Numerical/Experimental Investigation of the Presence of a Protuberance in a C-D Nozzle in Supersonic Regime to Control the Thrust Vector

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ABSTRACT

In this study, the effect of protuberance on the thrust vector of a supersonic jet was investigated as a new method in thrust vector control. For this purpose, a convergent-divergent nozzle was designed and fabricated. This nozzle is such that the nominal Mach number in the nozzle exit in full expansion condition is 2. The wall of the nozzle is equipped with pressure holes to measure pressure variations. Also, there is a hole on the nozzle wall to apply a protuberance inside the nozzle. Pressure sensors for pressure measurement and also the Schlieren system are used to check the outlet flow field. The total pressure in all experiments is constant and equal to NPR=6.6. Three-dimensional and multi-block numerical code is used for flow modeling. Also, the turbulence model k-ε, RNG is used to model the nozzle flow. An unstructured mesh has been used for modeling flow field within the nozzle and the outside domain. The results of this study show that the depth of penetration of the protuberance in the flow field has a significant effect on the amount of deviation and even the direction of the jet stream exited from the convergent-divergent nozzle. The maximum deviation of the jet outlet from the nozzle is 9.8 degrees, which is equal to penetration ratio of 0.4. In addition, these results indicate that with the increase in protuberance penetration within the nozzle, the nozzle axial thrust has slightly decreased.

KEYWORDS

Thrust Vector, C-D nozzle, Protuberance, Supersonic, Experimental aerodynamics

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1. Introduction

One of the most important steps in the design of flight vehicles is the design of the controlling system, which can safeguard the flight vehicle from any unwanted deviation. Thrust vector control is one way of the system controlling in the event of the aerodynamic forces are negligible. Using Secondary fluid injection is one of the usual methods for TVC and many studies has been carried out for increasing performance of SITVC [1-8]. Also, using tabs is another method for thrust vectoring. In this field, some researchers investigated the effects of the tab blockage ratio and the tab angle on the thrust vector angle [9-12]. In other studies the effects of using tabs on the generated sounds in the nozzle exit and heat loads due to exhausted hot gases on the tabs has been examined [13-14].

In this study a new method is presented for thrust vectoring based on the jet tab. In this method a cylindrical protuberance is used in the divergent part of a C-D nozzle to control the out flow deflection. For this purpose, an experimental study as well as numerical investigation has been carried out for assessment the performance of the presented method.

2. Methodology

In this study, a C-D nozzle with nominal Mach number 2 is used. Nozzle inlet, throat and outlet diameter are 16, 5 and 6.5 mm respectively. The divergent nozzle has a length of 50 mm. The pressure on the walls of the nozzle is measured. In all experiments the total flow pressure was constant and set to 5.7 bars. Pressure holes are connected to a pressure sensor box and transmitted to the computer via the data acquisition card. Nozzle forces are measured by a 2D force balance. Schlieren technique is used to visualize the jet flow. In numerical simulations, the full Navier-Stokes equations by finite volume approach is discretized. The Roe method is used to estimate the convective fluxes and the central difference method is used to estimate the viscous fluxes. The implicit method is also used to solve the equations and the accuracy of the numerical solution is second order. In addition, the RNG k-ε model is applied for estimation of Reynolds stresses.

3. Results and Discussion

To investigate the effects of the protuberance, it is installed in position 0.9 and the effect of the protuberance penetration ratio on the nozzle vector is measured. Figure 1 shows the changes in the deflection vector of the thrust vector obtained from the force measurements and schlieren images in the nozzle pressure ratio of 6.6 and in different penetration rates. In the following, Figure 2 shows the axial thrust force losses. These results show that by applying a protuberance inside the nozzle, the amount of deflection angle of the propulsion vector should increase up to 9.8 degrees in the penetration ratio of 0.4. Also, the amount of axial propulsion force decreases.

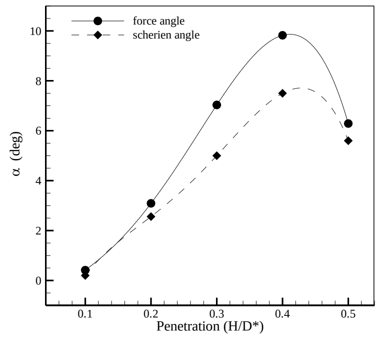

Figure 1. Diagram of thrust angle versus penetration ratio

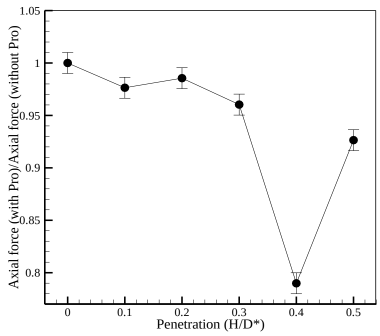

Figure 2. Diagram of thrust loss versus penetration ratio

In order to better understand the physics of flow, the effects of the presence of protuberance in the flow on the Mach number contours and pressure distribution of the nozzle walls are shown in Figures 3, 4. The results show that two shocks is created at the upstream of the protuberance and another shock is formed at downstream due to formation of a wake.

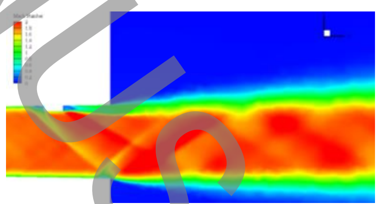

Figure 3. Contour of number and NPR = 6.6 and H/D* = 0.1

As can be seen before the protuberance, pressure on the nozzle wall increases, indicating a shock in the area. After the protuberance (on the side A), a sharp decrease is observed which relates to the blockage effects of protuberance. It is observed that these shocks have deflected the exhausted flow from the nozzle.

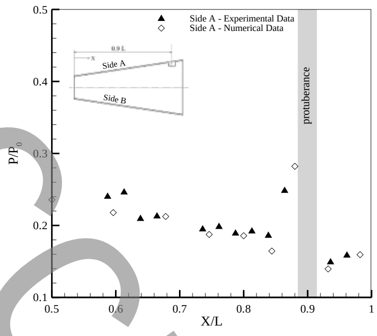

Figure 4. Diagram of pressure changes on the nozzle wall at penetration rate $H/D^* = 0.1$ (side A)

4. Conclusions

In this study, the effects of a protuberance on the thrust vector of C-D nozzle was investigated. The pressure on the wall and nozzle thrust were measured. Also Schlieren images were recorded. Numerical simulations were performed. Results show that:

-Before the protuberance, the pressure has increased sharply due to the formation of a bow shock upstream the protuberance and after the protuberance, the pressure has dropped sharply, due to the blockage effects of the protuberance.

- As the protuberance height increases, the bending shock becomes stronger and moves toward the nozzle throat.

- As the protuberance penetration rate increased, the outlet jet deflection angle increased up to 9.8° at $H/D^* = 0.4$. However, at higher penetration rates, the flow deflection does not show significant changes.

- The presence of protuberance also reduces the jet thrust force in addition to changing the direction of flow.

5. References

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