Study on the Interaction of Cavity Flow with Oscillating Shock Train

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Scramjet isolators experience oscillations in shock trains due to high back pressure fluctuations, leading to performance degradation and instability. Back pressure fluctuations of sufficiently large amplitudes can push the shock train to the inlet, causing the inlet unstart. It is thus imperative to suppress the shock train oscillations. Placement of a cavity in the isolator can manipulate the shock train oscillations, alongside their role in efficient fuel mixing. Interaction between a shock train at Mach number of 1.71 and a cavity shear layer was studied experimentally by Kumar and Vaidyanathan (2018), without any back pressure forcing. Inherent small amplitude oscillations (comparable to cavity depth) in shock train were observed, especially for larger cavity length to depth (L/D) ratio. Pandian et al. (2019) investigated the interaction between a transient shock train with a cavity shear layer. The shock train was made to move progressively downstream by increasing the inlet stagnation pressure. A mode switching phenomena was observed in the measured cavity surface pressure. In practical cases, large scale back and forth oscillation of the shock train is expected due to the back pressure forcing from the combustion chamber. However, to the best of our knowledge, there is no study focusing on the interaction between the shock train exhibiting large scale oscillations and a cavity shear layer. The present work concerns the mutual effects in the interaction between a cavity flow field and a shock train oscillating with large amplitude over the cavity shear layer in a generic isolator. Moreover, understanding the interplay between shock train oscillations and cavity shear layers is crucial for advancing scramjet technology and achieving stable, efficient combustion in hypersonic propulsion systems.

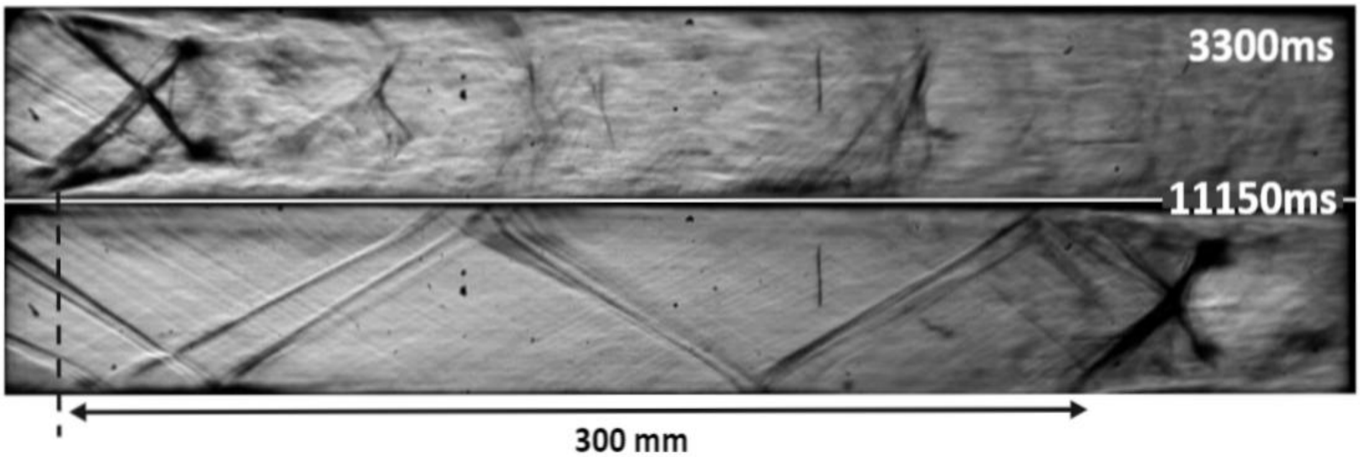

Figure 1. Baseline Shock Train Oscillation.

Experiments are performed in the supersonic isolator facility at IIT Madras. The facility has dimensions of 330 mm in length and a cross-section measuring 33 mm x 100 mm. A contoured nozzle delivers a supersonic flow of Mach number 2.2 at the isolator inlet. Downstream of the isolator section is a diffuser (with 7◦ divergence angle) which exits to the atmosphere. By setting appropriate total pressure (~ 2.2 bar), shock train was positioned in the isolator. Due to the inherent downstream perturbations developed in the diffuser, large-scale oscillations in the shock train were observed. This phenomenon is particularly evident in the baseline case, where the shock train exhibits oscillations of magnitude comparable to the length of the isolator itself, as observed from the two instantaneous schlieren images shown in Figure 1.

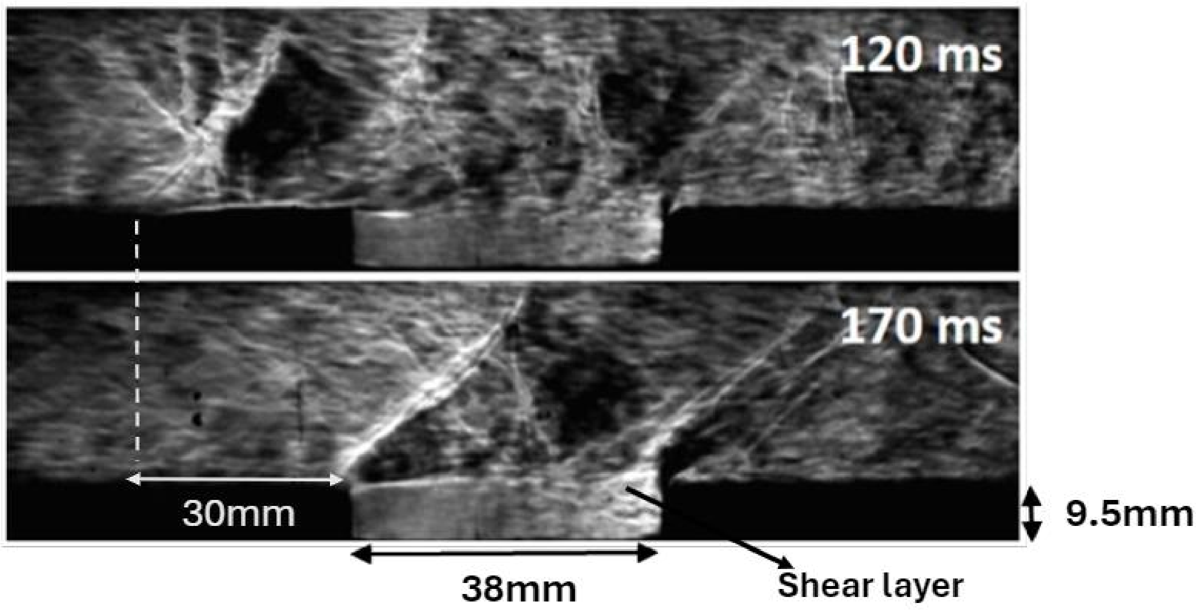

Figure 2. Cavity Shock Train Oscillation.

The bottom wall of the wind-tunnel has a 36 mm long cavity with 9 mm depth, the leading edge of which is located at 147 mm from the exit of the nozzle. Four fast response pressure transducers are placed at various locations: one inside the cavity; three on the top wall, with one upstream, one downstream, and one above the cavity leading edge. Figure 2 illustrates the extreme positions of the leading shock wave in the presence of the cavity, showcasing the significant impact of cavity placement on shock train dynamics. Evidently, the shock train oscillations are suppressed. Additionally, the pressure measurements obtained from the experiment were analyzed to establish correlations and coherence among the different locations where the pressure transducers are placed. With the shock train oscillating on the cavity, two different ranges of frequencies are observed to be significant in the (premultiplied) power spectral density of the wall pressure signal. Firstly, there is a low frequency content of the order of 10-100 Hz which is broad band. This seems to correspond to the shock oscillations. Secondly, there are distinct high frequency modes, at the following specific frequency values: 2 kHz and 6 kHz; these modes have much less energy than the low frequency content. Interestingly, when examining fully started case, the distinct modes occur at very different frequencies: 7 kHz, 15 kHz, and 23 kHz (Rossiter modes); there is no significant low frequency content in these signals. The different ranges of frequencies in the presence of the shock train suggests interesting dynamics associated with the interaction of the shock train with the cavity flow.. Further details of the analysis of pressure spectra and shock train behavior providing valuable insights into the underlying mechanisms shall be discussed in the full-length paper and the presentation.

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