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Passive Shock Control in Transonic Flow Field

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Abstract

In order to control the transonic flow field with shock wave, a condensing flow was produced by an expansion of moist air on a circular bump model and shock waves were occurred in the supersonic parts of the fields. Furthermore, the additional passive technique of shock - boundary layer interaction using the porous wall with a cavity underneath was adopted in this flow field. The effects of these methods on the shock wave characteristics were investigated numerically. The result showed that the flow fields might be effectively controlled by the suitable combination between non-equilibrium condensation and the position of porous wall.

Keyword: *compressible flow, non-equilibrium condensation, boundary layer, flow control*

1. Introduction

The transonic flow over the airfoil is characterized by a shock wave standing on the suction surface. In this case, the interaction between the shock wave and boundary layer becomes complex because the shock wave imposes an adverse pressure gradient on the boundary layer. Passive control technique using a porous wall and cavity system, when it is applied at the foot of the shock wave, is known to be effective in alleviating undesirable adverse pressure gradient of the shock wave - boundary layer interaction [1][2]. However, this control method essentially leads to large viscous losses caused by the porous walls, which can overcompensate the control benefit of the shock wave.

In recent years, possibilities for the control of flow fields due to non-equilibrium condensation have been clarified experimentally and numerically [3][4]. It is found from these works that when non-equilibrium condensation occurs in a supersonic nozzle, displacement thickness of boundary layer becomes thin behind the condensation zone. Furthermore, the development of boundary layer is reduced behind the shock wave and non-equilibrium condensation is effective to the reduction of high frequency components for oscillation of shock wave especially. Therefore, it is expected that the reduction of Mach number due to non-equilibrium condensation just before shock wave suppresses the separation of boundary layer generated by shock wave, and droplets generated by condensation suppress the fluctuation of flow field due to the shock wave instability.

In the present study, in order to control the transonic flow field with shock wave, a condensing flow is produced by an expansion of moist air in the nozzle with a circular bump model and shock waves are occurred in the supersonic parts of the flow fields. Furthermore, the additional passive technique of shock - boundary layer interaction using the porous wall with a cavity is adopted in this flow field. Computation is conducted to investigate the effectiveness of this kind of control techniques.

2. Computational Analysis

The governing equations under consideration were the unsteady two-dimensional compressible Navier - Stokes equations and droplet growth equation [5] written in the Cartesian coordinate system.

To close the governing equations above, Baldwin-Lomax model was employed in computations. A third-order TVD (Total Variation Diminishing) finite difference scheme with MUSCL was used to discretize the spatial derivatives, and a second order-central difference scheme for the viscous terms. A second-order fractional step was employed for time integration.

Figure 1 shows a computational grid of transonic nozzle flow field. The nozzle has a height of 60 mm at the inlet and exit, a radius of circular arc R^* =100 mm and a height of nozzle throat h^*=56 mm. The bump wall surface consists of two-dimensional slots, having the cavity of a dimension L (=20 mm)×D (=5 mm). A cavity on the bump wall has a slot wall. The width of opening area between slots is constant at w=0.6 mm. Hereafter, the slotted wall is denoted as a porous wall. The porosity of the porous wall is 0.18. x_p denotes the distance from nozzle throat to the leading edge of the cavity. Cases of R11 and R12 correspond to x_p=-3 mm and -5 mm, respectively. Values of the initial degree of supersaturation S_{01} and total temperature in the reservoir were set at 0.5 and 298 K, respectively. Total pressure in the reservoir was set at 102 kPa.

2. Results and Discussions

Figures 2(a) and (b) show contour maps of Mach number for Solid wall (S_{01}=0) and porous wall (S_{01}=0.5, R12), respectively. As seen from Fig.2(a), a shock wave oscillates periodically on the bump wall. In Fig.2(b), oscillation of the shock wave is suppressed effectively and the strength becomes weak in comparison with Fig.2(a). However, suppression of the oscillation was not confirmed for R11 (S_{01}=0, 0.5) and R12 with S_{01}=0.

As a result, it was found that suppression of the shock wave oscillation and reduction of the shock strength might be effectively attained by the suitable combination between non-equilibrium condensation and the position of porous wall.

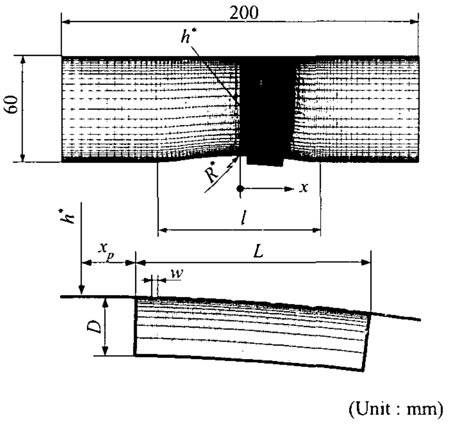
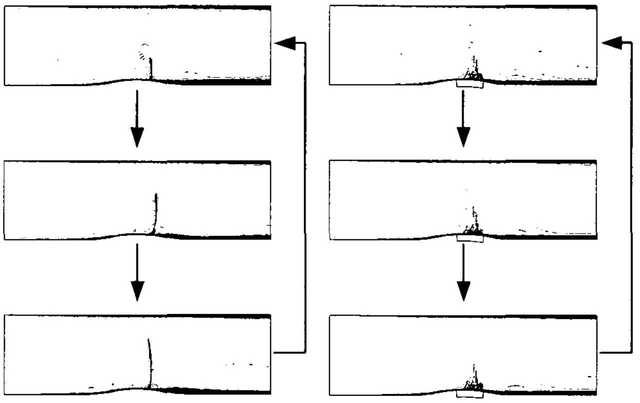


Fig. 1 Computational grid



(a) Solid wall, S_{01} = 0.0

(b) R12, S_{01} = 0.50

Fig. 2 Contour maps of Mach number

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