A NUMERICAL INVESTIGATION OF INJECTION ANGLE EFFECT ON LATERAL JET INTERACTION FOR REVOLUTION BODY

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Summary A numerical investigation has been conducted to determine injection angle effect on lateral jet interaction for a revolution body in hypersonic flow. Air is injected through a nozzle at 30 degree to 150 degree into a Mach 5.0 crossflow. Surface and space flow features of jet interaction flowfield are presented. As a result, the jet wrap-around effect will be enhanced if injection angle increases. However, the total amplification factor of normal force gets peak value when the injection angle is near 105 degree.

INTRODUCTION

The flowfield induced by a jet exhausting into a crossflow is a basic complex flow that can be found in many applications, such as supersonic combustion and reaction control system [1-3]. Jet issuing into the super/hypersonic free stream acts as an obstacle to the flow, and produces complex shock/shock interaction, separated and reattached flow. Although there are many studies devoted to the flowfield, only a few are related to the injection angle effect for a revolution body [4-5]. In this paper, our goal is to present the injection angle effect on characteristics of jet interaction flowfield and jet control efficiency by force amplification factors in hypersonic flow.

MODEL AND CALCULATING CONDITIONS

Research model is an ogive-cylinder body with a jet nozzle of Mach number 3.0 as shown in Fig.1a, the figure 1b shows the grid structure for the model. The nozzle injection angle θ_{jet} is defined as the angle between the jet direction and the freestream direction. The injection angle θ_{jet} can be changed from 30 to 150 degree. The calculation parameters are listed in Table1. And at the condition, the jet interaction flowfield near the nozzle exit keeps laminar separated flow[6].

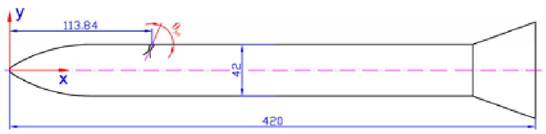

Fig.1a Model of revolution body with a jet nozzle

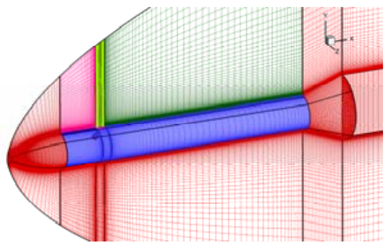
Fig.1b Grid structure of the model

Table 1 Calculation parameters

Freestream parameters				Jet parameter				Re(1/m)
M_∞	$\alpha(°)$	$P_{0\infty}(MPa)$	$T_{0\infty}\ (K)$	M_j	P_j/P_∞	$T_{0j}(K)$	$\theta_{jet}(degree)$	
5.0	0	0.79	293	3.0	73.6	293	30~150	1.62×10^7

RESULTS AND ANALYSIS

Validation of Numerical Method

Numerical method of a finite-volume approach with multi-block patched grid is used to solve the 3-D RANS equations to study the interaction flowfield. The interaction flowfield with a secondary flow injected into a super/hypersonic primary stream is complex, it is difficult to simulate the flowfield only by wind tunnel test or numerical method. The validation of the numerical method is very important by experimental results, it was accomplished by comparing the predictions with data from a previous wind tunnel investigation [6].

Spatial interaction characteristics

The pressure contour and streamlines in symmetric plane near the jet exit at θ_{jet} of 60, 90 and 120 degree are shown in Fig.2. The complex shock wave structures can be visualized. When the injection angle increases, the interaction between jet and external cross-flow is enhanced, and the stronger shock waves such as the separated shock wave and the bow shock wave are induced.

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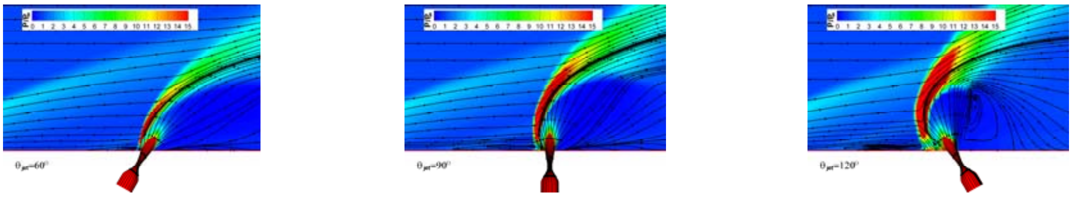

Fig.2 Pressure contour and streamlines on the symmetric plane near the jet exit at θ_{jet} is 60, 90 and 120 degree

Surface interaction characteristics

The surface pressure contours and streamlines on the top view at θ_{jet} of 60, 90 and 120 degree in jet-off case and in jet-on cases are compared in Fig.3. When the injection angle increases, the region of high pressure ahead of the jet exit is enhanced observably, and the separation zone ahead of the jet exit is extended significantly too. The surface pressure contour and streamlines on the side view are shown in Fig.4. It can be seen that the interaction region are wrapped around toward the bottom of the model, which is called jet wrap-around effects. The jet wrap-around effects will be enhanced if injection angle increases.

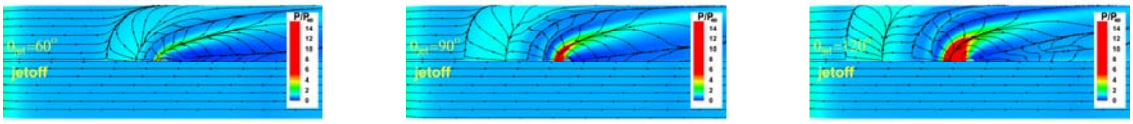

Fig.3 Surface pressure contour and streamlines on the top view at θ_{jet} is 60、90、120 degree with jet off case

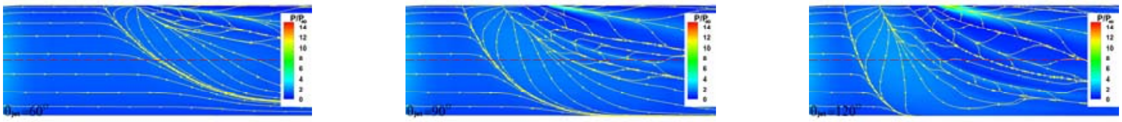

Fig.4 Surface pressure contour and streamlines on the side view at θ_{jet} is 60, 90 and 120 degree

Analysis of Jet control Efficiency

Ky is defined as the normal force amplification factor in order to quantify the efficiency of lateral jet control [7]. The curve of normal force amplification factor Ky at different θ_{jet} is shown in Fig.5. It can be seen that the change of Ky with θ_{jet} is nonlinear. As θ_{jet} is less than 105 degree, Ky increases with increase of θ_{jet}, whereas Ky decreases when θ_{jet} exceeds 105 degree. A peak value of Ky can be found near θ_{jet} of 105 degree, which reflects a most effective jet reaction control.

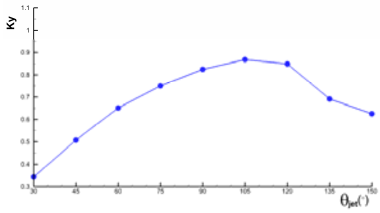

Fig.5 Normal force amplification factor versus θ_{jet}

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CONCLUSIONS

A numerical investigation of injection angle effect on lateral jet interaction for a revolution body in hypersonic flow is executed. When the injection angle increases, the interaction zone between lateral jet and external cross-flow is enhanced. The high pressure region and the separation zone ahead of jet exit are extended significantly. The jet wrap-around effects will be also enhanced if injection angle increases. However, the normal force amplification factor gets peak value when the injection angle is near 105 degree.

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