HiSST: International Conference on High-Speed Vehicle Science Technology
26–29 November 2018, Moscow, Russia

Numerical simulation of two shear layers interaction in double backward-facing steps

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Abstract

In this paper,the Navier-Stokes equations are solved in high-order accurate scheme to study the basic structure and regularity of the flow field in the interaction between supersonic jet and co-directional supersonic flow. The five order WENO scheme and the six order central difference scheme are used to discretize the convection term and viscous term respectively, and the time marching scheme is adopted in the three order Runge-Kutta scheme, and the parallel computation is performed by using MPI non blocking communication. A double backward-facing steps model constructed by ourselves is presented to study the interaction between the jet / supersonic flow shear layers . We find that the two shear layers interact to produce a jet, which we call the secondary jet. The secondary jet generated by the action has the characteristic of pulse and so on, focusing on the periodicity of infrasonic jet..

Keywords: *jet，supersonic，numerical simulation，shear layer，backward-facing step*

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1. Introduction

The interaction between jet and supersonic flow is an important instructure of aerodynamics. For example, in the typical dual-mode scramjet engine, to enhance airflow mixing, a fuel injection strut is used in the combustion chamber to achieve the purpose of mixing with the supersonic airflow. During the rocket launch process,supersonic jet is formed in the nozzle tail which interacts with airflow around the arrow and different types of jet are formed as the height changes.When the supersonic cruise missile is in the course of flight, The jet formed by the engine nozzle interacts with the airflow around the projectile[1-3]. Therefore, the interaction of jet and supersonic flow is very important, which has important engineering practical background and theoretical research value**.**

1.1. The physical model of the jet and co-directional supersonic flow

The physical model of the jet and co-directional supersonic flow is shown in fig.1. In this paper, a double backward-facing step model is constructed, which is composed of two steps of different lengths. We calibrated the two steps as shown in fig.1.Above the first step is supersonic flow, when supersonic flows through the back steps, a shear layer is formed at the corner of the back step, called the supersonic flow shear layer. The jet ejectes from the left end of the second step. Above the jet also produces a shear layer, called the jet shear layer. The area between the stream shear layer and the jet shear layer is called the recirculation zone. Due to the interaction of the two shear layers, the complex phenomenon in the reflow zone will be caused, as we will explain in detail in the following chapters

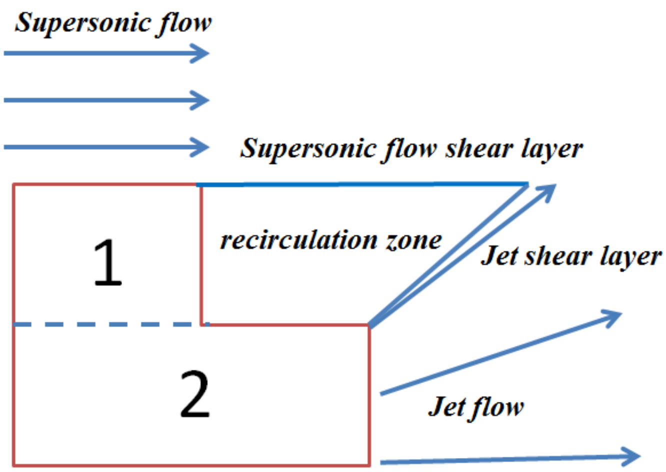

Fig.1 Computational domain of supersonic inflow and jet interaction

1.2 Basic flow field structure

Double backward-facing steps are used to construct two shear layers interaction. As fig.2 shows, the length of the DE is two times the length of the CD. We take the length of the CD as a dimensionless length.
Above the first backward-facing step,BC, is a supersonic incoming flow which Ma is 3. The supersonic flow is separated from the vertical plane of the first back step. The extension of the wall boundary layer in the direction of the flow forms a shear layer over the first backward-facing step ,we call it inflow shear layer.
A high temperature and high pressure jet whose Maher number is 3 is sprayed on the right side of the second back step,EF. First of all, the jet passes through the triangle shaped constant velocity core zone, in which temperature, density, etc. are constant. Jets separated at the corner of the steps, rapid expansion around the steps on the corner. Due to the outlet static pressure and the ambient pressure does not match ,an expansion sector is formed at the beginning of the jet. The streamline

gradually changes direction within the expansion sector until the fluid exits the expansion sector. A shear layer is formed outside the expansion sector, we called it jet shear layer.

A mixing zone is formed between the jet shear layer and the inflow shear layer. The flow velocity of air flow in this area is small and the kinetic energy is converted into internal energy. As a result of the complicated interaction between the jet shear layer and the inflow shear layer, complex wave structures such as Vortex, oscillation shock wave are formed.Temperature of the mixing zone is obviously larger than that of other regions.

Due to the interaction between the jet shear layer and the incoming shear layer, a jet impinges on the recirculation zone between the two shear layers which we call secondary jet. The secondary jet is shoot out periodically which we will elaborate in later chapters. The periodicity of the secondary jet is related to the fluctuation of shear layers. When the horizontal inclination of the jet shear layer reaches a certain level,new secondary jet shoots out.

After two shear layers act, two shear layers converge into a shear layer called mixed shear layer. Because the velocity of the shear layer is unmatched on both sides of the shear layer, it is affected by the Kelvin-Helmholtz instability. The Kelvin-Helmholtz Instability refers to the instability caused by the velocity shearing action between different fluid interfaces. When the two fluids have different speeds ,if they react each other, may cause the Kelvin-Helmholtz instability. Kelvin-Helmholtz (KH) instability arises when an interface between fluids is subject to a shear flow. One of the most important marks of the Kelvin-Helmholtz instability is the Kelvin-Helmholtz vortexs. Fluids are assumed to be incompressible inviscid in the vortex sheet model,.The Kelvin-Helmholtz vortexs are formed on the mixed shear layer, which results in the fragmentation of the mixed shear layer. Two shock waves are formed on both sides of the mixed shear layer. Because the pressure and density of the Kelvin-Helmholtz vortex are smaller than that of the surrounding environment, the pressure difference is formed. The fluctuation of pressure causes the disturbance to the shear layer, weak shock waves appear on both sides of the mixed shear layer. These weak shock waves are wrapped in two shock waves formed by two shear layers interaction.

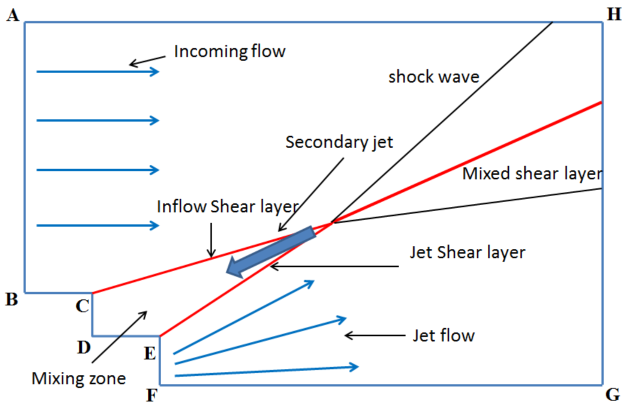

Fig.2 Basic flow field structure

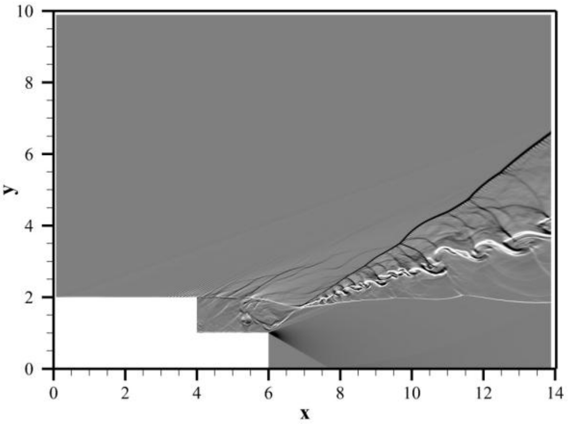

Fig.2 Density gradient of Basic flow field structure

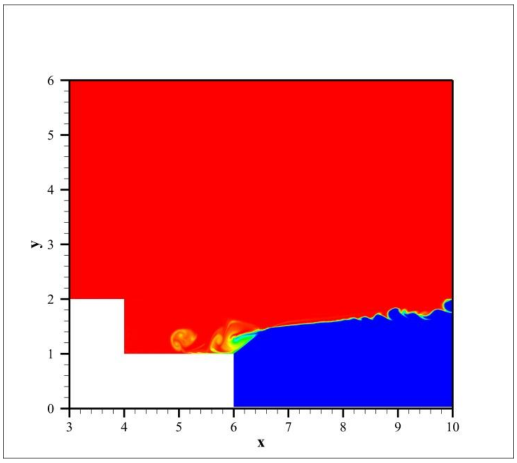

Fig.3 the secondary jet

References

In order to study the interaction between jet and supersonic flow,high accurate scheme is adopted to solve 2D Navier-Stokes equations studying the basic structure and law of interactions between jet and supersonic flow. The five order WENO scheme and the six order central difference scheme are used to discretize the convection term and viscous term respectively.Furthermore,the time marching scheme is adopted in the three order Runge-Kutta scheme, and the parallel computation is performed by using MPI non blocking communication. Double backwards-facing step is presented in this paper. We find that the two shear layers interact to produce a jet, which we call the secondary jet. The secondary jet generated by the action has the characteristic of pulse and so on, focusing on the periodicity of infrasonic jet..

Journal article

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