Control of Oblique Shocks in Supersonic Inlet by Energy Deposition

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I. Introduction

The thermal effect of electrical discharge plasma has been considered as a local flow control technique in shock-shock interactions.[1–3] One important feature of electrical discharge plasma associated with the gas heating is its strong spatial non-uniformity and nonequlibrium composition due to both recombination and vibrational-translational (V-T) relaxation. More than 90% of power deposition can be conserved in vibrational reservoir and dissociation of molecular gas[4] and is released downstream of the electric current location at a later time. This unsteady spatial and temporal behavior appears to provide higher performance with more efficient power consumption.[3]

The present study examines the effect of the near-surface discharges on the shock structures in a Mach 2 mixed compression inlet. Three discharges are placed upstream of the first compression corner. Four different input energy levels are considered. The effect of the streamwise location of the discharges will presented in the full paper.

II. Flow Configuration

According to the flight corridor, an air-breathing vehicle can fly at Mach number up to 5 at 15km. Therefore a Mach 2 mixed compression inlet is considered with the freestream condition at 15km, where the static temperature and pressure are $200\ K$ and $1.2 \times 10^4\ Pa$, respectively. Two oblique shocks are generated at two consecutive compression corners in the streamwise direction, and interact with each other at the cowl lip. The direct-connect inlet is considered first, and the free-jet set-up will be studied in another endeavor. The near-surface discharge is modeled as a steady cuboid heat source and incorporated into the energy equation. The cross section is 3×3 mm, and the length in the streamwise direction is 20 mm to emulate the effect of vibrational-translational (V-T) relaxation on gas heating.

On the lower wall of the inlet, two compression corners are 7° and 14° in sequence and the first expansion corner is placed at 60mm downstream of the first compression corner. The inflow is fixed at 80mm upstream of the first compression corner which is designated as $(x, y) = (0, 0)$, and the inlet height at the inflow is 60mm. The cowl lip is designed according to the inviscid shock theory.

Three discharges are 7mm apart in the spanwise direction starting at 3mm away from the spanwse edge on the lower wall. Their trailing edge is placed at 20mm upstream of the first compression corner.

III. Numerical Model

The governing equations are solved by numerical discretization of space (x, y, z) and time (t). The third order accurate AUSM scheme[5] is adopted for convective flux terms and the second order implicit method is used for time integration. The gradient reconstruction is based on node Green-Gauss method. Equations are solved using incomplete lower upper factorization (ILU), in conjunction with algebraic multigrid method. The time step is fixed at 1.0×10^{-8} s. The SST turbulence model is used for the viscous assumption.

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IV. Numerical Results

The steady state without discharges is obtained first. The pressure and Mach number contours are shown in Figs. 1 and 2, respectively. The oblique shocks interact with the boundary layer growing on both lower and upper walls, resulting in a small deviation of the shock interaction point from the designed cowl lip. However the mass flow rate is not affected by the shock upstream movement from the cowl lip in the direct-connect inlet.

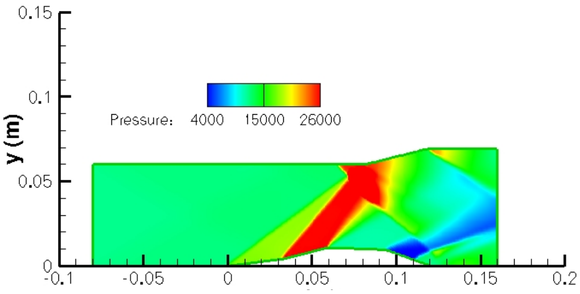


Figure 1. Pressure contours (SST)

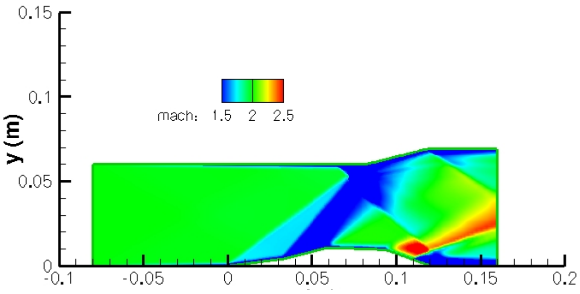
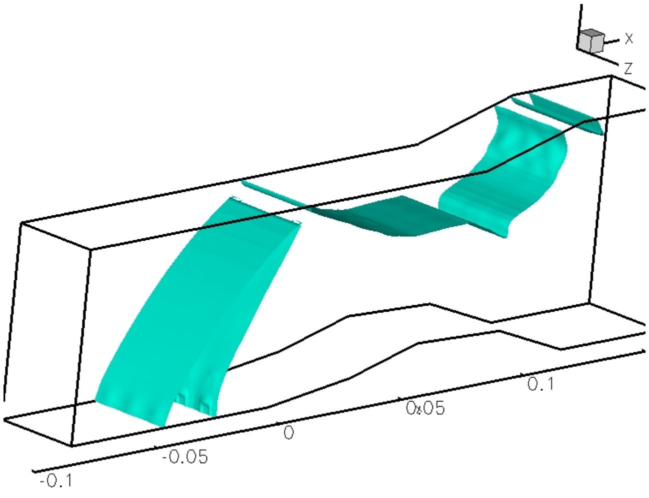


Figure 2. Mach number contours (SST)

Three discharges are integrated into the Navier-Stokes equations as a steady heat source. Four input energy levels (0.5kw, 1.0kw, 1.5kw and 8kw per discharge) are considered. In all the energy levels considered, the entire shock structure is moved upstream due to the spanwise arrangement of the discharges. Figs. 3 and 4 show the pressure and temperature iso-surface featuring the displaced oblique shocks for the input level of 8kw. Three distinguished ripples are associated with the three localized discharges.



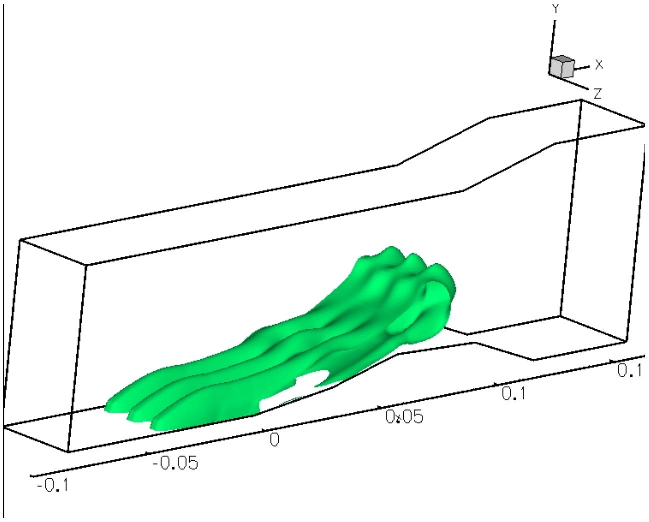


Figure 3. Pressure iso-surface at 25000Pa

Figure 4. Temperature iso-surface at 2000K

As the flow reach the asympotic state, the distance of the upstream movement is plotted as a function of energy level as shown in Fig. 5. The upstream movement is enhanced with increasing energy level. While the linear growth is observed for the lower energy levels, a saturation is most likely to occur as the energy level further increases.

V. Conclusions

A three-dimensional numerical study is performed to explore the effect of the near-surface discharge on the oblique shocks in a Mach 2 mixed compression inlet. The discharge is modeled as a steady volumetric heat source which is integrated into the energy equation. Results show that the discharges cause the oblique shocks to move

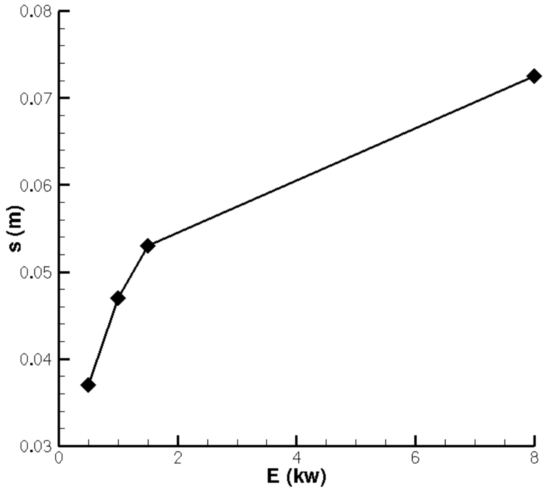


Figure 5. Shock movement with energy input level

upstream and the extent of movement increases with the energy level. The entire shock surface is observed to move upstream with ripples in response to the three localized discharges along the span.

VI. Acknowledgments

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