NUMERICAL INVESTIGATION OF INLET STARTING CHARACTERISTICS

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key words: *hypersonic; inlets; numerical simulation; starting characteristics*

Abstract

The starting characteristics of a hypersonic inlet on an X-51-like aircraft model are researched by use of CFD methods. Parameters effect including Mach number and angle of attack are investigated. A new starting phenomenon is found, and the produced mechanism of which is given. Effect on aerodynamics from that phenomenon are shown, lastly.

1 Introduction

Inlet design is one of the key technologies in scramjet design. Its starting performance is a key parameter to evaluate inlet design, and that determines the scramjet possible operating range. Many parameters affect the inlet starting performance. Such as inlet geometry, Mach number, angle of attack, etc. Several studies of the starting characteristics of three-dimensional inlets have been undertaken. Kantrowitz[1] investigated the maximum inlet shrinkage ratio of inlet start. Van Wie[2,3] proposed two key parameters of inlet start like inlet geometry shrinkage ratio and back pressure, and defined the two starting ways, namely the so-called "hard" start and "soft" start. Schmitz[4] analyzed the main factors affecting the performance of the inlet and studied the inlet start/not start feature. YUAN H.C[5], DING H.H[6] and CHANG J.T[7] investigate Mach number and angle of attack effect on inlet starting performance by numerical methods.

In this paper, effect of Mach number and the angle of attack are investigated again. Start Mach number and the angle of attack range like X-51 inlet are shown. Aerodynamics with inlet starting disturbance are given. A new phenomenon of inlet start seems to be found and analyzed.

2 Present approach

Hypersonic inlet starting is actually unsteadycourse, but that does not change inlet starting characteristics[8]. Quasi steady technique based CFD method is used to simulate hypersonic inlet starting flow field in this paper, which is like X-51 geometry[9]. Roe scheme is used for space discretization under the finite volume frame, entropy correction technique is adopted to avoid non-physical solutions. Venkat-akrishnan limiter [10]is adopted, LU-SGS implicit time integration method is introduced . Turbulence model of SST k-ωmodel and adiabatic wall boundary condition are used. The size of the first layer mesh is 1×10^{-5}m, y plus distance on the wall is about 1.0. The grid cell number are about 9 million for half model. Schematic of computation grid is shown in Fig.1.

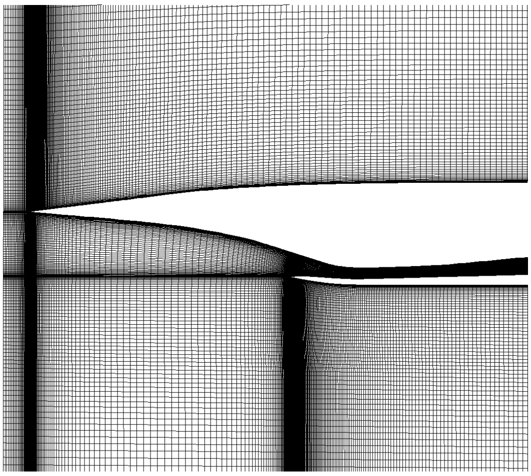
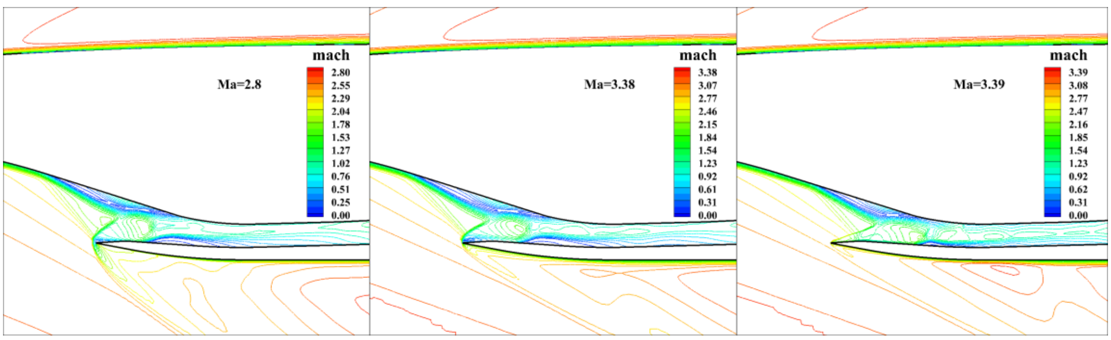


Fig.1 Schematic of computation grid

3 Results and discussion

Mach number effect of the inlet start have been analyzed at free stream Mach numbers from 2.8 to 4.0, 0°angle of attack, and the altitude is 20km. Angle effect of that are investigated at Mach number 4.0, the angle of attack from -15°to 15°, and the altitude is 20km.

The mach contours in symmetry plane for different free stream Mach numbers is shown in Fig.2, it can be seen that as Mach number increases, separated region on the up surface of inlet becomesmall, and bow shock wave on inlet lip is gradually close to the down surface. Detached shock wave appears near inlet lip at Mach number 2.8, and separated vortex on the inlet internal surface can be found. As increasing Mach number to 3.39, oblique shock wave emerges on inlet lip, and detached shock wave disappears. Separated vortex on the internal surface become small. When Mach number increases to 3.43, oblique shock wave on the lip is close to the wall more, and shock angle decreases. Moreover, separated vortex on the down surface disappears, and that on the up surface becomes small clearly.



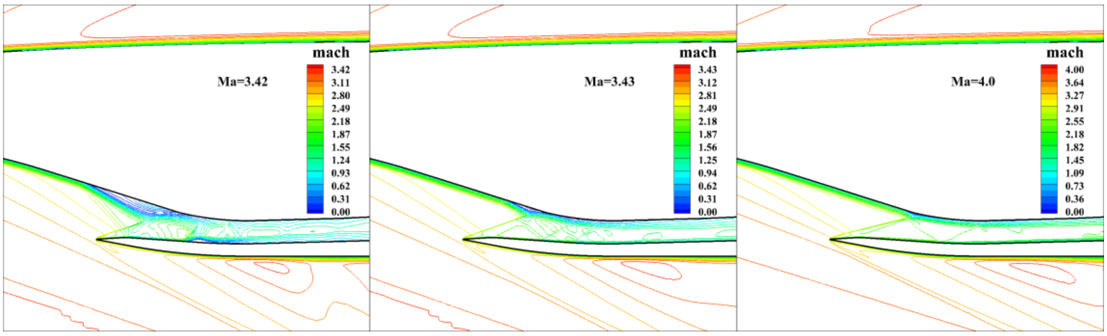


Fig. 2 Mach number contours in symmetry plane

The variation of mass captured coefficient and of total pressure recovery coefficient with Mach number of free stream are respectively illustrated in Fig.3 and Fig.4. Mass captured coefficient and total pressure recovery present piecewise linearity with Mach number increased. The two sudden rise can be found, which is mainly due to that detached shock wave evolves into oblique shock wave on the lip for first jump at Mach number 3.39, separated vortex on the down surface disappears and on the up surface reduces for second jump. Then inlet start happens immediately at Mach number 3.43. So it is concluded that inlet start process is not completed at moment, which takes on a gradual change process.

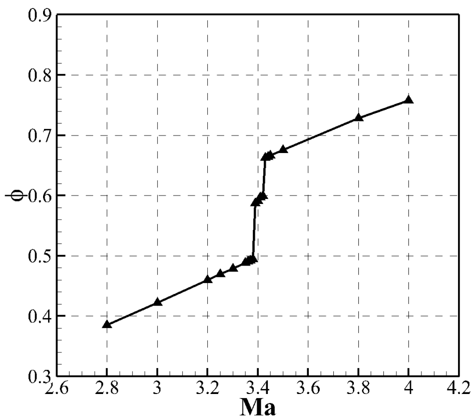


Fig.3 Variation of mass captured coefficient

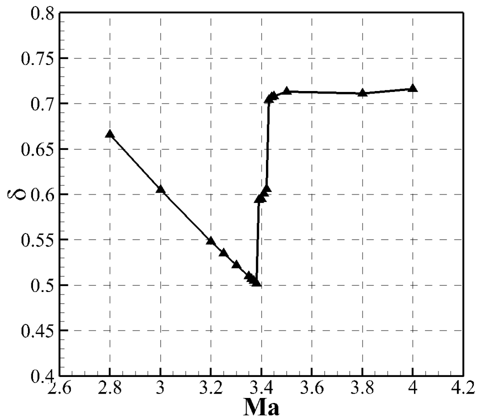


Fig. 4 Variation of total pressure recovery coefficient

The mach contours in symmetry plane for different angle of attack is shown in Fig.5. Flow fields at Mach number 4 are simulated with different angles of attack. At the -15° angle of attack, inlet keeps start flow structure, flow in the inlet entrance region is accelerated due to gas expansion, and no separated vortex structure can be found on the up and down surface. At the 9.2° angle of attack, a small separated vortex emergences on the up surface, but that never change internal flow structure. When at the 9.3° angle of attack, are detached shock wave appears on the lip, a bigger separated vortex can be found on the up and down surface. The inlet start does not happen at this angle.

The variation of mass captured coefficient and of total pressure recovery coefficient with angle of attack respectively are shown in Fig.6 and Fig.7. At the 9.3° angle of attack, both drop suddenly under the influence of shock wave on the lip which changes from oblique shock wave to detached shock wave. As angle of attack increases, capture area increases, which results in mass captured coefficient increasing, that is, decreasing angle of attack is in favor of inlet start.

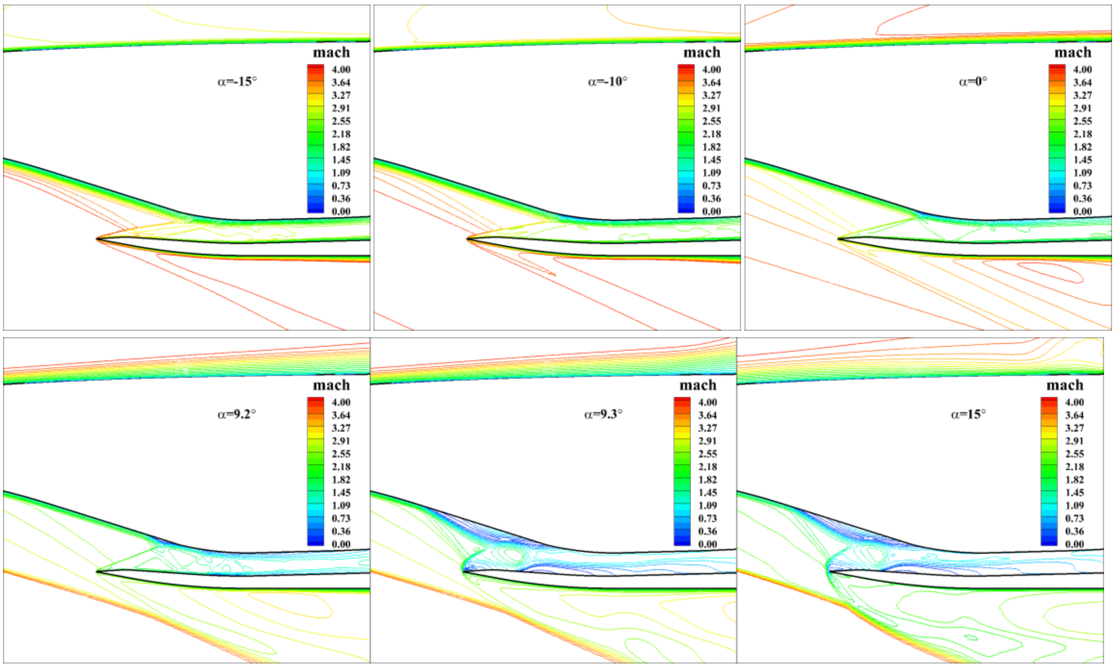


Fig. 5 Mach number contours in symmetry plane

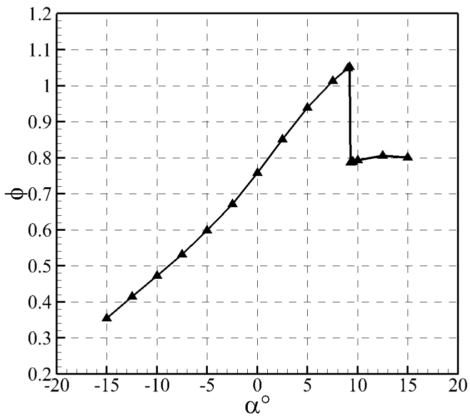


Fig. 6 Variation of mass captured coefficient

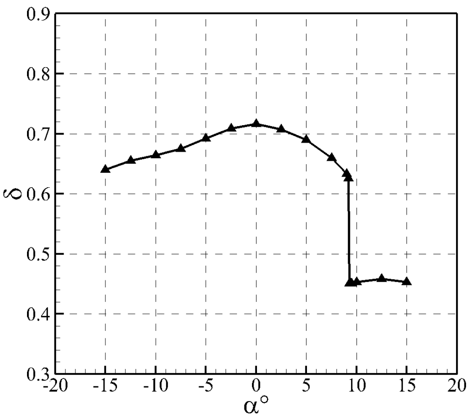
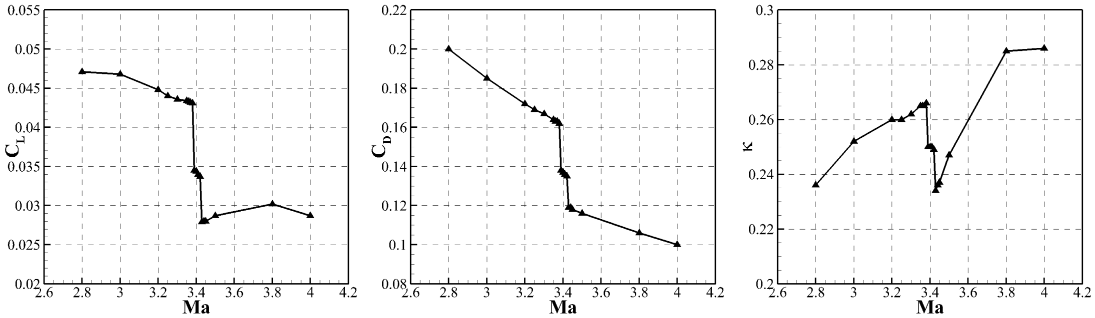


Fig. 7 Variation of total pressure recovery coefficient

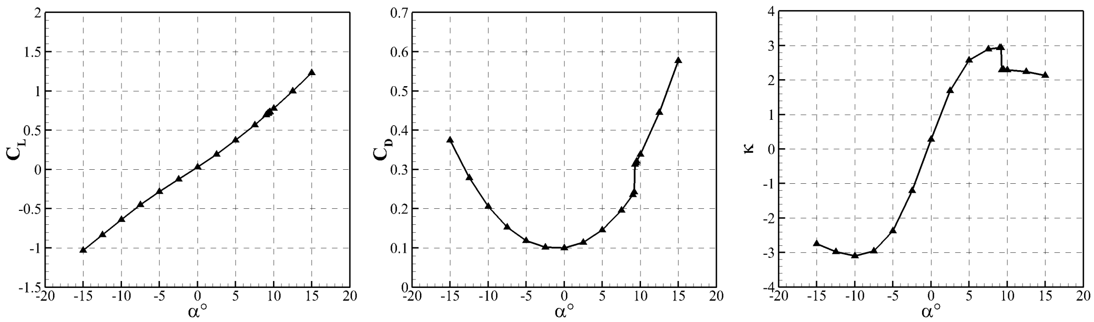
The Variation of aerodynamics with Mach number of free stream is shown in Fig.8. As Mach number increases, lift coefficient C_L and drag coefficient C_D decrease almost, lift-drag ratio κ increases almost except for two jump. C_L,C_D present piecewise linearity with Mach number variation. C_L,C_D and lift-drag ratio κ present two sudden variation corresponding with the Mach number of shock wave and separated vortex structure changed. That is, as Mach number increases, detached bow shock wave on inlet lip evolves into oblique shock wave at Mach number 3.39, which reduces C_L , C_D and lift-drag ratio κ first jumping. when Mach number increased to 3.43, separated vortex disappears nearly and C_L , C_D and lift-drag ratio κ decrease suddenly again.



(a)Cl~Ma (b)Cd~Ma (c) κ~Ma

Fig.8 Variation of aerodynamics with Mach number of free stream

The variation of aerodynamics coefficient with angle of attack of free stream is shown in Fig.9. C_L is linear variation with angle of attack. C_D decreases firstly, then increases and it reaches minimum at 0° angle of attack. Lift-drag ratio κ has linear variation at the angle of attack from -5° to 5°. Present aerodynamic characteristics are consistent with the results in reference [11].



(a)Cl~α (b)Cd~α (c)κ~α

Fig.9 Variation of aerodynamics with angle of attack of free stream

4 Conclusions

Hypersonic inlet start is simulated by CFD numerical method. The results shows that variation of mass captured coefficient and of total pressure recovery coefficient takes on two sudden jump as Mach number increases. Detached bow shock wave on inlet lip evolves into oblique shock wave at Mach number 3.39, which causes first jump. when Mach number increased to 3.43, separated vortex disappears nearly and that results in second jump. C_L,C_D and lift-drag ratio κ present two sudden variation corresponding with the Mach number of shock wave and separated vortex structure changed. C_L,C_D present piecewise linearity with Mach number variation. C_L is linear variation with angle of attack. C_D decreases firstly, then increases and it reaches minimum at 0° angle of attack. Lift-drag ratio κ has linear variation at the angle of attack from -5° to 5°.

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