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Aerodynamic Design of a Hypersonic Glide Vehicle Based on the Cone-Derived Wave rider Configuration Method

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ABSTRACT: Hypersonic glide vehicles are a novel type of hypersonic weapons that have received extensive attention. These vehicles can seriously challenge any defense system by traveling long distances of about thousands of kilometers in the atmosphere at very high speeds up to more than 20 Mach. In this research, the aerodynamic design of a hypersonic glide vehicle has been done based on the wave rider theory and conical-derived wave rider Method. In this study, a parametric method with three parameters, including cone shock angle β, dihedral angle φ, and compression ratio S, was introduced and used as a design code. In the design process, the HTV2 hypersonic glide vehicle was used as a reference model. To achieve configurations with operational dimensions, by changing the design parameters, four-wave rider configurations with the same dimensions as the reference model were identified. By analyzing these four configurations using the computational fluid dynamics method, the configuration with the best aerodynamic and volume results was selected as the preferred design configuration. Compared to the reference model, the preferred configuration has 36% more aerodynamic efficiency and 15% less volume, indicating the efficiency of the used method.

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1- Introduction

The methods commonly used for the aerodynamic design of hypersonic glide vehicles include those based on the theory of wave rider configurations, which create a higher lift-to-drag ratio than other configurations [1]. A wave rider is a supersonic or hypersonic vehicle in which the shock wave is attached to the leading edge throughout its length under specific design conditions (i.e., Mach number and free flow conditions). Due to the attachment of the shock wave to the leading edge, the large pressure behind the shock wave under the vehicle does not leak to the upper surface from around the leading edge. Hence, the flow field is trapped at the lower surface and its high pressure is maintained, causing a higher lift force on the vehicle. [2].

Although there has been some research on the design of hypersonic glide vehicles based on hypersonic configurations theory, such as that in [3, 4], not all aspects of wave riders as hypersonic glide vehicles have yet been studied. The present research simultaneously considered all three aspects of a wave rider, namely operational dimensions, aerodynamic efficiency, and configuration volume for operation as a hypersonic glide vehicle. The method used was validated by comparing its results with those of the HTV2 glide vehicle. Among wave rider design methods, the cone-derived wave rider technique has been selected due to its good volume and simpler design space. A parametric method with three parameters was employed as a design code for creating wave rider configurations. The overall design process in this research is as follows. First, the configurations with appropriate operational dimensions and volume obtainable from the design method are identified by varying the design parameters at specific increments within a suitable range. Since the operational dimensions of the vehicle are unknown at this stage, those of the HTV2 hypersonic glide vehicle are considered. Subsequently, these configurations undergo an aerodynamic analysis using computational fluid dynamics (CFD). The configuration with superior performance in terms of aerodynamic efficiency and volume is selected as the preferred design configuration. Next, the effectiveness of the designed configuration is determined by comparing it to HTV2 (as the reference model) in terms of volume, aerodynamic efficiency, and wave riding quality.

2- Design procedure

Wave rider configurations are usually built using an inverse design method. In the cone-derived technique, the wave rider configuration is extracted from the base flow around an imaginary cone under a supersonic or hypersonic regime. The top surface of the wave rider and its leading edge are created by projecting the top curve of the wave rider surface onto

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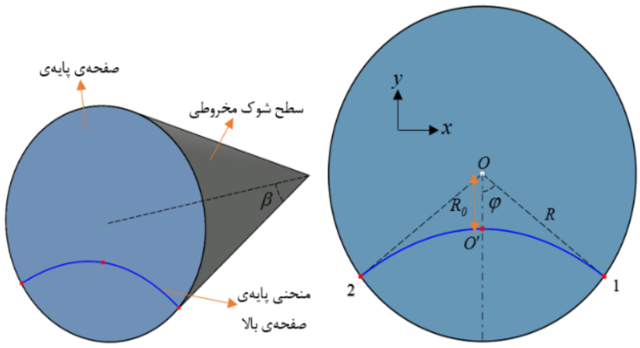

Fig. 1. The three design parameters of a cone-derived wave rider

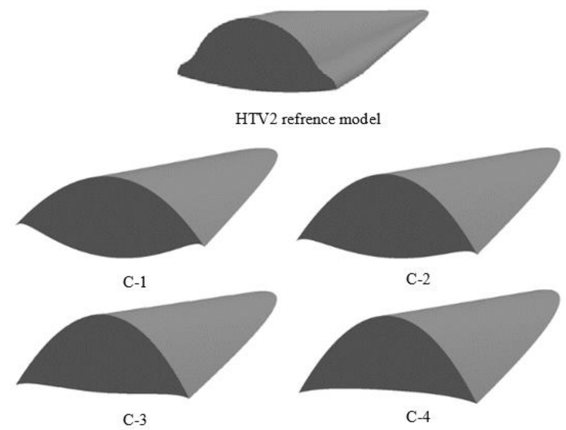

Fig. 2. The HTV2 glide vehicle and the four designed configurations

the hypothetical conical shock surface. Then, the wave rider configuration is divided into radial sections, and the bottom surface of the wave rider is obtained by numerically solving the following Taylor-Maccoll equation using the leading edge curve and the hypothetical conical shock. The wave rider configuration is obtained by connecting the created surfaces.

$$\frac{\gamma-1}{2}\left[V_{max}^2-V_r^2-\left(\frac{dV_r}{d\theta}\right)^2\right]\left[2V_r+\frac{dV_r}{d\theta}\cot\theta+\frac{d^2V_r}{d\theta^2}\right]-\frac{dV_r}{d\theta}\left[V_r\frac{dV_r}{d\theta}+\frac{dV_r}{d\theta}\left(\frac{d^2V_r}{d\theta^2}\right)\right]=0 \quad (1)$$

The design parameters of this research are the conical shock angle β and the curve parameters of the top surface of the wave rider, including the anhedral angle φ and the compression ratio S (R_0/R), which together determine the shape of the resulting wave rider. These parameters are displayed in Fig. 1.

3- Results and discussion

The suitable wave rider configurations in terms of dimensions were identified by considering a specific range and variation increment for the design parameters and specifying the maximum dimensional difference from the reference configuration (5%). Subsequently, low-volume configurations were eliminated, and four configurations with suitable dimensions and volume were selected and subjected to aerodynamic analyses and comparison with the reference model. Fig. 2 shows the configurations resulting from the design alongside the reference model. The dimensions of the designed configurations were similar to those of HTV2 with a maximum difference of 5%. Next, the flow fields around these configurations were aerodynamically simulated using ANSYS Fluent commercial software. For this purpose, the implicit density-based and steady solver using the Roe-FDS method was selected. Also, the ideal gas assumption was considered.

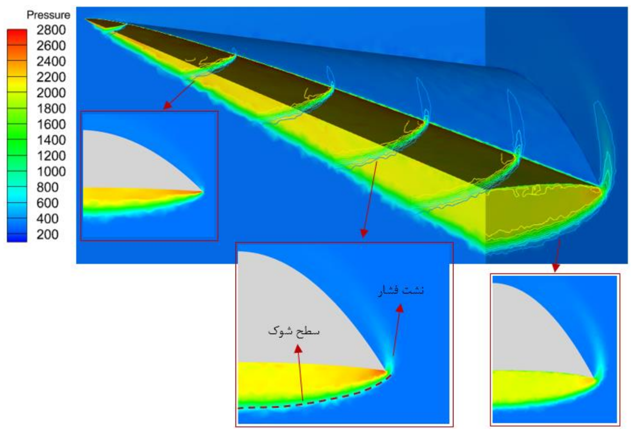

Fig. 3. Pressure distribution around the superior designed configuration

According to the results, the volumes of the designed configurations were lower than those of the reference model, but their lift-to-drag ratios were higher. The fourth configuration was selected as the preferred configuration with an aerodynamic efficiency 36% higher and a volume 15% lower than the reference model. If the volume is prioritized over aerodynamic efficiency, the third configuration can be considered a better choice with 26% more aerodynamic efficiency and 7% less volume than the reference model. Fig. 3 displays the pressure distribution around the preferred configuration compared to the reference model. As seen in the figure, pressure leakage was less in the preferred configuration than in the reference model, and a higher pressure entrapment occurred on the bottom surface of the preferred configuration due to its higher aerodynamic efficiency.

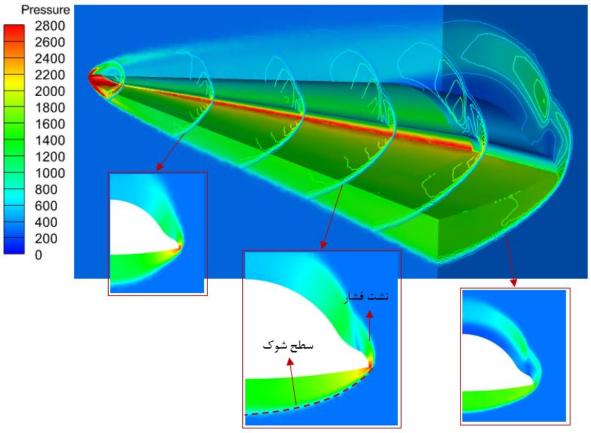

Fig. 4. Pressure distribution around the HTV2 reference model

4- Conclusion

In this research, a hypersonic glide vehicle was designed using the cone-derived wave rider method by considering its operational dimensions, volume, and aerodynamic efficiency. The results indicated that the designed configuration provided 36% more aerodynamic efficiency than the HTV2 hypersonic glide vehicle with 15% less volume. Accordingly, one may conclude that the cone-derived wave rider design method can result in good configurations for use as hypersonic glide vehicles in terms of dimensions, volume, and aerodynamic efficiency.

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