base of a bluff body." *Journal of Fluids and Structures* 48 (2014): 347-361.

[5] Lay, Keary A., Ryo Yakushiji, Simo Mäkiharju, Marc Perlin, and Steven L. Ceccio. "Partial cavity drag reduction at high Reynolds numbers." *Journal of Ship Research* 54, no. 2 (2010): 109-119.

[6] Loosen, S., V. Statnikov, M. Meinke, and W. Schröder. "Modal analysis of passive flow control for the turbulent wake of a generic planar space launcher." *CEAS Space Journal* (2018): 1-14.

[7] Rajasekaran, Jagannath. On the flow characteristics behind a backward-facing step and the design of a new axisymmetric model for their study. University of Toronto, 2011.

[8] Williams, D., and C. Amato. "Frontiers in experimental fluid mechanics." *Lecture Notes in Engineering, edited by M. Gadel-Hak (Springer-Verlag, New York, 1989)* 46 (1989): 337-364.
[9] Josyula, Eswar, Mark Pinney, and William B. Blake. "Applications of a counterflow drag reduction technique in high-speed systems." *Journal of Spacecraft and Rockets* 39, no. 4 (2002): 605-614.
[10] Khan, Sher Afghan, and E. Rathakrishnan. "Active control of suddenly expanded flows from overexpanded nozzles." *International Journal of Turbo and Jet Engines* 19, no. 1-2 (2002): 119-126.
[11] Kühn, M., M. Kühn-Kauffeldt, J. Schein, and A. Belinger. "Plasma actuators for active flow control based on a glow discharge." In *Journal of Physics: Conference Series*, vol. 825, no. 1, p. 012007. IOP Publishing, 2017.
[12] Buresti, Guido, GIACOMO VALERIO Iungo, and Giovanni Lombardi. "Methods for the drag reduction of bluff bodies and their application to heavy road-vehicles." *1st Interim Report Contract between CRF and DIA, DDIA* 6 (2007): 2007.
[13] Pathan, Khizar Ahmed, S. A. Khan, and P. S. Dabeer. "CFD analysis of effect of area ratio on suddenly expanded flows." In *Convergence in Technology (I2CT), 2017 2nd International Conference for*, pp. 1192-1198. IEEE, 2017.
[14] Pathan, Khizar Ahmed, S. A. Khan, and P. S. Dabeer. "CFD analysis of effect of Mach number, area ratio and nozzle pressure ratio on velocity for suddenly expanded flows." In *Convergence in Technology (I2CT), 2017 2nd International Conference for*, pp. 1104-1110. IEEE, 2017.
[15] Asadullah, Mohammed, S. A. Khan, Waqar Asrar, and E. Sulaeman. "Counter Clockwise Rotation of Cylinder with Variable Position to Control Base Flows." In *IOP Conference Series: Materials Science and Engineering*, vol. 370, no. 1, p. 012058. IOP Publishing, 2018.
[18] Asadullah, Mohammed, Sher Afghan Khan, Waqar Asrar, and E. Sulaeman. "Low-Cost Base Drag Reduction Technique." *International Journal of Mechanical Engineering and Robotics Research* 7 (2018): 428-432.