

Experimental Investigation of the Influence of Transverse Dual Protuberances on the Thrust Vector of a Supersonic C-D nozzle

Mohammad Reza Babaeyan¹, Mohammad Hojaji^{2,3}

1. Introduction

One of the essential steps in designing aerial vehicles is designing the controlling equipment, which can protect the aerial vehicle from any unwanted deflection. Thrust vector control is one way of controlling aerial vehicles when the aerodynamic forces are negligible. Different methods have been used to control the thrust vector. The use of tabs that are placed in the hot gas path is popular due to their simplicity. The use of jet tabs has been experimentally investigated by some researchers. In these studies, the effects of the tab angle in the nozzle outlet on the thrust vector angle were scrutinized. Also, the effects of tabs on the thrust vector control have been examined. The results showed the use of tabs causes the nozzle outlet deflection. Another researcher also investigated the effects of using corrugated tabs on thrust vector control. The results indicated that the use of corrugated tabs instead of simple tabs could also control the thrust vector and reduce the length of the diamond shocks. However, this method encounters different problems because of the permanent presence in the flow path. One of the problems is the negative effect of thermal loading on the tabs. In another study, numerically and experimentally the ways of heat diffusion through tabs was studied. Another method to control the thrust vector is secondary fluid injection in the nozzle flow. Many studies have been done on secondary fluid injection. In these studies the effects of secondary injection parameters and its location, number of injections and their arrangements on the thrust vector was numerically and experimentally investigated. This method has some disadvantages. In this method, hot flow causes valves to wear out; hence, researchers are still working on various new methods that are more affordable than the conventional methods. Researchers have recently examined protuberance that is placed on the divergent nozzle section. In a experimental study the effect of location and penetration ratios of cylindrical protuberance on the thrust vector of a Supersonic C-D nozzle was investigated. Besides, in another study, experimental investigation of the penetration effects of opposite dual protuberances on the thrust vector has also

conducted.

In the present experimental study, for the first time, the impacts of dual transverse protuberances on the nozzle thrust vector and the flow field is examined. For this purpose, in two different cases, the effects of one and dual transverse protuberances and their penetration ratios on the flow field is studied.

2. Experimental apparatus and conditions

In this study, a convergent-diverging nozzle with nominal Mach number 2 was designed and fabricated. The nozzle inlet diameter is equal to the settling chamber diameter (16 mm), throat diameter is 5 mm, and the outlet diameter is 6.5 mm. Besides, the total nozzle length is 86 mm, and the divergent section length is also 50 mm. Protuberances are placed in 40mm from throat in the divergent part of the nozzle. At the first case, one protuberance and in the second case, two transverse protuberances are placed in the nozzle in different penetration ratios of 0.1, 0.2, 0.3 and 0.4. Besides, pressure holes with a diameter of 0.7 mm are created on both sides of the nozzle wall. The stagnation pressure is considered constant in all experiments; as a result, the nozzle pressure ratio (NPR) is set to 6.6. Pressure holes on the nozzle wall are connected to Traftaq pressure sensors with the overall accuracy of 0.1% FS and converted using Advantech 41117 DAQ portable module. A two component balance with the overall accuracy of 0.5% FS is used to measure the axial and lateral forces of the nozzle.

3. Results and Discussion

In order to investigate the effects of protuberance on the flow field, the cylindrical protuberance, is installed at $X/L = 0.8$, while the protuberance ratios is equal to $H/D^* = 0.1, 0.2, 0.3$ and 0.4 . In Figures 2(a), changes in axial force are seen. Results show that axial force more decreases in the presence of transverse dual protuberances (case 2). Figure 2(b) also illustrates the deflection angle of thrust vector in various penetration ratios. In this figure, the thrust vector angle is obtained from equation (1).

$$\alpha = \tan^{-1} \left(\frac{F_s}{F_a} \right) \quad (1)$$

Results show deflection angle in the second case is more than the first case for the same penetration ratios. Also, there is a change in deflection angle sign in low penetration ratios in the first case. Pressure distribution on the nozzle wall (Figure 2) shows the pressure increases in the upstream of protuberance while decreases in the downstream because of the blockage effects of the protuberance. Moreover, stronger shocks and wakes are observed up and down stream of the protuberances in the second, respectively.

Figure 3 shows the Schlieren images of flow field at the nozzle exit for penetration ratio of 0.2. More deflection angle of the jet plume at the nozzle exit can be observed in the second case. It seems that the stronger shocks in the second case is the main reason of this phenomenon.

¹ M.Sc. Student, Department of Mechanical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran.

² Corresponding Author: Assistant professor, Department of Mechanical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran. Hojaji_m@pmc.iaun.ac.ir

³ Aerospace and Energy Conversion Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran.

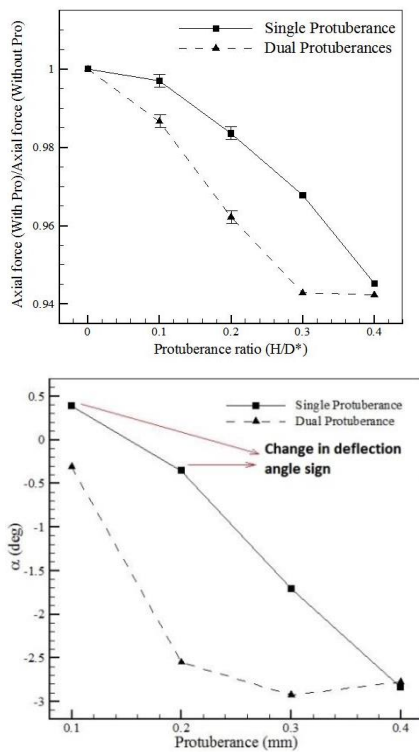


Figure 1. The axial force and deflection angle in different protuberances penetration ratios.

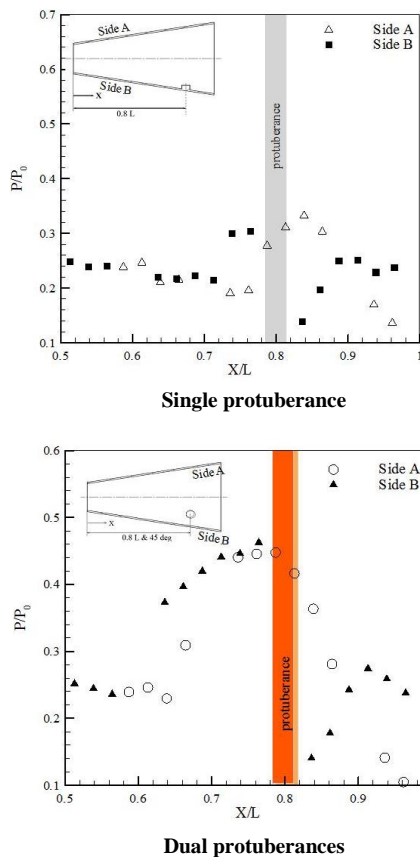


Figure 2. Static pressure changes on the nozzle wall ($H/D^*=0.3$)

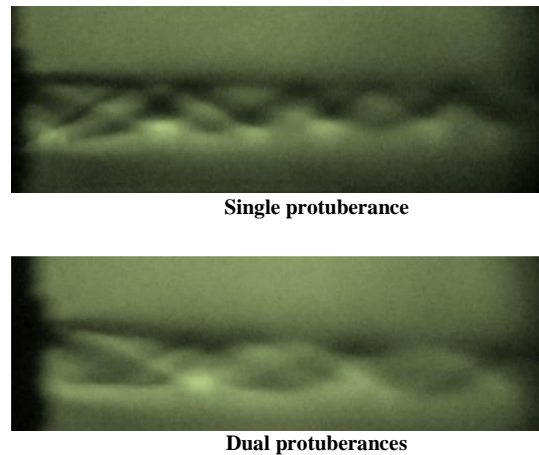


Figure 4. Schlieren images in nozzle exit at $H/D^* = 0.2$

4. Conclusion

In this study, effects of the use of dual transverse protuberances (DTP) as a new, low cost and simple method in controlling the thrust vector in a C-D nozzle, whose nominal Mach number is 2, was investigated. The protuberances are two cylindrical shapes that are placed in the divergence part of nozzle. Protuberances are installed in 80% of the length of the nozzle divergence section from nozzle throat transversely. The flow field was investigated by schlieren imaging, along with measuring the pressure distributions on the nozzle walls. Moreover, the thrust vector was measured using a force balance. The results show using the DTP in the nozzle can increase the angle of the thrust vector up to 3.5 degrees. Besides, no change in the deflection angle sign in compare to using a single protuberance is observed. Also, the results reveal that axial force more decreases in the presence dual transverse protuberances. But it dose not exceed from 5.5% in the examined conditions