30th Congress of the International Council of the Aeronautical Sciences
DCC, Daejeon, Korea ; September 25-30, 2016

NUMERICAL INVESTIGATION OF UNSTEADY INTERACTION CHARACTERISTIC INDUCED BY IMPULSIVE JET

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Keywords: *Numerical simulation; Impulsive jet; Jet interaction; Unsteady flow*

Abstract

The numerical method of unsteady lateral jet interaction is established. The divert control jet interaction flowfield for ogive-cylinder-flare configuration are simulated numerically with different inflow parameters. Detailed transient jet interaction flowfield structure is obtained. Variation characteristics of additional normal force coefficient(ΔCy) and the additional pitching moment coefficient(ΔCmz) with time are analyzed. The comparison with the steady solution shows that it's more appropriate to apply the unsteady method when the impulsive jet is applied.

1 Introduction

In recent years, reaction control system (RCS) has been applied to more vehicles due to rapid response time as well as the ability to perform at all speeds and altitudes, which is a very effective technique utilized for missile flight control.

The work time of solid impulse side thruster is very short. During the work, the pressure referring to time in the thruster chamber takes on a sharp wave form, which plotted in Fig. 1. On the interceptor missile surface, the interaction between lateral jet and the supersonic free flow leads to substantive regions of separation upstream and downstream of the injection port during jets operating.

In previous studies, people pay more attention to the steady interaction of lateral jet[1~4]. The investigation of unsteady effect for lateral jet interaction is not adequate. It's still And the unsteadiness and transience are significant properties of lateral control jet interaction flowfield. Dynamic loads and oscillations caused by the unsteadiness will impact on missile structure and the precision of control system. It is important for the design and optimization of vehicle control system to estimate precisely the unsteadiness of lateral jet interaction.

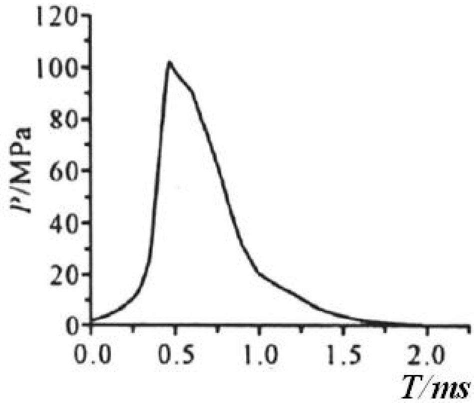


Fig. 1. P-t Curve of Impulsive Thruster

In this paper ,computational fluid dynamic (CFD) methodology[5] for predicting the unsteady flowfield properties that result from interceptor missile divert jet firings has been developed. The unsteady interaction flowfield of hypersonic freestream and supersonic divert jet over ogive-cylinder-flare configuration has been investigated numerically. The detail structures of the transient flowfield are obtained. Variation characteristics of the additional normal force coefficient (*ΔCy*) and the additional pitching moment coefficient (*ΔCmz*) referring to time are studied, which are compared with the steady and time-averaged solutions, indicating that there are significant unsteady interaction effect of impulsive thruster on missile aerodynamic properties.

2 Numerical Simulation Method

2.1 Governing Equations and Discretization Method

The computational results are obtained by solving three-dimensional compressible Navier-Stokes equations. The finite volume method is used to discretize the governing equation. Upwind-biased Roe flux-difference splitting scheme[6] of second-order accuracy is implemented for the spatial discretization of the convective terms, and the minmod limiter is used to remove solution oscillations. Central difference scheme is used for the calculation of viscous terms, the dual-time stepping method[7] (inner time integration using the LU-SGS scheme[8]) is employed for time discretization, the multigrid method[9,10] is used to accelerate the inner step convergence rate.

2.2 Boundary Conditions

On the body surface, no-slip, no-penetration and adiabatic wall conditions are imposed. At the inflow boundary, the free stream condition holds. At the outflow plane, an extrapolation of flow quantities is implemented. The flow is assumed to be symmetrical with respect to the pitching plane, so the symmetric boundary condition is employed.

For jet flow boundary, the nozzle exit parameters are used. Fig. 2. shows the pressure development of nozzle exit.

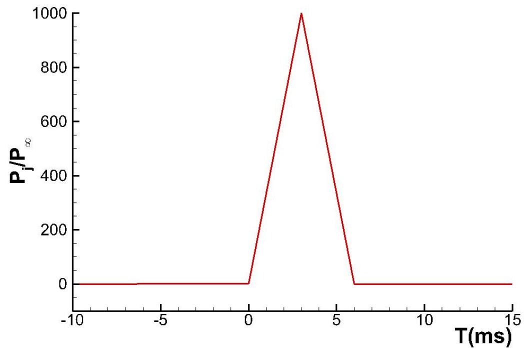


Fig. 2. The Jet Pressure with Time at Nozzle Exit

2.3 Initial Conditions

The initial steady state aerodynamic calculation is performed with local time stepping, without the divert jet firing, under the same inflow conditions. The solution of this calculation gives the initial conditions for the subsequent time accurate jet firing calculation.

2.3 Aerodynamic Properties Coefficients

In this paper, The additional normal force coefficient and the additional pitching moment coefficient are employed as measurements of the jet interaction effect on the control force and moment. The additional force and moment coefficients are defined as equation(1) and equation(2).

$$\Delta Cy = Cy_{jeton} - Cy_{jet} - Cy_{jetoff} \quad (1)$$

$$\Delta Cmz = Cmz_{jeton} - Cmz_{jet} - Cmz_{jetoff} \quad (2)$$

3 Model Geometry and Calculating Conditions

Test model geometry[11] is shown in Fig. 3, the divert jet locates on the center of gravity. The calculating conditions are listed in Table 1.

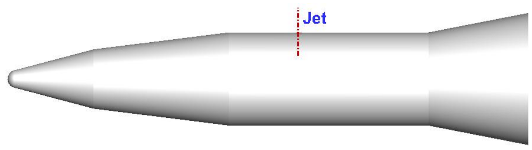


Fig. 3. Model Geometry

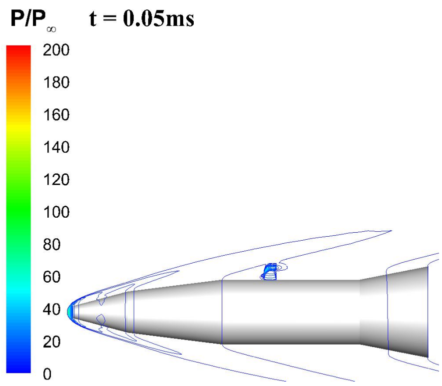
Table 1. Calculating Parameters

Inflow Mach number M_∞	Jet Mach number M_j	Angle of attack α(°)	Inflow Pressure P_∞(Pa)	Inflow Temperature T_∞(K)
8.0	3.3	0	149.101	264.164

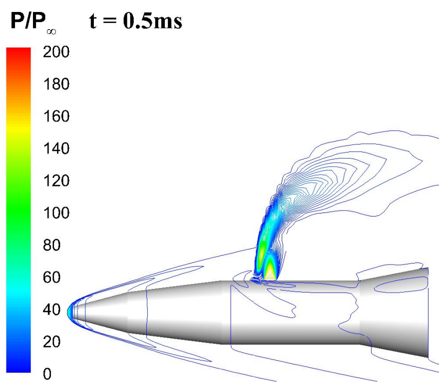
4 Results and Discussion

4.1 Unsteadiness of Flowfields

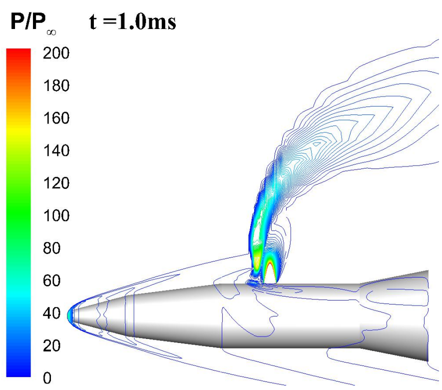
The pressure contours with different time are given in Fig. 4, the development of flow structure with time is provided. At 0.05ms, a weak bow shock is formed due to jet. At 0.5ms, with the height and intensity of bow shock strengthening, separated shock appears. At 1.0ms, compared with former times, the height of bow shock grow up and the separation region extend. The high-pressure region ahead of the jet has extended to the bottom of model body, which is known as wrap-around effect. At the time of 3.0ms, the strength of jet interaction gets higher than ever before, where the pressure of jet exit also reaches its peak value. At the moment of the shutdown of the thruster, there is residual influence in the jet flow, which shows the delay effect of the unsteady effect of flow’s viscosity. At the time of 6.4ms when the jet has completely shut down for a while, the main flow structure such as the bow shock has faded away on the whole while. At the time of 8.0ms, there's already no interaction exist in the flowfield.



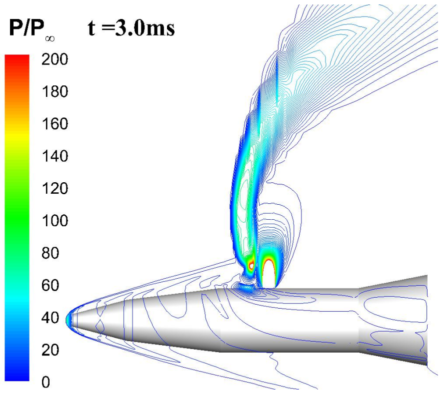
(a) t=0.05ms



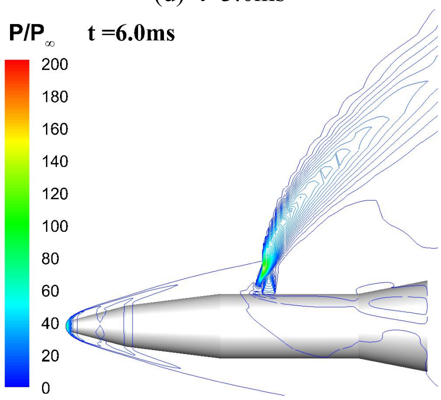
(b) t=0.5ms



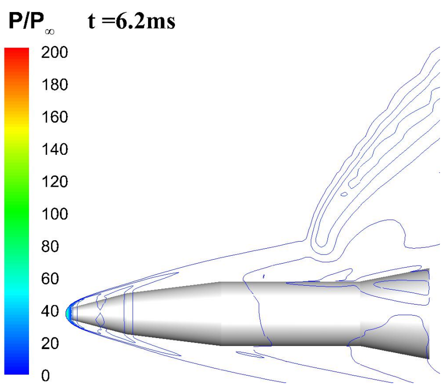
(c) t=1.0ms



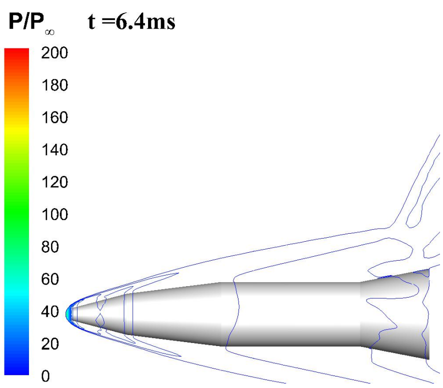
(d) t=3.0ms



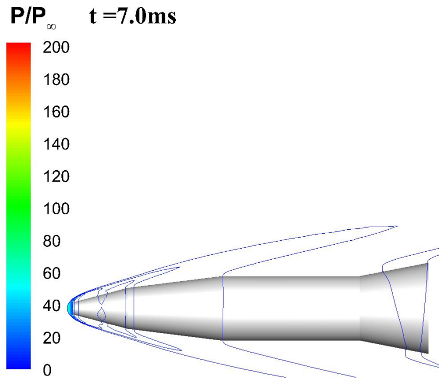
(e) t=6.0ms



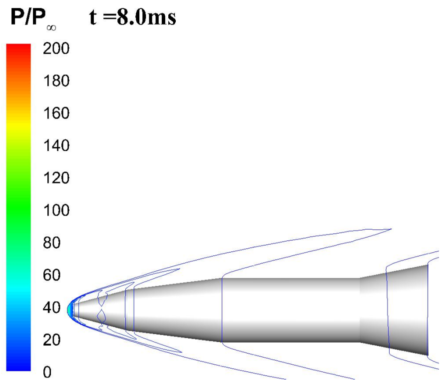
(f) t=6.2ms



(g) t=6.4ms



(h) t=7.0ms



(i) t=8.0ms

Fig. 4. Pressure Contours on Body Surface and Symmetric Plane at Different Time(M_∞=8.0,α=0°)

4.2 Unsteadiness of Aerodynamic Properties

Variation characteristics of additional normal force(ΔCy) and additional pitching moment(ΔCmz) with time is given in Fig. 5. and Fig.6. There are peak value at the start-up 1.6ms for additional normal force(ΔCy) and at 3.5ms for additional pitching moment(ΔCmz). And that there's a flat process from the start-up 3.5ms to 5.4ms for the additional normal force(ΔCy). When the jet shut down, there're both peak value and valley value for ΔCy and ΔCmz until reaching steady-state.

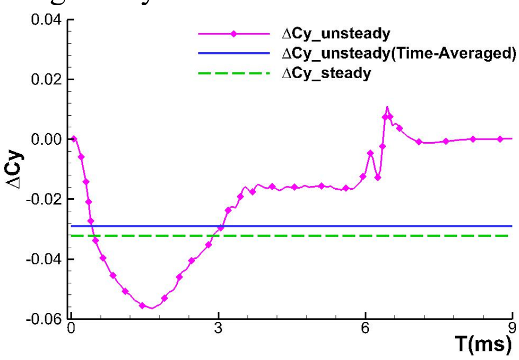


Fig. 5. Variation Characteristics of Additional Normal Force with Time(M_∞=8.0, α=0°)

Also the steady(P_j at nozzle exit is constant, viz. $P_j=P_\infty$) and time-averaged(The moment while impulsive jet is operating) unsteady value are introduced in Fig. 5. and Fig.6. It can be seen that the steady value of ΔCy is 1.1 times of the time-average value, and the steady value of ΔCmz is 1.25 times of time-average value

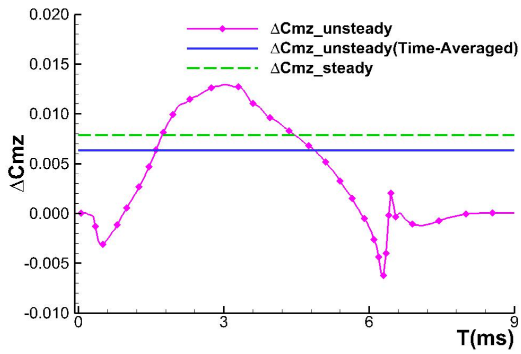


Fig. 6. Variation Characteristics of Additional Pitching Moment with Time(M_∞=8.0, α=0°)

5 Conclusion

Numerical methodology for unsteady hypersonic impulsive jet interaction flowfield simulation has been developed based on dual-time stepping method. The unsteady features of establishment of impulsive jet interaction flowfield over an ogive-cylinder-flare configuration are investigated. Detailed transient jet interaction flowfield structures are obtained. The variation characteristics of the additional normal force and the additional pitching moment are analyzed, and the comparison with the steady solution shows that it's more appropriate to apply the unsteady method when the impulsive jet is applied.

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