Effect of Cavities on Mixing of Coaxial High-Speed Jets

S Jeyakuma, K Karthik, J Sarathkumar Sebastin

Abstract: ***Cavity performance in coaxial supersonic jets is investigated experimentally in a supersonic flow facility. The coaxial jets issued from the supersonic nozzle enter into a supersonic combustor in which the cavities are incorporated. The primary jet is maintained at a Mach of 1.32, while secondary jet is designed for Mach of 1.00, 1.11 and 1.45. The open type cavities are axisymmetric. The primary flow is maintained at a temperature of 1050K and the secondary flow is at atmospheric temperature. Static and stagnation pressures are measured by using a conventional pitot probe to analyze the quantitative mixing performance and total pressure loss. Uniform momentum flux distribution is observed in cavity configurations compared with nocavity. A more uniform mixing, as well as minimum stagnation pressure loss, is observed for cavity configuration - 4, L/D = 1.53, than other cavity configurations***

Keywords: ***Cavity flow, Supersonic flows, coaxial jet mixing, stagnation pressure loss.***

I. INTRODUCTION

The main objectives in the design of Scramjet engine are fuel injection, mixing and combustion of air and fuel and flame holding. Various injection and flame-holding configurations are posted by many researchers for practical use. The transverse injection of fuel into the combustor is one of the simplest methods. This technique causes the fuel jet to interrupt the supersonic cross-flow in front of the injector, resulting in a bow shock. A modified transverse injection system with a greater mixing rate, with low stagnation pressure drop compared to a single injection [1][2]. The hydrocarbon combustion efficiency [3][4] was improved significantly in the latest year's transverse injection of petrol upstream of the cavity.

Yu et al.,[5] investigated a cavity flow's stable and unstable characteristics with a focus on the flow-induced cavity resonance phenomenon. It would therefore be a successful strategy to incorporate tandem cavities in the order of open and closed configuration to improve mixing and flame holding. Experimental studies [6] on cavities in an open flame of Mach 2 with angled injection showed that cavities with a tiny aspect ratio offer an outstanding flammability, while the flame length was shortened significantly by acoustic excitation with a comparatively lengthy aspect ratio. This study focusses to explore the performance of cavities in the vicinity of a coaxial jets in terms of quantitative mixing and stagnation pressure loss and compared with no cavity.

II. EXPERIMENTATION DETAILS

Figure 1 indicates the experimental configuration schematic in which two coaxial jets are used for isothermal experiments. The primary and secondary flow lines are branched off from a common air storage system and the flow is maintained using pressure regulating valves. The primary flow line is connected with a subsonic combustor which in turn is connected with a convergent divergent nozzle and the secondary flow surpass through the annular channel around the primary nozzle. The main nozzle offers a Mach flow of 1.32 and Mach of 1.0, 1.11 and 1.45 are performed in three different secondary flows. The main stream stagnation temperature is preserved at 1050 K by adjusting the fuel flow to the primary subsonic combustor and at room temperature (305 K) the secondary flow. The primary and secondary flows mix in a supersonic combustor of circular cross-section is fixed at the outlet of the nozzles (Table 1). The aspect ratio, L_m/D_m, of the supersonic combustor is 5.0.

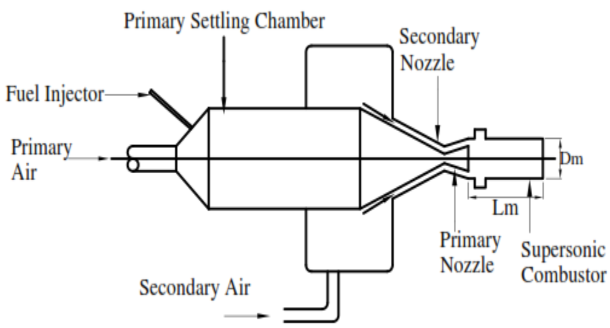

Figure.1. Schematic of experimental setup

The end view of the supersonic combustor assembly is given in Fig. 4. The cavities are connected to the combustor's flow inlet. The cavities are open type (L/D<10) and axisymmetric with different length and depth of the cavity configuration are given in Table 2.2. Different cavity configurations and various secondary flow Mach numbers are chosen for the study. Secondary fuel (kerosene) is injected upstream of the cavities in the transverse direction of

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the flow. Pitot and static pressures are measured using Pitot and static probes at the outlet of the combustor in the radial direction. A pressure transducer is utilized to receive the pressure signals from the probe. To move the probe in the radial direction of the flow field, a traversing arrangement is used.

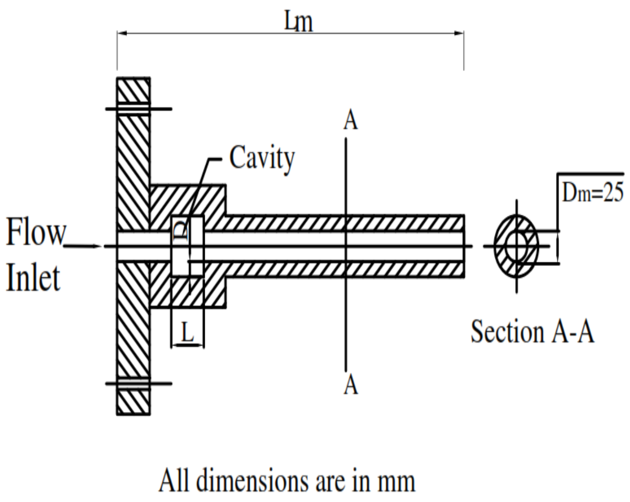

Figure. 2. Schematic of the Supersonic combustor assembly with Cavity Configuration

Table 1.Experimental Parameters

Parameter	Primary Jet	Secondary Jet		
		I	II	III
Stagnation Temp.(k)	1050	305	305	305
Stagnation pressure	2.8	2.0	2.4	3.4
Mach No.	1.32	1.0	1.11	1.45
Mass Flow Rate	0.152	0.069	0.083	0.117

Table 2. Cavity dimensions

Cavity No.	Length (L) mm	Depth (D) mm	L/D
1	20.6	32.02	0.643
2	20.18	24.10	0.837
3	15.48	20.1	0.770
4	15.3	10.0	1.53

III. RESULTS AND DISCUSSIONS

a. Momentum Flux distribution

Momentum Flux Distribution with different momentum and stagnation pressures, the coaxial jets enter the supersonic combustor. The distribution of momentum flux in the radial direction at the outlet of the supersonic combustor is a measure of the level of bulk mixing.

$$\mu = p\,(1+\gamma M^2) \qquad (1)$$

Where p is the static pressure measured value and Mach number M is calculated using the Rayleigh – Pitot formula from the measured values of static and stagnation pressures. Because of more operating pressure at the primary than the secondary, the primary jet has greater momentum than the secondary. The unmixed flow at the supersonic combustor exit plane is defined by a non-uniform momentum flux distribution.

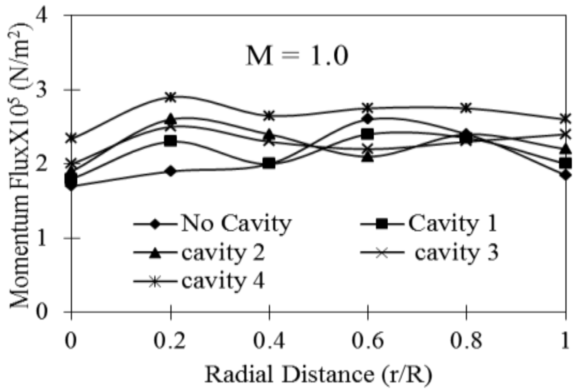

Fig. 3 Radial Distance Vs Momentum flux

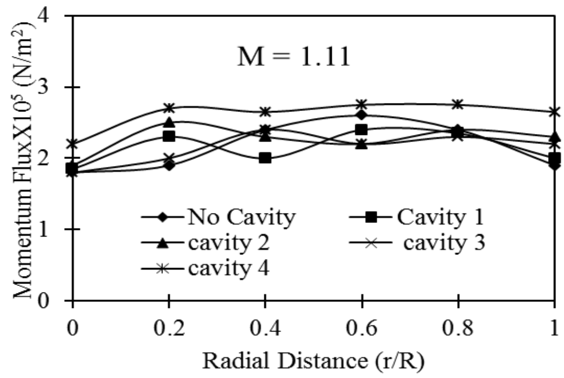

Fig. 4 Radial Distance Vs Momentum flux

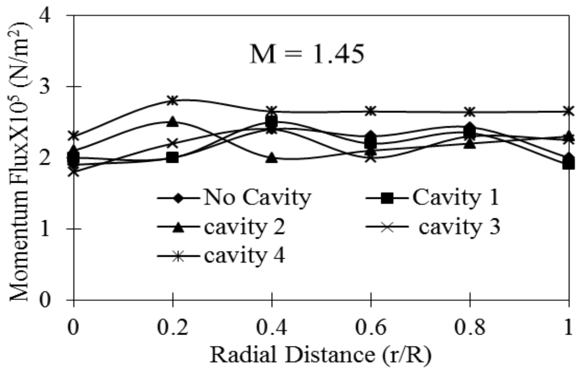

Fig. 5 Radial Distance Vs Momentum flux

Figure 3 to 5 shows the distribution of momentum flux for varying cavity configurations standardized by the combustor radial distance for an axial length of L_m/D_m = 5.0. L_m/D_m refers to the supersonic combustor's length-to-diameter ratio and r/R refers to the radial distance from the axis (r) normalized by the supersonic combustor radius. From the operating conditions, it is observed that there is a difference in momentum flux occurs between the primary and secondary flows due to variation in the operating

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pressures of the primary and secondary flows. From the plots it is observed that from M = 1.0 to 1.45 all the cavity configurations provides almost uniform momentum flux profiles sharing better uniformity of mixing of the two co-axial jets takes place inside of the supersonic combustor than no cavity configuration. It is also observed that for M = 1.45, the uniform momentum flux distribution indicate better uniformity of mixing of the two jets than the other two secondary flow Mach Numbers with the identical cavity configuration- 4.

b. Mixing Factor

Defining a parameter called Mixing Factor [7] (MIXF) quantitative mixing of varying cavities at diverse axial positions is quantified. This indicates that the degree of mixedness of the two streams obtained from the measured total pressure and is calculated as

$$MIXF = 1 - U \qquad (2)$$

where U is the radial non-uniformity of stagnation pressures with respect to P_{om},

$$U = \left[\frac{1}{R}\int_0^R\left(\frac{P_{01}(r)}{P_{om}} - 1\right)^2 dr\right]^{\frac{1}{2}} \qquad (3)$$

Where P01(r) is the shock-corrected total pressure value at the radial position r and R is the mixing duct radius. The mixing factor variations for different mixing duct cavities are shown in figure 6. From the plots, all the cavities provide almost identical mixing behavior of the two co-axial jets compare to no cavity. It also indicates that cavities-4 provide higher mixing factor than the no cavity and other cavity configurations. As the secondary flow travels through the cavity, shock waves interrupt the mainstream route from the leading and trailing edges of the cavity and increase the mixing of two coaxial jets.

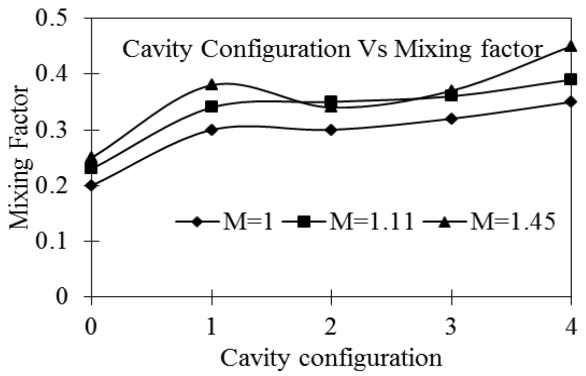

Fig 6 Cavity Configuration Vs Mixing Factor

c. Pressure Drop Factor

Due to improvements mixing of the two jets, the stagnation pressure loss of the two jets will be analyzed to optimize the configuration of the cavity. Figure 7 depicts the pressure drop factor normalized by the various cavity configuration for the supersonic combustor of L_m/D_m=5.0.

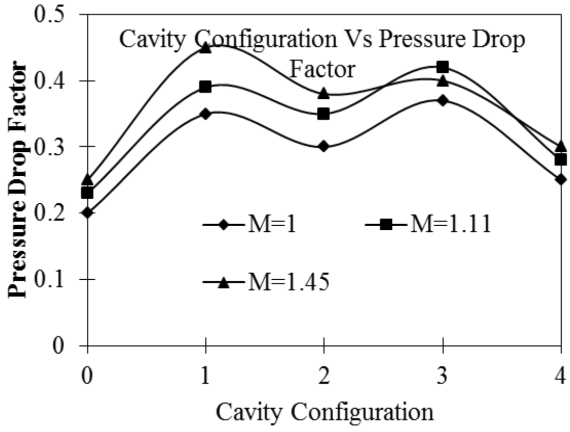

Fig .7 Cavity Configuration Vs Pressure Drop Factor

The plot indicates that no cavity creates less stagnation pressure loss than other cavity configurations. The cavity configuration-4 demonstrates less stagnation pressure loss from the above plots than other cavity setup revealed that the drag penalty produced by the cavity configuration-4 is lower than the other cavities. Further investigation is needed to analyze the flow pattern within the various cavity configuration.

IV. CONCLUSIONS

The investigations on cavities experimented in a coaxial supersonic flow facility. Stagnation pressure measurements are made at the exit of the combustor to analyze the uniform momentum flux distribution, mixing factor and stagnation pressure loss using numerous cavity configurations. With the increase in secondary flow Mach number, the uniform momentum flux distribution at the exit of the combustor shows mixing of coaxial air stream using the cavity configuration-4 of L/D=1.53. The L/D = 1.53 cavity configuration-4 offers a greater mixing factor with relatively less stagnation pressure loss than other cavity configurations indicates the superiority of coaxial jet mixing.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

NOMENCLATURE

To = Stagnation Temperature (K)
L_m = Length of the combustor (mm)
D_m = diameter of the combustor (mm)
L = Length of the cavity (mm)
D = depth of the cavity (mm)
r = incremental radius at the combustor exit (mm)
R= Radius of the combustor (mm)

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