Effect of circular exit shape base jet injection ratio on the velocity distribution along the wake axis of an elliptic cone

M Sundararaj[1*], S Elangovan[1] & BTN Sridhar[2]
[1]Department of Aeronautical Engineering, Bharath University, Chennai, India.
[2]Department of Aerospace Engineering, Madras Institute of Technology campus, Anna University, Chennai, India
***Corresponding author:E-Mail:sundarsonic@yahoo.com**

ABSTRACT

Time averaged mean velocity and velocity fluctuation along the wake axis of an elliptic cone with base-jet injection is presented. At subsonic free-stream velocity of 25m/s (Re= 0.6666 x 10^5), all the experiments were executed in a table top wind tunnel. From the base of the cone air at atmospheric temperature was injected from a circular exit shape base-jet at three different base-jet injection ratios (IR) as 0.5, 1.0 and 1.5. Constant Temperature hot-wire Anemometer (DANTECH- CTA) was used to measure velocity. Circular exit shape base-jets of three different sizes (AR = 0.005, 0.01 and 0.015) were used in the experiments. Some notable conclusions made from the experimental results are, at lower base-jet injection velocity effect on the location of wake axis parameters is insignificant, due to insufficient momentum of the base-jet to encounter the recirculating fluid. Irrespective of the jet size the rate of expansion of a jet injected from an elliptic cone is greater than that of circular cone.

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

1. INTRODUCTION

The main parameters affecting the combustion process in a combustor are closely related to the geometrical shape of the bluff body flame holder and the aerodynamic properties of the reverse flow region. In particular, the shape of the reverse flow region, and the location of front and rear stagnation points are important factors for flame stabilization. Circular cones are commonly used as bluff body flame holders for which one of the methods of fuel jet injection is base-jet injection. This type of combustors requires a fuel rich mixture at the flame front. Two dimensional shapes like circular, square, rectangle, triangle, elliptic are used for base jet injection in the combustor to get better combustion stability and efficiency. Bluff body should have smaller wake size, lower suction pressure in the wake and reduction of unsteadiness of wake flow.

Effect of equivalence ratio on axial velocity distribution and length or recirculation zone behind a triangular rod (two dimensional) was studied by Fujii (1981). Experimental and computational study of flow behind a circular cylinder with and without base-jet was done by (Papailiou, 2000; Bakrozis, 1999) discussed the effect of operating Reynolds number and air jet injection ratio behind a two-dimensional cylinder of square cross section. Unconfined annular flow with central jet was studied using laser sheet flow visualization method, by (Li, 1987; Ma, 1993) investigated the effect of blockage ratio of the central bluff-body, bluff-body angle and injection ratio on the mixing and recirculation of a concentric bluff-body burner.

In the present section effect of base-jet size (AR) on the wake axis parameters (L_{jp}, MRV and PASP) are analyzed. When the size of the jet is increased it leads to increase in mass flow for the same exit velocity. Increase in mass flow causes increase in momentum of the jet. In this section effect of increase in momentum of the base-jet on U_m and $(u')_{rms}$ is analyzed by means of changing the jet size.

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.

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 base-jet supply systems. Circular exit cross section jet was used with three different jet to base area ratio (AR = A_j/A_b) as 0.005, 0.01 and 0.015. 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. During the experiments base jet exit velocity (IR) 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.

3. RESULTS AND DISCUSSIONS

Mean velocity and velocity fluctuation distributions at different injection ratios (IR) of circular base-jet (AR = 0.005) is presented in Figure 3.1 and 3.2 respectively. From the mean velocity distribution of different IR jets it is known that the jet expansion rate within the reverse flow region of elliptic cone is relatively greater than that of a circular cone (Table 5.1 and 5.2).

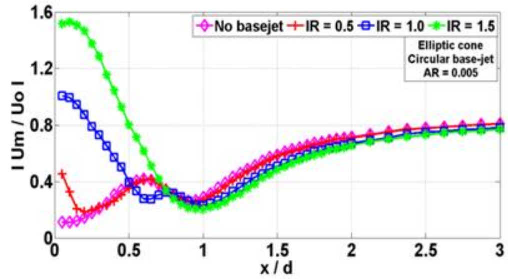

Figure.1. Mean velocity distributions at different IR along the wake axis of a elliptic cone with circular base-jet of AR = 0.005

It implies that for a constant AR, jet shape and IR base-jet, expansion of jet injected from an elliptic cone is quicker than a jet injected from a circular cone. Increase in IR causes increase in jet expansion rate behind elliptic cone also. At smaller IR (0.5), difference between magnitude of U_m between with and without base-jet is insignificant at the downstream of JSP. But, increase in IR causes significant change in mean velocity at the downstream of PASP (after 1d). After PASP, difference in magnitude of U_m of IR = 1.0 and 1.5 jets are 15% and 21% lower than U_m of without base-jet respectively.

Velocity fluctuation distributions of jet injected behind an elliptic cone is different than a jet injected from circular cone. A smooth transition is observed between maximum fluctuations to minimum fluctuation behind a circular cone. But for an elliptic cone from its maximum fluctuation to minimum fluctuation, rate of reduction is greater than that of circular cone at all IR. Downstream of the PASP of an elliptic cone also difference in magnitude of $(u')_{rms}$ between with and without base-jet is insignificant at all the tested IR. There is no difference in $(u')_{rms}$ is observed at the exit of IR = 0.5 and 1.0 but, IR increase to 1.5, 49% of increase in $(u')_{rms}$ is noted. Near to PASP (1d), velocity fluctuation of IR = 1.5 jet is 20% lower than that of without base-jet.

Effect of injection ratios on mean velocity distributions of AR = 0.01 circular base-jet is presented in Figure 3. At higher IR (1.5), there is no sign of reverse flow between JSP and PASP. Since the length of reverse flow region of elliptic cone is smaller when compare with the circular cone, high IR jets with higher momentum easily encounters the reverse flow along the wake axis. Values of L_{jp} of the higher IR jets also conforms the same information. At the downstream of PASP (after 1.0 d), maximum of 18% difference in mean velocity can be observed between U_m of with and without base-jet. Difference between the magnitude of U_m of IR = 1.0 and 1.5 is insignificant at the downstream of PASP.

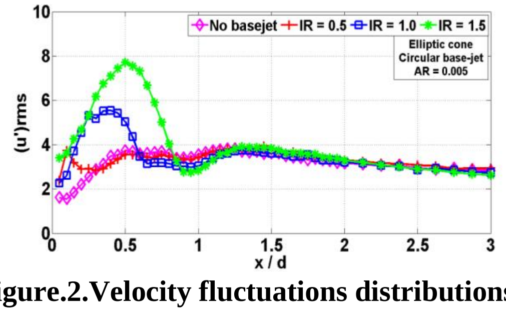

Figure.2.Velocity fluctuations distributions at different IR along the wake axis of a elliptic cone with circular base-jetofAR = 0.005

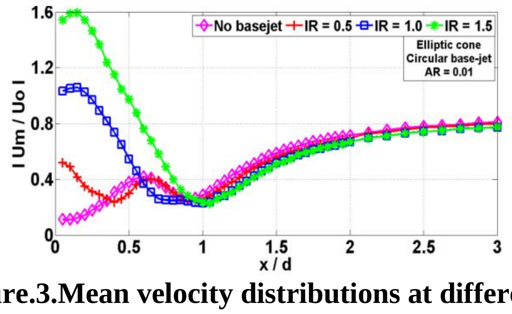

Figure.3.Mean velocity distributions at different IR along the wake axis of a elliptic cone with circular base-jet of AR = 0.01

Velocity fluctuation plot (Figure 3.4) shows that there is a remarkable increase in u' for increase in IR. While the IR increased from 0.5 to 1.0 and 1.5 results to 97% and 231% increase in u' at the exit with respect to u' of IR = 0.5 jet. At AR = 0.01 also there is no significant difference in magnitude of u' at the downstream of PASP as shown in figure 3.4.

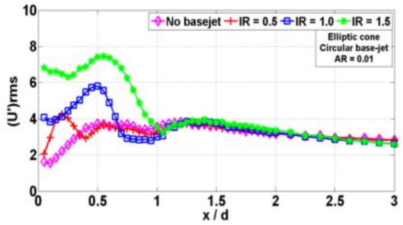

Figure.4. Velocity fluctuations distribution at different IR along the wake axis of a elliptic cone with circular base-jet of AR = 0.01

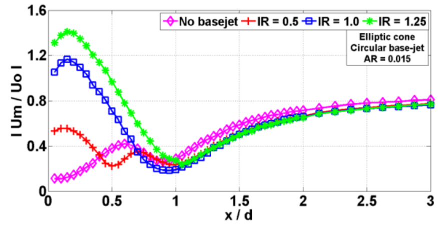

Figure.5. Mean velocity distributions at different IR along the wake axis of a elliptic cone with circular base-jet of AR = 0.015

Effect of IR of a circular shape base-jet (AR = 0.015) injected from an elliptic cone on mean velocity and $(u')_{rms}$ is presented in Figure 3.4 and 3.5 respectively. Behind the elliptic cone also at higher area ratio and IR formation of secondary vortex can be observed near the jet exit as the local acceleration. Downstream of PASP, significant difference (18% smaller) in U_m distribution is observed between with and without base-jet. After PASP there is no difference in magnitude of U_m of different IR base-jets. But magnitude of $(u')_{rms}$ distribution behind the PASP is similar for all the tested IR jets. Velocity fluctuation at the exit of the higher IR jets (IR = 1.0 and 1.25) 135% and 161% greater than the u' of IR = 0.5 jet respectively.

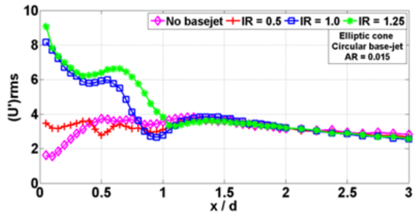

Figure.6. Velocity fluctuations distributions at different IR along the wake axis of a elliptic cone with circular base-jet of AR = 0.015

4. CONCLUSION

Effect of injection ratio (IR) of different area ratio (AR) circular base-jet on the wake axis mean velocity and its fluctuation were analyzed for an elliptic cone. From the analysis it is found that

At lower injection velocity (IR = 0.5), effect on the location of wake axis parameters is insignificant due to insufficient momentum of the base-jet to encounter the recirculating fluid. As the IR increased, length of base-jet penetration (L_{jp}) also increases due to the increase in jet momentum. Rate of increase of L_{jp} at lower IR is greater than at higher IR because of existence of acceleration and deceleration zone along the wake axis.

Increase in IR causes increase in expansion rate of base-jet along the wake axis. Expansion rate of base-jet injected from elliptic cone is higher than that of a circular cone. At constant IR increase in area ratio results to increase in fluctuation of the velocity at the jet exit. At higher IR and AR, generation of counter acting secondary vortex causing local acceleration for some distance from its exit.

REFERENCES

Anbazhagan R, Satheesh B, Gopalakrishnan K, Mathematical modeling and simulation of modern cars in the role of stability analysis, Indian Journal of Science and Technology, 6 (5), 2013, 4633-4641.

Bakrozis AG, Papailiou DD and Koutmos P, A study of the turbulent structure of a two-dimensional diffusion flame formed behind a slender bluff-body, Journal of combustion and flame, 119, 1999, 291-306.

Brindha G, Krishnakumar T, Vijayalatha S, Emerging trends in tele-medicine in rural healthcare, International Journal of Pharmacy and Technology, 7 (2), 2015, 8986-8991.

Brintha Rajakumari S, Nalini C, An efficient cost model for data storage with horizontal layout in the cloud, Indian Journal of Science and Technology, 7, 2014, 45-46.

Bruun H. H, Hot- wire anemometry principles and signal analysis, Oxford University Press, 1996.

Fujii S and Eguchi K, A comparison of cold and reacting flow around a bluff body flame stabilizer, Journal of Fluid Engineering, 103, 1981, 328-334.

Gopalakrishnan K, Prem Jeya Kumar M, Sundeep Aanand J, Udayakumar R, Analysis of static and dynamic load on hydrostatic bearing with variable viscosity and pressure, Indian Journal of Science and Technology, 6 (6), 2013, 4783-4788.

Jeyanthi Rebecca L, Susithra G, Sharmila S, Das MP, Isolation and screening of chitinase producing Serratia marcescens from soil, Journal of Chemical and Pharmaceutical Research, 5 (2), 2013, 192-195.

Kerana Hanirex D, Kaliyamurthie KP, An adaptive transaction reduction approach for mining frequent itemsets: A comparative study on dengue virus type1, International Journal of Pharma and Bio Sciences, 6 (2), 2015, 336-340.

Khanaa V, Mohanta K, Saravanan T, Comparative study of uwb communications over fiber using direct and external modulations, Indian Journal of Science and Technology, 6 (6), 2013, 4845-4847.

Khanaa V, Thooyamani KP, Udayakumar R, Cognitive radio based network for ISM band real time embedded system, Middle - East Journal of Scientific Research, 16 (12), 2013, 1798-1800.

Kumarave A, Rangarajan K, Algorithm for automaton specification for exploring dynamic labyrinths, Indian Journal of Science and Technology, 6 (5), 2013, 4554-4559.

Kumaravel A, Pradeepa R, Efficient molecule reduction for drug design by intelligent search methods, International Journal of Pharma and Bio Sciences, 4 (2), 2013, 1023-1029.

Li K and Tankin RS, A study of cold and combustion flow around bluff-body combustors, Journal of Combustion Science and Technology, 52, 1987, 173-206.

Ma HK, Chiou CH and Harn JS, Mixing and recirculation characteristics of a double concentric burner with bluff-body, Journal of Thermal Science, 2 (4), 1993, 294-303.

Papailiou D, Koutmos P and Bakrozis A, Simulation of fuel injection and flame stabilization in the wake formation region of a slender cylinder, Proc. The combustion Institute, 28, 2000, 91-99.

Sachithanantham P, Sa Nkaran S, Elavenil S, Experimental study on the effect of rise on shallow funicular concrete shells over square ground plan, International Journal of Applied Engineering Research, 10 (20), 2015, 41340-4134.

Sharmila S, Jeyanthi Rebecca L, Das MP, Production of Biodiesel from Chaetomorpha antennina and Gracilaria corticata, Journal of Chemical and Pharmaceutical Research, 4 (11), 2012, 4870-4874.

Sharmila S, Jeyanthi Rebecca L, Naveen Chandran P, Kowsalya E, Dutta H, Ray S, Kripanand NR, Extraction of biofuel from seaweed and analyse its engine performance, International Journal of Pharmacy and Technology, 7 (2), 2015, 8870-8875.

Udayakumar R, Khanaa V, Saravanan T, Saritha G, Cross layer optimization for wireless network (WIMAX), Middle - East Journal of Scientific Research, 16 (12), 2013, 1786-1789.

Vanangamudi S, Prabhakar S, Thamotharan C, Anbazhagan R, Dual fuel hybrid bike, Middle - East Journal of Scientific Research, 20 (12), 2014, 1819-1822.