CHAPTER 6

CONCLUSION

6.1 CONCLUDING REMARKS

The studies on mixing characteristics of supersonic circular, rectangular and triangular nozzles have been evaluated for free and co-flowing jets. The pressure based study capable of predicting supersonic jets in a quiescent domain has been applied to jet flows with inlet total pressures. The flow visualization using Schlieren system and CFD simulation results are also used to study the mixing characteristics. From this the following conclusions can be drawn. The differences between the CFD predictions and experimental measurements were within 5%. It confirms that the simulation results have a good agreement with experimental measurements.

1. The mixing efficiency of the circular co-flowing supersonic jet is lesser than that of triangular jets. The triangular jets displayed a higher spreading rate relative to circular jet due to interaction of the vortex structures. But the rectangular jets have better spreading rate over triangular jets due to the possession of greater vortices and edges.

2. The increased mixing rate of supersonic jets appears to be due to differential expansion of the jet for greater area ratios. This mixing enhancement is confined to $x/D < 10.6$. It is observed from the radial pressure profiles that greater area ratios improve the mixing characteristics.
3. Co-flow is found to influence the characteristics of central jet development. Due to coflow and differential expansion the mixing span increases. Coflow influences the potential core length of supersonic jets significantly. The potential core length of the central jet without coflow is about 20% less than that of with coflow. Also the increased inlet conditions provide an increased core length for all cases due to increased shock cells.

4. The secondary stream strongly interacts with the primary jet upon discharging from the coaxial nozzle. The presence of lower pressure in the base region of the coaxial nozzle with a finite lip thickness causes compressive turning of the individual stream, resulting in oblique shock waves. These shock waves dramatically change the individual stream.

5. A Mach disk appears near the jet axis as the consequence of the interaction between the oblique shock waves. Downstream of the Mach disk, the flow is subsonic. Outside the Mach disk, the flow is decelerated through the oblique shock waves, but the flow can be still supersonic with a reduced Mach number. Thus, strong shear action is generated due to this velocity difference.

6. The oblique shock waves affect the annular stream, and the pressure increase through the oblique shocks changes the local flow conditions in two contacting streams. The expansion waves generated inside the inner jet alter the flow direction of the annular stream. If the pressures at the boundary of the two
contacting streams are matched properly, the reflection of the expansion waves can be cancelled. Otherwise, it reflects only as a weak compression wave, resulting in an additional weak oblique shock.

7. The coaxial jet flow is subject to strong shear actions downstream of the shock system. The primary inner jet becomes subsonic downstream of the Mach disk. It interacts with the surrounding supersonic flow and becomes again supersonic further downstream. The shearing process slows down, and the radial extent of the supersonic interface region becomes narrow. The annular mixing occurs at the subsonic secondary stream boundary.

8. The non-circular shapes of inner jets influence the mixing in greater extend due to the vortices present in it. The rectangular jets dominate well comparing with other shapes due to more vortices. It is evident from the flow visualization and also has good agreement with computational results.

9. The secondary subsonic flow inhibits the primary stream in all the cases of the study. It is evident from the potential core study. Co-flow is found to modify the characteristics of central
10. Jet half-width at all Mach numbers indicates that the main jet spread is reduced by the co-flow. For underexpanded sonic condition the shock-cells are protected by the surrounding co-flow, making the central jet to travel to a greater axial distance. Co-flow is effective in modifying the shock-structure and mixing characteristics of the central jet.

11. The core length of the underexpanded sonic central jet increases with increase of increased inlet pressure conditions. An increase of 76% in core length is obtained at $5.5 \times 10^5$ Pa for case C3. Similar variation has been noticed for all other operating conditions and shapes of inner jets. The number of shock-cells increases in the presence of co-flow and the classic Mach disc at greater inlet pressure conditions for without co-flow is modified as a simple oblique shocks crossover point.

6.2 FUTURE SCOPE OF WORK

The non-circular jet shapes like rectangular and triangular shapes are used for this research work. Apart from this some more non-circular shapes like cruciform, elliptical and hexagonal shapes can be used to study the effect of jet shapes on the mixing characteristics.

Only three different area ratios are taken into consideration for the present study. In future there is a wide scope in varying the area ratios and the corresponding effects in the jet propagation can be studied.
In the present study flow visualization using Schlieren system and pitot probe is used to measure total pressure in the downstream. Instead of this, Non-intrusion methods like LDV or LDA or PIV can be used to measure the velocity and turbulence properties.

The circular outer jet shape is used for the coflowing annular study irrespective of the inner jet shapes like rectangular, triangular and circular. In the future study outer jet shapes can also be changed to any noncircular shapes and the mixing characteristics of the coaxial flow can be studied.

There is a wide scope on acoustic study on supersonic non-circular jets can be carried out to analyze the possibilities of reducing the supersonic jet noise.