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Aerodynamic Configuration Design of Flight Demonstrator for Real Gas Effect

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Abstract

Real gas effect is one of the key technical challenges for reusable orbital vehicle development. Conducting flight demonstration is an effective way to understand the real gas flow characteristics. In this paper, investigation on the aerodynamic configurations of flight demonstrators, which are designed according to the requirements of flight tests for real gas effect studies, are conducted. The real gas effect is simulated by the numerical method with the equilibrium gas model. By analyzing the influence of real gas effect on the aerodynamic characteristics of different types of aerodynamic shapes, the aerodynamic design principles for real gas effect demonstrator are summarized. The aerodynamic configuration that satisfies the requirements of real gas effect flight tests is proposed.

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Keywords: real gas effect; equilibrium gas; aerodynamic configuration; numerical simulation

1. Introduction

Reusable orbital vehicles represent one of the major directions of future aerospace transportation system development. The 3 flight tests of the U.S. X-37B reusable orbital vehicle since 2010 caused great interests on this type of vehicles around the world. This type of vehicles usually have very complex aerodynamic shapes and very large range of the variation of flight conditions. The aerodynamic challenges focus on the high Mach number, high altitude and median Reynolds number regime, where the high temperature real gas effect plays an important role.

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Early attention on the high temperature real gas effect caused by the space shuttle, in which case large discrepancy of trimmed body flap deflection was found between the flight result and the predicted data in hypersonic velocities[1]. Computational study indicated that the differences between flight and pre-flight predictions of hypersonic pitching moment were attributable primarily to Mach number and real gas effects[2].

The capability of ground facilities is not able to simulate the real gas effect caused by high Mach number during the entry flight. The prediction of real gas effect relies on numerical simulation. However, the validity and precision of the numerical simulation technique has still not been fully testified and verified due to the lack of enough flight test data. Therefore, conducting flight demonstration tests is the effective approach to fully understand the real gas flow characteristics. In fact, fight demonstration for critical technology using simplified aerodynamic configurations may reduce the risks of reusable orbital vehicle development. And it was a widely adopted technical approach. Typical examples include the U.S. ASSET[3] and PRIME[3] program, the USSR BOR-4[4] orbital flight test, and the Japanese HYFLEX[5] flight experiment. These flight tests provided necessary technological foundations for the development of the Space Shuttle, the "Buran" program, and the "HOPE" program.

In the present work, studies on the aerodynamic configuration design of a flight demonstrator are conducted according to the requirements of real gas effect flight test. The real gas effects on the aerodynamic characteristics of the flight demonstrator are estimated using the proposed numerical simulation method. The aerodynamic configuration that satisfies the requirements of real gas effect flight tests is proposed.

2. Aerodynamic configuration design of flight demonstrator

In order to study the real gas effect on the aerodynamic characteristics of reusable orbital vehicles under relatively low costs and technical risks, the aerodynamic configuration of the flight demonstrator should be designed according to the following requirements:

1) To simplify the system and reduce the costs, the aerodynamic shape of the demonstration vehicle should be as simple as possible. But the basic configuration characteristics of the reusable orbital vehicles, for instance, the blunt nose, need to be maintained.

2) Trimmed angle of attack set around 30°, simulating the high angle of attack entry flight of the reusable orbital vehicles.

3) Static stable in the pitching, yawing, and rolling directions.

4) In order to investigate the real gas effect, aerodynamic characteristics of the demonstrator need to be sensitive to real gas effect, taking the trimmed angle of attack as a measured parameter.

5) Typical flight conditions: H=50km, Ma=15.

Fig.1 shows the 5 typical configurations analyzed during the aerodynamic design process. J01 and J02 are axial-symmetrical configurations. J03~J05 are planar symmetrical configurations. The aerodynamic shape characteristics of the J01~J05 configurations are summarized in Table 1. Center of gravity coefficient of the configurations, which are determined according to the requirement of trimmed at 30° angle of attack, are given in Table 2.

The design of the J01~J04 configurations consider only the longitudinal characteristics. By analyzing and comparing the influences of real gas effects on longitudinal aerodynamic characteristics and the mechanisms of how the influences work, the basic design principles for longitudinal characteristics of real gas effect demonstrator are summarized, based on which, J05 is designed with additional consideration of lateral-direction characteristics. Detail analysis is given in section 4.