論 文 の 内 容 の 要 旨

論文題目　　Bow Shock Instabilities and its Control in front of Concave shaped Blunt Nose at Hypersonic Mach Number 7
(マッハ７極超音速気流中において凹面形状鈍頭物体前方に生じる離脱衝撃波の不安定性とその制御)

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The flight path of spacecraft entering to the atmosphere of earth or any other planet is subjected to go through different flow regimes. It starts with non-continuum free molecular flow regime and further goes through low Knudsen number flight to chemically reacting, peak dynamic pressure and peak heating hypersonic flow regime. In later stages before stopping to the ground, it passes through supersonic and subsonic flow fields. The three main requirements for the design of re-entry vehicle are higher drag, better heat transfer and accuracy of trajectory. Blunt bodies are best suited and utilized for having higher drag and detached bow shock associated with it, in supersonic and hypersonic flows. However, different curvature of blunt nose may have different aerothermodynamic performance. In this study, a concave shaped blunt nose is desired to work as hypersonic decelerator during re-entry mission. In early 1960's, the cavity in front of blunt nose was experimentally studied and found it has better heat transfer properties. However, during the wind tunnel tests for cavity in front of blunt body, it was found that the flow field in front of cavity is highly unstable and in high supersonic and hypersonic flow, the bow shock formed in front of blunt nose cavity have sudden violent large amplitude fluctuations. Later in numerical studies, the large amplitude bow shock fluctuations were not observed. However, small amplitude shock oscillations with acoustic frequency of the cavity were observed. From previous researches, the physics of bow shock instability in front of cavity is not fully understood. To utilize the concave shape blunt nose as hypersonic decelerator, it is necessary the bow shock in front of concave shape geometry should be stable, otherwise large amplitude oscillatory or uncontrolled bow shock may have dynamic effect on the re-entry vehicle. As a first step, the experiments were conducted at hypersonic Mach number 7 for concave shape hemispherical shell along with flat plate and convex shape blunt nose to have a comparative analysis of these three basic geometries. During the experiments, the force measurement and time-resolved flow visualization was performed by using high-speed camera with Schlieren system at 50000 frames per second. Further to characterize the bow shock fluctuations from the time-resolved high-speed video, an image processing method have been established to get the bow shock fluctuation data as a time series. From the analysis of time series of bow shock fluctuations, it is found that the bow shock in front of concave shaped blunt nose behaves like a nonlinear oscillator similar to duffing oscillator, which has nonlinear restoring force. Hence, the analogies are drawn from the duffing oscillator to understand the flow phenomenon involved in large amplitude bow shock fluctuations. Further, from the captured high-speed image frames, proper orthogonal decomposition have been performed, which gives information regarding two kind of orthogonal modes in large amplitude bow shock fluctuations as back and forth flow motion and flow moving from the sides of concave cavity. However, it was also found that the higher modes may be combinations of these two modes. Based on above understanding of large amplitude bow shock fluctuations in front of concave shaped blunt nose, two kind of passive control methods are employed to the concave shaped blunt nose to have dual objectives, one is to understand the mechanism of bow shock instability by analyzing the effects of different passive controls, second to have the best flow control mechanism to stop the large amplitude bow shock fluctuations. One kind of passive control method is based on the flow around the edge of concave cavity as flat base, notch and tab control. The second kind the passive controls are based on the back and forth flow in the cavity as breathing control, spike control and crosswire control. For the study of passive control methods experiments were performed in hypersonic wind tunnel at Mach 7 for all the control methods studied. And the effectiveness of control methods are analyzed with force measurement and bow shock displacement analysis, which was obtained by using the high-speed time-resolved Schlieren video. By the studies of flow control, it is found that the cavity based control methods spike and crosswire works better than other control mechanism studied. However, other passive controls methods were also partial effective but their effect was not as promising as crosswire and spike. This gives the further understanding of vortical motion in the cavity, which may introduce the nonlinear effect for bow shock in front of concave cavity fluctuation system. The vortex manipulation offered by crosswire works best among the other control methods.The experimental analysis was mainly based on only one direction Schlieren flow visualization, hence, the numerical simulations in front of concave hemispherical shell along with flat and convex blunt nose are performed by solving unsteady compressible Navier-Strokes equations for wind tunnel test conditions. From the numerical simulations, the onsets of large amplitude bow shock motion have been captured and further flow phenomenon has been explained.