EFFECT OF COFLOW ON SONIC JET

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Abstract. The sonic coflow effect on the core length of sonic primary jet was experimentally investigated in this research work. A circular convergent nozzle was used for both core and coflow jet studies. The 1mm annular gap was maintained between the coflow and core nozzles. The nozzle pressure ratio (NPR) was varied from 3 to 5, insteps of 1 for both the nozzles. For each primary NPR, the NPR of coflow was varied, and the shadowgraph flow visualization was carried out. From the shadowgraph visualization results it was observed that the sonic primary jet core length increases with increasing pressure ratio without coflow. With sonic coflow, the primary jet core length started to increase further with increasing coflow NPR. That is, the increase of sonic coflow NPR at each sonic primary jet NPR resulted in the elongation of core. Therefore, the introduction of coflow has resulted in core length elongation at all the levels of underexpansion. The primary jet core elongation due to the presence of coflow resulted in the weakening of shock strength in the primary jet core.

Keywords: Jet, Coflow, Core Length, Supersonic Core, Visualization

1. Introduction

The emerging advancements in aerospace engineering have contributed to the development of cutting edge technologies in aircraft exhaust systems, combustion chambers and fuel injectors etc. Coflow jets involve the interactions of two fluids, which improve the mixing between them. Coflow jets are also employed in aircraft turbine engines to reduce the noise developed by the core supersonic jets. Under certain conditions, imperfectly expanded jets generate a discrete tone denoted as screech. This discrete part of aeroacoustics jet noise arises in addition to broadband associated shock noise and jet mixing noise. Furthermore, the jet aeroacoustics noise can be altered by providing a control on the coflow, consequently reducing the noise level. Lovaraju and Rathakrishnan [1] experimentally investigated the outcome of
subsonic and coflow sonic jets. The coflow jet was found to alter the core jet shock strength and mixing characteristics. The primary jet core length of sonic jet at underexpanded levels increased with increase of nozzle pressure ratio (NPR). Keshav Ramesh Sharma et al. [2] conducted shadowgraph flow visualization to recognize the outcome of secondary coflow sonic jet on a core Mach 2 jet. The coflow NPR of sonic jet has been changed to a fixed NPR of the core Mach 2 supersonic jet. The Mach 2 supersonic jet's core length increased due to the existence of a sonic coflow. The core length was extended further as the NPR of the sonic coflow was increased. Hemant Sharma et al. [3] reported the outcome of subsonic and coflow sonic jets on the supersonic core of Mach 1.43 and Mach 2 jets. The primary jet core length elongation due to the presence of coflow was noticed at all the levels of expansion. Srinivasarao et al. [4] studied in the presence of coflow, thin and thick lip core sonic nozzles of NPRs 3, 5, and 7 are underexpanded. In the presence of coflow, a nozzle with a thick lip jet resulted in a core length reduction and served as a mixing promoter as compared to a thin lip nozzle jet. Shadowgraph visualization clearly showed that as compared to a thin lip nozzle with coflow, the jet from a thick lip nozzle (with coflow) has less shock cells. Murakami and Papamoschou [5] investigated the mixing characteristics of single stream, dual stream coaxial and eccentric nozzle configurations. They found that the eccentric configuration's mixing characteristics are better than the coaxial nozzle. Debiasi and Papamoschou [6] revealed the underexpanded and overexpanded pressure matched conditions of high speed axisymmetric jet acoustics characterization. They found that the existence of coflow practically decreasing the screech noise. Lee et al. [7] performed impact pitot pressure measurements along the jet axis and done shadowgraph flow visualization to demonstrate the coflow jet's near-field flow structure effect. The outcome of the coflow secondary stream on the primary core supersonic jet is greatly dependent only when the primary core jet is underexpanded or overexpanded.

Most of the coflow studies in literature used a single feed system for both primary and secondary nozzles, which means the operating condition (NPR) of primary and secondary jets remains same. In addition, there is limited information in the literature about the sonic coflow effect on the sonic primary jet core length over a range of secondary NPR. For this, the primary and secondary NPRs have to be controlled separately. Sonic coflow's effect on the primary core sonic jet is studied in the current study by varying the stagnation pressures of both the primary and secondary settling chambers independently. Each primary sonic jet NPR has a different secondary sonic jet NPR. The NPR of both sonic jets is changed in steps of one from 3 to 5. Shadowgraph technique is used to quantify the core lengths of core and coflowing jets.

2. Open Jet Arrangement and Experimental Model

This experimental work is carried out in the High Speed Aerodynamics Laboratory at SRMIST Kattankulathur, Department of Aerospace Engineering. An open jet setup capable of performing coflow study is used to perform the experiments. Figure 1 represents the set-up schematic. The nozzle model has a convergent primary circular nozzle enclosed by circular convergent secondary coflow nozzle. The annular gap between the primary nozzle and secondary coflow nozzle is 1mm. Figure 2 displays a photo of the nozzle. The pressure controlling valves at the inlet of the primary and secondary settling chambers, as shown in Figure 1, control the NPR of the sonic primary jet and sonic secondary coflow separately.
3. Shadowgraph System

Shock waves existing in the jet are visualized with the help of shadowgraph setup available at SRMIST. The images are photographed using a DSLR camera.

4. Results and Discussion

For a fixed sonic primary jet NPR 3, 4, 5, the sonic secondary coflow NPR is changed from 3 to 5, and the waves are captured using shadowgraph technique. The NPRs 3, 4 and 5 are underexpansion levels of the sonic jets. The shadowgraph images are used to find the core length of jet. The axial distance at which supersonic flow exists in a sonic jet is called the core length [8]. In the current work, this axial distance is found from the shadowgraph images; hence the calculated core length is only approximate. The sonic primary jet core length increased with rising NPR in the absence of a sonic coflow jet from the secondary nozzle. In pressure ratios 3, 4, and 5, the core of the sonic primary jet was around 5.5D, 10D, and 13.1D, respectively. The strength of the shocks was observed to increase as the NPR was increased.
Figure 3 shows the sonic primary jet core length without sonic coflow. It was observed that as the sonic coflow jet NPR increases, the sonic primary jet core length also increases. It was also noticed that as NPR of the sonic secondary coflow increases, the primary jet core length elongates for all the sonic primary jet NPRs. With a fixed sonic primary jet NPR 3, the sonic coflow NPR was varied (NPR 3, 4, 5) and the calculated core lengths were found to be 7.3D, 7.9D, and 8.5D respectively. Similarly the elongation of the sonic primary jet core length for NPRs 4 and 5 for sonic coflow NPRs 3, 4, and 5 are 10.6D, 10.9D, 11.6D and 14.3D, 14.8D, 15.2D. Figure 4 shows the shadowgraph findings of a sonic primary jet NPRs 3, 4, and 5 with sonic secondary coflow at NPRs 3, 4, and 5. The introduction of coflow has resulted in core length elongation of core jet at all the levels of underexpansion. As a result, the elongation of the sonic primary jet's core length due to the existence of sonic secondary coflow indicates that the primary sonic jet's mixing with the ambient fluid is reduced. This occurs because the secondary nozzle's sonic coflow encloses the sonic primary jet, preventing the sonic primary jet from mixing with ambient fluid. The sonic primary jet shock structure was significantly altered by sonic coflow. In addition, shock waves at all NPRs were weakened due to the core elongation of the primary jet caused by coflow.

![Figure 3. The sonic core jet shadowgraph images at NPRs 3, 4 & 5.](image-url)
A. core NPR 3 & coflow NPR 4
B. core NPR 3 & coflow NPR 5
C. core NPR 4 & Coflow NPR 4
D. core NPR 4 & coflow NPR 5
E. core NPR 5 & coflow NPR 4
F. core NPR 5 & coflow NPR 5

Figure 4. Sonic primary jet shadowgraph images with sonic coflow.

5. Conclusion
This experimental study demonstrates that the sonic primary jet core length is significantly affected when sonic secondary coflow is present. As the sonic coflow NPR is increased for each primary jet NPR, the sonic primary jet core length is found to increase. This happened at all three primary NPRs (3, 4, and 5). Sonic primary jet's core length elongation occurs since the sonic coflow from the secondary nozzle encloses the sonic primary jet, preventing it from interacting with ambient fluid. However, the shock waves were weakened due to the extension of the sonic primary jet core length.

References
[1] Lovaraju P and Rathakrishnan E 2011 Experimental Studies on Co-flowing Subsonic and Sonic Jets Flow Turbulence Combustion 87 115-32
[2] Keshav Ramesh Sharma, Akash A, Vishal R, Rajkumar S, Bharadwaj K K and Aravindh Kumar S M 2020 Control of mach 2 jet using sonic coflow IOP Conf. Series: Materials Science and Engineering 912 022016
[3] Hemant Sharma, Ashish Vashishtha, Lovaraju P and Rathakrishnan E 3-6 March 2008 Characteristics of Sonic and Supersonic Co-flow Jets 2nd International Conference on Recent Advances in Experimental Fluid Mechanics at Vijayawada.
[4] Srinivasarao T, Lovaraju P and Rathakrishnan E 2014 Characteristics of Underexpanded Co-flow Jets Applied Mechanics and Materials 575 507-511.
[5] Murakami E and Papamoschou D 2000 Mixing layer characteristics of co-axial supersonic jets 6th AIAA/CEAS Aeroacoustics Conference.
[6] Debiasi M and Papamoschou D 2001 Noise from Imperfectly Expanded Supersonic Coaxial Jets *AIAA JOURNAL* 39 (3) 388-395 DOI:10.2514/2.1348

[7] Lee K H, Setoguchi T, Matsuo S and Kim H D 2003 The effect of the secondary annular stream on supersonic jet *KSME International Journal* 17 1793-1800

[8] Rathakrishnan E 2010 Applied Gas Dynamics *Wiley Hoboken* 485-563