EFFECT OF THERMAL ACTUATORS ON DRAG REDUCTION IN A MACH 8 BOW SHOCK

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Summary An extensive numerical study is conducted to investigate the effect of a two-dimensional thermal actuator on the shock structures in front of a Mach 8 bow shock. A thermal actuator is added upstream of the bow shock. Both single and repetitive pulses are studied to examine the efficiency and effectiveness of the thermal actuators. The wave drag reduction is observed for both types of pulses.

INTRODUCTION

Wave drag reduction is of great significance in the sustained flight of hypersonic vehicles. In recent years, there has been intense research activities in understanding the physics of energy deposition and its application to flow control for supersonic flight, such as drag reduction, lift enhancement, flow separation control, etc. Comprehensive reviews on this topic can be found in Zheltovodov[1], Fomin *et al*[2], Bletzinger *et al*[3] and Knight[4].

The objective of this paper is to investigate the mechanism of both single- and repetitive-pulsed thermal actuators for wave drag reduction in a Mach 8 bow shock. The computational conditions and model configuration are obtained from the experiments [5, 6]. The commercial flow solver FLUENT is used with the second-order AUSM scheme for convective fluxes and the second-order implicit scheme for time integration. The modification of the bow shock by the thermal actuators is presented in detail.

FLOW CONFIGURATION AND NUMERICAL MODEL

A two-dimensional Mach 8 bow shock is formed in front of an infinitely long cylinder with radius of $R = 38$ mm. The static pressure and temperature at freestream is 855 Pa and 123.5K, respectively [5, 6].

Thermal actuator takes form of a laser energy deposition in this study. Previous study [7, 8] has shown that the real gas physics has little effect on the propagation of the blast wave formed by the laser pulse, thus ideal gas assumption is adopted in this study. Plasma formation is beyond the scope of this study.

A Nd:YAG laser (532nm, 10ns pulse duration, 10Hz repetition rate) is used for the single pulse study. The excitation beam is focused with a 250 mm focal length lens resulting in a focal region of approximate 3mm^3. The blast wave formed by the laser pulse becomes spherical by 5 to 10 μs after the pulse [9]. Thus, the laser pulse is simplified as a spherical thermal spot with radius of 0.89mm. In two-dimensional study, the laser pulse can be viewed as a thermal ray, which is modeled as an infinitely long cylinder with radius taken the same as that for the spherical spot. More details can be found in [8].

The grid configuration is shown in Fig. 1. The grid in the radial direction is structured uniformly within R away from the surface and then coarsened between R and $3R$ with a stretching ratio of 1.02. The smallest spacing is $0.01\Delta_{th}$, where $\Delta_{th} = 15.8$mm is the stand-off distance obtained from the empirical formula [10]. The uniform grid spacing is used in the circumferential direction with grid points of 601. The total number of grid cells is 0.24 million.

The commercial software FLUENT is used with the second-order AUSM scheme for convective fluxes and the second-order implicit scheme for time integration. The pressure far field condition is imposed at the inflow and outflow boundary, and the slip condition enforced on the wall.

RESULTS

Baseline case

A two-dimensional viscid simulation is performed to capture the bow shock at Mach 8. The surface pressure is in good agreement with the experiment [5] as shown in Fig. 2, where $p0$ is the computed pressure at the stagnation point. The computed standoff distance is 16.5mm. The relative error is less than 5% in comparison with the theoretical value.

Single laser pulse

Once the baseline flow structure is obtained, a single laser pulse is placed on the x-axis and 25mm $(0.66R)$ upstream of the cylinder. A blast wave is formed due to instantaneous deposition of the laser pulse, and propagates downstream to interact with the bow shock and the wall. As the blast wave hits the surface, the pressure increases as shown in Figs. 3(a) and 4(a). However as the blast wave is reflected from the wall, the surface pressure begins to decrease (Figs. 3(b) and 4(b)). A pair of vortices are formed due to the misalignment of the pressure and density gradient. As the vortices move away from the stagnation point, the surface pressure oscillates accordingly (Figs. 3(c) and 4(c)).

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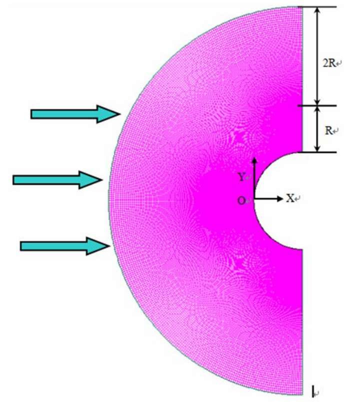


Figure 1. Grid configuration

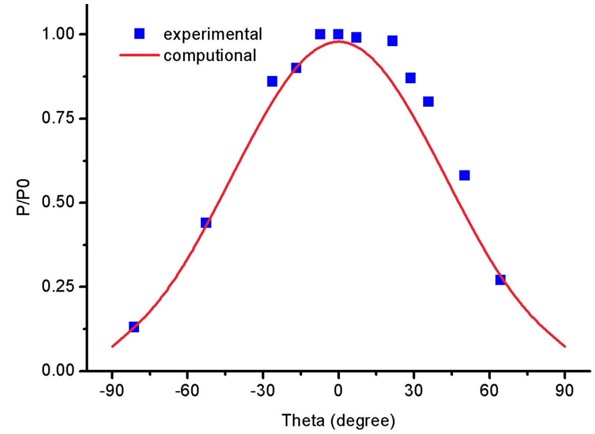
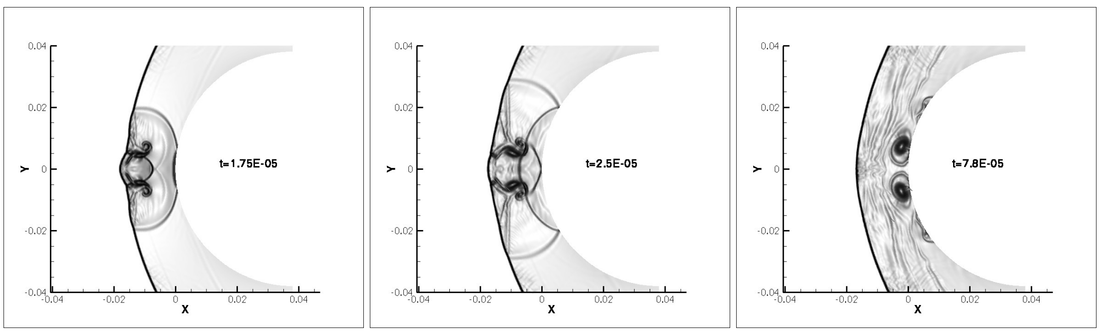


Figure 2. Surface pressure without laser pulse

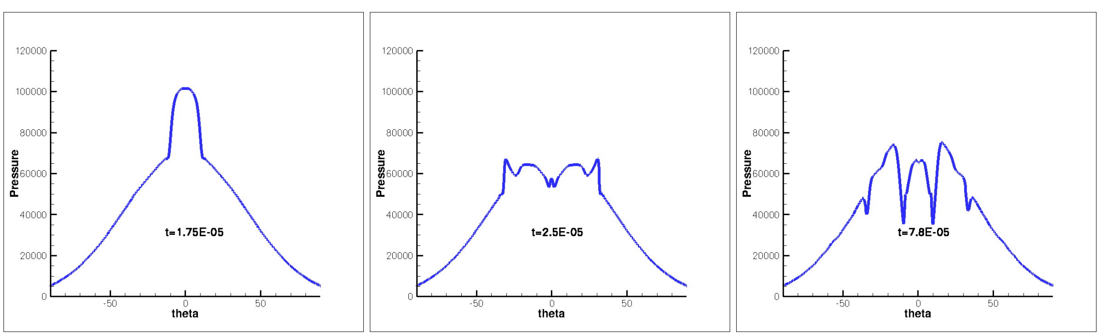
Repetitive laser pulse

To be presented in the full paper.



(a) $t = 1.7e^{-5}$s (b) $t = 2.5e^{-5}$s (c) $t = 7.8e^{-5}$s

Figure 3. Numerical Schlieren images



(a) $t = 1.7e^{-5}$s (b) $t = 2.5e^{-5}$s (c) $t = 7.8e^{-5}$s

Figure 4. Surface pressure with a single pulse

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