CHAPTER 6

CONCLUSIONS

A series of experiments has been conducted to study the flow characteristics of straight and slanted entry nozzles run by supersonic stream. For the sake of comparison identical geometry nozzle is also being tested by attaching it to a stagnation chamber. Computational study is also carried out by time marching technique for a C-D nozzle kept in supersonic stream. Based on the analysis the results are summarized as follows.

6.1 EXPERIMENTAL STUDIES

1. Comparison of measured pressure distribution with the isentropic theory for the nozzle run by stagnation chamber with almost zero inlet velocity reveals that, in the incompressible region ($M < 0.3$) the agreement between the measured and theoretical value are almost 100%. In the compressible subsonic region also the agreement seems to be reasonably good. But the moment the flow becomes supersonic the measured pressure is higher than the isentropic theoretical pressure due to the decrease of area caused by the boundary layer growth, which is not accounted for in the isentropic theory.

2. Present results clearly demonstrate that, a straight or slanted entry C-D nozzle placed in supersonic free jet stream can
choke and deliver supersonic stream at its exit in spite of the shock at the inlet of the nozzle, for the range of Mach numbers and pressure ratios tested.

3. Placing the nozzle in supersonic stream at the same NPR of Laval nozzle shifts the separation location to the upstream. In spite of the reduced static pressure with supersonic stream the flow could able to accelerate, choke at the throat and expand as supersonic flow in the diverging portion of the nozzle, up to the separation point.

4. With increase of jet Mach number, the NPR for the driven nozzle decreases, leading to an increase of overexpansion level of the driven nozzle. This causes early separation.

5. It is found that, the presence of shock at the inlet of driven nozzle affects the inlet flow characteristics. But it does not affect the flow characteristics downstream of the throat except shifting the separation location. Thus the separation location is found to be a strong function of NPR only.

6. The Mach number ratio across the discontinuity for shock-induced separation is found to be approximately equal to 0.81 and it closely agrees with the prediction ratio of 0.8, reported in literature.

7. The empirical separation criterion of Schilling closely matches with the experimental incipient separation pressure for NPRs greater than 5. It is also evident that, in general a separation criterion that uses the ambient pressure $P_a$ is quite difficult to establish because two independent physical mechanisms,
namely the flow separation and recirculation, must be accounted for within one single relation.

8. It interesting to note that for all slanting angles, in the divergent section at the point of minimum wall pressure, the difference between experimental and 1-D isentropic case is about 33-39%.

9. Shadowgraph pictures of the flow field around the driven nozzle clearly shows that, in spite of the detached shock upstream of the inlet, the slanted nozzle could able to choke and deliver supersonic flow at its exit.

6.2 COMPUTATIONAL STUDIES

1. From the numerical results it is found that shock stand-off distance is function of freestream Mach number only. The shock stand-off distance is compared with results obtained from commercial software and found to be satisfactory.

2. Assuming the portion of the shock near the nozzle axis to be a normal shock, it is found that, the property variation along the center line after the shock compares well with the isentropic relation. When the freestream Mach number is increased, the shock shifts closer to the lip and also the increase in the freestream Mach number causes the shock shape to become less parabolic, which could be due to increase in strength of the shock.

3. The value of centreline entropy jump across the inlet shock matches well with the normal shock table. The entropy variation with freestream Mach numbers is found to be linear.
Further, the entropy jump across the shock is function of Mach number alone.

4. The present numerical algorithm with the domain divided into two parts requires a relatively short time to get converged solution. Further, even the coarsest mesh is sufficient to achieve satisfactory results.

5. Total pressure loss across the inlet shock increases with freestream Mach number linearly. The pressure recovery reduces from 80% at freestream Mach number 2 to about 60% at freestream Mach number 3.8.

6.3 SCOPE FOR FURTHER RESEARCH

1. Different nozzle shapes may be fabricated and tested in various inlet condition.

2. The numerical code can be extended for different nozzle shapes.

3. Viscous effects can be included in the numerical scheme.

4. Effect of angle of attack on the flow characteristics can be analysed.