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Study on the Design of Supersonic Axisymmetric Multicompression and Quasi-isentropic Inlets

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Abstract

Based on the characteristics method, the design method of axisymmetric multi-compression and quasi-isentropic compression inlets are developed. For the multi-compression inlets, the solution strategy of shock wave angle for the least total pressure loss is designed. For quasi-isentropic compression inlets, the design criteria of wall of quasi-isentropic compression inlets is come up with that the left Mach lines starting from the wall should intersect at the lip. The wall of axisymmetric multicompression and quasi-isentropic compression inlets under the condition of mach 4 is designed, and the numerical simulation results calculated by FLUENT shows that the distribution of the shock waves meet the design requirements, which validates the design method of this paper. The comparative study of the two kinds of inlets shows that: the quasi-isentropic compression has the advantage of total pressure recovery, while the drag on the wall of the quasi-isentropic compression is similar with that of three shock compression.

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Keywords: Hypersonic; Characteristics method; Axisymmetric inlet; Multicompression; Quasi-isentropic compression

1. Introduction

Inlet is an important part of scramjet engine, which are perfect propulsion system of hypersonic aerocraft in the future. Axisymmetric inlets [1] are firstly concerned because of its advantages such as simple structure, high-usage of windward area, easy to manufacture, high compression efficiency, easy to carry and launch [2]. Inlets compress gas with shock waves or compression waves to meet requirements of combustor's entrance conditions. Using

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compression waves to compress gas is an isentropic process, with little loss of total pressure, but it requires a long compression wall. In the other way, using shock waves to compress gas can decrease the length of compression wall, but the loss of total pressure will increase. So, in order to decrease the loss of total pressure, the usual way is using multicompression with several oblique shock waves, or using a single oblique shock wave and a series of expansion waves which we call quasi-isentropic compression. How to design the angle of each compression wall and the shape of isentropic compression wall is a key research direction in this field, which concerns the compression performance and total pressure loss.

At present, the research on working process of two-dimensional shock waves has been well developed, and the best design method of two-dimensional shock waves has been come up with[3,4]. But this method isn't suitable for designing axisymmetric multicompression inlets.

In this paper, based on the characteristics method, the design method of axisymmetric multicompression and quasi-isentropic compression inlets are developed, and the performance of the two kinds of inlets are contrasted. Firstly, the inlets design tool based on characteristics method is developed. Secondly, the design methods of axisymmetric multicompression and quasi-isentropic compression inlets are come up with based on theory analysis. Thirdly, the wall of axisymmetric multicompression and quasi-isentropic compression inlets under the condition of mach 4 is designed with the method. At last, FLUENT is used to do numerical simulation which validates the design method and analyses the performance of the two kinds of inlets.

2. The Research of Inlet Design Method

2.1 Characteristics Method

Characteristics method is a simple and quick method to solve inviscid supersonic flow field, and the shape of inlet wall can be get by this method if shock angle is given. The characteristics equation and compatibility equation can be get by control equations of axisymmetric, inviscid, compressible, steady and isentropic flow. For rotational flow, there are three characteristic lines: a streamline and two Mach lines. There are two compatibility equations on streamline and one compatibility equation on each Mach line [5].

The characteristics equation along the streamline is [6]:

$$\left(\frac{dy}{dx}\right)_0 = \lambda_0 = \frac{v}{u} \tag{1}$$

The characteristics equation along the Mach line is [6]:

$$\left(\frac{dy}{dx}\right)_\pm = \lambda_\pm = \tan\left(\theta \pm \alpha\right) \tag{2}$$

Where $\theta = \tan^{-1}\left(\frac{v}{u}\right), \alpha = \sin^{-1}\left(\frac{1}{Ma}\right)$, *Ma* is Mach number, *u* and *v* are velocity components.

The compatibility equation along the streamline is [6]:

$$\rho v_0 dv_0 + dp = 0 \tag{3}$$

$$dp - a^2 d\rho = 0 \tag{4}$$

The compatibility equation along the Mach line is [6]:

$$\frac{\sqrt{Ma^2-1}}{\rho v_0^2} dp_\pm \pm d\theta_\pm \mp \frac{\sin\theta dx_\pm}{yMa\cos\left(\theta \pm \alpha\right)} = 0 \tag{5}$$