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Novel methodology for wide-ranged multistage morphing waverider based on conical theory

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ABSTRACT

This study proposes the wide-ranged multistage morphing waverider design method. The flow field structure and aerodynamic characteristics of multistage waveriders are also analyzed. In this method, the multistage waverider is generated in the same conical flowfield, which contains a free-stream surface and different compression-stream surfaces. The obtained results show that the introduction of the multistage waverider design method can solve the problem of aerodynamic performance deterioration in the off-design state and allow the vehicle to always maintain the optimal flight state. The multistage waverider design method, combined with transfiguration flight strategy, can lead to greater design flexibility and the optimization of hypersonic wide-ranged waverider vehicles.

1. Introduction

Waverider configuration is the main type of aerodynamic shape for hypersonic vehicles [1], which has high lift-to-drag (L/D) characteristics, since it can move through air at high speed by riding the shock wave created by itself [2,3]. Hypersonic vehicles take off from the ground or launch pad, and fly through the atmosphere to carry out missions [4]. During this process, the flight environment and conditions change greatly; therefore, traditional fixed configurations cannot adapt to a wide range of parameter variation [5]. Designing a traditional waverider is usually based on a single fixed Mach number, while the aerodynamic characteristics at the off-design point of such a configuration decrease substantially, which cannot meet wide-ranged flight requirement for future hypersonic vehicles [6]. Therefore, introducing morphing technology into the waverider's aerodynamic configuration design can effectively solve the problem of aerodynamic performance deterioration at the off-design point [7]. In recent years, with the development of aerodynamics, computer technology and multidisciplinary optimization fields, designing hypersonic morphing vehicles has become possible in principle [8–10].

In this study, the multistage waverider design method based on conical theory is put forward as a new evolution of wide-ranged vehicles. Additionally, multistage waverider configuration can be used as morphing by combining the transfiguration flight strategy.

2. Design and generation of multistage morphing waveriders

As shown in Fig. 1, a traditional single stage waverider configuration is composed of three surfaces; namely, the free-stream, compression-stream, and base surface. The leading-edge curve is defined as the intersection of the free-stream and compression stream surface; the trailing-edge curve of the free-stream surface is defined as the intersection of free-stream and base surface.

The single stage conical waverider generation program begins by providing the basic curves and design parameters as well as the flow parameters of the basic flow field. Herein, the basic curves include the trailing-edge of the free-stream surface and the shock wave curve on the base plane of the vehicle; design parameters include the shock angle and Mach number; flow parameters include local static pressure, local density, local velocity and local flow direction angle. By combining flow and design parameters, the basic flow field and basic conic can be solved uniquely by using the rotational characteristic line method. In the above flow field, the leading-edge curve can be obtained by the free streamline method, and the trailing-edge curve of compression-stream surface can be obtained by the streamline tracing method.

Similar to the single stage conical waverider generation program, the multistage waverider generation program begins by providing the basic curves, design parameters and the flow parameters of the basic flow field. However, the design parameters contain a fixed shock angle and several

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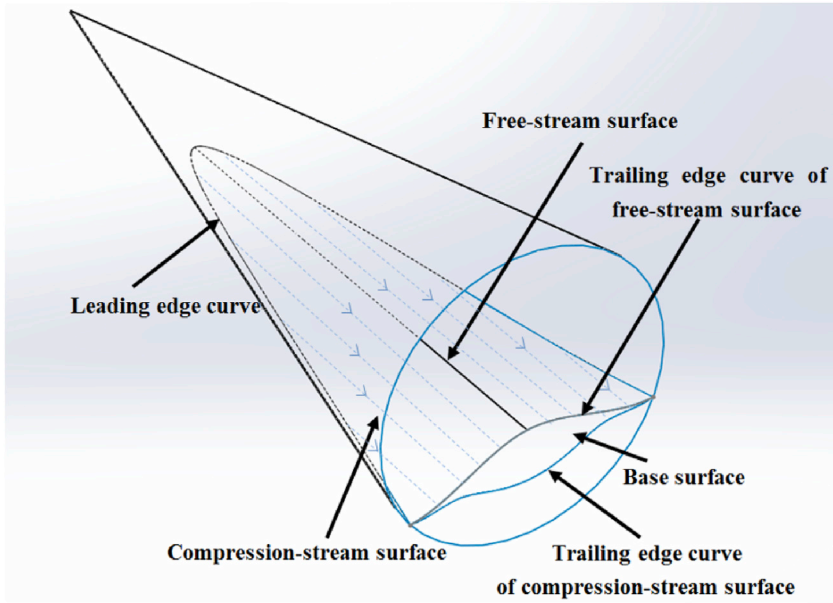
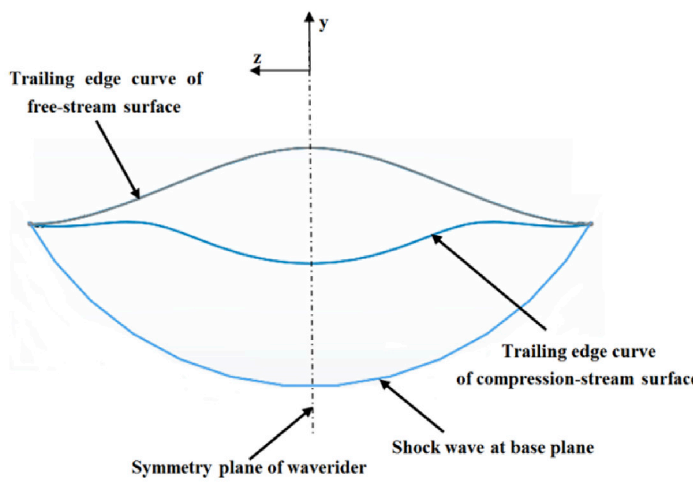


(a) Isometric view



(b) Rear view

Fig. 1. Properties of a single stage waverider.

different Mach numbers, which are determined by flight mission requirements. When giving the fixed shock angle β and flow parameters, the supersonic axisymmetric conical flow field can be determined uniquely, which as shown in Fig. 2. Furthermore, different basic conics would be solved when different Mach numbers are given.

When generating the multistage waverider, the first step is to abstract the flight Mach number range according to flight mission requirements, so as to determine the stage number of the multistage waverider. To simplify the description, we choose the flight Mach number ranges at *Ma*12-Ma6 as an example to introduce the design method of the multistage waverider. The design Mach number can be divided into four equal pieces; namely, $Ma_1 = 12$, $Ma_2 = 10$, $Ma_3 = 8$ and $Ma_4 = 6$. In other words, the designed multistage waverider is a four-stage vehicle.

As shown in Fig. 2, the flow field is obtained based on the fixed shock angle; thus, the shock wave curve at the base plane is fixed. When providing the trailing-edge curve of the free-stream surface, the leading-edge curve can be obtained by the free streamline method in the basic flow field. Subsequently, the leading-edge curve and trailing-edge curve of the free-stream surface can form the free-stream surface of the multistage waverider. Moreover, by using the first stage Mach number as a design parameter, the basic conic can be solved and the trailing-edge curve of the compression-stream surface for the 1-stage waverider can be obtained by the streamline tracing method. Additionally, the compression surface of the 1-stage waverider is obtained by lofting a group of streamlines. Analogically, the compression surfaces of other stages can be obtained by using $Ma_2 = 10$, $Ma_3 = 8$ and $Ma_4 = 6$ as design parameters. Finally, the trailing-edge curve of the free-stream surface and trailing-edge curve of compression-stream surface for the 1-stage waverider can form the base surface. Fig. 3 shows the surface definitions of the four stage waverider.

The multistage waverider can be used as a morphing vehicle since it can fly based on transfiguration flight strategy. The application of smart materials and structures in the multistage waverider is one of the transfiguration flight strategies. By using smart materials, the multistage waverider can change its configuration adaptively, according to flight mission and requirement. Thus, the vehicle can maintain waverider characteristics during each flight Mach number. Another transfiguration flight strategy is throwing the compression-stream surfaces as cowlings. When using the multistage waverider as a gliding vehicle, the compression-stream surface of 1-stage, 2-stage and 3-stage can be