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Studies on Combustion in Supersonic Flows

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Combustion studies are carried out on co-axial supersonic streams by transverse injection of fuel (kerosene) in a combustor using wall mounted axisymmetric cavities. The primary flow is maintained at a Mach number of 1.32 and the secondary flow is sonic. The combustor is attached at the exit of the nozzles. The cavities are attached at the inlet of the combustor. Temperature measurements are made at the exit plane of the combustor. Higher combustion efficiency and rise in stagnation temperature is observed for cavity configurations than for no-cavity under identical operating conditions.

Key Words: **Supersonic flows, Combustion, Fuel.**

INTRODUCTION

In supersonic combustion ramjet engines the fundamental aspects are fuel injection, ignition and flame holding. An efficient fuel injection system must be needed for mixing of air and fuel within the shortest combustor to achieve successful combustion. Different injection systems have been proposed[1–4] for rapid mixing: both flush mounted injectors and intrusive injectors. However, these injection systems do not initiate the combustion process. The other two important factors are ignition and flame holding[5] that leads to the design of fuel injection systems. Once ignition is established, the efficiency of combustion depends on mixing of air and fuel. The goal of the flame holder is to reduce the ignition delay and to provide a continuous source for the chemical reaction to be established within a short distance. Flame holding can be achieved by the organization of recirculation area and interaction of shock waves in the flow path. However, these stabilization techniques[6] have the drawback of increased stagnation pressure loss due to strong bow shock waves in the flow path.

Recent publications have presented the advantage of cavities as both fuel injection and flame holding in supersonic combustion engines[7, 8]. A cavity

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exposed to a flow is classified into two categories. In both cases, a shear layer separates from the upstream lip and reattaches downstream. For L/D < 7–10, the cavity is termed open because the upper shear layer reattaches to the back face. Small aspect ratio cavities (L/D < 2–3) are controlled by transverse oscillation mechanism, whereas in large aspect ratio cavities longitudinal oscillations become the important mechanism[8]. The high pressure at the rear face as a result of the shear layer impingement increases the drag of the cavity. For L/D > 10–12 the cavity flow is termed closed, because the free shear layer reattaches at the bottom of the cavity wall. Increase of pressure in the back wall vicinity and a decrease in the front wall result in large drag losses.

Yu and Schadow[9] conducted experiments on rectangular wall mounted cavities to enhance mixing of supersonic reacting and non-reacting jets. Their results revealed that for reacting jets, the cavity reduced the after burning flame length by 30% with modified intensity. Vinogradov[10] investigated experimentally the scramjet combustors operating on kerosene, where cavities were used as flame holders. A row of hydrogen fuel injectors placed in front of a cavity was used to achieve sustained combustion. The present study reveals the combustion characteristic of supersonic streams past wall mounted axisymmetric cavities. The distributions of stagnation temperature at the exit plane of the combustor as a measure of mixing and combustion efficiencies are analyzed.

EXPERIMENTAL

Studies are conducted using a blow-down type co-axial jet facility. Fig. 1 shows the diagram of the experimental test rig. The hot gases are produced at the primary flow using a subsonic combustor of kerosene as the fuel and the outer secondary flow is maintained at atmospheric temperature issuing co-axially. At the nozzle exit, the two streams enter into a mixing duct of circular cross-section which acts as a supersonic combustor. Cavities are attached at the exit of the nozzles. Secondary fuel is injected at the upstream of the cavities. The primary and secondary flows are at Mach numbers of 1.32 and 1.0, respectively. Due to the limitations of the experimental setup the primary flow is maintained at a temperature of 1050 K. Temperature measurements are made at the exit of the supersonic combustor using a calibrated Wrinkler type total temperature probe (having a radiation shield) with a chromel-alumel thermocouple.

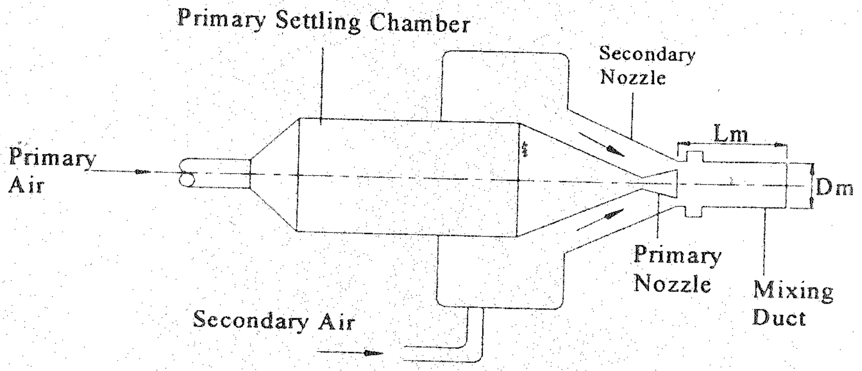
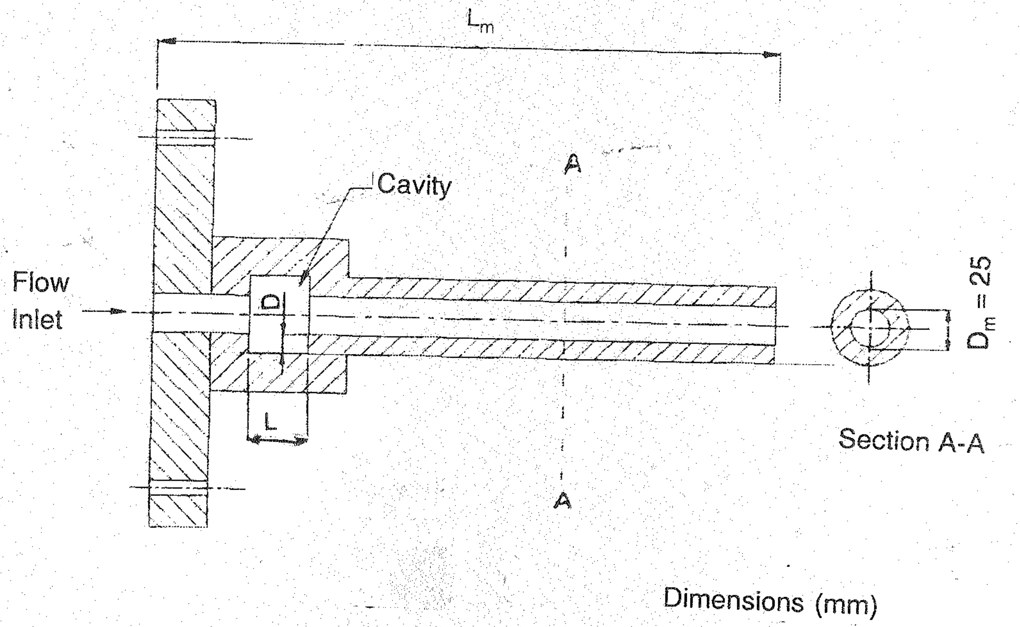


Fig. 1. Schematic diagram of the experimental setup



RESULTS AND DISCUSSION

Figs. 3–6 show the stagnation temperature distribution normalized by the radial distance of the mixing tube at an axial length of $L_m/D_m = 5.0$ for different cavity configurations. In all these plots the results are compared with the no-cavity. From the plot it is observed that the stagnation temperature is higher at the centre of the combustor as the hot primary jet issues along the axis and the lower temperature away from the axis indicates poor mixing between the two jets. For the cavity configuration, the stagnation temperature profile is not uniform for the secondary fuel flow rate of 0.00224 kga/s and the rise in temperature is marginal for the cavity and no-cavity configurations than without injection. The stagnation temperature profile tends to be uniform for the fuel flow rate of 0.00312 kg/s showing better mixing of the two streams taking place inside the combustor.

Combustion efficiency

The efficiency of supersonic combustion is calculated as the ratio of the measured temperature rise to the theoretical temperature rise. The rise in theoretical temperature is determined from the flow rates fuel air streams assuming that

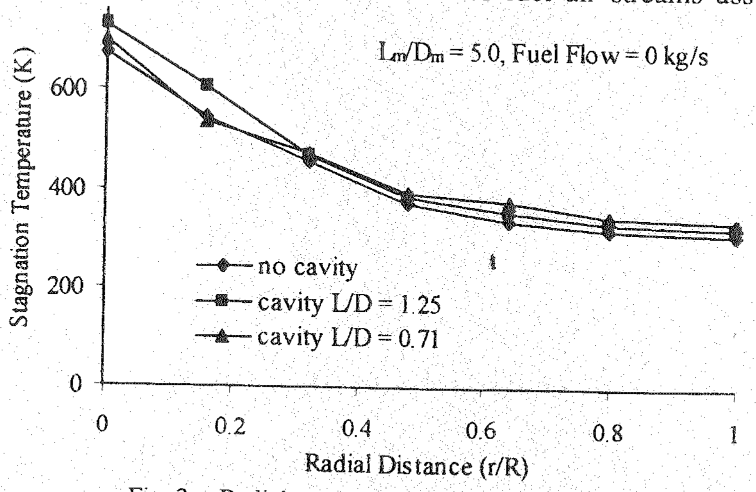


Fig. 3. Radial stagnation temperature distribution

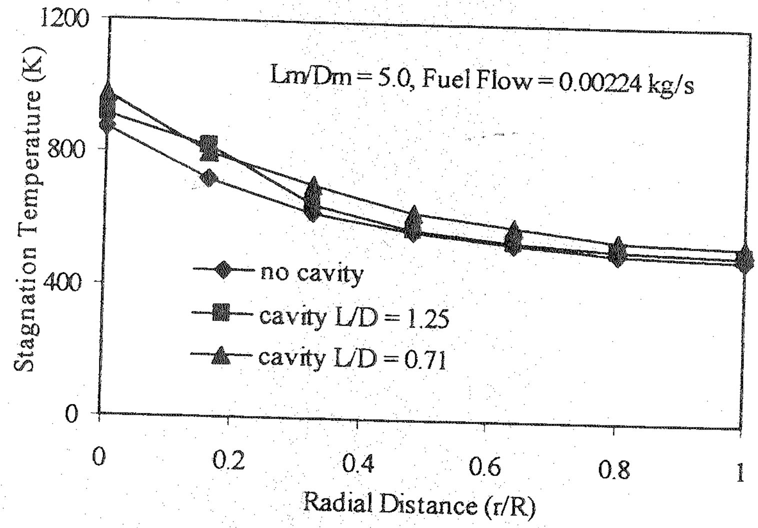


Fig. 4. Radial stagnation temperature distribution

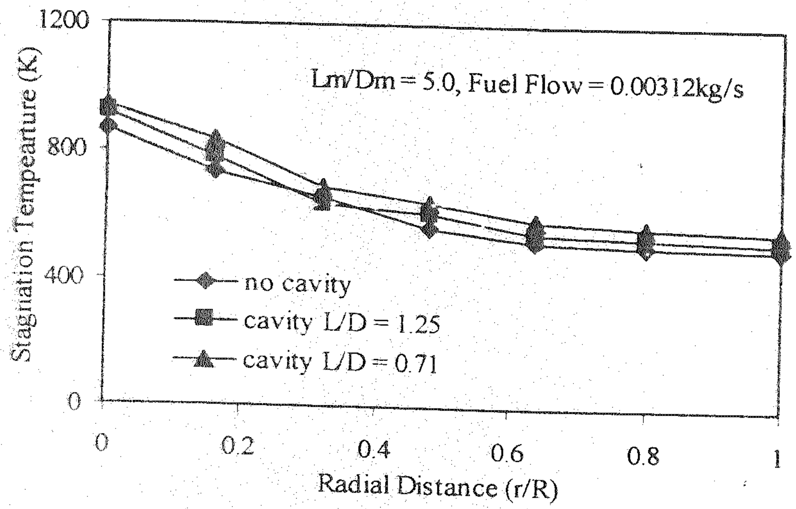


Fig. 5. Radial stagnation temperature distribution

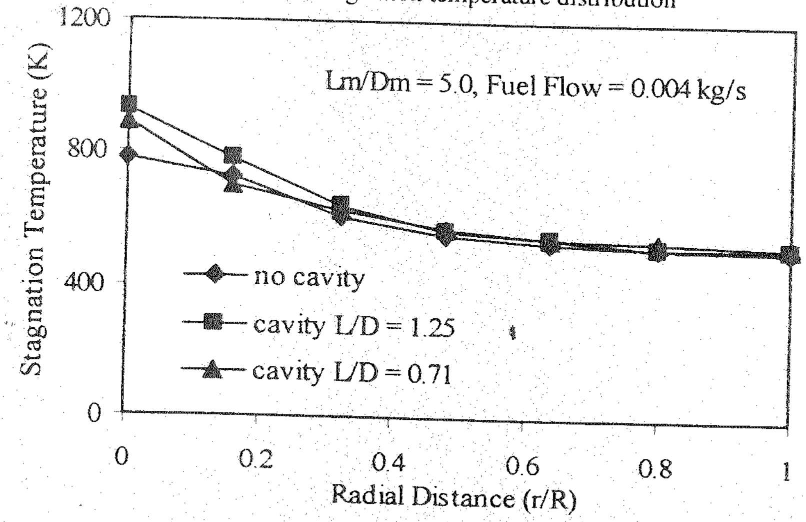


Fig. 6. Radial stagnation temperature distribution

combustion goes to completion adiabatically. The efficiency thus calculated provides the performance of the supersonic combustor in comparing cavities with no-cavity configuration is shown in Fig. 7.

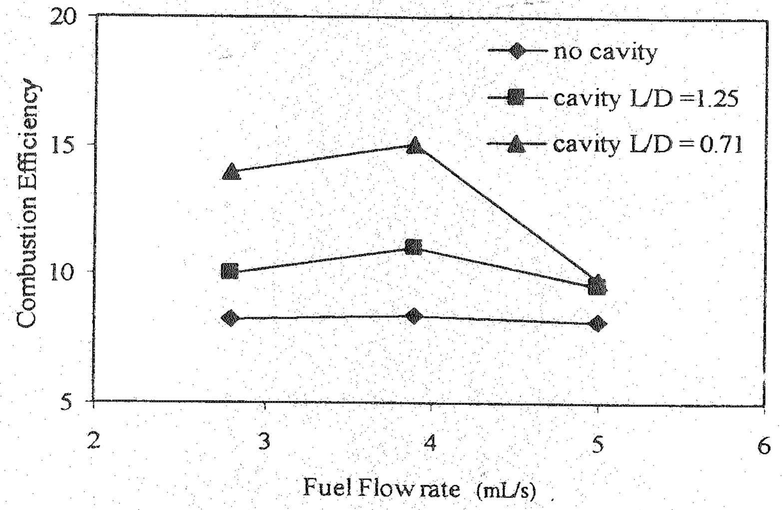


Fig. 7. Combustion efficiency *vs.* fuel flow

Conclusion

Experiments are conducted on supersonic combustion using cavities as the potential device for different fuel injections. The secondary air temperature is maintained at ambient condition and the secondary fuel is injected upstream of the cavity. The rise in temperature across the combustor and combustion efficiency for the different fuel flow rates are experimented and compared with the no-cavity configuration. The conclusions of the present study are:

- Cavities provide a more uniform stagnation temperature profile than no-cavity revealing the enhancement in mixing of the two jets is obtained using cavities.
- Rise in stagnation temperature across the combustor is observed with the increase in the secondary fuel flow rate.
- The combustion efficiency achieved by the supersonic combustor with the cavity configurations is more than no-cavity by the transverse injection of the secondary fuel. The combustion efficiency enhances with the increase in the secondary fuel injection.

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