ABSTRACT

In the aerospace industry, the mixing enhancement of a jet and its core length is essential for reducing infrared radiation, mitigating aeroacoustic noise, improving combustion characteristics, and vectored thrust. In subsonic and sonic flow domains, the passive mixing devices like nozzles with non-circular curvature shed vortices of varying size due to their non-uniform azimuth curvature. Hence, they appeared to be effective mixing promoters. Besides, a tab essentially modifies the boundary layer characteristics at the nozzle exit causing the manipulation of the vortical structures to shed from it, particularly in supersonic flows. Therefore, it is equally important to investigate the effects of a tab when placed inside the nozzle (commonly referred to as strut).

On the other hand, in the supersonic flow, the tabs deployed at the nozzle exit shed the mixed size mixing promoting vortices that are critical for enhanced mixing. With this in mind, the current study investigates the mixing characteristics of subsonic and sonic jets using non-circular nozzles. Moreover, the present study investigates the effects of a tab (also called the thrust vectoring capability of a tab) deployed at three different locations in the divergent portion of a convergent-divergent nozzle. Subsequently, the efficacy of the plain and the corrugated tabs deployed at the exit of the nozzle is investigated at the supersonic flow region.

The present study is carried out in three parts; the first part examines the effect of two non-circular nozzle exit shapes (elliptic and square) on the mixing efficacy in subsonic and sonic flow regimes. The circular nozzle is also tested for comparison. Both qualitative and quantitative experiments have been conducted to determine the mixing efficacy of non-circular nozzles. Pitot pressure measurements in the axial and transverse directions were performed to quantify the potential core length and spreading characteristics. The shadowgraph technique was used to visualize the waves at the underexpanded jets of NPR 3.0, 4.0, and 5.0. Among the configurations investigated, the elliptic geometry is observed to be superior in reducing the potential core length and increasing the spreading of the jet. A maximum reduction in core length of 19.4% and rapid decay was accomplished with an elliptic shape with the sonic condition at the nozzle exit. Pitot pressure profiles at various axial locations show that the spread rate for the elliptic and square jets is higher than the circular jet. In the case of the elliptic jet, the maximum spreading was observed along the minor-axis plane than the major-axis plane. Because of this differential spread in non-circular jets, the jet switches the axes at a certain downstream distance. Interestingly, the elliptic jet switched the axes two times, whereas the

square jet showed only once. The differential spreading of the elliptic jet along major and minor axis planes is confirmed by Shadowgraphic images.

The second part investigates the effects on the flow characteristics when a tab (strut) is deployed in the divergent portion of a Mach 1.84 nozzle (thrust vector controllability). The strut height was varied as 1.5 mm, 2.5 mm, and 3.5 mm. The strut is more effective in deflecting the jet flow field in the presence of an adverse pressure gradient prevailing at the nozzle exit. A maximum jet deflection is achieved with a 3.5 mm strut, deployed at the divergent-portion's mid-section (X/L = 0.72). The superior performance of the longest strut is due to the generation of a stronger bow shock, which eventually increases the pressure imbalance at the nozzle exit and leads to a larger jet deflection.

The third part explores the effects of a pair of tabs of aspect ratio 1.5, mounted diametrically opposite to each other at the outlet of a Mach 1.75 circular nozzle, at varying levels of expansions, ranging from overexpanded to underexpanded jet states. In addition, to generate the vortices of mixed-size, three corrugation geometries, namely, rectangular, triangular, and semicircular, are configured along the tab edges. Both quantitative and qualitative investigations are carried out by using the pitot probe to measure the stagnation pressures and by utilizing a shadowgraph technique to visualize the flow field. The corrugated tabs generated a significant mixing, and among them, the tabs with triangular corrugations are found to be most effective. A maximum reduction of about 99.7% in the supersonic core is obtained with triangular corrugated tabs at near-correct-expansion, corresponding to a nozzle pressure ratio (NPR) 5. Interestingly, the semicircular corrugated tab significantly reduces the asymmetry near the nozzle exit plane. The shadowgraph images confirm the efficacy of different corrugated tabs in reducing the strength of the waves prevalent in the supersonic core.