Experiments on Control of Large Amplitude Shock Train Oscillations using Bleed

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ABSTRACT In scramjet engines, the control of shock train dynamics within the isolator duct—positioned between the inlet and the combustion chamber—is critical for engine stability and performance. The formation of a shock train or pseudo-shock system arises from the interaction of a precombustion shock, necessitated by the high pressure in the combustion chamber, with the boundary layer (Matsuo K. et al. ,1999). Previous studies have highlighted shock train dynamics' complexity, showing sensitivity to incoming turbulence, shock-induced flow separation, and pressure fluctuations at the inlet (Li N. et al., 2021) and combustion chamber (Saravanan R. et al., 2021). These factors may lead to flow separation and unstart (Wagner J.L et al., 2009). In particular, the back pressure fluctuations can result in large scale oscillations of shock train, potentially causing the shock train to enter and unstart the inlet. Thus, having a means to mitigate the unsteadiness of the oscillations is crucial. The isolator facility at IIT Madras is intended to study such large-scale oscillations and their controllability. With a large angle 7° diffuser downstream of the isolator section, inherent large amplitude oscillations (comparable to isolator length) of the shock train were observed, despite very low levels of fluctuations in settling chamber pressure and no back pressure forcing. This large-scale oscillation is also observed to be accompanied by lateral oscillation of the interaction point of the leading shock, leading to the speculation that the oscillations are driven by the flapping of flow in the diffuser section with periodic lateral asymmetries. Motivated by these observations, our experimental work investigates the potential of using suction slots strategically placed along the diffuser's top and bottom walls to stabilize shock trains without external vacuum systems. Leveraging the high-pressure differential between the diffuser and the upstream region, we explore the feasibility of mitigating flow asymmetry. For investigations into shock-train oscillations, an isolator test rig is connected to the settling chamber exit at IIT Madras's open-jet facility. The setup as shown in Fig.1 includes a Mach 2.4 contoured nozzle leading to a section with wedges simulating upstream disturbances. The top plate contains ramp of angle 10° for a length of 17 mm, after which it turns horizontal again. The shock generated by the ramp is made to impinge on another ramp of angle 5° (and length 34 mm) at the bottom wall before it turns back horizontal, causing shock induced separation. After the ramps, the distance between top and the bottom walls remain 33 mm. The isolator section, 33 mm high, 330 mm long, and 100 mm wide is placed downstream of this section. The length of the upstream section is designed such that at the inlet of the isolator section, the inviscid Mach number is 2.2. The flow from the isolator exits into atmosphere through the diffuser which contains suction slots on top and bottom walls as well as an elliptic shaft which may be rotated to simulate back pressure forcing. Experiments are done without as well as with the back pressure forcing. Additionally, we propose bleed air recirculation to enhance the engine efficiency by reducing shock-boundary layer interaction in the upstream ramp. By leveraging high-resolution static pressure measurements, dynamic pressure assessments post-suction, and schlieren visualization, the study not only contributes to a more nuanced understanding of shock train dynamics but also proposes viable strategy for performance improvement in scramjet engines.

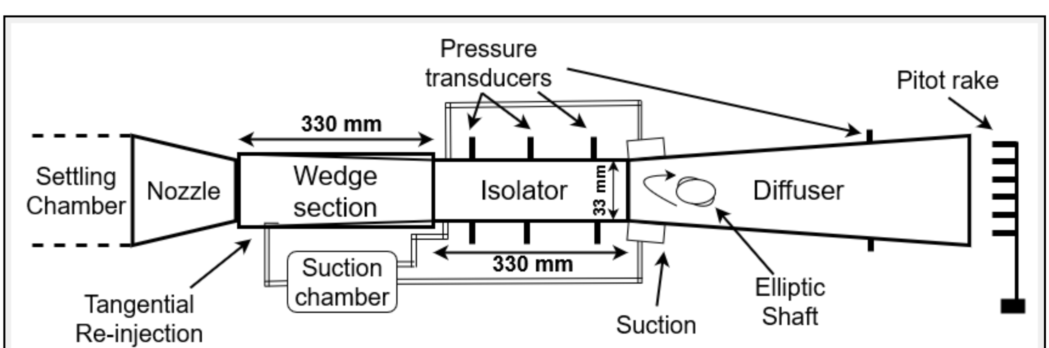

Figure 1: Schematic of the Experimental Setup

Fig. 2 shows instantaneous schlieren images of shock train for the baseline case (without downstream forcing using rotating shaft) at two different time instances which depicts the large amplitude of the oscillations without using the suction-based mitigation technique (but with the upstream waves). Experiments with the control mechanism are underway, and further details shall be discussed in the full-length paper and the presentation.

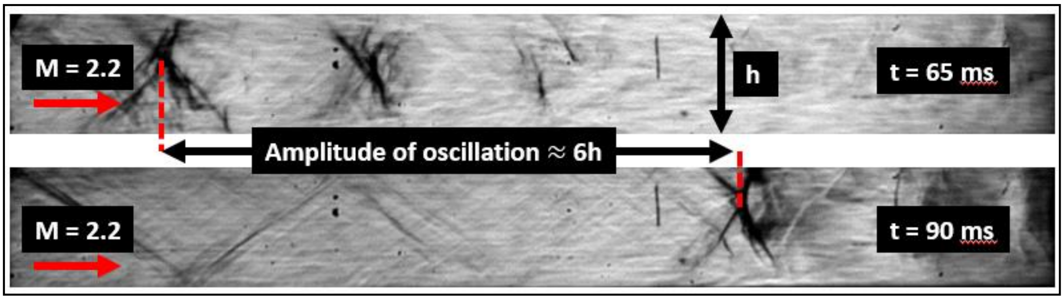

Figure 2: Instantaneous schlieren images of shock train visualized in the isolator rig for baseline case (without suction and downstream forcing) with upstream waves.

REFERENCES

- Matsuo, K., Miyazato, Y., and Kim, H.D (1999). Shock train and pseudo-shock phenomena in internal gas flows. Progress in Aerospace Sciences, 35(1), 33–100
- Li, N., Chang, J., Xu, K., Yu, D., and Bao, W (2021). Instability of shock train behaviour with incident shocks. J. Fluid Mech, vol. 907, A40.
- Saravanan, R., Desikan, S.L.N., and Muruganandam, T.M. (2021). Isolator characteristics under steady and oscillatory back pressures. Physics of Fluids, 32(9), 96-104
- Wagner, J.L., Yuceil, K.B., Valdivia, A., Clemens, N.T., and Dolling, D.S. (2009). Experimental investigation of unstart in an inlet/isolator model in mach 5 flow. AIAA Journal, 47(6), 1528–1542