Effects of Freestream Disturbances in front of Spiked Blunt Nose at Hypersonic Flow

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Abstract

This study is motivated to understand the effects of various freestream disturbances on pulsating bow shock formed for spiked blunt nose at hypersonic flow. The acoustic, vortical and entrpy freestream disturbances are modelled as time-dependent boundary conditions in a computational domain consists of spiked blunt nose at hypersonc flow. In the preliminary study at hypersonic flow Mach 6, it is demonstrated with 2D axidmmetric simulations that the high-frequency acoustic disturbances with certain amplitudes can control the large amplitude pulsation mode by influencing it with high-frequency oscillations and stabilizing it, once the high-frequency disturbances are removed. This active flow control can find its application also in engine unstart cases for scramjet engines.

1 Introduction

A spiked blunt nose in front of supersonic and hypersonic flow is considered an effective drag reduction technique. However, the flow-field in front of a spiked blunt nose is subjected to small amplitude oscillation and large amplitude pulsation fluctuations. Further, similar unstable flow-field configuration can also be observed, while unstart of scram jet engines. In many previous numerical studies of spiked blunt nose or scramjet inlets, most of the time a constant inflow boundary condition is assumed, however the experimental studies are always subjected to various freestream disturbances such as acoustic, vortical, entropy disturbances, and foreign particles, which may affect the time response of many unstable flow fluctuations. With the motivation to actively control the large amplitude bow shock fluctuations by introducing disturbances at various spatial locations in the domain, this study lays down the preliminary work to develop understanding of attenuation of freestream disturbances in front of a spike blunt nose at hypersonic Mach number 6. The objectives of current study are: 1) to model fast and slow acoustic waves in front of spiked blunt nose and 2) understand the attenuation mechanism to manipulate the unsteady flow-field.

2 Preliminary Results & Full Paper Content

In the preliminary study, the two-dimensional axisymmetric unsteady Navier-Stokes equations are solved for compressible laminar hypersonic flow (Mach 6) in front of the spike blunt nose using in-house developed solver. Fig. 1a shows the overall computational domain and boundary conditions used. Fig. 2b shows the generated structured grid of size 201 x 121 for spike of length L/D = 2.0 with minimum grid size near the wall as 2 µm. The grid independence study and validation of the solver has been performed in previous research [2]. The inlet condition has been modelled at Mach 6 hypersonic flow with stagnation pressure 400 kPa and stagnation temperature 500 K. The spatial inviscid fluxes are evaluated by Lious-all speed AUSM+up scheme and upwind biased third order MUSCL interpolation. The viscous flux and source term are evaluated by using 2nd order central difference scheme. The third order explicit three step TVD Runge-Kutta Method has been used for time-integration. The computation has been performed for 12 ms with a physical time-step of 1×10^{-9} sec. Initially high-frequency freestream acoustic disturbances of 20 kHz are modelled [1] with time-dependent inlet boundary conditions with various pressure amplitudes $\varepsilon = 0$ (constant boundary condition), 0.5 % and 1%. Figure 2a shows the non-dimensional pressure variation at the flat face of blunt nose with time. With constant boundary large amplitude fuctuations are observed up to 6 ms. With switch freestream acoustic disturbances at T = 2ms with amplitudes 0.5 % & 1%, the large amplitude pulsation transit into high frequency shockwave oscillations and later turn into stable flow field, when the disturbances are switched off. The full paper will further model vortical and entropy disturbances to understand their receptivity for pulsating bow-shock formed in front of spiked blunt nose.

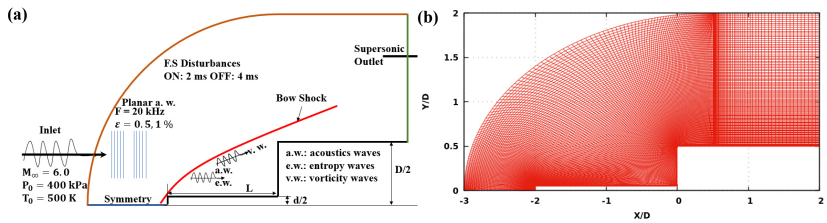

Figure 1: (a) Computational domain with boundary conditions (b) Computational grid of size 201×121 used for simulations.

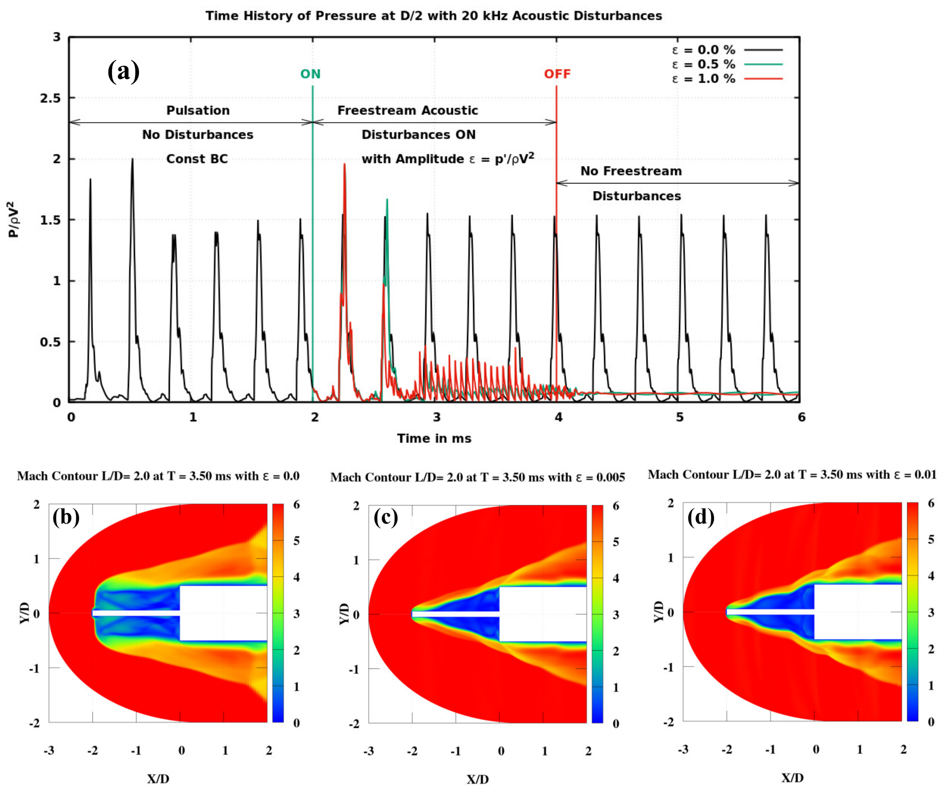

Figure 2: (a) Time history of non-dimensional pressure with freestream disturbances of various amplitude & Mach contours at single time-step, while the freestream disturbances are switched on at with amplitude (b) $\varepsilon = 0$ (c) $\varepsilon =$0.5 %, and (d) $\varepsilon =$1%

References

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