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Technical Notes

TECHNICAL NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes should not exceed 2500 words (where a figure or table counts as 200 words). Following informal review by the Editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Performance of Aft-Ramp Cavities for Flame Stabilization in Supersonic Flows

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Introduction

THE fundamental and difficult-to-realize requirements of supersonic combustion needed in hypersonic airbreathing engine are ignition and flame holding. Cavities have gained the attention of scramjet community as a promising tool for ignition by creating a hot pool of radicals and for flame stabilization [1,2]. Experimental investigation conducted with supersonic reacting flow using open cavities showed that stable combustion can be achieved by optimizing the cavity dimensions [3]. Studies on the various aspects of flame-holder cavities highlighted the importance of cavity aft-wall ramp on the stability and flammability limits [4]. Further investigation revealed that for open cavities, aft-ramp angle plays an important role in the flame-holding performance [5,6]. The discussions point out the fact that the performance of such cavities is highly geometric specific and can vary considerably with change in cavity geometries.

The main focus here is to compare the effect of decrease in ramp angle on the stability of the internal flowfield and fluid entrainment into the cavity for different aspect ratios. Unsteady and steady pressure measurements inside the cavity are the diagnostic methods used in this study.

Details of the Experiments

The blowdown supersonic test facility consists of a convergent–divergent nozzle designed for a Mach number of 1.76 ± 0.02 (total pressure of 5.3 bar and temperature of 305 K) exiting into the test section. The constant area rectangular test section is of 56 mm width, 30 mm height and 300 mm long. Two cavity configurations: a low aspect ratio ($L/D = 3$) and a high aspect ratio ($L/D = 6$) as shown in Fig. 1, are used in the experiments. Cavity length is fixed as $L = 60$ mm and the depth chosen are $D = 20$ and 10 mm, to give the required L/D ratios. L is measured up to the center of the ramp and ramp angle $\theta = 30$, 45, 60, 75 and 90 degrees are designed for each aspect ratio. A piezoelectric pressure transducer [PCB, Piezotronics, USA, Model 112A22] is flush-mounted with the cavity fore wall for unsteady pressure measurements. The sensitivity of the transducer used for unsteady measurements is 100 mV/psi. The sampling frequency employed for data acquisition is 100 kHz based on the estimated frequency of the cavity tones. The scan time for each of the samples is 10 μs, which is 5 times the rise time of the transducer. Fast Fourier Transform is performed on the voltage output signals to give amplitude Vs frequency plot. Root mean square (rms) value of the pressure fluctuations is also found and is normalized with the free stream dynamic pressure to reduce in to coefficient form ($C_{p\mathrm{rms}}$). Static-pressure ports are arranged uniformly 10 mm apart along the cavity floor for mean surface pressure measurements. A pressure scanner [Scanivalve Corp., Model SDIU MK1] is used to scan the pressure data. The response time of the transducer is 0.1 ms and its sensitivity is 75 mV/psi. The specified accuracy of the transducer is $\pm 0.1\%$. The measured mean floor-pressure values are also reduced to pressure coefficient C_p and are presented in graphical form for comparison. The uncertainty of the experimental data is estimated to be 0.32% for the pressure coefficient values.

Results and Discussions

Stability of the Cavity Flowfield

Acoustic signature is acquired from the fore wall of the cavities, $L/D = 3$ and 6 for different ramp angles and are shown in Fig. 2. It is interesting to see that, oscillation inside the cavity is considerably reduced after modification of the aft wall to a lower ramp angle and the cavity is almost stable for $\theta = 30$ deg. Dominant peak amplitude of 560 Pa at the second harmonic frequency of 4728 Hz is obtained for the low-aspect-ratio rectangular cavity ($L/D = 3$). Corresponding amplitude for the high-aspect-ratio cavity ($L/D = 6$) is 211 Pa and is at the first harmonic frequency of 2136 Hz. Shifting of the dominant mode from second harmonic frequency to first is observed for the low-aspect-ratio cavity with decrease in ramp angle. This can be as a result of the fact that, aft-ramp cavities appearing longer to the shorter wave length modes and is consistent with earlier investigation [7].

The dominant oscillation frequencies measured are compared with that of the Rossiter prediction [8] as given in Table 1. It is found that the measured frequencies approach those of the semi-empirical model with a decrease in ramp angle.

The rms pressure fluctuations are obtained from the fore wall for the preceding two cavity configurations and are compared, as shown in Fig. 3. The magnitudes of $C_{p\mathrm{rms}}$ obtained for the low- and high-aspect-ratio cavities (no ramp) are 0.018 and 0.007, respectively. These values are found to be in reasonable agreement with those reported from similar flow conditions [8,9]. It is important to see that the suppression rate with a decrease in ramp angle is high for the low-aspect-ratio cavity. The low-aspect-ratio cavity ($L/D = 3$) becomes more stable for a lower ramp angle than that of the high-aspect-ratio cavity ($L/D = 6$). This can be thought to be a direct consequence of changes in the main stream entrainment into the preceding cavities with a change in ramp angle. Here, it is justifiable to believe that the low-aspect-ratio cavity can entrain more fluid from the main stream with shallower ramp angles than with the high-aspect-ratio cavity,

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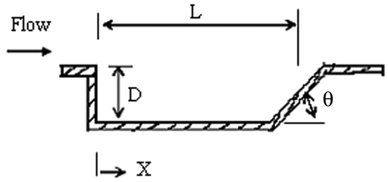
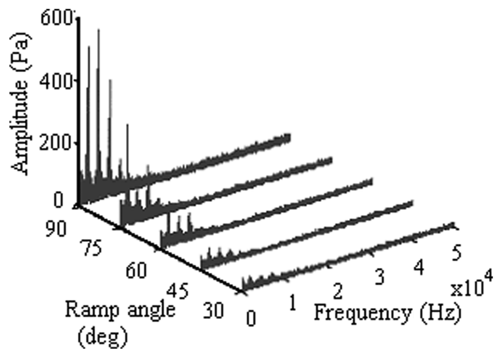
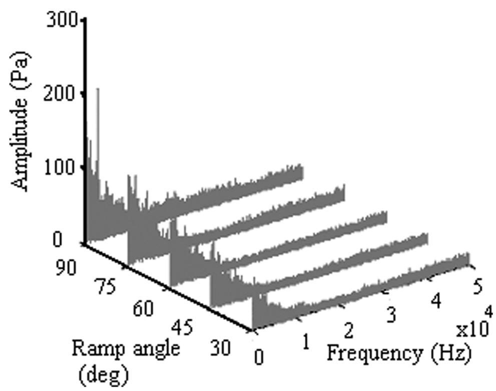


Fig. 1 Cavity with aft-wall ramps.



a) L/D = 3



b) L/D = 6

Fig. 2 Comparison of the acoustic signature inside the cavity with different ramp angles.

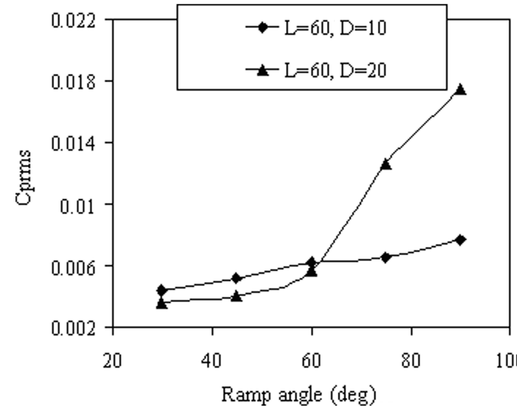
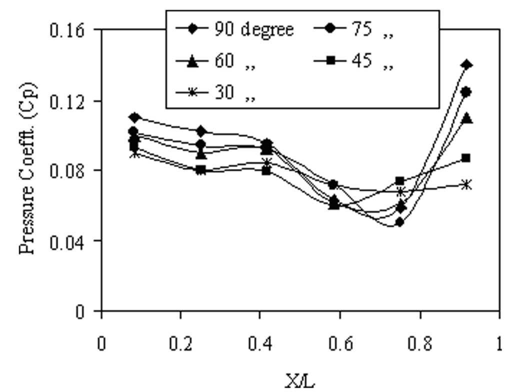
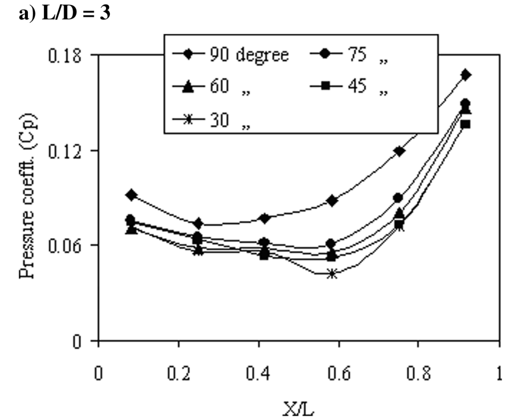


Fig. 3 Variation of C_{prms} with ramp angle.



a) L/D = 3



b) L/D = 6

Fig. 4 Comparison of floor-pressure variation with ramp angle.

due to added cavity depth. The static-pressure variations inside the cavities can throw more light onto this important aspect.

Cavity Pressure Distribution

The centerline floor-pressure data are acquired for the preceding cavities and the pressure coefficient C_p values are plotted against the nondimensional cavity length X/L, as shown in Fig. 4. X is measured from the cavity fore wall. It is found that the pressure level along the cavity floor decreases with a decrease in ramp angle, indicating the reduction in fluid accumulation inside the cavity. It is shown that for given cavity dimensions, a shallower ramp angle could entrain more fluid from the main stream, which consequently results in a reduction in the cavity-residence time [10]. But it is seen here that for a high-aspect-ratio cavity (Fig. 4b), the pressure level is not altered much by the lower ramp angles, compared with that of the low-aspect-ratio case (Fig. 4a). That means that for the high-aspect-ratio cavity, the effects of a decrease in ramp angle to a lower value to control the entrainment rate and the pressure in the recirculation region are not very significant. These results are supportive of the aforementioned stability phenomena.

Table 1 Comparison of experimental and calculated frequencies

Ramp angle, deg	Experimental, Hz $L/D = 3$	Experimental, Hz $L/D = 6$	Rossiter, Hz
90	0.2957	0.2698	
75	0.2751	0.2526	0.2390
60	0.2597	0.2253	$n = 1$
45	0.2545	0.2185	
30	0.2500	——	

Conclusions

The results of the experimental investigation on aft-wall ramp cavities indicate that cavities with a lower ramp angle can be effectively used for suppression of oscillations and entrainment control. The low-aspect-ratio cavity is more stable with a lower aft-ramp angle than the high-aspect-ratio cavity. In general, the improvement in the flame-holding characteristics with aft-wall modification for the high-aspect-ratio cavity is less significant than that of the low-aspect-ratio case.

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