ISSN: 0974-2115
www.jchps.com Journal of Chemical and Pharmaceutical Sciences

Analysis of base-jet exit shape on the wake axis mean velocity and velocity fluctuation behind circular cone

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ABSTRACT

Length of the basejet stagnation point obtained from the time averaged mean velocity distribution along the wake axis of a circular cone under isothermal conditions is presented. At low subsonic speed of 25m/s (Re= 0.6666 x 105), all the experiments were executed. Air at atmospheric temperature was injected at three different base-jet injection ratios as 0.5, 1.0, and 1.5 from the base of the cone. Constant Temperature hot-wire Anemometer was used to measure velocity. Circular, square and hexagonal cross section shape base jets of size one percentage of base area (AR = 0.01) were used in the experiments. Some notable conclusions made from the experimental results are, as the basejet momentum ratio increased the jet stagnation point length also increased logarithmically. At constant momentum ratio, the effect of corner vortices generated (loss in momentum) from the square jet causes decrease in length of jet stagnation point than an equivalent area ratio circular jet. Hence a square cross section basejet mixes early with primary jet than an equivalent area circular jet at constant momentum ratio.

KEY WORDS: Subsonic wake Jet, wind tunnel, separated flow, Jet stagnation point, and Hot-wire anemometer.

1. INTRODUCTION

Flame holder is an important component which is needed for anchoring and stabilising the flame in a combustion chamber. The wake behind the bluff body shaped flame holder provides the recirculation zone necessary for proper mixing of fuel and air ensuring efficient combustion. The recirculation zone has the beneficial effect of increasing the residence time during combustion. The flame stability in a combustor is found to be significantly affected by the residence time of the air-fuel mixture within the reverse flow region. (Abdollah, 2008; Saha, 2000), studied the aerodynamic properties of two dimensional bodies. Many researchers analysed the effect of bluff body shape on the flow field parameters experimentally. Two dimensional bluff body wake characteristics have been studied extensively but very limited work has been carried out relating to three dimensional bluff body characteristics. Calvert studied the pressure, velocity and velocity fluctuation distribution behind different circular cones. Roshko (1965), proposed a similarity parameter based on the base pressure along the wake axis. From the earlier studies it is seen that mostly circular jets issuing from base of the circular cones have been investigated. The shape of the base jet can be expected to have a profound influence on the mixing and flow characteristics in the wake region. The present work is focused on this particular aspect.

2. EXPERIMENT

Wind Tunnel: A closed jet type test section subsonic table top wind tunnel with four blade propeller at the circular exit was used for the experiment. A 15HP three phase induction motor used to power the propeller via variable speed gear box. A Rectangular shape test section of 240mm x 180mm cross section and 660 mm long centrally houses the test model. The experiments for which results are presented in this paper are carried out only at 25 m/s free stream velocity (Reynolds number 0.6666 x 105 based on model diameter). A two dimensional traversing mechanism is attached on the side wall (5mm thick) of the test section with due care about the flow disturbance and leakage of the air. A support for the CTA probe was firmly attached with the probe holder to hold and move the CTA sensor along the wake axis.

Test Model and Base Jet Assembly: Brass circular cone of fineness ratio (l/d) 2.75 was fabricated by CNC milling. Length (l) and base diameter (d) of the cone are 110.4mm and 40.5 mm respectively. The cone is made hollow for the convenient mounting of basejet supply systems. Circular, square and hexagonal exit cross section jets are used with the jet to base area ratio ($AR = A_j/A_b$) 0.01. Air required for the injection is supplied by a two stage reciprocating compressor through 1.6mm tube after filtering dust and moisture. An integrated pressure regulating valve (PRV, 0 – 10kgf/cm^2) cum moisture filter is used to avoid the intrusion of dust or moisture into the base jet which will severely damage the CTA sensor.

Base Jet Injection: During the experiments basejet exit velocity was controlled by the pressure regulating valve available near an air reservoir. Before the experiments all the base jets undergo the velocity calibration. Before starting the experiments hot-wire sensor is calibrated by using available velocity calibrator. A standard one dimensional sensor calibration procedure was followed. Twenty four calibration velocities were selected between 0 to 50 m/s. Modified King's law of first type equation ($E^2 = a + b*U^n$) was used (Bruun, 1996) to correlate calibration voltage and velocity.

3. RESULTS AND DISCUSSIONS

Figures 3.1 and 3.2 show the normalized mean velocity and velocity fluctuation $(u')_{rms}$ distributions at base jet IR = 0.5 (U_j = 12.5m/s). It can be noted that mean velocity of the square jet appears to be higher than that of other jets at the upstream of jet stagnation point (JSP). There is no considerable difference in location of JSP, maximum reverse velocity point (MRV) and primary air stagnation point (PASP) of all the three jets at this IR. At the downstream of PASP, increase in IR causes a little difference in U_m between with and without base-jet.

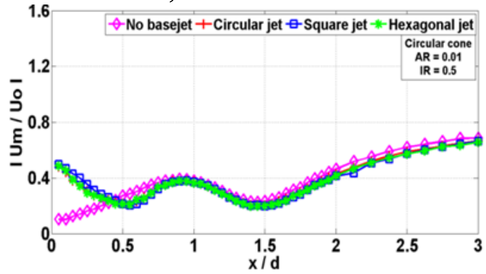

Fig.1. Mean velocity distributions of different base-jet shapes along the wake axis of an circular cone with AR = 0.01 and IR = 0.5

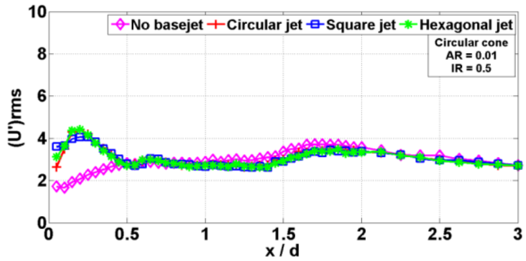

Fig.2. Velocity fluctuation distributions of different base-jet shapes along the wake axis of a circular cone with AR = 0.01 and IR = 0.5

There is no significant difference between U_m distribution of circular and hexagonal base jets when the jets are injected at IR=1.0 as shown in Figure 3.3.Mean velocity of the square jet is averagely 15% smaller than that of other two jets within the jet active region (between jet exit to JSP). Existence of approximately 24% higher $(u')_{rms}$ (Figure 3.4) of square jet than the other jets could causes this difference in mean velocity distribution. High velocity fluctuation leads to (loss of energy) reduction in mean velocity (up to 0.75d) for square jet. Injection of different shapes of base-jet does not affect both U_m and $(u')_{rms}$ at the downstream of JSP. Due to base-jet injection averagely 23% reduction in $U_m$is observed compare to the U_m of without base-jet after PASP (1.5d to 3d). At the downstream of JSP, difference in $(u')_{rms}$ of different jets is insignificant. But near to PASP, $(u')_{rms}$ of base jets is averagely 22% smaller than that of without base-jet.

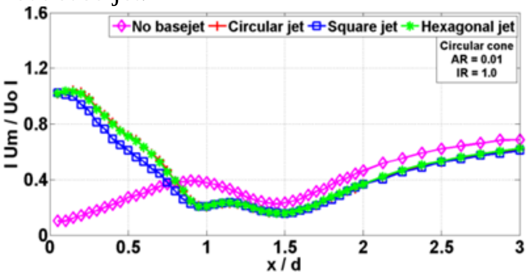

Fig.3. Mean velocity distributions of different base-jet shapes along the wake axis of an circular cone with AR = 0.01 and IR = 1.0

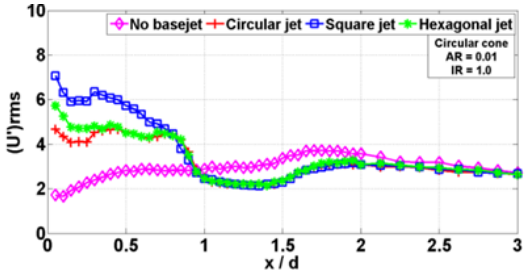

Fig.4. Velocity fluctuation distributions of different base-jet shapes along the wake axis of a circular cone with AR = 0.01 and IR = 1.0

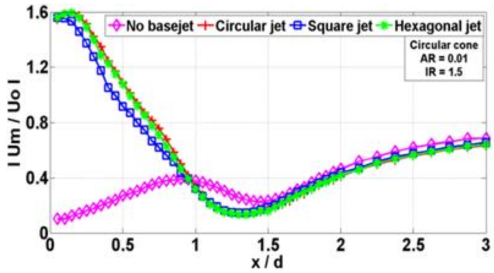

Fig.5. Mean velocity distributions of different base-jet shapes along the wake axis of an circular cone with AR = 0.01 and IR = 1.5

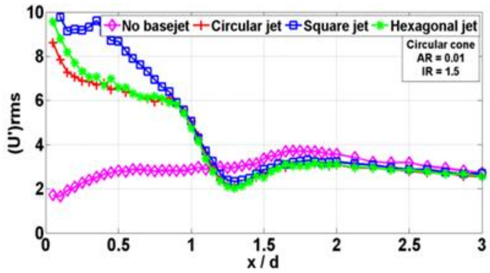

Fig.6. Velocity fluctuation distributions of different base-jet shapes along the wake axis of a circular cone with AR = 0.01 and IR = 1.5

Similar to the IR=1.0, at higher injection ratio (IR = 1.5) 14% difference in mean velocity is observed between square base-jet and other two jets within the jet active region as shown in Figure 3.5 and 3.6. Same area ratio square base-jet was injected instead of a circular jet and this cause 23% greater fluctuation within the jet expansion region. At higher IR, after the JSP there is no significant difference in mean velocity and $(u')_{rms}$ between the different shape base jets. At the same time, injection of base-jet caused maximum of 13% difference in mean velocity between with and without base jets at the downstream of PASP.

4. CONCLUSION

Mean velocity and velocity fluctuation distribution along the wake axis of a circular cone was measured and discussed when three different shape base-jets of AR = 0.01 are injected. Based on the experimental results the following notable conclusions can be drawn.

At smaller injection ratio (IR = 0.5), effect of base-jet shape is insignificant on the location of wale axis parameters (LJP, MRV and PASP) compare to the without base-jet.

At higher injection ratio mean velocity of circular and hexagonal shape jets are acting similar in magnitude compare with the square shape jet in the jet active region. Since the velocity fluctuation of square jet is greater (loss of energy) than circular and hexagonal jet, hence the mean velocity of square jet may be smaller than other jets.

Downstream of the JSP there is no effect of base-jet shapes on the mean velocity and velocity fluctuation at all the injection ratio. Base-jet injection causes reduction in mean velocity in the far wake region between with and without base-jet. At higher area ratio the effect of corner vortices generated (loss in momentum) from the square jet causes decrease in length of jet stagnation point than an equivalent area ratio circular jet. Hence a square cross section base jet mixes early with primary jet than an equivalent area circular jet at constant momentum ratio.

5. ACKNOWLEDGEMENT

Coressponding author greatly acknowledge the support extended by Department of Aerospace Engineering, Madras Institute of Technology (MIT), Anna University, for conduct of experiments during his Ph.D program at MIT.

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