

# Simulation of Flow through Suddenly Expanded Duct

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## ABSTRACT

**In the present study the computer simulations were conducted to control the base pressure with micro jets. In the present study the attention was focused on the static pressure at the base of suddenly expanded duct. The flow parameters considered in the present investigation are the Mach number available at the exit of nozzle and the Nozzle Pressure Ratio. The geometrical parameters considered are the area ratio between the enlarged duct cross-section and the exit area of the nozzle, which is kept 2.4, and the L/D ratio of suddenly expanded enlarged duct, which is varied from 10 to 1. All the simulations were conducted with as well as without microjets control.**

**Keywords— Area ratio, L/D Ratio, Nozzle Pressure Ratio, Simulation.**

## ARTICLE INFO

### Article History

Received :29<sup>th</sup> February 2016

Received in revised form :

1<sup>st</sup> March 2016

Accepted : 4<sup>th</sup> March 2016

**Published online :**

**6<sup>th</sup> March 2016**

## I. INTRODUCTION

The pressure at the blunt base is substantially low compared to the atmospheric pressure. The flow field at the base which is very complex is one of the significant and complex problems in fluid dynamics. The flow at the base will be wave dominated. When the flow at the nozzle exit is under influence of favourable pressure gradient, under these conditions when the jets are operated, wave will be positioned at exit of convergent nozzle, where as in the case of correctly expanded case still waves are bound to be there at the nozzle exit, however, for correctly expanded case these waves are very weak. It is well known that at subsonic speed due to the sub-atmospheric pressure in the base the magnitude of the base drag will be 10% of the net drag, whereas the major contribution will be from the skin friction drag. However, at transonic speed the component of the base drag is significant and it may be 60 % of the net drag. Therefore, even a little enhancement in pressure at the blunt base could lead to substantial decrease in the drag and ultimately increase in the range of the projectiles and missiles. The issues of suddenly expanded flow of high speed flow at the blunt base; like at base of unguided rockets, shell and their relation with pressure at the base which; is normally sub-atmospheric and hence; is governed by the sub-atmospheric pressure at the base. In view of

above it has been the subject of intensive study for many years due to its academic interest and its real-world applications. In order to reduce base drag and improve the base pressure several research and experimental has been done. For finding the base pressure there is an alternate option available, in contrast to the experimental method, which is computer based simulation and analysis. There are two big advantages to performing a simulation rather than actually building the design and testing it. The biggest of these advantages is money. Designing, building, testing, redesigning, rebuilding, retesting,... for anything can be an expensive project. Simulations take the building/ rebuilding phase out of the loop by using the model already created in the design phase. Most of the time the simulation testing is cheaper and faster than performing the multiple tests of the design each time. Considering the typical budget cheaper is usually a very good thing. For example in the case of an electric thruster the test must be run inside of a vacuum tank. Vacuum tanks are very expensive to buy, run, and maintain. One of the main tests of an electric thruster is the lifetime test, which means that the thruster is running pretty much constantly inside of the vacuum tank for 10,000+ hours. This is pouring money down a drain compared to the price of the simulation.

The second biggest advantage of a simulation is the level of detail that you can get from a simulation. A simulation can give you results that are not experimentally measurable

with our current level of technology. Results such as surface interactions on an atomic level, flow at the exit of a micro electric thruster, or molecular flow inside of a star are not measurable by any current devices. A simulation can give these results when problems such as it's too small to measure, the probe is too big and is skewing the results, and any instrument would turn to a gas at those temperatures come into the conversation. One can set the simulation to run for as many time steps he desire and at any level of detail desired the only restrictions are one's imagination, programming skills, and CPU capability.

The aim of this project work is to find base pressure ratio  $P_b/P_{atm}$  using very popular analysis software ANSYS for both cases i.e. with and without control.

## II. LITERATURE REVIEW

Kurzweg [1] conducted experiments in supersonic wind tunnels before 1951 for 3 years (N.A.C.A. and N.O.L.) showed that the pressure at the base of bodies is essentially a function of parameters that govern the boundary layer. Hence, the base pressure is closely connected to surface friction and heat-transfer phenomenon. Experimental results obtained by him in the N.O.L. supersonic tunnels in a Mach range 1.5-5.0 on cylindrical bodies with and without boat-tails with conical heads under various systematic mechanical and thermodynamic variations of the boundary layer are presented and compared with theoretical results. Wick [2] studied experimentally for sonic flow. He conducted experiments for suddenly changing area. His main concern was to find the influence of boundary layer. Korst [3] wrote comment on the boundary layer effects. He wrote Comments on suddenly changing area of sonic condition. He compared his theoretical results which utilize a two-dimensional flow model. Wood [4] studied the effect of base bleed on a periodic wake. He concluded that Base bleed reduces the drag of an aerofoil, by delaying the onset of instability in the separated shear layers. The proportion of vorticity which actually enters the vortex sheet after being shed from the model falls from an initial value of about 0.5 as the shear layers increase in length. In his experiment, the optimum bleed was given by a bleed coefficient of 0.125. This gives a drag reduction equal to that produced by a long splitter plate and it was thought that little further improvement is possible by any method of wake interference. No attempt was made by Wood to explain either how base bleed stabilizes the shear layer or why very small bleed quantities appear to have the reverse effect. The method used by the Wood to determine the properties of the vortex street was an indirect one, based on the assumed validity of the VON KARMAN vortex street. Heskestad [5] found that for one particular geometry, Reynolds number, and suction rate beyond critical value the initial border to the remaining pocket of separated flow behind the step appeared common to expansion ratios greater than a certain minimum. On the other hand, turbulence was found to propagate increasingly faster into the potential core of the flow as expansion ratio increased. Roache [6] obtained a new method of implementing the re-compression condition which improves convergence properties for base bleed. A criterion for selection of the wake radius ratio was included in the flow model, thus eliminating all empirical parameters except the jet spread parameter (eddy viscosity). Calculations were made for base pressure, with and without base bleed, on cylinders, sharp cones, and on blunted cones.

## III. METHODOLOGY

### A. Conceptual Details:

The magnitude of base pressure in such a flow field, i.e. suddenly expanded flow, depends on numbers of parameters such as inlet velocity, pressure, viscosity, level of turbulence (i.e. Reynolds no.) etc. But in our project we will focus only on following three parameters for simulation as area ratio of 2.4, varying length to diameter ratio & use of microjet as an active control. By varying above stated parameter results and simulation are obtained and results are tabulated and plotted on graph.

### B. Software and Analysis Detail:

#### 1) Software Used

In the project ANSYS is used for analysis and simulation. ANSYS is very popular software used in both researches and industries. ANSYS offers a comprehensive software suite that spans the entire range of physics, providing access to virtually any field of engineering simulation that a design process requires. Organizations around the world trust ANSYS to deliver the best value for their engineering simulation software investment.

#### 2) Analysis Details:

Geometry: Geometry is as shown in fig. 1.

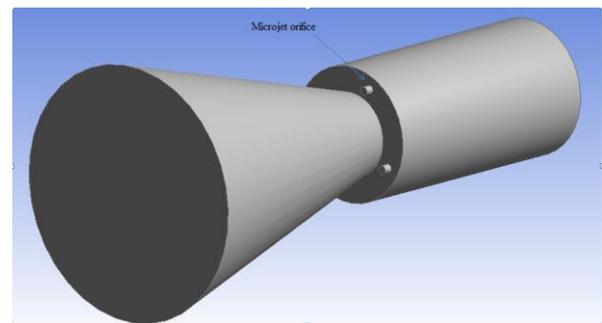


Fig. 1 Geometry

Mesh: Since geometry is not of very complex type, default mesh provided will be used. The mesh is shown in following fig. 2.

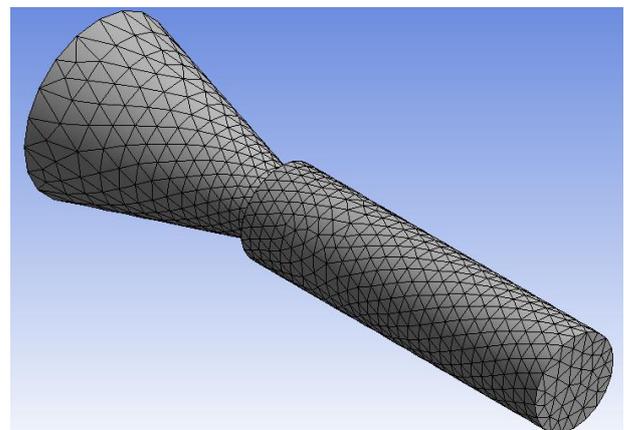


Fig. 2 Meshing of the model

Solver setting in fluent: The solver type used is, "pressure based", which enables the pressure-based Navier-Stokes solution algorithm. In time setting, flow is set to be steady.

1) Model details: Effect of temperature, heat exchange and radiation etc is not considered. Flow is set to be turbulent and k-epsilon model was used.

2) Material: Air as the fluid is used. Reason of choosing air is that, most of the experimental study of sudden expansion type of flow has been conducted using air. It helps us to compare our results with that of experimental one, in a better way.

The material of the pipe used is Aluminum.

3) Boundary condition: As mentioned earlier following combination of NPR (Nozzle Pressure Ratio) and L/D is used along with area ratio 2.4, L/D : 1, 2, 5, 6, 8 & NPR : 1.5, 2, 2.5, 3.

All the above setting gave a convergent result within 200 iterations for all values of NPR and L/D. Convergence criteria, for every equation was set to 0.001 which is the default value.

**IV.RESULT**

The present simulation study focuses on efficacy of the control in form of microjets as an active flow controller, located in the region of base of suddenly enlarged tube having same axis as that of nozzle, to modify static pressure at base and also to study how it is going to manipulate the flow field. The parameters considered in the present experimental study are the area ratio ( $A_2/A_1$ ) set to 2.4, (L/D) ratio, Mach number and Nozzle pressure ratio (NPR for level of expansion). All measured parameters like static pressure at base( $P_b$ ), static pressure at wall( $P_w$ ) converted into non-dimensional thru dividing them by ambient pressure (atmosphere) to which flow from suddenly expanded axi-symmetric duct was discharged.

$P_b/P_a$  Variation vs. L/D Ratio:

The results are shown in figs. 3 to 6. When the simulations were conducted to control the pressure at the base either to increase or decrease and to accomplish this goal the solver setting is kept such that flow exiting from the nozzle experiences becomes either correctly expanded or under expanded case. While scanning the literature it was concluded that weak waves will be located at the exit of the nozzle for underexpanded condition. To predict effect of expansion level on pressure at base in the presence of control and in the absence of control the static pressure at base was plotted with respect of L/D and NPR are presented. From the second order shock expansion theory it is concluded that, whenever an expansion fan is coming out from the exit of the nozzle the viscous shear layer emanating from the nozzle will get deflected towards the center line of the nozzle due the presence of the shock. Which is in turn likely to delay the reattachment of the flow with the enlarged duct wall and this will result in a larger length of the reattachment as compared to a case when the shock is not present. The reattachment length will strongly affect the strength of re circulation, increment or decrement of this span will change static pressure at base.

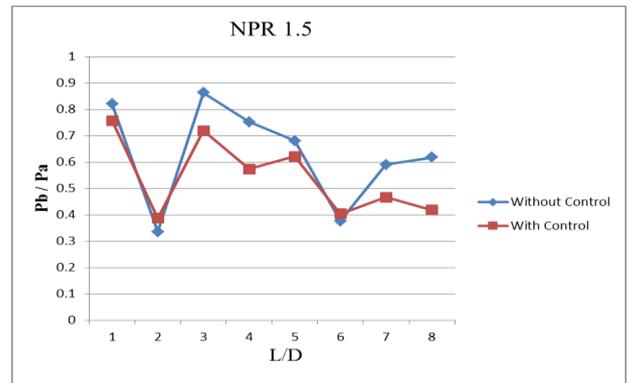


Fig. 3  $P_b/P_a$  Variation vs. L/D Ratio NPR=1.5

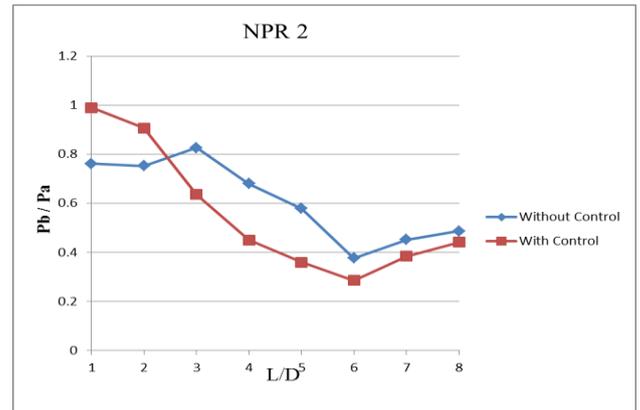


Fig. 4  $P_b/P_a$  Variation vs. L/D Ratio NPR = 2

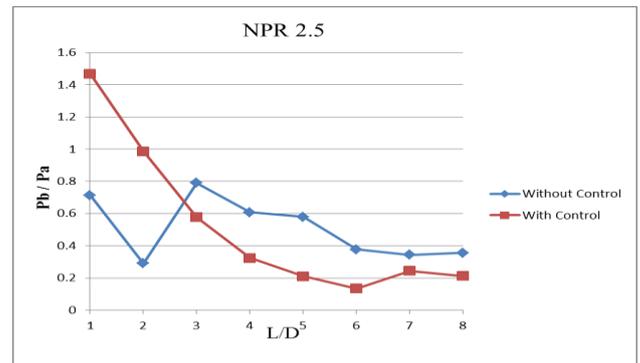


Fig. 5  $P_b/P_a$  Variation vs. L / D Ratio NPR = 2.5

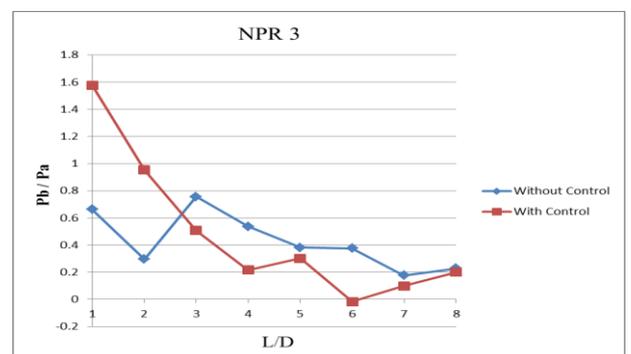


Fig. 6  $P_b/P_a$  Variation vs. L/D NPR = 3

## V. CONCLUSION

The Conclusion from this project it is evident that all these parameter that is length to diameter ratio, area ratio and use of microjet are very effective in controlling the base pressure of suddenly expanded flow field. Base pressure is mainly dependent upon these parameters. In this work, an attempt has been made to compare the experimental results with the simulation using the ANSYS software. As from the simulation we can conclude that we are getting output near to experimental data. Further we can simulate the results for different higher area ratios.

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