# Abstract

The mixing enhancement of a jet and its characteristics are essential for numerous aerospace applications, such as reducing the infrared radiation of combat fighter aircraft, mitigating aeroacoustics noise in passenger aircraft, improving combustion characteristics in high-speed jet engines and scramjet engines, and producing vectored thrust for controlling spacecraft and missiles. These applications have rekindled interest in and study into jet flow mixing processes and strategies for controlling them. However, the slow growing rate of the shear layer due to compressibility effects is one of the biggest technological obstacles. The mixing process is severely suppressed at high-speed flow conditions (particularly when jet Mach number is above 0.3) because of the compressibility effects.

The jet mixing can be achieved through various passive control techniques. Passive jet control is often based on two mechanisms: making the flow more unstable and creating large-scale spanwise vortices into the flow. This is accomplished by incorporating stationary devices into the flow system (such as vortex generators, tabs, and so on) or by utilising geometrical modifications (such as non-circular exit geometry of the nozzles, grooves, notches, a cut-out at the exit of nozzle, and use of multi jet) to alter the shear layer stability characteristics. The lobed nozzle exit, ramps, tabs, notches, grooved configurations, and chevrons are common streamwise vortex generators, and non-circular exits of the nozzle like triangular, square, elliptical, etc. generate disturbance in the near-field area to enhance mixing. Keeping this in mind, the current study investigates the mixing characteristics of supersonic jets using plain and corrugated tabs. Moreover, the present study investigates the effects of different geometries of the tabs on the mixing characteristics of a sonic jet. Subsequently, the current study also investigates the influences of semi-circular, square, and triangular grooves on the mixing behaviour of an axisymmetric supersonic jet.

The present study is carried out in three parts; the first part examines experimentally the mixing augmentation of twin tabs mounted along a diameter at the outlet of a convergent-divergent Mach 1.62 circular nozzle. The usefulness of the plain and grooved tabs is examined at various expansion levels prevailing at nozzle outlet. The tab's performance is assessed through pitot pressure distribution measured along and perpendicular to the jet centerline at different nozzle pressure ratios (NPRs). The shadowgraph technique visualized the shocks and expansion fans in uncontrolled and controlled jets. With the introduction of

uncorrugated or plain tabs at the nozzle outlet operating under overexpanded conditions corresponding to NPR 4, the length of supersonic core (SCL) was decreased only by 35.4%. On the other hand, the corrugated or grooved tabs under similar conditions decreased the SCL substantially. Interestingly, the performance of grooved tabs was best at underexpanded conditions associated with NPR 6, where the SCL was reduced by about 88%. The pressure profiles also established the superiority of tabs with grooved edges in mixing augmentation without introducing any significant asymmetry to the flow field. In addition, the shadowgraph images also confirmed the weakening of shock strength and reduction of shock-cell length in the case of grooved tabs at the nozzle exit compared to the plain nozzle.

The second part examines the effect of different tab geometries on sonic jet mixing. The circular nozzle is also examined for comparison. The mixing efficiency was determined using both qualitative and quantitative studies. Pitot pressure measurements were taken in both axial and transverse directions to determine the possible core length and spreading characteristics. The shadowgraph approach was used to visualise the waves at the correctly expanded and underexpanded jets of NPR 2.0, 3.0, and 4.0. Among the configurations tested, the square tab shape was shown to be superior in terms of minimising potential core length and enhancing jet spread. A controlled jet with varying tab geometry and sonic conditions at the nozzle exit resulted in a roughly 50% reduction in core length and quick decay. Pitot pressure profiles at various axial positions reveal that controlled jets have a larger spread rate than circular jets.

The last part explores the effects of two grooves configured at the exit of a Mach 1.73 convergent–divergent nozzle at diametrically opposite locations have been numerically and experimentally investigated. The convergent-divergent nozzle has a 13mm exit diameter and a 10mm throat diameter. Three groove geometries, semi-circular, square, and triangular, were created at the nozzle exit and continued along the divergent section for up to half of its length. Grooves enhance the nozzle's exit area by 10%. The study is conducted at the nozzle outlet for several expansion levels, namely overexpansion, proper expansion, and underexpansion. The supersonic potential core reduction is most pronounced in semi-circular grooves, with a reduction of 43%. In comparison, triangular and rectangular grooves see a reduction of 25%, which is lower than that observed in semi-circular grooves. Although the Mach 1.73 jet at NPR 4 has an adverse pressure gradient, it is evident that the grooves significantly improve the mixing process. The realisable k-ε turbulence model accurately simulates low Mach number supersonic free jet flow with an inaccuracy of less than 7%. The Mach contour plots indicate that the inclusion of a groove causes a local expansion of the jet boundary, resulting in a distinct lateral spread.