64th International Congress of ISTAM
09-12 December, 2018, Indian Institute of Technology, Bhubaneswar, India

SECTION – FM PAPER ID

Experimental Studies on the Thrust Vector Control of a Supersonic Nozzle using Struts

Thillaikumar T.[1], Lakshmi Srinivas[2], B.T.N. Sridhar[3] and Mrinal Kaushik*[4]

[1, 4] Department of Aerospace Engineering, Indian Institute of Technology, Kharagpur-721302, India
[2, 3] Department of Aerospace Engineering, Madras Institute of Technology, Chennai-600044, India

[*] Corresponding Author's E-mail: mkaushik@aero.iitkgp.ac.in

Thrust Vector Control (TVC) is a technique, used to manipulate the direction of the thrust, which essentially controls the attitude of an aerospace vehicle. This technique has received a great attention since long due to its practical application in developing the control systems for attitude adjustment and performing the manoeuvres. Thrust vectoring can be accomplished with either the mechanical or the fluid systems. A mechanical system such as, a moving pintle used for changing the throat area of a convergent-divergent nozzle, requires a drive-mechanism [1, 2]. The throat area can also be modified by introducing a secondary flow in the direction perpendicular to the primary flow, which results an interaction between these flows [3, 4]. Indeed, this flow configuration exhibits high reliability and requires no drive-mechanism. However, this configuration needs a large storage tank to store a sufficient quantity of fluid for injection into the main flow. Clearly, the injection of an auxiliary fluid flow as thrust vector control makes the system heavier and less attractive for longer flight durations. To overcome these limitations, a small solid body (or strut) is inserted into the primary flow. Interestingly, a strut, deployed in the convergent-divergent nozzle, controls the thrust vector in the same way as the injected fluid in transverse direction. Also, the strut thrust vector control (STVC) is geometrically simple, light weight and cost effective as compared to fluid injection system.

In this study, the thrust vector control efficacy of a triangular-shaped strut, placed in the divergent portion of a Mach 1.84 axisymmetric convergent-divergent (C-D) nozzle, was quantitatively as well as qualitatively investigated. The strut height was varied as, H = 1.5 mm, 2.5 mm and 3.5 mm. The throat and exit areas of the nozzle were, 113.09 mm^2 and

167.41 mm^2, respectively. At correct-expansion, the stagnation pressure in the settling chamber was maintained at 578 kPa. In turn, the nozzle pressure ratio (NPR = p_0/p_a) was 5.7. However, since the experiments were carried at NPR = 3.95, an overexpanded condition were prevailing at the nozzle exit. The static pressures were measured at different wall mounted ports in the divergent-portion. The semi-divergence angle of the C-D nozzle is 1.517^0. Both C-D nozzle and strut was made of stainless steel. The waves prevailing at the nozzle exit were visualized using Schlieren technique.

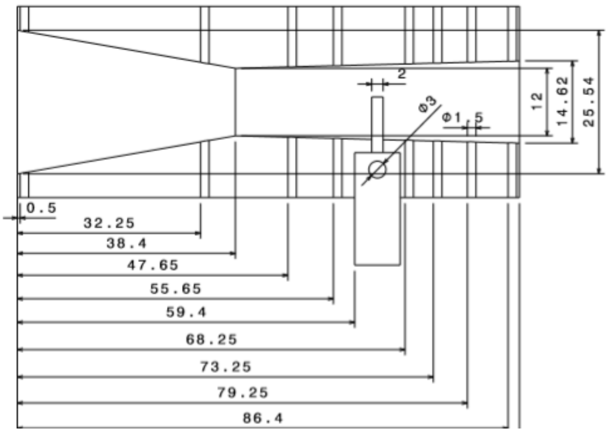

Figure 1. Schematic diagram of the nozzle controlled with strut

To quantify the thrust vector control efficiency of strut, the variation of non-dimensional wall static pressure was plotted against the non-dimensional axial distance. The wall static pressure (p) was made non-dimensional with stagnation pressure (p_0) and the axial distance was made non-dimensional with nozzle length (L). The non-dimensional static pressure (p/p_0) variation for the lower and upper surfaces of the divergent-section, are shown in Figures 2-3.

Figure 2 shows the wall static pressure distribution over the lower surface of the divergent-section. It can be seen that, the flow first accelerates soon after entering the convergent-section, attains the choking at the throat and further accelerates in the divergent-section, up to x/L = 0.64 for both uncontrolled and strut controlled nozzles. At x/L = 0.64, the static pressure falls below than the ambient pressure, which produces a local suction effect. However, at the subsequent port location (x/L = 0.78), a significant rise in static pressures for the struts of heights 2.5 mm and 3.5 mm, are observed. In fact, when a strut is introduced in the divergent portion of the nozzle, it produces a strong oblique shock which in turn increases the static pressure downstream. Notice that, the impingement of this shock wave on nozzle wall essentially leads to the boundary layer detachment. Moreover, with increase of strut height a rise in static pressure was also observed in all the cases. Furthermore, at the farthest port location corresponding to 0.84 L, an initial drop in static pressure is see which subsequently rises to freestream value for both the struts of heights 2.5 mm and 3.5 mm. This gradual rise in pressure indicates the reattachment of the flow to the wall. However, at same location an insignificant rise in pressure for 1.5 mm strut implies the generation of a weak oblique shock by this strut.

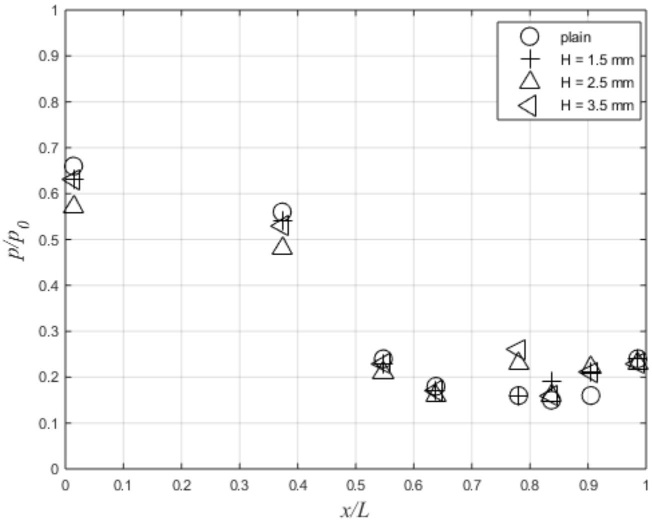

Figure 2. Wall static pressure variation (lower surface)

The wall static pressure variation at the upper surface of divergent-section is shown in Figure 3. For both uncontrolled and controlled nozzles, the flow is found to be accelerating up to x/L = 0.78; with a rapid increase pressure for 3.5 mm strut. This is because of the boundary layer detachment caused by the bow-shock generated at the strut, which further extends till the upper surface of the nozzle. In far field, the pressure gradually rises to freestream value for all the configurations.

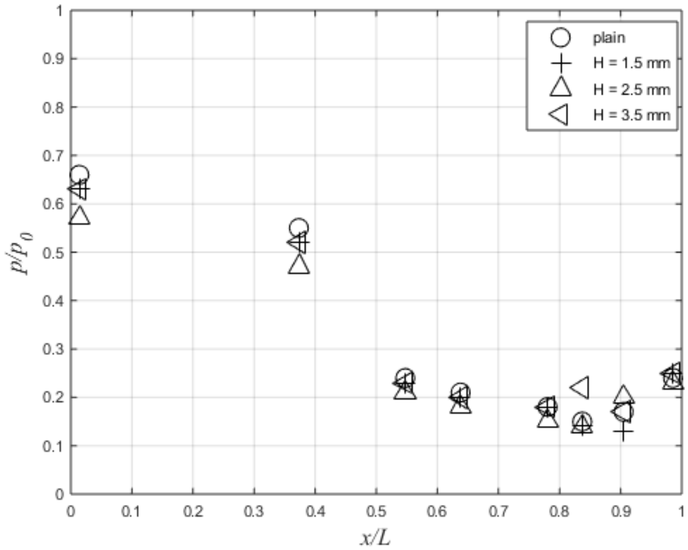

Figure 3. Wall static pressure variation (upper surface)

In order to visualize the wave structure in both uncontrolled and strut controlled nozzles, the Schlieren flow visualization technique is currently being used.

References

[1]. Hong-Gye Sung, Kiyeon Jeong, and Junyoung Heo, “Performance characteristics of a pintle nozzle using the conformal sliding mesh technique”, Aerospace Science and Technology, 61, 85-94, (2017).

[2]. J. Lee, B. Park, and W. Yoon, “Parametric Investigation of the Pintle Perturbed Conical Nozzle Flows”, Aerospace Science and Technology, 26, 268-279, (2013).

[3]. H. Sung, and J. Heo, “Fluidic Thrust Vector Control of Supersonic Jet Using Co-flow Injection”, Journal of Propulsion and Power, 28, 858-861, (2012).

[4]. P.J. Yagle, D.N. Miller, K. B. Ginn, and J.W. Hamstra, “Demonstration of Fluidic Throat Skewing for Thrust Vectoring in Structurally Fixed Nozzles”, Journal of Engineering for Gas Turbines and Power, 123, 502-507, (2001).