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High-speed unsteady flows past two-body configurations

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Abstract This paper presents a detailed investigation of unsteady supersonic flows around a typical two-body configuration, which consists of a capsule and a canopy. The cases with different trailing distances between the capsule and canopy are simulated. The objective of this study is to examine the detailed effects of trailing distance on the flow fields and analyze the flow physics of the different flow modes around the parachute-like two-body model. The computational results show unsteady pulsating flow fields in the small trailing distance cases and are in reasonable agreement with the experimental data. As the trailing distance increases, this unsteady flow mode takes different forms along with the wake/shock and shock/shock interactions, and then gradually fades away and transits to oscillate mode, which is very different from the former. As the trailing distance keeps increasing, only the capsule wake/canopy shock interaction is present in the flow field around the two-body model, which reveals that the unsteady capsule shock/canopy shock interaction is a key mechanism for the pulsation mode.

1. Introduction

Shock/shock interactions, and wake/shock interactions appearing around two-body configurations often lead to crucial aerodynamic and aerothermodynamic problems for spacecraft at supersonic and hypersonic speeds.[1–4] Various shapes of two-body configurations associated with shock/shock and wake/shock interactions are used in a variety of applications in aeronautics, such as supersonic parachutes for re-entry capsules. In the Mars landing missions, the capsules reach super-

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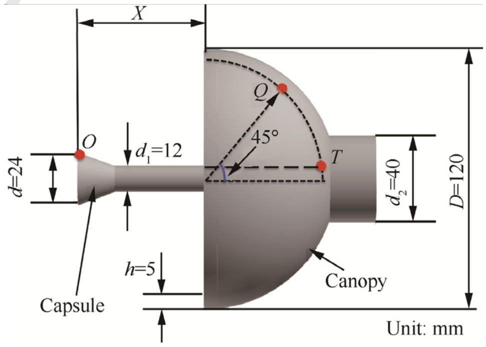
sonic speeds after entering Martian atmosphere and supersonic parachutes are deployed to slow the capsule down to subsonic speeds.[5] From the 20 century late 60s and early 70s, the supersonic parachute problems have been investigated widely using the experimental methods.[6,7] Mayhue[6] and Steinberg[7] et al. showed that the suspension line length ratio (i.e., the ratio of the length of the suspension line to the diameter of the canopy) directly affects the drag coefficient of parachute system at supersonic speeds. Steinberg et al.[7] also presented the mutually interfering flow field between the forebody and canopy as a function of trailing distance by a water-table experiment. With advances in compute performance and numerical modeling techniques, numerical simulations of the flow fields around the two-body configurations emerged and the corresponding flow physics could be investigated in detail. Lingard et al.[8,9] carried out the early simulations on the flexible parachute system (including capsule and flexible canopy) under supersonic conditions, and first showed the aerodynamic interference between the capsule wake and the canopy shock. The effects of the capsule wake, Mach number and trailing distance on the performance of the flexible parachute were examined. Sengupta et al.[10,11] conducted the numerical and experimental investigations on subscale Mars Science Laboratory (MSL) parachute models (including capsule and canopy) and presented that the flow instability of the parachute system originates from the aerodynamic interference between the canopy shock and the capsule wake, and is dependent on the Mach number Ma, the Reynolds number Re, the capsule shape, and proximity to a forebody. In order to fully understand the complex unsteady flow field around such two-body configurations, a rigid capsule-canopy model and the Detached Eddy Simulation (DES) method were employed by Barnhardt et al.[12] to investigate the effects of such wake/shock interaction on the flow instability. They illustrated that the time-dependent deficit in the wake interacts with the canopy shock, which causes the flow field around the capsule-canopy model to become highly unsteady. Gidzak et al.[13,14] further investigated the rigid capsule-canopy model using DES method and compared their data with those from wind tunnel tests. It was revealed that the time scale for the canopy motions is larger than the one for its drag variations. Xue et al.[15] simulated the rigid two-body configurations with a rather small trailing distance (X/d = 2.38, d/D = 0.2, capsule half-cone angle is 20°) and found that another aerodynamic interaction occurs, where the shock ahead of the capsule interacts with the shock wave ahead of the canopy, and the unsteady flow field around the two-body system exhibits the pulsation mode, which was caused by upstream propagation and lateral expansion of the complicated wake/shock and shock/shock system. Xue et al.[16] and Nishiyama[17] numerically and experimentally investigated the coupling effects of the trailing distance (X/d) and the ratio of the diameter of capsule to that of canopy (d/D) on the unsteady flow field around the two-body configurations (capsule half-cone angle is 20°), where d/D was mainly chosen from 0.33 to 0.4, and X/d was chosen from 1.25 to 10 for each d/D case, and it was found that four unsteady flow modes occur under the effect of trailing distance for all the d/D cases; however, very little is understood on the flow physics of the four flow modes and the mechanisms leading to the transition. Moreover, Xue et al.[18] further presents that the capsule half-cone angle (10–30°) has a significant effect on the unsteady flow mode around a two-body configuration (X/d = 3.75, d/D = 0.2). Hatanaka et al.[19] investigated the mechanism of shock oscillations ahead of a rigid hemispherical canopy in a supersonic flow.

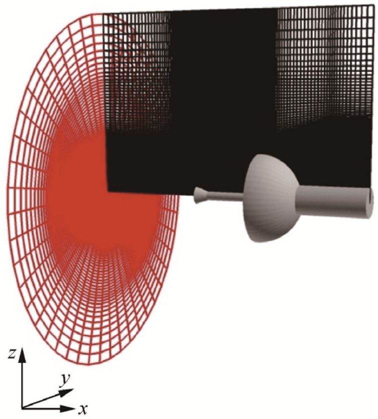
This paper aims to further explore the supersonic flow field around the two-body (capsule-canopy) configuration, similar to the parachute system, to understand and analyze the flow physics of the different flow modes[16] around the parachute-like two-body models in great detail, and to examine the mechanism leading to the transition. Numerical simulations were performed for three-dimensional (3D) rigid canopy-capsule two-body models (mimicking the supersonic parachutes) with different trailing distances at a fixed d/D value (d/D = 0.2). The effects of the trailing distance on the flow field will be thoroughly investigated. The computational results will be compared with the experimental data from the Institute of Space and Astronautical Science (ISAS)/Japan Aerospace Exploration Agency (JAXA).[17]

2. Two-body models

The rigid two-body system employed in the numerical simulations consists of a capsule and a canopy. The two-body model is shown in Fig. 1(a). The original shape of canopy is a hemisphere with the diameter D of 120 mm and the thickness h of 5 mm. The diameter of capsule frontal surface, d = 24 mm, and it takes a conical form with a half-cone angle of 20°. X is the axial distance from the capsule frontal surface to the inlet of the canopy, and X/d the two-body trailing distance. This



(a) Two-body model used in present computation



(b) Grid of two-body model for Case C

Fig. 1 Two-body model used in present computation and Grid of two-body model for Case C.

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