Abstract
The Effect of freestream velocity and Ellipticity ratio on the similarity distribution of the static pressure along the wake axis of the elliptic cones is presented. A cone of elliptic cross section produces separated flow at the downstream of its base. Within the separated region the flow is observed to be opposite (reverse) to the main outer flow. To obtain the length of reverse flow region, magnitude and location of maximum reverse velocity and reattachment point knowledge of pressure distribution behind a body is essential. Experiments were carried out for three different test section freestream velocities 6m/s, 15m/s and 25 m/s (Reynolds numbers 0.16 x 10^5, 0.4 x 10^5 and 0.667 x 10^5 based on cone effective diameter respectively). Ellipticity ratio 1 and 3 with constant fineness and bluntness ratio of 2.75 and 0.049 respectively were considered for the experiments. A Digital Sensor Array –DSA was used for static pressure measurements. The pressure sensor has the capability of 1 PSI differential pressure range with +/- 0.12% full-scale accuracy. Good similarity in wake axis static pressure distribution is noted for different freestream velocity behind a circular cone. But, Similarity in pressure distribution is not observed along the wake axis of an elliptic cone at tested lower freestream velocity (6 m/s).

Keywords: Elliptic Cone, Pressure Coefficient and Similarity Parameter, Wake Pressure

Nomenclature

- **a** - Semi major axis of an ellipse
- **b** - Semi minor axis of an ellipse
- **a/b** - Ellipticity ratio (ER)
- **(C_p)** - Coefficient of pressure
- **l** - Length of the elliptic cone
- **d** - Effective base diameter of the cone
- **l/d** - Fineness ratio
- **Pin** - Static pressure at the test section inlet plane
- **x** - Coordinate in the stream wise direction
- **Uo** - Freestream velocity
- **(C_p)_max** - Maximum value of coefficient of pressure
- **(C_p)_min** - Minimum value of coefficient of pressure
- **P_max** - Maximum pressure
- **(x)_{p,max}** - Location of **(C_p)_max**
- **(x)_{p,min}** - Location of **(C_p)_min**

1. Introduction

In industrial combustion system to attain flame stabilization, use of a component called flame holder is necessary. A flame holder is a bluff-body used to anchor the flame in combustor. By creating reverse flow region behind a flame holder as shown in Figure 1, combustion system provides a place to mixing of fuel and air. Low velocity exists in the recirculation zone results to increase in residence time during the combustion. Because, stability of the flame in a combustor is depends on the residence time of the air-fuel mixture within the reverse flow region.
Aerodynamic properties of two dimensional bodies were studied by many authors\textsuperscript{1,2}. Effect of bluff body shape on flow field parameters were well analysed experimentally by many authors\textsuperscript{3–7}. But, limited number of study only carried out with three dimension bluff body\textsuperscript{8,9}. Extensively studied about the pressure, velocity and velocity fluctuation distribution behind different circular cones studied\textsuperscript{10}. Similarity of pressure distribution along the wake axis of different semi apex angle circular cone was studied using the parameter $C_{p1}$ (Eq. 3). Calvert modified the similarity parameter based on base pressure proposed by Roshko et al.\textsuperscript{11} into Equation 2 (based on minimum pressure along the wake axis). The non dimensionalized distance $x'$ is calculated based on the location of both maximum and minimum pressure along the wake axis (Eq. 1). Since both the test models are of different geometrical shapes (circular and elliptic), it is essential to check similarity of the flow parameters along the wake axis. Hence two different similarity parameters Equation 2 and Equation 3 were considered for analysis of pressure distribution of circular and elliptic cone at different subsonic velocities.

\begin{equation}
  x' = \frac{x - (x)_{p,\text{min}}}{(x)_{p,\text{max}} - (x)_{p,\text{min}}}
\end{equation}

\begin{equation}
  C_{p1} = \frac{C_p - (C_p)_{\text{min}}}{1 - (C_p)_{\text{min}}}
\end{equation}

\begin{equation}
  C_{p2} = \frac{C_p - (C_p)_{\text{min}}}{(C_p)_{\text{max}} - (C_p)_{\text{min}}}
\end{equation}

2. Experiment

2.1 Setup

A table top subsonic wind tunnel (Figure 2) available in the CAP Laboratories, Department of Aerospace Engineering, Madras Institute of Technology, Anna University was used for the experimentation. Size of the test section (width, height and length) is 240mm, 180mm and 600mm respectively. Four baled propeller available at the tunnel exit is powered by a 15 Hp three phase induction motor via a variable speed gear box. Four different freestream velocities inside the test section can be achieved (6, 15, 25 and 48 m/s) by operating the propeller at different speed as 500, 1000, 1500, and 3000 RPM respectively. In this study experiments are conducted at 6 m/s, 15 m/s and 25 m/s and corresponding Reynolds numbers of the flow (based on cone effective base diameter) are 0.16 x 105, 0.4 x 105 and 0.667 x 105 respectively. To mount the traverse mechanism, 5mm thick transparent acrylic sheet was used as the side walls of the test section. Test section has a detachable base to easily mount the different test models. A two dimensional traverse mechanism is attached on the side wall of the test section with due care about the flow disturbance and leakage of the air. A Pitot static probe (0.5mm diameter tapping) was firmly attached with the probe holder of the traverse mechanism to move it along the wake axis. Traverse can move up to maximum of 250mm from the cone base along the flow direction with minimum displacement of 0.5mm.

2.2 Test Model

Elliptic cones of semi axis ratio (a/b) 1 and 3 were fabricated by CNC milling from Brass. Fineness ratios of both

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Flow structure behind a circular cone. [RSP – Rear Stagnation Point, MRV – Maximum Reverse flow Velocity, PASP – Primary Air Stagnation Point, e – Length of reverse flow region, P – Centre of Vortex].}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Experimental setup for static pressure measurement. [1 – Test model (cone), 2 – Static pressure probe, 3 – Connecting hose, 4 – DSA(Digital Sensor Array), 5 – Probe support and 6 – Traverse mechanism].}
\end{figure}
the cones were maintained constant as 2.75 by maintaining length \((l = 110.04\text{mm})\) and effective base diameter \((d = 40.5\text{ mm})\) as constant. A hollow double convex column of width 30mm and thickness 6mm supports the model inside the test section. The elliptic cone is mounted coaxially inside the test section by aligning the axis of the cone and test section in a single line. Experiments were carried without at 0° angle of attack with respect to horizontal and vertical axis of the test section. Major axis of the elliptic cone always kept parallel to the base of the test section.

### 3. Data Acquisition

A Digital Sensor Array –DSA, Scanivalve Corporation (DSA 3217 / 16 Px), was used to measure the static pressure along wake axis of the cone. The scanner is capable of measuring one PSI differential pressure (Range +/- 1 PSI) with 0.12% of full scale accuracy. DSA Link V4.03 software was used to interface DSA module and the computer. The pressure was measured at 25 different locations (up to 3 times base diameter) with 5mm distance between points along the wake axis. Pressure data was acquired at 30 FPS (Frames per Scan) with 100 samples per frame during all the experiments. A dedicated MATLAB program reduces the raw pressure data into average static pressure, \(C_p\) and plots against the non-dimensionalized distance \(x/d\).

### 4. Results and Discussion

Effect of freestream velocity on \(C_p\) distribution along the wake axis of a circular cone is presented in Figure 3. At 6m/s, \(C_p\) distribution is little higher than that of other two speeds between cone base and \((C_p)_{max}\) due to the existence of minimum reverse flow velocity near to the base. Location and magnitude of the \((C_p)_{max}\) for all three velocities remains same (1.7d), which shows that there exists a similarity in the length of reverse flow region of circular cone for tested freestream velocities (6, 15 and 25 m/s). Downstream of the \((C_p)_{max}\), difference in \(C_p\) distribution is insignificant at the tested velocities. Location of the \((C_p)_{min}\) along the wake axis falls at 0.6 times the base diameter \((0.6d)\) on the other hand the \((C_p)_{max}\) at 1.73 times base diameter \((1.73d)\). For a circular cone, \((P)_{max}\) is greater than the freestream static pressure at all the tested velocity. Hence a positive \(C_p\) value can be observed \(((C_p)_{max} = 0.028)\).

Similarity parameter of \(C_{p1}\) distribution along the wake axis of a circular cone at three different freestream velocities is presented in Figure 4. Collapse of the pressure data is better except at \((C_p)_{max}\) for 6m/s freestream velocity only considerable difference in \(C_{p1}\) can be observed near the \((C_p)_{max}\) (at 1d). A parameter based on both maximum and minimum pressure \((C_{p2})\) holds good similarity in pressure distribution along the wake axis of a circular cone at different velocity (Figure 5) compare with \((C_{p1})\).

Figure 6 shows the coefficient of pressure \((C_p)\) distribution along the wake axis of an elliptic cone at different freestream velocity. As the freestream velocity increased,
pressure at the base decreases considerably due to the decrease of minimum pressure \((C_p)_{min}\) along the wake axis. Decrease in magnitude of the \((C_p)_{min}\) is occurring but, there is no notable change in its location with respect to the freestream velocity. Between \((C_p)_{max}\) and \((C_p)_{min}\), difference in pressure distribution is insignificant for all the tested freestream velocity. Maximum pressure at 15m/s and 25m/s is lower than the freestream static pressure due to the decrease in recirculation length behind an elliptic cone. Location of \((C_p)_{max}\) and \((C_p)_{min}\) of elliptic cone is 1.3d and 0.54d respectively which is shorter than that of circular cone.

Similarity parameters \(C_p1\) and \(C_p2\) distribution along the wake axis of an elliptic cone is presented in Figures 7 and 8 respectively. On both cases similarity profile pertaining to 6m/s acting different than other two velocities. But the parameter \(C_p1\) holds good similarity in pressure distribution behind the elliptic cone compare with the \(C_p1\) for the higher (15 and 25m/s) freestream velocity.

5. Conclusions

From the analysis of similarity of static pressure distribution along the wake axes of circular and elliptic cones, important conclusions can be drawn from the discussion as follows. For circular cone similarity parameter based on both maximum and minimum pressure \((C_p)_{p2}\) holds good similarity between all the tested freestream velocities than that of \(C_p1\). This is strongly agreed with the conclusions of Calvert J R about the similarity of the static pressure distribution. For an elliptic cone the parameter \(C_p2\) holds good similarity except at low velocity (6m/s). Hence, better similarity in pressure distribution can be observed behind both circular and elliptic cone with respect to the similarity parameter \(C_p2\).

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7. References